# The Dynisco Injection Molders Handbook

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*Sponsored by Dynisco Inc.*

# PREFACE

Over the years 1984 to 1989, we published a series of articles on the molding of thermoplastics materials in the monthly magazine British Plastics and Rubber ( BP & R). These articles were very well received and we also received a large number of requests for reprints. The articles were also subsequently translated into languages other than English.

In order to cater for what is obviously a need in both the thermoplastics, and the thermosetting, molding industries, we therefore brought the information together and produced it in book form. To make the material easier to handle we produced it in the form of several books and this is one of them. We can only hope that the information so presented, serves you well and that you find the information useful.

Thanks are due to our many friends and colleagues throughout the molding industry for their useful help and advice; in particular, the company Moldflow (Europe) Limited deserve a special mention as they allowed us to estract information from their extensive database. Thanks are also due to Dynisco who sponsored this particular project. The information presented in this publication is intended to give the reader an overview of the injection molding process as listed in the index of this book. More detailed information on, for example, the processing of specific grades of materials, should be obtained from the manufacturers of the material or, from the suppliers or, from the suppliers of the injection molding equipment. We therefore suggest that, the user of such machines and materials, seek and adhere to, the manufacturers or suppliers current instructions for the handling of each grade or type of material they use. Any determination of the suitability of the material for any use contemplated by the user, and the manner of processing and use, is the sole responsibility of the user who must satisfy himself/herself that the material as processed meets the needs of a particular product or use.

The information presented in this publication was based on our knowledge and experience and represents the opinion of us, the authors, and not necessarily the opinions of any other person or organization. To the best of our knowledge the information is accurate; however we do not assume any liability whatsoever for the accuracy or completeness of such information. Such information is given in good faith but in view of the many factors that affect processing and properties, the data so presented does not relieve processors from the responsibility of carrying out their own tests and experiments; neither does the data presented imply any legally binding assurance of certain properties, ease of processing or, of suitability for a given purpose. It is also not our responsibility to ensure that proprietary rights are not infringed and that relevant legislation is observed.

To the extent that any hazards may have been mentioned in this publication, we neither suggest nor guarantee that such hazards are the only ones which exist. We strongly recommend that anyone intending to rely on any suggestion or recommendation (or to use any equipment, processing technique or material mentioned in this publication) should satisfy himself/herself that all applicable safety standards can be met. Remember, there is a need to reduce human exposure to many materials to the lowest practical limits in view of possible long-term adverse effects.

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# PLASTICS AND POLYMERS.

Over the past 50 years the usage of plastics materials throughout the world has increased dramatically: it now stands at approximately 100 million tons

## Polymers

Most commercial plastics, also known as resins in North America, are based on the element carbon and are synthesized, or made, from simple, oil-based raw materials These starting materials are called monomers and these simple, low molecular weight materials are put together, by a process known as polymerization (polymerisation), so as to form polymers This term means that the final product consists of many identical, repeat units Because the final molecular weight, or mass, is so large the material may also be referred to as a 'high polymer' or, as a 'macromolecule' All plastics are polymers but it cannot be processed like a plastics material unless it is modified

## Types of Plastics Material

A plastic is a polymer, which is capable of being shaped or molded under conditions of moderate temperature and pressure Distinguished from a rubber/elastomer, by having a higher stiffness/modulus and a lack of reversible elasticity There are two main categories of plastic and these are thermoplastics and thermosetting plastics (thermosets) Thermoplastic products, for example in injection molding or an extrudate, may be softened and reshaped whereas a thermoset product cannot In terms of tonnage thermoplastics are by far and away the most important Many plastics are based on one monomer and are known as 'homopolymers': some are based on two monomers and are known as copolymers'

## Amorphous and Crystalline

Thermoplastics materials may be divided into two main categories; these are amorphous and crystalline An amorphous, thermoplastics material is usually a hard, clear, rigid material with a low shrinkage and a low impact strength such a material is polystyrene A crystalline plastic also contains amorphous material and so may also be known as a semi-crystalline, thermoplastics material Such plastics are usually tougher, softer, but can have a higher heat distortion temperature, than an amorphous, thermoplastics material: such plastics are also translucent, or opaque, have a high shrinkage and a high specific heat The best known example of a semi-crystalline, thermoplastics material is the plastics material known as polyethylene

# NAMES AND ABBREVIATIONS (PLASTICS).

There are two main categories of plastic and these are thermoplastics and thermosetting plastics (thermosets) In terms of tonnage thermoplastics are by far and away the most important As such materials are also the ones most widely used in the injection molding industry, this section will concentrate on thermoplastics materials

## Common Names.

The names for most thermoplastics begin with 'poly' and then this term, which means 'many' is followed by the old fashioned name for the monomer from which the plastic is derived, i e the name is source-based Because of this practice we get names such as polystyrene and polyethylene for homopolymers When the plastics material has more than one word in the name, parentheses, or brackets, may be put around the words so that we get poly(vinyl chloride) However this practice is not however, universally used and so names such as 'acetals' and 'cellulosics' are also encountered Other, more logical systems of nomenclature have been proposed but as yet, they have not been adopted

## Alternative Names.

Many plastics are known by more than one name, for example, acetals may be known as polyformaldehyde or, polyoxymethylene When this is so then the alternative name(s) should be listed so that cross-referencing is possible

## Abbreviation(s).

Because of the complex, chemical names used to describe polymers, they are nearly always referred to by abbreviations Such abbreviations take the form of a short string of capital letters; each capital letter refers to the part of the common name If the plastics material begins with 'poly' then the first letter is P the other letter(s) are derived from the monomer unit Names such as polystyrene and polyethylene are thus shortened to PS and PE respectively (see Table 1)

## Some Relevant Standards.

Many standards organisations, for example, the American Society of Testing and Materials (ASTM), the British Standards Institution (BSI) and the International Standards Organisation (ISO), issue standards which specify what letters shall be used See ASTM standard D1600-86 (that is standard number D1600 revised/published in 1986) and called 'Standard abbreviations of terms related to plastics'  There was a British standard published in 1978 - see BS 3502 1978: the corresponding ISO standard is ISO 1043 1978  There is now another ISO standard ISO 1043-1 which was published in 1987 and which is called 'Basic polymers and their special characteristics'  It has the number ISO 1043-1  1987 (E)  (The nomenclature of rubbers and lattices are described in ISO 1629)

## Standard and Non-Standard Abbreviations.

It must be appreciated that both standard and non-standard abbreviations are used  Often materials appear, and become used, before the standards committee has issued its suggestion  By this time a 'non standard' abbreviation has become established or more than one abbreviation may 'appear' for the same material  The thermoplastic elastomer, known as polyether ester elastomer, may be referred to as PEEL or, as COPE (from copolyester) or, as TEEE (thermoplastic elastomer ether ester) or, as YBPO (an American suggestion)  Another abbreviation is TPE-E  that is thermoplastic elastomer - ether based

## Abbreviation Use.

Because of the possibility of confusion, it is suggested that when abbreviations are used in publications that their first occurrence in the text should be enclosed in parentheses, i e brackets, and preceded by the written word being abbreviated  So, for the first time, polystyrene would appear in an article as polystyrene (PS)  Subsequent references to such words in the publication can then be by means of the abbreviation  The abbreviations given in Table 3, this table summarizes the injection molding conditions of various thermoplastics, are those in common use

## Some Suppliers.

The suppliers are not necessarily the manufacturers as like any other commodity, plastics are bought and sold on a world-wide basis; some companies also specialize in making plastics compounds by, for example, adding fillers and in such a case, the resultant compound may be marketed under their own trade name, see Table 3 for a list of some abbreviations and trade names/trade marks

## Trade Names or Trade Marks.

Where possible the name associated with a particular Company's polymer should be known - this is because in some molding shops, plastics are often only known by their trade name or trade mark  An alphabetical list of some commonly encountered trade names/ trade marks is given in Table 4

# ABBREVIATIONS USED FOR RUBBERY MATERIALS.

Rubbery materials, and compositions based upon them, are commonly referred to by a number of letters which refer to the monomers on which the polymer is based The standard recommended practice (D1418-72A) issued by the American Society for Testing Materials (ASTM) is the most widely used for the nomenclature of rubbers (elastomers) and lattices This practice recommends that the rubbers be grouped and coded into a number of classes according to the chemical composition of the polymer chain The classes are:

M - Rubbers having a saturated chain of the polymethylene type
N - Rubbers having nitrogen in the polymer chain
O - Rubbers having oxygen in the polymer chain
R - Rubbers having an unsaturated carbon chain, for example natural rubber and synthetic rubbers derived at least partly from diolefins
0 - Rubbers having silicone in the polymer chain
T - Rubbers having sulfur in the polymer chain
U - Rubbers having carbon, oxygen and nitrogen in the polymer chain

Of these various types, the 'R' and 'M' classes are the most commercially important

The 'M' class includes:

CM - Chloro-polyethylene
EPDM - Terpolymer of ethylene, propylene and a diene with the residual unsaturated portion of the diene in the side chain
EPM - Copolymers of ethylene and propylene

The 'R' class is defined by inserting the name of the monomer(s) before the word 'rubber' from which it was prepared (except for natural rubber) The letter immediately preceding the letter R signifies the diolefin from which the rubber was prepared (except for natural rubber) Any letter(s) preceding the diolefin letter signifies the comonomer(s) Commonly encountered members of this class are

BR - butadiene rubber (BR is also known as polychloroprene)
IIR - isobutene-isoprene
IR - isoprene synthetic (IR is also known as cis-polyisoprene)
NBR - nitrile-butadiene (NBR is also known as acrylonitrile butadiene rubber or, nitrile butadiene rubber)
NR - natural rubber
SBR - styrene-butadiene rubber

# FLOW TESTS.

Because most methods of shaping plastics are melt processes, such as injection molding and extrusion, the measurement of melt flow properties is extremely important A large number of tests have been devised to measure such properties but, in general, such tests may be grouped into low shear rate tests and high shear rate tests

## Flow Rate (FR).

Usually referred to as MFR or MFI, the terms mean the same and stand for melt flow rate and melt flow index respectively This test is widely used, particularly for polyolefins, as the test is easy to do and to understand A heated plastics material (for example, PE) is forced through a hole of a certain size (a die), at a specified temperature, by a specified weight The amount of PE extruded in 10 minutes is called the MFR and results are reported as, for example, MFR (190, 2,16) = 2,3 This means that the temperature was 190°C and a load of 2 16kg was used Under these conditions, 2 3g of the plastics material was extruded in 10 minutes, MFR is a low shear rate test, for example, the shear rate may only be $1s^{-1}$ Larger weights than 2 16kg may be used and different temperatures may also be used, what is used depends upon the material and upon the grade of material For UPVC a weight of 20kg may be employed and the temperature suggested in ASTM D 3364 is 175°C, that is 347°F

## Extrusion Testing.

In some establishments, checks are made on the incoming raw material by using a small, single-screw extruder as a rheometer Usually a rod die is specified and the machine is set at specified temperatures The extrusion behaviour is measured over a range of screw speeds and graphs are plotted of output against screw speed, temperature against screw speed and die swell against screw speed One of the big problems is maintaining the set temperatures as, any alteration in screw speed alters the extrusion cylinder temperatures; the melt temperature often alters significantly as the screw speed is changed As a range of screw speeds are employed, the shear rates employed can become quite high and so, this type of equipment can be regarded as a high shear device

## Flow Path:Wall Thickness Ratio.

This is another way of indicating the ease of flow of a plastics material The test is performed on an injection molding machine under specified conditions and using 'typical' molds The result is expressed as a ratio If the ratio is quoted as being 150:1 then this means that if the wall thickness of the molding is 1mm then, the maximum length of flow possible will be approximately 150mm Because the amount of flow possible is dependent upon wall thickness, the flow ratios may be quoted for a range of wall thicknesses, for example, 1, 2 and 3mm/0 04, 0 08 and 0 12in As a range of gates are employed, the shear rates employed can become quite high and so, this type of equipment is regarded as a high shear device

## Spiral Flow Length.

This test is not a standard test although it is widely known in the injection molding industry The test is performed on an injection molding machine under specified conditions and using a mold which has an unusual cavity cut into one half The cavity consists of an Archimedean spiral which is fed from the centre via the sprue As material is forced into the cavity, flow continues until the material sets or cools The test is not a straight forward rheological test as hot material is flowing into a cooler mold After ejection, the spiral is measured, either the weight or the length is recorded The result is expressed, for example, as a certain length produced under specified conditions

When this test is being performed, it is important to hold the screw cushion size constant while changing another machine setting, for example, while changing the temperature or, the injection rate As an injection molding machine is employed, the shear rates employed can become quite high and so, this type of equipment is regarded as a high shear device

## Flow Tab Length.

This test is not a standard test although it is widely known in the injection molding industry The test is performed on an injection molding machine under the production conditions and using the production mold Somewhere within the system, for example, at the end of a runner, a graduated tab is added As material is forced into the cavity, then this flow tab is also partially filled at the same time After ejection, with the component, the length of the flow tab is measured The result is expressed, for example, as a certain length produced under the specified production conditions and is entered on the production records The test is not a straight forward rheological test as hot material is flowing into a cooler mold As an injection molding machine is employed, the shear rates employed can become quite high and so, this type of equipment is regarded as a high shear device

## Minimum Molding Pressure.

This test is not a standard test but was fairly popular when injection molding machines were only fitted with an injection pressure control; this valve controlled the injection line pressure and therefore indirectly, the speed of injection. The test is performed on an injection molding machine under the production conditions and using the production mold. At a specified time, component production is stopped but the machine continues molding the components using the set cycle; the injection line pressure is progressively reduced until the cavity, or one of the cavities, begins to short. The result is expressed, for example, as a pressure (psi or bar), used under the specified production conditions and is entered on the production records. As an injection molding machine is employed, the shear rates employed can become quite high and so, this type of equipment is regarded as a high shear device.

## Reciprocating Screw Rheometer (RCR).

The job of a laboratory capillary rheometer (LCR), a high shear rate rheometer, can be performed by an in-line screw, injection molding machine provided that, the machine is equipped with a suitable (a nozzle) pressure transducer and that the injection speed can be set and held at a specified value. The cylinder, or barrel, is charged with the plastics material using a slow screw rotational speed and a low back pressure; this charge of material is allowed to stand in the barrel for, say, 2 minutes. The use of such conditions will promote temperature uniformity and should give residence times similar to those found in a LCR. The melt is then purged from the barrel, into the air, and the pressure/speed/melt temperature recorded: if a melt temperature cannot be measured directly then the temperature of the purged material may be measured using a probe. The conditions are then changed and the measurements repeated.

## High Shear Rate Rheometry.

Such flow testing is commonly done by forcing the heat-softened, plastics material through a specified die, using a ram, at a known ram speed and material temperature: the pressure opposing flow is measured. The ram speed is then changed and the new pressure (opposing flow or, needed to maintain this speed), is measured and recorded. The ram speed is then changed, the pressure recorded etc. This procedure is repeated at different cylinder, or barrel, temperatures. For each ram speed a pressure is recorded. Knowing the barrel dimensions and the ram speed, the volumetric flow rate through the die can be calculated. In turn the shear stress and the shear rate may then be estimated and used to construct flow curves.

Characterization of material's shear flow properties is therefore done, over a temperature range, using an imposed rate, laboratory capillary rheometer (LCR).

## Imposed Rate Testing.

While most high shear rate rheometers are of the imposed rate type, i.e. imposed ram speed, machines are also available in which the melt is extruded by means of an inert gas under pressure. In this case the weight of material extruded is noted. Using the melt density and volume extruded per unit time is calculated and from this the shear rate is determined. Both this type of machine and the Flow Rate equipment may be referred to as an imposed pressure type rheometer.

## Moisture Content.

With many plastics materials, the level of water.moisture in the material fed to the processing equipment must be kept below very small values. For example, the material fed to an injection molding machine must have a moisture level of below 0.2%. This is usually to prevent the production of moldings with a poor surface finish; however, the water can act as a flow promoter. This means that if the flow properties of a production material are being assessed then the sample used, for flow testing, must have the same water content as the production material.

# EFFECT OF PROCESSING ON PROPERTIES.

Most commercial plastics, also known as resins, are based on the element carbon and are synthesized, or made, from simple, oil-based raw materials. These starting materials are called monomers and these simple, low molecular weight materials are put together (polymerized) so as to form polymers. This term means that the final product consists of many identical, repeat units; because the final molecular weight (or mass) is so large, the material may also be referred to as a 'high polymer' or, as a 'macromolecule'.

## Plastics.

A plastic is a resin, or polymer, which is capable of being shaped or molded under conditions of moderate temperature and pressure. There are two main categories of plastic and these are thermoplastics and thermosetting plastics (thermosets). Thermoplastic products, for example an injection molding, may be softened and reshaped whereas a thermoset molding cannot. In terms of tonnage, and usage in injection molding, thermoplastics are by far the most important.

## Amorphous and Crystalline.

Thermoplastics materials may be divided into two main categories; these are amorphous and crystalline. An amorphous, thermoplastics material is usually a hard, clear, rigid material with a low shrinkage and a low impact strength. A crystalline plastic also contains amorphous material and so may also be known as a semi-crystalline, thermoplastics material. Such plastics are usually tougher, softer, but can have a higher heat distortion temperature, than an amorphous, thermoplastics material: such plastics are also translucent, or opaque, have a high shrinkage and a high specific heat. The ability to crystallize depends on many factors; such factors include the regularity of the polymer molecule and the degree of branching.

## Long Chain Structure.

The high polymers, chains or 'macromolecules', on which plastics are based are incredibly long and, because of the carbon to carbon bond, on which they are based, they are also not normally straight. (there may be 50,000 atoms linked together in a long chain-like molecule or structure: the chains are also of different lengths.) When there is no order in the system, i.e. if it is an amorphous material, the chains prefer to exist in a random, coiled-up state (just like the shape you would get if you dropped a piece of string on the floor). The separate chains (the separate, long chain molecules) are also normally intertwined one with the other. If crystallization is possible then the chains, or portions of the chains, may lie side-by-side in a more ordered fashion. Because of, for example, the length of the chains involved and the chain entanglements involved, a thermoplastics material does not crystallize completely on cooling; this is why it is called a 'semi-crystalline, thermoplastics material'. Such crystalline materials contain both crystalline and amorphous regions.

## Orientation.

When a molten polymer is made to flow then this occurs because the polymer chains slip, or slide, one over the other. Layers slip one over the other in what is called 'laminar flow'. As the individual, plastics molecules move, one relative to the other, then this causes the molecules to change their direction or 'orientation'. (Reasons for this change are, for example, chain entanglements and friction between layers). The chains become 'drawn out' in the direction of flow and, because of the rapid cooling employed in injection molding, this orientation is 'frozen in': the product contains what is referred to as, frozen in stresses or, frozen in strains. The injection molding contains molecules which are orientated in the flow direction: this means that we have a grain effect just like the one that exists in wood. Because of the grain, the wood is stronger in one direction than it is in another.

## Effect of Orientation on Properties.

Because of the grain effect in wood, the wood is much stronger in one direction than it is in another. Injection moldings are also much stronger in one direction than they are in another. However, it is not often that commercial use can be made of this effect. This is because if an injection molding is struck or dropped then, it always fails in the weakest direction. This is in the flow direction; it fails 'across the grain'. This is because of the weak interchain forces which bind the orientated molecules together.

## Differing Crystallization.

A molten polymer is made to flow by applying a force, sometimes referred to as a stress, to the melt. This causes orientation to occur and, this in turn causes the plastics material to have different properties in differing directions. However, for a plastics material which is capable of crystallization, then additional complications usually occur. This is because the amount and type of crystal structures will depend on, for example, the amount of orientation and the stress applied during cooling. For a particular plastics material there is not just one crystal type or sort but usually more than one. The crystalline structure of a molding made from a semi-crystalline, thermoplastics material is usually very complicated and can vary even from one surface to another, i.e. through the thickness of an injection molding. Apart from the reasons already mentioned, this could be due to the rate of cooling involved. The crystal structures are unlikely to be perfect and so we can also have crystal defects as other complications.

## Object of Injection Molding.

The object of injection molding is to produce identical moldings of the required quality at a specified rate and at an agreed cost. Identical moldings can only be produced if everything is kept the same. It is not just a matter of feeding the injection molding machine with a consistent raw material. Even if this is done then it is still possible to vary the properties of the injection moldings. This could be done by, for example, changing the injection speed, the melt temperature or, the injection molding pressure. Changing machine settings will change orientation and./or crystallinity. Such changes can bring about truly, staggering changes in the properties of injection molded components, this means that consistency, and control, is the key to successful injection molding.

# MATERIAL DETECTION OR IDENTIFICATION.

Complete identification of most polymer products can be very difficult if not impossible. However, in many cases this is often not required; what is required in many cases is the separation, or identification, of lots of molding materials whose identity has been lost or, an indication of the type of material used to make a component. In such cases, the use of simple tests is justified.

## Simple Tests.

Simple tests include a preliminary examination, density, melting point and behaviour on heating. The tests should be done in the order shown; if the density determination is high, for example greater than 1.7 $gcm^{-3}$ (SG greater than 1.7) then the material could well be a fluoropolymer and heating tests should not be done because of the danger from the fumes evolved. In any heating test, only a very small sample should be employed for the same reason and a fume cupboard should be used.

## Preliminary Examination.

The component, or material, should be examined for transparency, color, method of manufacture, its resistance to cutting etc. This is because, for example, such an examination can give a strong indication as to the type of material used to make a specific component. The dimensions and weight of a component should also be noted together with any ejection marks, flash lines etc.

## Density.

Very often the absolute density of the material is not required; what is required is an approximate value. This may be obtained by seeing if the material sinks or swims in a limited range of liquids. These may include water and saturated magnesium chloride; the former has a density of 1$gcm^{-3}$ and the latter has a density of 1.34$gcm^{-3}$. (When the density units are expressed in $gcm^{-3}$ then, the value is the same as the specific gravity value.) If the material is filled, then the density will usually be higher than that of the unfilled material: this is because most inorganic fillers, the most common fillers, have a relatively high density. If a weighed sample of the material is completely burnt then, the inorganic filler content may be easily estimated.

## Melting Point.

Once again a very accurate value is often not required. The simplest way of obtaining an approximate value is by heating a small sample of the material on a metal hot plate while measuring the temperature rise and the temperature of the hot plate just below the plastics material; a heating rate of approximately 50°C/hour, or 90°F/hour, should be used. An amorphous, thermoplastics material will not have a sharp melting point whereas a semi-crystalline, thermoplastics material will usually have a sharp melting point. It is useful to have a glass rod so that the sample may be moved, or prodded, during heating. Some details of melting points and softening points are given in Table 5.

## Behaviour on Heating.

Thermoplastics soften on heating whereas thermosetting plastics (thermosets) do not - once the temperature reaches a certain point they decompose. An amorphous, thermoplastics material will soften over a wider temperature range than a semi-crystalline, thermoplastics material; these have sharp melting points. Often this test may be combined with the previous one.

# MATERIALS AND COMPONENTS HANDLING.

The subject of materials and component handling is a subject that in many molding shops appears to be ignored so that material and molding contamination is common. The most common cause of material contamination is water and that of moldings is oil and/or grease. Far too often a lot of time and money is spent on improving the injection molding operation while ignoring the subject of handling.

## Material Supply.

Most materials are supplied as granules or pellets and are usually supplied in either bags or, in bulk containers. When supplied in 50lb/22.6kg bags, then the material is often supplied in 20 bag (1,000lb) loads. If supplied in 25kg/55.1lb bags then, the material is often supplied in 1,000kg/2240lb lots.

Supplying the material in bags, or sacks, is not the only way that the material can be supplied: considerable discounts may be obtained if the plastics material is purchased in bulk and, supplied in, for example, bulk containers. With some materials, this form of supply may not be acceptable as, for example, excessive water absorption may occur.

No matter how they are delivered, the materials must be carefully looked after as plastics are expensive and many will burn relatively easily. Plastics materials are contaminated extremely easily simply by leaving bags, containers, or hoppers, open. Therefore always keep materials covered.

## Testing of Materials.

Most molding materials are accepted as being satisfactory until something goes wrong during the actual injection molding operation. It makes sense however, to inspect the material and note color, particle size, particle size consistency and any obvious contamination. There is no point in molding 'out-of spec' material: 'out-of spec' moldings will be the result. If possible, the ease of flow of the material should be checked during injection molding using a flow tab (an extension to the runner) or, by noting the ease of mold filling or, by the use of a nozzle pressure transducer. The presence of surface splay, or silver streaking, will indicate if the molding material, needs drying. This, for many materials, should be checked before molding commences.

## Moisture Content.

With many plastics materials, the level of water/moisture in the material fed to the injection molding machine, must be kept below very small values, for example, below 0.2%. This is usually to prevent the production of moldings with a poor surface finish: with some materials, for example PC, the injection moldings can be weakened by the use of 'wet' molding material. Simple tests may reveal the presence of surplus moisture, for example, by heating pellets of the suspect material between glass slides. Machines are available for measuring water content: may be done electrically or, by reacting the moisture with calcium carbide. In many molding shops, the raw materials are dried as a matter of course so as to prevent faults in production.

## Material Handling.

All storage and unloading areas must be kept clean and dry; to minimize the fire hazard, the store rooms should be separated from the injection molding shop by fire resistant doors. Store the materials away from direct sunlight and on properly constructed racks. Usually the use of unheated storage areas, with natural ventilation, is sufficient. Ensure that the material does not stagnate in the stores by adopting a strict stock control policy. Adopt a strict first-in, first-out policy (Fi-Fo). Strict stock control is important, as within a shipment of material there could be several different batches and one of these could be faulty. By adopting a strict stock control system, a faulty batch can be readily identified and isolated thus preventing further defective moldings being produced.

## Feed Forms.

Many plastics materials are available in more than one feed form, for example, granules or powder. If the material is available in more than one feed form, then feeding problems will probably be encountered if a mixture of feed forms is used. In terms of output efficiency, spherical granules (of approximately 3mm (0.118in) diameter) are the most efficient. Fine powder is the worst, followed by regranulated material, then by cube cut granules and then by lace cut granules (granules made by chopping strands with a circular cross-section).

When plastics materials, in fine powder or dust form, are used then, the dangers of using such ‘dusty’ materials should be appreciated. For example, all equipment must be properly earthed (electrically grounded).

## Dust.

When plastics are conveyed in automatic systems, then the dangers of dust generation should be appreciated. All equipment must be properly earthed as there is a danger of fire or explosion when dust is involved. Try and avoid generating dust and take steps to minimize breathing it in (ingestion) if you are working in a dusty atmosphere, handling fine material or, handling any dry powder. All working areas must be well ventilated, skin contact should be avoided and face masks worn. It may not be the plastics material that is harmful, it could be an additive that is used in conjunction with the plastics material, for example, a colorant or stabilizer.

## Water Contamination.

When the plastic is brought into the molding shop, allow the material to reach work-shop temperature as this will save the material becoming contaminated by condensation. For example, before the containers are opened, after being brought from store, allow them to stand in the injection molding shop for 8 hours: this applies particularly during the colder months and at times of high humidity. At such times it is advisable to store the day's requirements in the molding shop.

## Drying.

Most plastics materials are supplied dry and ready for use although some are 'wet' and must be dried before being injection molded. Many plastics, and particularly engineering plastics, absorb water (they are hygroscopic) and, if this is so, they must be dried before use (in many injection molding shops, the materials are dried as a matter of course as this saves any argument). Alternatively, the water (moisture) content in a wet material may be reduced to an acceptable level by the use of a vented machine: this will reduce not only the water content but will remove other substances which are gases (volatiles) at injection molding temperatures. However, with some materials, for example PC, the use of a vented machine may result in a loss of properties as a result of heating the plastics material while it is in contact with water. Such a loss of properties may not be immediately apparent as the moldings may appear satisfactory; the impact strength in service may not, however, be satisfactory.

A measure of how much water a material will absorb is given by how much it will absorb in 24 hours at room temperature. If greater than approximately 0.2%, drying is usually necessary; if less, this means that drying is not normally necessary. If drying is required, then dry in either a hot air oven, in a desiccant dryer or, in a vacuum dryer. The last two methods are the more efficient as they are quicker and reduce the water content to lower values. They take approximately half the time necessary when using a hot air drier and, for some materials, they are the only way of getting them dry (see Table 6).

## After Drying.

After drying the material it should not be placed into an open hopper for extended periods of time where it will reabsorb moisture for, when molding hygroscopic materials (such as ABS, acrylics, cellulosics and SAN) this can produce moldings having splash or splay marks on their surface. Once the material has been placed in the molding machine hopper then the hopper lid must be immediately replaced so as to prevent contamination and so as to prevent accidents, for example, finger trapping. Some materials will require the use of a heated hopper assembly.

## Calculating Hopper Size.

Material usage for a given machine/mold combination should be calculated to determine how much material should be loaded into the hopper to prevent storage for any length of time, preferably using a heated hopper assembly. Care should be taken to ensure that the hygroscopic materials are in the hopper for no longer than 1 hour. Consider the example where of a machine which is producing 6 components at a cycle time of 24 seconds (24s). The weight of each component and the feed system is 14 grams (14g) and 12 g respectively, therefore the total shot weight is (6 x 14) + 12 = 96g. Given the following formula, the material consumption (Q) in kilos per hour (kg/h) can be calculated as follows:

$$Q = \frac{\text{total shot weight (g)} \times 3600}{1000 \times \text{cycle time (s)}}$$

$$= \frac{96 \times 3600}{1000 \times 24}$$

$$= 14.4\,\text{kg/h}$$

Therefore the hopper should be filled with 14.4 kg, the level noted accordingly, and it should not be topped up beyond this point.

## Molding Contamination.

Oil and/or grease contamination usually occurs after ejection of the moldings (for example, it drops from the toggles, platen bushes and hydraulic cylinder seals) and should be corrected immediately; it should be kept under control by preventative maintenance. (Using all-electric machines it is now possible to produce moldings under clean room conditions). A common cause of grease contamination is grease leaching from around the ejector pins; this is particularly true for ABS. The mold should be stripped and cleaned thoroughly and then, re-assembled using a white PTFE based lubricant. Many plastics attract dust at a tremendous rate and this can be extremely difficult, and expensive, to remove. It is far better to stop the problem occurring in the first place by, for example, keeping the moldings covered at all times and handling them as little as possible. When they are handled, or moved, the dangers of scratching the injection moldings should be remembered (they will even scratch each other if rubbed gently together); many injection moldings are damaged in transit because of poor packing. If touched with the bare hands then grease can be transferred to the moldings and this, again, can be very troublesome, for example, in electroplating. Clean, dry gloves should be worn when injection moldings are handled unless it has been proved that this precaution is unnecessary.

# DRYING.

Most plastics materials are supplied dry and ready for use although some are 'wet' and must be dried before being molded. It makes sense however, to prevent water contamination occurring as, even if the material is going to be dried, this will reduce energy consumption. A measure of how much water a material will absorb is given by how much it will absorb in 24 hours at room temperature. If greater than approximately 0.2%, drying is usually necessary; if less, this means that drying is not normally necessary. However, in many shops the materials are dried as a matter of course as this saves any argument over what needs to be dried and if so, for how long. (When PET is molded it may be necessary to use exceptionally dry material, i.e. with a moisture content no higher than 0.01%.

## Preventing Condensation.

When the plastic is brought into the molding shop, allow the material to reach work-shop temperature as this will save the material becoming contaminated by condensation. For example, before the containers are opened, after being brought from store, allow them to stand in the molding shop for 8 hours; this applies particularly during the colder months, and at times of high humidity. At such times it is advisable to store the day's requirements in the molding shop, unopened, before use.

## Vented Machines.

The water (moisture) content in a wet material may be reduced to an acceptable level by the use of a vented machine: this will reduce not only the water content but will remove other substances which are bases (volatiles) at molding temperatures and will also give very efficient color compounding. The basic idea behind a vented molding machine, is that the melt is first compressed and then, it is decompressed. That is, by screw compression, the plastics material is changed to a melt, contaminants are changed to gases and, by reducing material pressure the volatiles are 'flashed off' through a vent port. The melt is then recompressed and passed to the front of the cylinder or barrel. Vented machines are sometimes seen as molding machines. However, it must be remembered that the action of heating some plastics in contact with water can cause decomposition, or degradation. Because of the screw designs on which they are based, such machines have good mixing characteristics.

## Oven Drying.

If oven drying is required, then dry in either a hot air oven, in a dessicant dryer or, in a vacuum dryer. Oven drying (convection drying) is popular as it is relatively cheap to install and easy to operate. However, it is not very efficient and contamination often happens. The plastics material is placed in thin layers (below 10mm/0.394in thick) inside a convection oven; a fan assisted oven is better. The drying conditions for different materials are shown in Table 6. Drying times are rated in hours and care should be taken to avoid material change by plasticizer loss or oxidation. In order to stop the air becoming saturated with water vapor, some of the air should be bled off and the trays should be covered with fine net, or gauze, to prevent contamination. Ideally the air should be filtered and recirculated as this will remove contaminants and save on energy.

## Calculating Hopper Size.

After drying the material it should not be placed into an unheated hopper for extended periods of time where it will reabsorb moisture for, when molding hygroscopic materials, such as ABS and PA 66, this can produce moldings having splash or splay marks on their surfaces. Material usage for a given machine/mold combination should be calculated (see the section on Materials and components handling) so as to determine how much material should be loaded into the hopper so as to prevent storage for any length of time. Care should be taken to ensure that the hygroscopic materials are in the unheated hopper for no longer than 1 hour.

## Vacuum and Desiccant Drying.

More efficient drying results if, plastics materials can be dried while a vacuum is applied during the drying process. However, because of the practical difficulties involved, vacuum drying is not often used in the molding industry. A more popular method is desiccant drying. The air is passed over/through a 'molecular sieve desiccant' which removes the water from the air: this lowers the dew point of the air to, for example, -40°C/-40°F. The hot, dry air is then used to dry the plastics material.

These last two methods of drying plastics are more efficient than oven drying as, they are quicker and reduce the water content to lower values. They take approximately half the time necessary when using a hot air dryer and for some materials, they are the only way of getting them dry.

## Hopper Dryers and Heated Hoppers.

With these two systems the plastics material is dried, or kept dry, on the molding machine. With the simplest systems, heaters heat the metal hoppers. Such a system is useful if the plastics material has been dried elsewhere as, its use prevents condensation occurring. A heated hopper is not necessarily therefore, hopper dryer. To get through the molding material of a predetermined time. To get the required residence time, the hopper must be relatively large (this can be calculated as shown in the section on Materials and Components Handling. Unless the material has the required residence time, such systems are again best referred to as hopper heaters rather than as hopper dryers. The efficiency is improved if the air is dried by passing it through/over a desiccant dryer: each machine may be fitted with its own dehumidifying dryer.

## Volatile Elimination.

When a plastics material is dried then water is often not the only contaminant that is removed; materials which are gases at processing temperatures are also extracted from the plastic in the form of volatiles. Such volatiles therefore include water and organic materials such as monomers. In a molding shop/factory, which is processing, for example, PS; the acrid, biting stink of badly processed material is often painfully obvious. One of the substances which causes this horrible odor is styrene. Now, organic chemicals, such as styrene, should be treated with great care and respect as they are harmful to the human body. The processing conditions should be adjusted to minimize their formation and any, which are formed, should be disposed of in an acceptable way and not allowed to pollute the molding shop/factory atmosphere.

## Volatile Disposal.

What is often seen rising from the die/nozzle area of a molding machine, is volatile matter formed by the burning of plastics material: such plastics material may have 'wept' from the die/nozzle during molding or, have been left there after purging. It is very important to keep the outside of the die/nozzle, and of heaters, spotlessly clean as otherwise harmful gases are formed. The operating conditions, for example, the barrel temperatures, should be kept at values (that is, as low as possible) which will minimize gas formation and any escaping volatile matter should be burnt in a catalytic burner, mounted above the machine. As some volatiles, for example, some flame retardants, cannot be burnt in this way, the shop/factory should also be equipped with an efficient extraction system.

# COLORING

Amorphous thermoplastic materials are transparent and so are available in a wider color range than semi-crystalline, thermoplastics materials. However, in general, all plastics are available, or can be made in a wide range of colors.

## Compounded Material.

Traditionally all plastics were molded from colored granules but now, because of the ease with which color may be added at the machine, there is increasing use of color concentrates or masterbatches in conjunction with natural, or un-colored, material. However, compounding still remains the most accurate coloring technique and gives the most precise, and reproducible, color. It also gives the best density of color and is the most suitable for small runs. Most commodity plastics are colored on the injection molding machine whereas most engineering plastics are sold already colored, i.e. fully compounded.

## Masterbatches.

Masterbatches may be solid or liquid and a wide color range is possible from such blends. The solid ones are the most popular with approximately 60% of all in-house, color addition being done by solid masterbatch. Such solid masterbatches may be basd on a wax-like carrier (a universal carrier) or, on the base polymer (polymer specific concentrate). Such concentrates are the cheaper of the two. Before a universal masterbatch is used it is important to check that it is suitable for use with the plastic; some masterbatches are claimed to be universal but this claim should be treated with caution. Masterbatches are also available which contain other additives, for example, UV absorbers.

## Masterbatch Advantages.

Masterbatches may be used by dry-blending the resin with the masterbatch and feeding the mixture to the molding machine or, the masterbatch may beadded (dosed) actually on the injection molding machine. The use of masterbatches results in:

i) cheaper color - compared to compounded material,
ii) reduced dusting problems - compared to dry pigmint use,
iii) reduced raw material costs - as only natural material is ordered, bulk purchases may be arranged and,
iv) simplified storage - as only natural material is ordered and stored.

However, the use of masterbatch mixtures can cause problems.

The usual problem is one of color shade differences between different machines; caused by inaccuracies in the dosing equipment. Another is separation of the masterbatch from the plastic in the hopper when dry blends are used.

## Liquid Color.

With this system the colorant is dispersed in a liquid carrier so as to give a liquid masterbatch which can be easily dispensed, or metered, during processing. Despite initial optimism, liquid colors are now not widely used. Most successful applications seem to be on long runs with one color where the precise metering, for uniform color, can be established and held. A major problem is one of cleaning up if they are spilt; another is one of maintaining dosing accuracy.

## Dry Color.

The cheapest way of coloring plastics is by the use of dry colorants, however one main disadvantage is that it tends to be a messy and dusty process. To ensure color consistency throughout a production run (i.e. to improve accuracy and consistency), sachets or cartons holding the correct amount of colorant, for a specific size lot of plastics material, are available.

When using dry colorants it is imperative to ensure that the surfaces of the granules are uniformly covered with the colorant in order to achieve satisfactory dispersion of colorant in the polymer melt. The type of blending technique (e.g. single or multi axis rotation) and the blending time should be standardized, so as to ensure that uniform coverage of granules by colorant is obtained. Once a successful procedure has been established this should be maintained in order to achieve color uniformity.

Care must also be taken to ensure that the colorant does not absorb moisture, during storage, as agglomerates will readily occur; such agglomerates can give color shading or streaking in the molding. Because of the toxicity problems many powdered pigments (e.g. cadmium based) require careful handling; such problems help explain why the use of dry colors is declining.

## Note.

Whatever the method used to color the natural polymer, it must be borne in mind that the properties and dimensions of the molded part can be considerably affected by the type of dye or pigment used.

# REPROCESSING.

The ability to reclaim faulty moldings, and the feed system, produced during the molding of thermoplastic materials, is very often a mixed blessing as it can lead to the attitude that the production of faulty moldings does not matter. 'After all, the moldings can be ground up to give reclaimed material and so used again' is an often heard comment.

## Wasted Effort.

Moldings can be reclaimed but think of the wasted time and effort: it costs an awful lot of money to keep an injection molding machine running, so it makes sense to try and get the injection molding machine running properly and consistently so that reject moldings are not being produced. In other words, try and get it right first time. Once the plastic moldings are produced then ensure that they are looked after. Remember that plastics attract dust and so do not leave moldings exposed to the atmosphere: keep them covered and try to avoid handling them if at all possible.

## Material Changes.

During the molding process there should be little or no change in the plastics material. Any change is usually undesirable. Some of the change that can occur are:

a) water contamination - caused through the material absorbing water or by condensation;

b) oxidation - when plastics are heated in contact with oxygen then they will 'oxidize' or combine with the oxygen: the first sign of this is a change in color and then a change in properties;

c) overheating - if overheated, even if there is no air present, then plastics will suffer decomposition or thermal degradation: often gases are produced which can be dangerous;

d) dust contamination - it is easy to generate static electricity on plastics and this attracts dust, or dirt, very quickly.

## Effect of Additives.

Some materials can speed up (they catalyze) chemical changes, for example, copper causes a rapid change in hot PP. What this means is that the addition of any material to a material/resin should be done with care and only done when it is certain that addition will not cause an undesirable change. This means that every additive should have been tested and only tested additives used in production. What this means is that if a pigment or color masterbatch has been specified then there must be no substitution with another until the new material has been tested and approved.

## Ruthless Rejection.

When faulty moldings and feed systems are scheduled for reclamation then they should be looked after very carefully and only those parts which are free from contamination and color changes should be used. This is because it is common practice to blend virgin (new) material with reclaimed material (regrind) and if the reclaimed material is contaminated, then a lot more reject material is produced, If unchecked the problem can quickly get out of hand. So, ruthlessly reject any moldings or any feed system which is suspected of being contaminated or degraded. That is, only reclaim good quality material.

## Regular Inspection.

Keep all material which is to be reclaimed, covered. Keep the grinder and the storage containers spotlessly clean. Inspect the grinder blades regularly for breakage, bluntness and wear and then replace when necessary. Put the reclaimed material through equipment which will remove dust or fines, metal fragments and water. Then treat this material as new stock, for example, store the reclaimed material in tightly sealed containers in a clean, dry storeroom. Blend with virgin material in a precisely agreed ratio.

## By the Press Granulation.

Regranulation of feed systems can also be carried out at the molding press by means of an auger regranulator assembly. The entrance section of the regranulator is positioned adjacent to the chute of the molding machine into which the feed system falls when ejected from the mold. Once the material has been regranulated, it is then automatically blended, at the required ratio, with virgin material and the mixture is then fed into the molding machine hopper. This type of process has two distinct advantages as it minimizes the risk of contamination and the need to re-dry hygroscopic materials; however, this type of assembly does take up invaluable floor space around the molding machine.

## Runnerless Molding.

Many moldings are produced using injection molds in which the feed system is not ejected at the end of the cycle. The feed system is kept hot so that when the next injection shot is made the incoming material flows through the still hot feed system. As the sprue and runner system is often the thickest part of the shot it nearly always takes the longest time to cool and thus slows up production if it must be cooled for ejection purposes. By eliminating a cold feed system we save on reclaiming and can speed up the cycle.

# OPERATING SEQUENCE OF A SCREW MACHINE.

An in-line reciprocating single screw machine in shown in Figure 1. If we assume that the machine has just completed a shot then the operating sequence will be as follows (if a thermoplastic material is being molded).

(i) The mold closes - this is usually done by a hydraulic system, either direct hydraulic, toggle or lock and block.

(ii) The mold is clamped - clamping pressures should be kept low but they generally are about 2 tsi (31 $MNm^{-2}$) of the moldings projected area.

(iii) The injection unit or carriage moves forward; this implies that sprue break has been employed.

(iv) The screw is pushed forward - most commonly the screw is not rotated as it is pushed forward by the hydraulic ram(s). As there is only melt in front of the screw, pressure losses are low. On many machines the injection speed can be varied during the stroke so as to minimize molding faults.

(v) The screw is held in the forward position (dwell under pressure) - after the screw has penetrated a pre-set distance into the barrel. Then the pressure is dropped to the second stage pressure by means of a micro-switch and striker or, a transducer inside the mold initiates the pressure switch-over. This drop is usually set to occur just as the melt fills the mold. Apart from the energy savings, other benefits result, for example, lower molding weight, more consistent molding weight and lower stress levels in the moldings (which results in parts with superior properties). The amount of melt which remains in front of the screw after injection is completed (the screw cushion) should be adjusted to give the minimum consistent with good pressure transmission, for example, 0.118in/3mm on small machines is suggested.

(vi) Cooling then commences - during this part of the cycle a number of events are scheduled to occur. For example:

a. The screw rotates and this causes material to be pumped forward. The pressure developed pushes the screw back and the amount of screw travel is used to regulate the feed by making the injection assembly strike a limit switch which turns off the screw motor. By regulating the oil flow from the injection ram assembly then the pressure which the screw must overcome before it can return (back pressure) can be increased so as to improve the mixing. Keep the back pressure and the screw revolutions as low as possible.

b. At the end of the screw rotation the screw is pulled back hydraulically so as to decompress the melt. This action is called suck-back, or decompression, and it helps to prevent the melt from drooling from the nozzle. In this way the need for a shut-off valve may be eliminated.

c. The injection unit is withdrawn so as to affect the sprue break, e.g. by 0.236in/6mm.

d. While all this is happening, heat is constantly being removed from the mold, and therefore the molding, by circulating a cooling fluid through channels in the mold. As the screw improves melt temperature uniformity it is found that the total heat content is reduced, compared to a ram machine, and therefore cycle times are shorter. Not only does the screw function as a mixer but it also functions as a heat generator and therefore, with care, melt temperature gradients can be minimized. This is of great assistance if heat sensitive materials (e.g. UPVC) are to be processed.

(vii) The mold opens - when the cooling timer lapses then this causes the moving mold half to be withdrawn so that the molding may be ejected. On many machines this ejection is done hydraulically as this enables the ejection force and speed to be matched to that required.

(viii) The mold remains open - even on semi-automatic cycles (i.e. where the machine does one complete sequence of operations and then stops) it is usual to automatically time the mold open stage so that consistent cycles result. When this timer lapses then the cycle starts again.

It should be noted that the feed to such injection molding machines is very often a mixture of virgin material, regranulated material (regrind) and colorant (often contained in a solid masterbatch). Such materials must be kept clean and dry; a regular ratio of the materials must also be used if machine operation and part consistency is to be maintained. Regranulation (of sprues, runners and faulty moldings) is usually achieved by feeding such scrap through a grinder which may be located by the side of the machine.

# THE BARREL.

It is assumed that the type of machine being used is a single screw type; this is because that type of machine is the most popular. It is the screw and the cylinder, or barrel, which interact to convey, melt and generate pressure within the plastics material. It is essential that this is done in a controlled way as we must have uniformly plasticized material, of constant composition, at the required, controllable rate. To achieve this, the barrel must be made very accurately; the total out-of-alignment error, after all machining, must be less than one half of the screw/barrel clearance.

## Barrel Construction.

Because the pressures generated within a molding machine can reach very high values, machine cylinders, or barrels, must be made to withstand these high pressures. They are made form thick walled, alloy steel tube or pipe and are usually designed to operate at up to 25,000psi (175MNm$^{-2}$); they have a minimum burst pressure of 50,000psi (350MNm$^{-2}$). The feed throat is cut through the barrel wall and the size of the feed opening is approximately the same size as the barrel diameter. At the other end of the barrel, provision is made to attach the nozzle e.g. by means of a clamping nut or end-cap.

Feed zone cooling, and/or temperature control, is very important. Until recently, the feed zone was simply kept cool by circulating water through channels in the feed throat: if this was not done then, the hopper could become 'bridged' i.e. blocked. Now, for the processing of, for example, engineering plastics, the temperature of the feed zone is controlled at a relatively high level so as to improve plasticization and/or, cycle times.

## Wear Resistant Barrels.

The screw and barrel assembly operate in a very aggressive environment which can cause severe wear problems; each year the environment gets worse as material modification becomes more common. To improve the wear resistance of the cylinder or barrel, it may be modified or, lined.

Modification is by, for example, nitriding or ion implantation but these treatments are not as good as lining. Lining is done with a wear resistant alloy. This wear resistant layer may be cast in during barrel manufacture or, the liner may be inserted subsequently (used, for example, to rebuild a worn machine). Such barrel assemblies are known as 'bimetallic cylinders' or as 'bimetallic barrels' and are used when abrasive compounds are being processed. As it is easier to replace a screw than a barrel then, the barrel must be harder than the screw.

## Zoned Heating.

For ease of control, the barrel, is divided into zones or regions. Each of these zones is fitted with its own heating system (unlike extruders, injection molding machines are not usually fitted with heating/cooling systems). The smallest machine will have three zones and larger machines may have twelve. Each of these zones is controlled by a temperature sensor and associated equipment, for example, a microprocessor-based, three term (PID) controller.

It should be noted that it is the melt temperature which is important and that the cylinder temperatures quoted for the processing of a specific material are only guidelines. If you have no experience of processing a particular grade of material, then start with the lowest settings recommended. Measure the melt temperatures which result and then adjust the machine settings to obtain the desired melt temperature. For a given machine, the actual cylinder settings to achieve the suggested melt temperature, will depend on as well, for example, the screw rotational speed and the back pressure.

## Increasing Pressure.

In order to get good quality melt from a screw, it is important that the material be uniformly heated/melted and well mixed. Proper melting and mixing requires that the correct screw be used and that sufficient pressure (or back pressure) is present in the barrel so as to obtain mixing and thermal uniformity. By creating resistance to oil escape (the oil which was used to force the screw forward) back pressure can be built up within the barrel. The improved mixing which results is paid for as the screw takes longer to retract and there is more wear and tear on the machine drive system. Keep the back pressure as low as possible, consistent with air exclusion, the melt temperature uniformity required and the degree of mixing required.

## Screen Packs and Breaker Plates.

In extrusion, screen packs, supported by the breaker plate, are usually used to build up pressure. The screen pack consists of layers of fine, steel mesh, cut to size, and assembled in layers. The coarsest mesh (20 or 40) is placed next to the breaker plate, followed by the next coarsest (40 or 60); then by the next (60 or 80), right the way up to the finest (e.g 200). This construction gives support; to get additional support, some coarse screens are also put on the downstream side. This assembly i.e. the screen pack, is placed inside a recess in the breaker plate where it is held in position by a screwed-in plate. A large number of large holes pierced in the breaker plate (e.g 0.125in or 3.2mm) allow the melt to reach the pack; the fine mesh removes contamination, improves mixing but builds up the pressure losses. Such assemblies have been used on injection molding machines e.g. on ram machines where poor mixing is common and where drooling, of low viscosity melts, is a problem. Screen packs are not commonly seen on screw machines.

## Nozzles.

The melt usually flows from the nozzle into the sprue, but on some molds the nozzle forms part of the mold wall as it extends to the base of the component. There are two other, main types of nozzles, that is, open and sealing. Use an open nozzle as far as possible as they are cheap and give less possibility of stagnation. Such nozzles may be used even with comparatively low viscosity melts if the injection molding machine is equipped with decompression. In some cases a sealing-type nozzle must be used: such a nozzle acts like a valve and traps the material (either plastics melt or gas) in the cylinder, or barrel.

Ensure that the nozzle seats correctly into the sprue bushing (sprue bush) and that the hole in the tip is slightly smaller than the hole in the sprue bushing; this will allow the sprue to be withdrawn easily through the mold. The hole in the sprue bushing should be smaller by 1 mm (0.040 in); nozzle radius should be smaller than the sprue bushing radius by 0.5 mm (0.020 in).

## Filters and Mixing Nozzles.

Inhomogeneities can be removed from plastics melts by the use of extended nozzles which contain a filter element: that is, an insert with flow channels separated by narrow bands or gaps. It is these narrow bands which remove contamination and improve mixing. By extending this principle even better mixing results from the use of stationary mixers. These fit between the barrel and the nozzle and work by dividing and re-combining the melt, many times by making the melt flow through, for example, stainless steel channels.

## Venting.

When injection molding some materials there is a need for cylinder, or barrel, venting: this is to allow for gas escape. In most cases this gas is simply air but it could be a vapor given off by the compound, for example, water or, a monomer. If it were prevented from escaping then, it would be compressed by the melt and carried to the mold; here it would expand and cause bubbles in the product. To allow the gas to escape, before it reaches the nozzle/die, the melt is decompressed part-way along the cylinder or barrel: this is done by decreasing, or reducing, the screw root diameter. At this point a vent, a hole or port, is located in the barrel and the vapor escapes through this. The root diameter of the screw then increases and the devolatilized melt is conveyed towards the nozzle. Machines equipped with this facility are known as ‘vented machines’. There should be a catalytic burner or, a good fume extractor fitted above such vents as the extracted vapors should be treated as harmful.

# THE SCREW.

It is assumed that the type of machine being used is a single screw type; this is because that type of machine is the most popular. It is the screw and the cylinder, or barrel, which interact to convey, melt and generate pressure within the plastics material. It is essential that this is done in a controlled way as we must have uniformly plasticized material, of constant composition, at a constant and controllable rate.

## Screw Details.

Unless otherwise specified it is assumed that the machines have a general purpose (GP) screw installed. With such general purpose screws the channel depth changes along the length of the screw; it is deepest under the hopper and shallowest at the screw tip. This means that the screw has a compression ratio and it is there to compensate for the effective reduction in volume that occurs on melting the plastics granules. The compression ratio is related to channel depth so if the depth is 9.54mm (0.375in) under the hopper and 3.18mm (0.125in) at the tip, then the compression ratio is said to be 3:1. Typically general purpose screws have a compression ratio of approximately 2.2/2.5:1 and a length to diameter ratio (L:D) of about 20:1.

## Screw Zones.

Typically, general purpose screws have three distinct zones: these are the feed zone, the compression (plasticating) zone and the metering (pumping) zone. The feed section starts at the rear of the hopper and has a constant depth. Then, the root diameter of the screw increases gradually from the end of the feed section to the start of the metering section where it becomes constant again. The feed section is approximately 50% of the length (50%L), the transition section is about 30%L and the metering section is 20%L (including the sliding ring valve).

## Valves.

No matter what type of screw is used, it is usual to employ a back-flow valve on the tip of the screw (with some materials, for example UPVC, the use of a valve may not be possible. Drooling from the nozzle is prevented by means of either decompression (suck-back) or, by means of a nozzle valve. When valves are used they must be inspected regularly as they can easily become worn or damaged. Shut off nozzles are not widely used nowadays due to material leakage, and degradátion, taking place within the nozzle assembly.

It is more usual to use an open nozzle on a machine fitted with decompression.

## Decompression.

Many machines are fitted with decompression or suck-back. After the screw has finished rotating, it is drawn back hydraulically so as to suck material away from the nozzle tip. This facility allows the use of an open nozzle. Keep the amount of suck-back as small as is practicable as the introduction of air can cause problems with some materials, for example, with PA 66 where processing temperatures are high.

## Screw Cushion.

For most molding runs the amount of screw rotation must be adjusted so that there is always a pad, or cushion, of material left after the screw has finished injection; this ensures that the screw forward time is effective and a constant hold pressure is being applied. On small injection molding machines this cushion may be 3mm (0.118in); on larger machines it may be 9mm (0.354in). No matter what screw cushion size is used it must be kept constant. Nowadays, the screw cushion size may be controlled to within 0.1mm/0.004in.

## Screw Size.

When a molding machine is purchased, then the buyer is offered a choice of screw sizes; three are usually available and these may be referred to as A, B or C. They have different screw diameters and allow an appropriate match of shot size (the feed system volume plus the molding volume) to barrel capacity. However, because they have different screw diameters, not only will the shot capacity vary but so will other things, for example, injection pressure and plasticizing capacity. Normally A type screws have the lowest shot capacity, and the highest injection pressure, whereas C type screws have the highest shot capacity and the lowest injection pressure.

## Dedicated Screws.

As general purpose screws are designed to suit as wide a range of plastics as possible, it can be said that a general purpose screw will not be the ideal answer for the injection moulding of a specific material, for example PA 66. A screw designed for this semi-crystalline thermoplastics material must provide a greater heat input than one designed for an amorphous, thermoplastic material. If a machine is therefore dedicated to one plastic for a long time then it is well worth considering purchasing a specially designed screw.

## Zero Compression Screws.

If a conventional screw is used to process a plastic material then, because of the compression ratio on the screw, a large amount of heat will be generated. To avoid this heat generation, machines are now being built which have screws with zero compression, that is, the depth of the screw flight is the same along its length. Such screws give very little mixing but they do stop excessively high melt temperatures (melt temperature override) being generated. Mixing can be improved by the use of mixing sections (for example, fluted sections) located at the screw tip.

## Mixing Pins and Sections.

A conventional screw does not necessarily mix the feed stock that well; this is because of the way that the material flows, or is transported, along the screw. The material at the centre of the flight can easily remain undisturbed, that is, the output from the machine will not be of uniform quality (it will be inhomogenous). To improve mixing, by braking up laminar flow, use is sometimes made of pins which protrude from the root of the screw into the plastics material or, and more usually, the tip of the screw is fitted with mixing sections or elements. The screw is in effect lengthened so that a section of rings, cams or kneading discs may be fitted. Such screws have been used to improve the dispersion of elastomers (rubbers) in PP when such rubbers have been added at the injection molding stage.

## Barrier Design Screws.

The flight of a conventional, single start screw s often filled with a mixture of solid plastic and melt: the solid plastic floats or ‘swims’ in the melt and it is difficult for the screw to grip that solid resin. To improve the ability of the extruder to produce melt, and to give more uniform melt, barrier design screws are used in the extrusion industry. They are two start screws, i.e. the screw has two separate flights which are separated by the flight land; as the resin melts it is transferred to the other flight. That is, the screw employs the melt pool and solid bed separation principle which gives improved output per rpm and a lowering of melt temperature. As yet, such screws are mainly used in the extrusion industry.

## Wear Resistant Screws.

The wear resistance of the screw may be improved in various ways (apart from using correct operating conditions). For example, if the screw is deep nitrided to 67 to 70Rockwell C (HRC) this will improve wear and will also give protection against chemical attack: it will also stop plastic adhering, and then decomposing, on the screw. Ion implantation is now used a standard by some machine manufacturers because of the good wear resistance it imparts.

The screw need not be of the same composition all over as those parts which are subject to the severest use can be built from alloys which give extra protection. For example, the screw may be constructed from a central shaft of alloy steel and then it may be surfaced with a wear resistant alloy; the required flight form is then machined from this alloy covering.

## Venting.

When injection molding some materials there is a need for cylinder, or barrel, venting: this is to allow for gas escape. In most cases this gas is simply air but it could be a vapor given off by the compound, for example, water or a monomer. If it were prevented from escaping, then it would be compressed by the melt and carried to the mold; here it would expand and cause bubbles in the product. To allow the gas to escape, before it reaches the die, the melt is decompressed part-way along the cylinder or barrel; this is done by decreasing, or reducing, the screw root diameter. At this point a vent, a hole or port, is located in the barrel and the vapor escapes through this. The root diameter of the screw then increases and the material is conveyed towards the nozzle. Machines equipped with this facility are known as 'vented machines'.

## Screw Rotational Speed.

Some of the heat necessary to plasticize the plastic comes as a result of rotating the screw; the faster it is rotated, the higher, in general, is the temperature. This is because the screw surface speed is increasing and as this increases so does the amount of shear. However, a high screw speed can result in uneven melt temperatures. Because of the importance of the screw surface speed, the screws on larger machines should be rotated more slowly than those on smaller machines: this will keep the shear rate down and stop localized overheating. The speed of rotation will also differ from material to material. Rigid PVC is limited to a maximum, screw surface speed of 0.25ms$^{-1}$ (15m/min or, 49ft/min), whereas with other more shear resistant materials, higher speeds can be employed.

## Conversion.

To convert from rpm to ms$^{-1}$, multiply the rpm by the screw diameter in mm and then by 0.0000524. For example: to determine the actual screw speed for a 30mm (1.18in) diameter screw, so as to achieve a screw surface speed of 0.25ms$^{-1}$ (49ft/min), the procedure is as follows:

Surface speed = diameter of screw x screw speed x 0.0000524. This equals 0.25 = 30 x screw speed x 0.0000524
Therefore, the screw speed (rpm) = 0.25/30 x 0.0000524. This equals 159 rpm.

# PLASTICIZATION, SHOT CAPACITY AND RESIDENCE TIME.

It is assumed that the type of machine being used is a single screw type; this is because that type of machine is the most popular. An in-line screw unit will therefore be used to plasticize the plastics material.

## Shot Capacity.

Machines are often rated in terms of the amount of PS that they can inject in one shot; they may be rated in terms of ounces or grams. An alternative system rates them in terms of the melt volume that they can inject.

## Plasticizing Capacity.

Machines are often rated in terms of the amount of PS (pounds or kilograms) that they can uniformly plasticize (plasticise), or raise to a uniform molding temperature, in one hour. This is known as the plasticizing (plasticising) capacity.

## Different Materials.

PS, used for machine rating, is an amorphous, thermoplastic material and such materials have a different heat input requirement to that required by a semi-crystalline, thermoplastics material. Because of this it is usually necessary to under-rate the shot capacity of the injection cylinder when molding materials other than styrene-type plastics. A useful rule of thumb is to use 75 to 80% of the rated barrel capacity so as to minimize melt residence time and so allow injection molding at higher melt temperatures; this will give better melt flow while avoiding decomposition. If an injection cylinder is under-utilized (below 35%), then lower melt temperatures will be required if decomposition is to be avoided; this in turn can mean higher injection pressures, more frozen-in stresses and less stable injection moldings.

## Estimation of Plasticization Capacity.

To determine whether the standard of product quality can be maintained throughout the production run, a simple formula relating output and plasticization capacity may be used. This is as follows:

$$t = \frac{\text{the total shot capacity (g)} \times 3600}{\text{the plasticizing capacity of press (kg/hour)} \times 1000}$$

Where t = minimum cycle time that the mold should be run at with the specified plasticizing capacity and shot weight. What this means, is that if the mold is run at a cycle time lower than t then, the molding machine is unable to sufficiently plasticize the material, to achieve a uniform melt viscosity, and therefore the molded components will be subject to some variation (e.g. dimensional, visual etc). It is particularly important to match the output and plasticization capacity, in the case of fast cycling molds producing thin walled or close toleranced components.

## Barrel Residence Time.

The rate of decomposition of plastics is dependent on both temperature and time. For example, a plastic may be degraded by a short exposure to a high temperature or by a longer exposure at a lower temperature. How long the plastic is in the injection cylinder is therefore important. The actual residence time may be determined experimentally by, for example, measuring the time taken for a colored plastics material to pass through the injection cylinder. May be calculated very roughly by the following formula:

$$\frac{\text{rated capacity of injection cylinder (g)} \times \text{cycle time (s)}}{\text{shot weight (g)} \times 30}$$

Please note that some material will be in the injection cylinder, or barrel, for longer than the calculated value as some material may hang up in the system.

## Screw Flight Material.

The above formula does not take account of the material which is contained within the flights of the screw, particularly in the compression and metering zones. Although it is correct to use the rated capacity of the injection cylinder in the above formula, it must be understood that the additional volume of material contained within the flights of the stated zones should also be included to give a more accurate residence time. To calculate this volume details of the screw geometry need to be known. For convenience, a factor of 1.7 x the rated capacity of the injection cylinder is often used so as to eliminate the need for calculations.

## Importance of Residence Time Calculation.

As general practice one should always calculate the residence time for a material with a particular machine. This is particularly important when molding small shot weights on large machines as the material can suffer degredation which is not always visually detectable. If the residence time is too short then the material will not be uniformly plasticized; if too long then the material will be degraded. The aim must be to keep the residence time uniform by, for example, ensuring that the material (resin) fed to the machine is of constant composition and of uniform size and shape. Any signs of machine component failure, or wear, should be reported to maintenance.

# HEATING AND COOLING.

Commercial plastics are poor conductors of heat, have poor thermal stability and have high specific heats. What this means is that we are trying to put a lot of heat into a material which cannot conduct it away and which will degrade if it does not. What is more, after the material has been shaped, the heat must be removed so as to keep the thermoplastics material to the required shape. Because of the poor heat transfer properties of plastics, this heat removal step can control how fast the product is produced.

## Barrel Heating.

Most injection molding machines for thermoplastics have electrically heated barrels. The barrel is heated by means of resistance coils or cuffs, which are strapped or bolted around the cylinder, or barrel. Upon demand, initiated by a thermocouple, electricity is passed through the wire, inside the coil, and the resistance to flow causes the temperature to rise. With a PID controller (proportional, integral, derivative) then, when the set point is approached the power is progressively reduced and then finally turned off completely at the set point. (Also see the section on Starting Up).

## Zoned Heating.

For ease of control, the injection cylinder or barrel is divided into zones or regions. Each of these zones is fitted with its own heating system or, in rare cases, with its own heating/cooling system. Each of these systems is controlled by a temperature sensor and associated equipment, for example, a microprocessor-based PID controller. A PID controller will put in enough heat to bring the temperature up to the set point and overshoot should not occur. (With some materials, e.g. UPVC, overshoot can be very serious as it causes degradation even before molding commences.) So that heater failure may be easily spotted, ammeters should also be fitted; if a heater fails (burns out), then even if the controller is demanding power the ammeters will show that power is not flowing and the heater band must be replaced.

## Cylinder Temperature Settings.

It should be noted that it is the melt temperature which is important and that any cylinder temperatures quoted are only guidelines. (Melt temperature is measured in the nozzle or, by extrusion of the material into the air or, by 'shooting' the material into the air.) If you have no experience of processing a particular grade of material, then start with the lowest settings recommended. Usually the first zone temperature is set at the lowest value as this helps prevent premature melting and bridging of the material (resin) in the feed throat. The temperature of the other zones then gradually increase until the nozzle is reached: at the nozzle tip it is often lowered slightly to prevent drooling. The mold is also heated/cooled: because of the size of many molds, the mold may also be divided into zones but, unless otherwise stated, these should be set to the same value.

## Melt Temperature.

This is as measured in the nozzle or by an air shot technique. If measured by an air shot technique, then great care should be taken during the measurement so as to ensure that purging of the hot plastic does not cause an accident. This is because a plastic melt is hot enough to cause severe burns and it also adheres to the skin; burns are a common injury in injection molding shops. For this reason it is recommended that gloves and face shields are worn when handling hot material or when there is any danger of being splashed with plastic melt, for example, during start-up or purging. To obtain greater accuracy, when doing an air-shot, the tip of the measuring probe should be pre-heated to the temperature that it is expected to measure. For a given machine, the actual injection cylinder settings to achieve this melt temperature will depend on, for example, the screw rotational speed, the back pressure the shot size and the molding cycle.

## Hopper Block Cooling/Heating.

To ensure that the material freely enters the feed section of the screw, cooling water is passed around the hopper throat assembly. The flow rate and temperature of the cooling water are important as they affect how the material is plasticized within the barrel. If the water passing around the hopper throat is from the main supply then it may be subject to a seasonal temperature variation, for example, 38°F, or 3°C, in the winter and 73°F or 23°C in the summer. Such a variation can affect melt temperature and cause product variations. It is best to use a closed loop, water recirculating system as this saves both on water and on scale build-up. With such a system it should be easy to arrange for hopper block heating if desired.

## Screw Cooling/Heating.

This is not often done as it is difficult to engineer on an injection molding machine. Done by circulating water through a bore, or drilling, which comes in from the rear end of the screw. Screw cooling is done either to cure i) a feeding problem, or to improve operating consistency or, (ii) to improve mixing or to minimize material decomposition. In the first case it is only necessary to cool the screw in the feed section while in the second case it is necessary to bore out the whole length of the screw. That is, almost as far as the screw tip. In this case the cooling water freezes a layer of material at the screw tip and this effectively increases the compression ratio of the screw. Mixing efficiency is improved but the output rate goes down and the power consumption goes up. A big disadvantage in both cases is that the actual temperature of the screw is not usually known.

## Feedstock Temperatures.

The temperature of the material fed to the molding machine should not vary excessively as, if it does, the output will vary. Usually this is not a problem. It can be a problem if the material is heated and if sufficient residence time is not allowed in the dryer. If PVC powder blends are being molded then, these should always be cooled (if molded without a hopper heater) as otherwise feedstock temperature variations will occur as the molding run continues and such variations will cause product variations. Some machines are now operated with heated feed throat assemblies so as to achieve more consistent plasticization.

## Heat Input During Operation.

Once an injection molding machine is operational then the heat necessary to plasticize the material within the injection cylinder can come either from the barrel heaters or from the effort needed to turn the screw. (This amount of heat can be calculated if the specific heat of the plastic is known and if the difference between the processing temperature and the input temperature is also known - see Table 7.) It is now thought best to adjust the screw rotational time so that it is as long as possible - that is, reduce the screw rotational speed so that the screw is rotating for approximately the whole of the cooling cycle. This will minimize the amount of frictional heat and decrease overshoot. When operated in this way the barrel heaters will simply put in enough heat to bring the temperature up to the set point and overshoot should not occur. This is important as most molding machines have no means of removing excess heat, that is, they do not have a cooling system on the barrel. On some machines, the heat generated from screw turning can be so great that the heaters never come on, once the injection molding machine is running at operational speed. (If a machine is designed to operate without using external heaters it is known as an 'adiabatic machine'.) If the heaters do not come on, then the set point of the controllers is being exceeded and the material is coming from the nozzle at a higher temperature than that specified. This extra heat must be removed and lengthens the molding cycle.

## Shear Heat.

Mold filling is often accomplished very quickly, for example, in less than 1 second. To do this high pressures are required and the effort that is expended is turned into heat as the material is forced or 'sheared' along. This heat is not spread uniformly throughout the material but is highest where the shear rate is the highest: that is, where the layers of material are being sheared one over the other at the highest rate. This shear heating can be so high that it can cause localized overheating, for example, in the case of UPVC. This is why maximum shear rates are quoted for many plastics materials. If high screw surface speeds are used during plasticization then, shear heat can also be generated when the melt is being prepared for the next shot.

## Specific Heat and Enthalpy.

The amount of heat that is contained in the melt per hour can be calculated if the output rate, the specific heat and the melt temperature is known. This is because mass, multiplied by the specific heat, multiplied by the temperature difference equals heat content or enthalpy. This is as shown in Table 7. In that table the temperature difference between a typical processing temperature and a typical mold temperature has been used, to indicate the magnitude of the heat removal problem and to show how different it is for each material. The difference between an amorphous, thermoplastics material and a semi-crystalline, thermoplastics material should be noted. (As the specific heat changes with temperature, an average specific heat, over the temperature range from melt to room temperature, is quoted. Specific heat may be quoted in Btu/lb°F or in cals/g°C or in J/kgK.)

## Heat Calculations.

The heat contained in the molten material (resin) is either lost to the surrounding air, to the machine or, it is removed by the cooling system. If heat losses to the surroundings are ignored then enthalpy data may be used to calculate the amount of fluid (usually water) that needs to be circulated through the mold cooling system (so as to remove the heat carried in by the plastic). This is done, for cold runner molds, by assuming that all of the heat contained in the components must be removed but that only half of the heat contained in the feed system needs to be removed before ejection takes place. For hot runner molds, only the components are considered; assume that all of the heat contained in the components must be removed.

## Minimize Heat Input.

Once an injection molding machine is operational then the heat necessary to plasticize the material can come either from the barrel heaters or from the effort needed to turn the screw. Operate the machine so as to minimize the amount of frictional heat and so as to decrease overshoot. This is important as most injection molding machines have no means of removing excess heat, that is, they do not have a cooling system on the barrel. If excess heat is generated then the only way of removing it is via the mold cooling circuits. This is obviously wasteful.

## Mold Cooling System Design.

The majority of molds are designed with insufficient cooling channels and therefore require a longer period of time to dissipate the heat than should ideally be required. This in turn, directly effects the overall cycle time. When processing thermoplastic materials, the heat which is carried into the mold is removed by:

a. conduction into the machine;
b. radiation; and
c. a fluid circulated through the mold.

In most cases (c) is the most important and is usually achieved by water circulation through water/glycol mixtures and oil are also used.

For a given material, the rate at which this heat is removed from the mold is dependent upon the number of cooling channels, the length of cooling channels, the diameter of the cooling channels and the rate at which fluid is circulated. It is essential to ensure that the correct amount of fluid is circulated, at the correct rate, for each part of the mold. (See the section on calculating the cooling requirements for a mold.)

## Mold Temperatures.

Always check that the mold is set, and is running, at the specified mold temperature. This is very important as mold temperature affects both surface finish and molding dimensions. It is the surface temperature of the mold which is important and this should be measured using, for example, a surface probe. Such measurements should be checked during the actual molding operation and the temperature of the fluid, used to control the mold temperature, adjusted in order to maintain the desired cavity surface temperature. Both mold halves should be fitted with appropriate measuring devices so that both the temperature of the fluid, and the amount of fluid being circulated, may be measured. All these measured values must be recorded.

## Uniform Cooling.

Cooling the injection molding uniformly may mean cooling the mold at different rates, in different areas, so as to get uniformity of component cooling. The aim must be to cool the component as quickly as possible while ensuring that faults such as poor surface appearance, changes in physical properties etc. are not encountered. Each part of the molding should be cooled at the same rate, This often means that non-uniform cooling must be applied to the mold, for example, cool water should be fed into the inner parts of the mold cooling system (particularly in the area of the gate) and warmer water into the outer parts. This technique is essential when molding flat components to close tolerances, or large components that include long melt flow lengths from the gating position.

## Barrel Cooling.

Barrel cooling is not very often seen on injection molding machines but is sometimes seen on large machines. Such cooling systems use either air or water and the cooling system is usually actuated, or switched on, by the same instruments that control the heating system; usually the cooling zones are the same as the heating zones. The simplest systems use air blowers, or fans, which are switched on when the set temperature is exceeded and when the heating has been switched off. The system may consist of ceramic encased, heating elements mounted in a stainless steel shell with each zone provided with a centrifugal blower mounted under the barrel. Where serious temperature overshoot is a problem then water cooling may have to be employed.

## Oil Heating and Cooling.

An injection molding machine uses a large amount of electricity, for example, a 40 tonne/ton machine will use approximately 8 to 9 kW/h. Most of this heat finds its way into the hydraulic system where it must be removed; if it is not removed then the oil will be degraded and the machine will not run properly (it could also be seriously damaged). Oil heating/cooling is very important but is often totally overlooked.

Preheat the oil to operating temperature before commencing the production run, for example, to 45°C or 113°F. Once at operating temperature then the oil cooling system must be capable of removing the heat which is being given to the oil and of holding the oil at the specified temperature. To remove the heat, water is passed through a coil (heat exchanger) at the base of the oil reservoir.

To save on scale problems (and on water) closed loop, water recirculating systems are used; these lose the heat by means of a heat exchanger; this heat can be recovered and used.

## Temperature and Cooling Checks.

Always check that the machine is set and running at the temperatures specified on the record sheet. This is very important as, for example, temperature affects both surface finish and output. All measured values must be recorded on the setting sheet and must be checked at specified intervals.

# TEMPERATURES.

The measurement and control of temperature is very important in injection molding and yet, despite the relative simplicity of making the measurements, most injection molding machines do not have enough temperature measuring points or circuits.

## Temperature Sensing.

On most injection molding machines, temperatures are sensed by means of thermocouples. Basically a thermocouple consists of two dissimilar wires which are joined at each end. If one end is made hotter than the other a small electrical signal will result: the more it is heated, the greater will be the electrical signal. If one end is kept at a stable temperature (reference temperature) then the thermocouple may be calibrated so that a simple and accurate measurement of temperatures may be made. The measurement may be displayed in either analogue or digital form. Usually the temperatures are displayed in either °C or in °F.

## Temperature Control.

Thermocouples are also widely used as the sensors for temperature control systems. The temperature required is set on the control instrument (the set point) and the output from the sensor is compared with that generated at the set point. In the simplest systems, when the set point is reached the power is turned off and is then turned back on again when the temperature drops below the set point. Such a system is referred to as 'on-off' control as it is either on or off.

## P & I & D.

The three initials stand for 'proportional, integral and derivative' and what they stand for, is used in temperature control in order to improve control accuracy. In a simple on-off system, the electric power is turned off at the set point when the desired temperature is reached: such a simple system can result in a number of problems, for example, temperature overshoot and/or poor control - the temperature is different from what is set.

The three terms (P & I & D) are often put together to form a three term controller: as the set point is approached the indicated temperature enters what is called the proportional band. Within that band, the power is gradually, and progressively, reduced so that overshoot does not result. If the actual temperature is different from the set temperature then, for example, the proportional band is shifted so as to eliminate the error (droop).

## Melt Temperature.

It should be noted that it is the melt temperature which is important and that the injection cylinder temperatures quoted are only guidelines. The melt temperature is measured in the nozzle or by an air shot technique. (If measured by an air shot technique, then great care should be taken during the measurement so as to ensure that purging of the hot plastic does not cause an accident). For a given machine, the actual injection cylinder settings to achieve this melt temperature will depend on, for example, the screw rotational speed, the back pressure, the shot size and the molding cycle.

## Temperature Settings.

If you have no experience of processing a particular grade of material, then start with the lowest settings suggested. For ease of control, injection cylinders are divided into zones however, all temperatures may be set to the same value. If the cycle times are long or, if working at high temperatures, set the first zone temperature to a lower value; this will prevent premature melting and bridging. Before commencing molding ensure that the hydraulic oil, the hopper block, the mold and the barrel are all at the correct temperatures.

## Temperature Recording.

The machine setting record will indicate what temperatures need to be recorded. Included are oil temperatures, water temperatures, mold temperatures and melt temperatures. A large number of temperature measuring points should therefore be available. What is also useful in the injection molding shop, is a portable, electronic, temperature sensor or thermometer and a range of probes. Such an instrument allows melt temperatures, oil temperatures etc. to be easily checked.

# PRESSURES.

In order to fill the mold quickly, before the plastics material sets in the feed system, high injection pressure must be employed. This in turn means that high clamping pressures must be employed and so, injection molding machines generate, and use, large forces. This means that they can be very dangerous and must be only handled by people who know what they are doing.

## The Hydraulic System.

Most injection molding machines are driven, or powered, by a power unit which is located in the base of the machine, that is, the machine is self contained. The power unit is most commonly an electric motor which drives a hydraulic pump or pumps. These pumps circulate fluid through the system and when there is resistance to the flow of hydraulic fluid, pressure builds up; the pump tries to maintain the rate of flow and so, in order to protect the pump against the pressure which it itself generates, the pressure in the hydraulic system is limited by means of relief valves. Pressure is usually measured in either bar, pounds per square inch (psi) or, in megaNewtons per square meter ($MNm^{-2}$).

## Injection Pressure.

This is the pressure which is causing the material to flow; may be approximately measured by a transducer located in the nozzle or in the hydraulic line. It does not have a constant value but increases as mold filling becomes more difficult. There is a direct relationship between injection line pressure and injection pressure.

## First Stage and Second Stage Pressure.

During the mold filling part of the molding cycle, high injection pressures may be needed in order to maintain the desired mold filling speed. Once the mold is full then this high pressure may not be necessary, or even desirable. In many cases, a high, first stage pressure may therefore be followed by a lower, second stage pressure. When molding some semi-crystalline, thermoplastics materials, for example nylon and acetal, then the use of second stage pressure may not be required as abrupt changes in pressure can cause undesirable changes in crystalline structure.

## Clamping Pressure.

To oppose the injection pressure a clamping pressure must be applied. One should not automatically use the maximum available but should estimate what is required from a consideration of the projected area. The projected area of a molding is the largest area that can be seen if the molding is viewed from the direction of clamp force application. For most molding jobs it is approximately 2 tons per square inch (2tsi) or 31 megaNewtons per square meter ($31MNm^{-2}$). This is however, a low figure and should only be treated as a very rough rule of thumb because, for example, once the molding has any depth then side wall forces must also be considered.

## Back Pressure.

This is the pressure that the screw must generate, and exceed, before it can move back. Back pressure is generated by rotating the screw against the restriction of the plastics material which is contained in the cylinder, or barrel. Back pressures may reach 250 bar or, 25MNm$^{-2}$ or 3600spi. The use of such high back pressures can improve color dispersion and material melting, but it is paid for as it increases the screw retraction time, reduces fiber lengths in filled systems and imposes stress on the injection molding machine. Keep as low as possible and in any event do not exceed 20% of the machines (maximum rated), injection molding pressure. Some back pressure may be needed simply to stop the screw pushing itself (auguring) too easily out of the cylinder, or barrel; for example, 5 bar or 0.5MNm$^{-2}$ or 73psi.

On some machines it is possible to program the back pressure so as to compensate, for example, for the effective reduction in screw length which occurs during plasticization; such a reduction means less heat input and therefore a drop in temperature. However, on many machines it is difficult to sensibly set the machine as there is no easy way of measuring the effects of the changes.

## Cavity Pressure.

This is the pressure that the plastics material exerts inside the cavity and which tries to open the mold and which also tries to distort the mold. It may be sensed by means of a transducer and the signal so produced used to actuate the switch from first stage pressure to second stage, holding pressure. This process is called cavity pressure control (CPC).

## Line Pressure.

This is sometimes referred to as gage (gauge) pressure as it is often measured by means of a gage which is set in the hydraulic line or pipe. It is the pressure in the main supply line from the pump and is not the injection pressure. Line pressure is usually capable of being adjusted and the line pressure should be adjusted to suit the particular molding run.

## Nozzle Pressure.

Nozzle pressure is the pressure measured inside the nozzle. It is, approximately, the pressure which is causing the material to flow. It does not have a constant value but increases as mold filling becomes more difficult. There is a direct relationship between nozzle pressure, line pressure and injection pressure. In screw machines, the nozzle pressure is approximately 10% lower than the injection pressure (as calculated from the gage in the hydraulic line). Pressure losses in ram machines are much higher and can reach 50%.

## Screw Cushion.

Screw cushion is the amount of material which is left in the barrel after injection is completed. The amount of screw cushion is either measured in inches or in millimetres; on small machines it is usually 3mm or 0.118 inches. It is very important to precisely control the amount of screw cushion as it directly affects the amount of pressure that is transmitted from the hydraulic system into the mold. If there is insufficient screw cushion, it is possible to have a gage pressure and yet not have pressure on the material. This is because the screw has come up against restraints or stops and yet, there is often no way of knowing this. An accurate measure of screw cushion is therefore important.

# SPEEDS.

Until comparatively recently it was not possible to easily measure, and display, the speed of movement of any part of the injection molding machine. With the development of transducers and micro-processor controls the situation has changed so that, both linear and rotary speeds can be easily measured, displayed and recorded thus improving the accuracy, and repeatability of the injection molding process.

## Hydraulic Systems.

Most injection molding machines are driven, or powered, by a power unit which is located in the base of the machine, that is, the machine is self contained. The power unit is most commonly an electric motor which drives a hydraulic pump or pumps. These pumps circulate fluid through the system at a certain rate or speed. Commonly, linear movements are obtained by feeding the hydraulic fluid to a cylinder or ram; rotary movements are obtained by feeding the hydraulic fluid to a hydraulic motor (this is basically a pump running in reverse).

## Obtaining Speed.

The greater the volume of hydraulic fluid fed to a hydraulic cylinder or motor (hydraulic actuators) the greater will be the rate of movement (the speed) obtained. Conversely if the flow is reduced, or throttled, then the slower will be the speed. Alterations in speed can be obtained in various ways. For example, the output from several pumps may be combined to obtain higher speeds or, the fluid stored in an accumulator may be utilized at the appropriate moment. If the output from the pump is fed to the hydraulic actuator via a servovalve then, the speed may be reduced to a preset value (the servovalve responds to preset electrical signals which cause oil flow restriction by moving the valve spool). Such a system allows, for example, the injection speed to be altered during the actual mold filling stage.

## Pressure.

It must be appreciated that it is only when there is resistance to flow that pressure exists or builds up: no resistance to flow, no pressure. The power unit (the electric motor and the hydraulic pump) circulate fluid at a certain rate through the hydraulic system: that is, it tries to maintain the rate of flow no matter what resistance the circuit offers (in order to protect the pump against the pressure which it itself generates, the pressure in the hydraulic system is limited by means of relief valves). On most injection molding machines now produced, speed is selected initially and the hydraulic system gives the pressure necessary to maintain that speed. Speed is usually measured in millimeters per second (mm/s or, $mms^{-1}$) or, in feet per second (ft/s) or, in inches per second (in/s). Pressure is usually measured in either bar, pounds per square inch (psi) or, in megaNewtons per square meter ($MNm^{-2}$).

## Injection Speed.

This refers to the speed of mold filling, that is when the screw is acting as a ram. When molding thin sectioned components, high injection speeds (sometimes called "screw displacement rates") are essential in order to fill the molding before freezing occurs. However, a better surface finish is obtained on moldings with thicker sections by using a slower speed. Many molding faults, for example jetting and air trapping, may be avoided by using a range of speeds (that is, programming the injection speed), during the mold filling stage.

No matter what speed is used it should be recorded on the setting record along with the injection time. This is the time to reach the pre-set, first stage, injection pressure and is part of the screw forward time (SFT).

## Mold Venting.

Because of the speed of mold filling, the mold must be vented to allow for gas escape; in most cases this gas is simply the air in the cavity. If it were prevented from escaping then, it would be compressed by the incoming melt and the subsequent rise in temperature (the diesel effect), would cause the plastic to burn. Vents must be placed near weld lines and also near the last areas to be filled. Typical vents are slots 6 to 13mm (0.25 to 0.5in) wide and 0.01 to 0.03mm (0.0005 to 0.001in) deep; such slots are located on the mating surface of one of the mold halves.

## Screw Rotational Speed.

The screw is rotated in order to fill the cylinder, or barrel, with plastics material for the next shot: as the material is pushed forward, the screw is pushed out of the barrel. Some of the heat necessary to plasticize the plastics material comes as a result of rotating the screw; the faster it is rotated, the higher is the temperature. Although high screw speeds are possible, it does not follow that a high speed should be used. It is better to adjust the rotational speed to suit the injection molding cycle by, for example, reducing the speed of rotation to the lowest value possible. This will give more uniform temperatures, reduce wear on the machine and reduce the residence time at the front of the injection cylinder.

## Screw Surface Speed.

When screw speed is discussed, it is nearly always discussed in terms of the rpm, that is, in terms of the number of revolutions per minute. However, the use of rpm can lead to problems as not all screws are the same size: the larger the screw, the faster will the outside surface move when it is rotated at the same rpm as a smaller screw.

Because of the importance of screw surface speed, the screws on larger machines should be rotated more slowly than those on smaller machines: this will keep the shear rate down and stop localized overheating. The speed of rotation will also differ from material to material. Rigid PVC is limited to a maximum of $0.25ms^{-1}$ (15m/min or, 49ft/min), whereas with other more shear resistant materials, higher speeds can be employed. To convert from rpm to $ms^{-1}$, multiply the rpm by the screw diameter in mm and then by 0.0000524.

## Dry Cycling Speed.

This is the amount of time that the machine needs to do one complete cycle when it is operated dry, that is, without any material in the injection cylinder.

## Mold Closing Speed.

This is the time needed to close all parts of the mold together. Just like the mold opening speed, it should be set to as high a value as possible, as it is an 'idle' speed (that is, it produces nothing). However, the speed selected should not cause mold damage: for this reason it should be possible to program the mold closing speed so that initial mold opening, and final mold closing, are done relatively slowly.

# VELOCITY PRESSURE TRANSFER AND PRESSURE CONTROL.

During the early days of injection molding, it was realized that the injection mold could be become over-packed with plastics material if high injection pressure were used for the whole of the filling part of the injection molding cycle. This is because of the compressibility of plastics melts. Such over-packing results in overweight moldings, which take a long time to cool and which are often unsatisfactory in service.

## Hold Pressure.

During the initial, mold filling part of the molding cycle, high injection pressures may be needed in order to maintain the desired mold filling speed. Once the mold is initially full then the cycle enters the 'holding phase' and in which, the screw (acting as a ram) pushes in extra material to compensate for material shrinkage. This may be done at a lower, second stage pressure or, at the same initial high, filling pressure: this high pressure may not be necessary, or even desirable. In many cases, a high first stage pressure is therefore followed by a lower, second stage pressure. However, when molding some semi-crystalline, thermoplastics materials, for example nylon and acetal, then the use of second stage pressure may not be required as abrupt changes in pressure can cause undesirable changes in crystalline structure.

## Velocity Pressure Transfer.

Many modern injection molding machines have closed loop control of the injection molding stroke/speed. A sensor is used to track the screw position (often referred to as ram position) and the position of the screw with respect to time can be plotted. The information from the sensor is also fed to a controller and this asks for progressively higher injection (line) pressure so as to maintain a constant injection molding rate. The pressure progressively increases because the resistance to flow progressively increases as the mold fills. At a certain point in the injection molding stroke, for example, when the mold is full or when the gate freezes, the resistance to flow becomes very high and it becomes unrealistic to expect the screw to maintain the desired rate. At this point control is shifted from being velocity controlled to being pressure controlled: This point is known as Velocity Pressure Transfer or, VPT.

## VPT Options.

If a second stage, holding pressure is required then, a signal which initiates the changeover, must be generated. Changeover at the VPT may be set, or triggered, in the following ways:-

i) Screw position- also known as path dependent switchover or, as screw positional control or, as positional control;
ii) Hydraulic pressure- also known as line pressure or, as line pressure control;
iii) Cavity pressure control - also known as CPC or, as cavity pressure changeover control;
iv) Nozzle pressure- also known as melt pressure;
v) Mold opening force; and,
vi) Mold opening position.

Of these options, (i), (ii) and, (iii) are the most widely used.

## Screw Position Switching.

Because of it's ease of incorporation, screw position switching (also known as path dependent switchover or, as screw positional control or, as positional control) is very widely used. The screw (sometimes referred to as the ram) is pushed forward hydraulically and this transfers the plastics material (the melt) from the barrel into the mold. When the screw reaches a certain point within the injection cylinder, or barrel, then, it trips a switch. This action, replaces one hydraulic valve (set at a high, pressure value) with another, set at a lower, pressure value. Inconsistencies can however, easily arise because of, for example, wear on the screw valve and/or, within the injection cylinder. By replacing the screw position switch with a pressure switch then, a more accurate system is created.

## Pressure Switching.

A pressure transducer may be used to initiate the VPT transfer. Of the various places available for pressure transducer location, the following two are the most widely used: within the hydraulic line which feeds the hydraulic cylinder and which, in turn, pushes the screw forward and from the mold (cavity pressure control to CPC). See the section on 'Cavity Pressure Control'. However, in both cases the pressure transducer simply acts as a pressure switch, as a pressure (switch) value is selected by the operator; when the pressure measuring circuit 'sees' this value then it tells the hydraulic circuit to change to the hold pressure. That is, this action replaces one hydraulic valve (set at a high, pressure value) with another, set at a lower, pressure value.

## Forms of CPC Control.

There are two main types of CPC control which are classified according to the transducer position in relation to the injection mold. When the pressure transducer is located within the injection mold then the transducer may be called a direct pressure transducer. When the pressure transducer is located outside the injection mold then the transducer may be called an indirect pressure transducer. In such a case, the pressure transducer is located in the mold ejector plate and pressure is transferred to it, by one of the ejector pins. Both systems are referred to as 'CPC control'.

Direct pressure transducers are more difficult to engineer as the pressure transducers must be built to withstand melt temperatures and still give consistent readings over very long production periods. For this reason, indirect pressure transducers are more common although systems using direct pressure transducers provide the greatest molding weight repeatability and dimension repeatability, since the transducer is closer to the component being molded.

## Comparison of Systems.

Changeover at the VPT, is often set, or triggered, in the following ways:

i) Screw position - also known as path dependent switchover or, as screw positional control or, as positional control;

ii) Hydraulic pressure - also known as line pressure or, as line pressure control; and

iii) Cavity pressure control - also known as CPC or, as cavity pressure changeover control;

Of these three systems, CPC consistently gives the best results in terms of molding weight repeatability and, in terms of dimensional repeatability; it is approximately twice as good as the other two systems (these ar roughly similar although line pressure control is approximately 10% better). Nowadays, with modern position transducers, it is possible to get accurate control with screw position control but, even with modern transducers, it is still often not as good, as a system switched with a pressure transducer.

## CPC Control.

Of the various VPT options currently available, CPC appears to be the most suitable as control is exercised from where it is required.

The pressure in the mold controls, for example, molding shrinkage and component weight. However, CPC has not made the impact expected because of reasons such as, the mold modification required (many trade molders have a large number of molds), setting difficulties, transducer calibration problems, ease of transducer damage and the high cost of transducer repair. Many molders also believe that there has been a significant improvement in machine design and operation in recent years so that, there is no longer a need for such sophistication. However, even the accuracy of a modern machine can be significantly improved by the use of a VPT transfer initiated by a pressure transducer.

# CAVITY PRESSURE CONTROL.

During the initial, mold filling part of the molding cycle, high injection pressures may be needed in order to maintain the desired mold filling speed. Once the mold is full then this high pressure may not be necessary, or even desirable. If a second stage, holding pressure is required then a signal which initiates the changeover must be generated. Changeover at the Velocity Pressure Transfer point (VPT) may be set, or triggered, in various ways: of these, cavity pressure control (also known as CPC or as cavity pressure changeover control) is usually the most accurate. See the section on Velocity Pressure Transfer and Pressure Control.

## Forms of CPC Control.

CPC control may be exercised from a pressure transducer in direct contact with the melt (ideally located within the injection mold), or from a pressure transducer not in direct contact with the melt. Although, in general, direct pressure sensing is best and should be selected wherever possible, the transducers are more expensive as they must be built to withstand melt temperatures and still give consistent readings over long production periods: a witness mark will be present on the component and in some cases, this will be objectionable. Such transducers are sometimes known as 'direct pressure measurement transducers'.

In cases where there are space limitations, or hardened steel cavities have been used, an indirect pressure transducer may be used. That is, a pressure transducer is selected whose temperature-sensitive electronics are located away from the hot melt. An indirect transducer is located outside the injection mold cavity and receives its information via a pin. For example, the pressure transducer is located in the mold ejector plate and force is transferred to it, by one of the ejector pins. The use of pins can sometimes cause errors as the pins can stick or bend.

Both systems are referred to as 'CPC control' although systems which use an indirect transducer (for example, located in the ejector plate) are more common. Such a CPC system consistently gives good results in terms of molding weight repeatedly and in terms of dimensional repeatability.

## Transducer Importance and Calibration.

No matter what system is used, it is important to have a transducer which is robust, reliable and which gives consistent results. However, even the best transducers can give poor results unless they are installed correctly and checked periodically. This usually means, for example, in the case of an indirect transducer, that the user must ensure that the equipment has been calibrated to suit the size of ejector pin being used. This is because the indirect type of transducer is a force transducer.

Pressure (P) is force (F) per unit area (A). So, if we want to know the pressure then we must know the size (the area in contact with the melt) of the ejector pin we are using. The force on the ejector pin equals the area of the ejector pin multiplied by the cavity pressure. That is, $F = P \times A$. The area (A) of the pin equals $\pi$ times the diameter (D) squared divided by 4. Or, $0.7855 \times D \times D$.

The direct type of pressure transducer is a true pressure transducer and so such calculations, to establish which range of transducer to use, are not necessary.

## Mold Modifications.

The mold is modified so that it will accept a transducer. The modification required depends upon the type of transducer being installed. The use of a 'slide' type of transducer (an indirect transducer) requires, for example, that an accurately machined slot is made in the ejector plate behind an ejector pin in one of the mold cavities. The strain gage transducer is then carefully pushed into the slot and connected to the controller which, in turn, is connected to the switch which controls the change from high to low pressure.

The use of a direct transducer requires that an appropriately machined, mounting hole be made in the mold. The direct in-cavity transducer is mounted in the mold with the tip of its solid sensing probe shaped to conform to the contours of the mold cavity or runner surface (if required).

## VPT Setting.

Once the transducer has been installed, the molder must then select a critical cavity pressure at which to change from filling pressure to hold or mold packing pressure. This critical (switch or trip) pressure is selected by observing what peak cavity pressure is associated with an acceptable molding without CPC control. A switch pressure (approximately 10% lower than the desired peak cavity pressure) is then set on the controller: when this pressure is reached (during mold filling) the switch is made from high to low pressure. The highest cavity pressure is noted and if different from the desired peak cavity pressure then the switch pressure is adjusted. Some adjustment is demanded because the injection molding machine is unable to provide instantaneous switchover as the pressure rise in the cavity is so rapid.

## VPT Accuracy and Setting.

It is very important that the VPT point is capable of being set very precisely and that it is also very reproducible. If these conditions cannot be met then moldings with varying properties will result. As the object of injection molding is to produce moldings with identical properties, any variation of component properties is obviously unwelcome. The VPT is capable of being set by the machine operator provided that he/she is given appropriate monitoring equipment: this is necessary so that it is possible to 'see' exactly what is being set, where the set point is located and how reproducible is the set point.

## Transducer Checking.

During use, the pressure measuring system should be checked periodically so as to ensure that the preset values are being obtained. This often means simply using the built-in shunt calibration system. When this circuit is energized, the display will read 80% of full scale.

## Orientation and VPT Transfer.

To decrease the level of orientation in the molding it is important that the mold is filled as quickly as possible and that the plastics melt is not sheared while it is being cooled - what is called cold, creeping flow. Such an undesirable situation could result if the VPT point was set at the wrong position, for example, if control was handed over, from velocity to pressure, too soon. If the gate was still open, and if the packing pressure was only high enough to give slow filling then a high level of internal stress in the molding would result: this is because the level of retained orientation is being maximized by cooling the molding while filling slowly. In such a case it would be better to increase the packing pressure so as to raise the mold filling rate.

## Transducer Location.

Once the transducer type has been selected then the decision must be made as to its location. The maximum pressure recorded during the mold filling stage depends upon the position of the transducer in the mold. Pressure is highest in the gate region and therefore locating the transducer in the gate region would seem an obvious choice. However, such a location can often lead to the formation of pressure spikes, i.e. an erratic signal is the result. If one of the teeth of the spike is occasionally higher than the switching pressure, then premature switching may be the result. For monitoring purposes, a gate location is good but it is not necessarily good for control purposes. Locating the pressure transducer away from the gate, towards the centre of the component, is generally the best location point. (In some cases, for example when molding ceiling light diffusers, the transducer has been located at the far end of the cavity as it has been found that this gives moldings of more consistent length - important for fitting reasons.)

With a balanced, multi-cavity mold, it is usually best to fit the transducer in a typical cavity or in the cavity that is causing the most problems. With an unbalanced, multi-cavity mold it is best to measure the pressure within a cavity (or the runner system) located 50% to 75% along the melt flow path. If the filling pattern is unknown then the pressure should be measured near the sprue or within the machine nozzle.

## Product Monitoring.

The quality of many injection moldings is often only assessed, for example, by a simple visual examination. However, it is often preferable to assess the moldings by methods which give numerical answers; the figures so produced may then be easily subjected to statistical analysis. Usually the moldings are either weighed or a dimension is checked. Weight is often easier, and simpler, to measure than a dimension of a molding: this is because of developments in modern, digital balances.

If a series of injection moldings are produced, and both the weight and a dimension are measured, it is often found that there is no direct correlation between the weight variations and the size variations. A heavy molding does not necessarily give the molding with the largest dimensions, nor does the lightest molding give the molding with the smallest dimensions. This could be due to the fact that the wrong dimensions are being checked as, for example, there could be a variation in mold thickness, caused through mold opening, and the length is being checked. (Such inconsistencies could also be due to inconsistent packing or to the compressibility of the plastics melt.) However, to obtain minimal, dimensional variations it is best to minimize weight variations.

## Use of Regrind.

Many injection molding machines run on a mixture of new (virgin) material and reclaimed (regrind) material. Surprisingly, the use of some regrind may improve the performance of an injection molding machine, i.e. it's use may give more consistent moldings. (It is thought that with some materials, there is better feeding of the material onto the screw if some regrind is used.) The exact amount of regrind will have to be determined experimentally, and once found, then the ratio must be held precisely.

## Clamp Pressure Consistency.

The injection molding machine must be capable of applying a consistent clamping force to the mold if consistent moldings are to be obtained. This is because there is a tendency nowadays to reduce clamping forces to the lowest value possible so as to reduce running costs and to reduce wear and tear on the machine. In such cases, relatively small changes in clamping force cause (for example, by mold temperature variations) can alter the amount of mold parting on injection and the amount of mold distortion.

Direct lock machines (direct ram) give, in general, more consistent clamping forces, and are more maintenance free, than toggle machines. Such direct ram machines have an inherent, and automatic, compensation for mold size changes; caused by changes in mold temperature.

## Mold Size Adjustments.

Changes in clamping force can arise on many injection molding machines because of changes in mold temperature. Such changes are usually associated with toggle (hydromechanical) machines. For example, if a 100 ton (100 t) machine is set to give maximum clamping force at 25°C (77°F) then, if the mold temperature rises to 40°C (104°F) the clamping force can easily reach 110 t. If the mold temperature rises to 65°C (149°F) the clamping force can easily reach 120 t.

Direct ram machines automatically compensate for such changes in mold size. On toggle machines, it is necessary to correct for these temperature variations by, for example, changing the mold height. A sensor (transducer) is needed to measure the tie bar extension/contraction, or to measure tail-stock deflection, and the signal so generated is fed back to a mold height, adjustment motor. Such a device can lead to reductions in component variations when used with CPC.

## Temperature Control.

Because of the effect of changes in component dimensions, caused through mold temperature variations, it is very important to control the mold temperature precisely, for example, to within +/- 1°C (+/- 1.8°F). The same degree of control must be exercised over the temperature of the hydraulic oil and of the plastics melt. The importance of melt temperature control is more readily appreciated, as it obviously effects material color and material flow. Oil temperature control is often just as important, even though it may not be so obvious. If the oil temperature changes, then the way the injection molding machine performs also changes, and component weight/dimensions also changes. So, machine consistency is vitally important if CPC is to be made most effective.

## Use of Statistics.

Changes in injection molded components can be readily identified, and quantified, if the changes are capable of being statistically analyzed. Such analysis is not necessarily difficult as the use of only relatively simple statistics can yield a surprising amount of useful information. On many machines, if fitted with microprocessor control, the control system can display the results of such statistical calculations.

# NOZZLE PRESSURE CONTROL.

During the initial mold filling part of the mold cycle, high injection pressures may be needed in order to maintain the desired mold filling speed. Once the mold is full then this high pressure may not be necessary, or even desirable. If a second stage, holding pressure is required, then a signal which initiates the changeover must be generated. Changeover at the Velocity Pressure Transfer point (VPT) may be set, or triggered, in various ways: of these, nozzle pressure control (also known as NPC, or as melt pressure control) seems to hold a lot of potential. See the sections on Velocity Pressure Transfer and Pressure Control and on Cavity Pressure Control.

## NPC Control.

In NPC control, a pressure transducer is located within the nozzle of the injection molding machine, or within an adaptor which fits between the nozzle and the cylinder, or barrel. The same type of transducer is used in both cases. Such transducers are expensive as the pressure transducers must be built to withstand high melt pressures, and high melt temperatures, and still give consistent readings during production. Such a NPC system consistently gives good results in terms of molding weight repeatability and, in terms of dimensional repeatability and there is no need to change the transducer when the mold is changed. However, the transducer is located in an exposed position where during, for example, the clearing of a blocked sprue, it may be seriously damaged.

## Transducer Importance and Calibration.

It is important to have a transducer which is robust, reliable, and which gives consistent results. NPC transducers usually have armored steel sheaths and comparatively thick sensing diaphragms, for example, 0.008in (0.2mm) thick. The diaphragm should also be constructed from a corrosion, and wear, resistant material. However, even the best transducers can give poor results unless they are installed correctly and checked periodically. This usually means, for example, that the user must ensure that the pressure measuring system is checked periodically so as to ensure that correct values are being obtained. May be checked by means of, for example, an 80% shunt: when this circuit/switch is actuated, 80% of the full scale reading should be obtained.

## Nozzle Modification and VPT Setting.

The nozzle, or the nozzle adaptor, is modified so that it will accept a transducer. This means that an accurately machined hole, machined to suit the transducer, is made in the nozzle, or the nozzle adaptor. The hole must be accurately machined so as to ensure that plastics material does not enter, block and stagnate within any dead space, for example, within the angular space formed between the transducer tip and the mounting hole.

The strain gage transducer is then carefully inserted into the hole, tightened (but not over-tightened) and connected to the controller: this, in turn, is connected to the electrical switch which controls the change from high to low pressure., The molder must then select a critical, or peak, nozzle pressure at which to change from filling to hold pressure. This pressure is selected by observing what critical, or peak, nozzle pressure is associated with an acceptable molding. This acceptable, switch pressure is then set on the controller, and when this pressure is reached (during mold filling) the switch is made from high to low pressure. (See the sections entitled VPT Setting, Orientation and VPT Transfer, Product Monitoring etc, in the section entitled Cavity Pressure Control).

## Reciprocating Screw Rheometer (RCR).

The job of a laboratory capillary rheometer (LCR) can be performed by an in-line screw, injection molding machine provided that the machine is equipped with a suitable (a nozzle) pressure transducer and that the injection speed can be set and held at a specific value (see Flow Properties). The use of such an instrumented machine may be used, not only to give MPC, but also to check on the consistency of the injection molding material before, or during, the production operation.

If the measurements are made without an injection mold, for example, using an air shot technique, then the process may be referred to as an 'off-line RSR' test or measurement. If the measurements are made with an injection mold, for example, making measurements during mold filling, then the process may be referred to as an 'on-line RSR' test or measurement. In both cases, the melt temperature must be carefully and accurately controlled.

## Line Pressure.

Melt pressure is measured, or sensed, by a melt pressure transducer which is located, when fitted, within the nozzle/die. Such transducers are useful because they can improve productivity and efficiency: however, they are relatively expensive, and because of their location, they can easily be damaged. For these reasons, they are often not seen in production. Most usually 'injection pressure', or line pressure, is measured and/or recorded: a gage, fitted in the hydraulic line, is used. Such gages are often not very accurate and will not be capable of displaying rapid pressure variations. For these reasons a line pressure transducer is more useful. Such a device measures the oil pressure which is being used to achieve the injection speed and when the mold is full, it will indicate the line pressure necessary to achieve the mold filling/packing pressure.

## Line Pressure and Nozzle Pressure.

On a screw injection molding machine, the maximum line pressure will be approximately 2,000 psi. The nozzle pressure will be approximately 20,000 psi (less about 10% due to frictional losses and back-flow). The reason for the difference between the two pressures is that the line pressure acts on a large area ram which, in turn, is connected to the screw. There is usually a 10:1 ratio between the diameter of the ram and the diameter of the screw. If losses are ignored, then an injection line pressure of 2,000 psi on a 10 inch ram translates to 20,000 psi at the nozzle-end of a one inch screw.

## Detecting Leakage.

Nozzle pressure transducers are often incorporated to detect leakage (back-flow) around the valve fitted at the nozzle end of the screw. Such back-flow valves are also called slip ring valves and anti-back-flow valves. The nozzle pressure transducer will detect a loss in holding pressure more readily than line pressure transducers.

# PROCESS MONITORING.

Once the injection molding machine is set up and running, it is very important to ensure that, for example, melt temperature and melt pressure are consistent. If either the temperature or the pressure varies, then the product will also vary; because of their importance this section will concentrate on these parameters or, on related parameters. These settings are not the only settings, or parameters, that need to be held to constant values: the machine setting chart will indicate what needs to be recorded/monitored. However, before something can be controlled it must be capable of being measured.

## Measurement.

Process variables, such as temperature and pressure, are measured by a transducer or sensor (a temperature transducer is called a thermocouple). The output from the transducer is sent to a display unit where it may be displayed, in either analogue or digital form, and/or recorded. A display of such processing parameters as melt temperature and pressure can therefore be extremely useful and can lead to significant improvements in productivity. For this reason the display must be clear and easy to read. So that information is not lost, the equipment must not be over-damped (this is done to give steadier readings). Often the displayed output is only recorded if something is going wrong but a record of when it ran perfectly is very useful. The display may also have over or under alarms built in so that warning is given if the process is varying.

## Melt Temperature.

This temperature must be kept constant because if it varies then the viscosity, or ease of flow, of the material will also change and this will, in turn, introduce product variations. (Temperature variations can be smoothed out by using a static mixer upstream of the nozzle/die (i.e. between the screw tip and the nozzle/die) but if the injection molding machine is designed and operated correctly, this should not be necessary.) If the temperature goes too high then the plastics material/resin will also burn or degrade. Degradation is also dependent on the residence time in the injection cylinder.

## Melt Temperature Measurement.

May be measured by a melt temperature thermocouple, by means of an infra-red temperature transducer or, by using an air shot technique. If a melt temperature thermocouple/sensor is used then, the tip of the melt thermocouple must be approximately one quarter of an inch (6mm) away from the barrel/nozzle wall so that it does not pick up the temperature of the metal. (The thermocouples which feed the temperature control system, should be sunk as deep into the barrel wall as safety will allow). If nozzle pressure control is used, and if the transducer is mounted in an adaptor, then the same adaptor may be used to house a melt temperature thermocouple. An infra red probe has a much faster response time, and is more accurate, than a thermocouple based system but is much more expensive: such probes can be installed in a standard 1/2-20 UNK-2B mounting hole (as used for pressure transducers). A sapphire lens at the measuring tip is used to transmit the infra red energy to the measuring system via a fiber optic assembly.

## Air Shot Technique.

An air shot technique is more usual, for melt temperature measurement, as it is relatively simple to do uses in-expensive equipment and the purging can be inspected for signs of decomposition, or degradation but take great care as an accident can easily occur. For example, wear safety glasses or a face shield and heat resistant gloves: only purge the material from the barrel when you have received training in this technique and when you are certain that other people are not in the immediate area. Purge the plastics material onto a heat resistant, non-metallic board, remove from the nozzle area and immediately insert a thermocouple into the melt: recharge the injection cylinder by rotating the screw. Shoot the new charge from the barrel, place on the board and insert the now hot thermocouple into the new shot: stir and note the highest temperature. The melt temperature is the highest temperature noted.

## Line Pressure.

Injection molding machines have a a gage fitted in the hydraulic line and it is usually the maximum value shown on this gage which is recorded as the injection molding pressure. (The gage shows however, the line pressure.) Such gages are often not very accurate and will not be capable of displaying rapid pressure variations. For these reasons a line pressure transducer is more useful. Such a device measures the oil pressure which is being used to achieve the injection speed and when the mold is full, it will indicate the line pressure necessary to achieve the mold filling/packing pressure. It is best to measure the melt pressure as well as the line pressure if possible as this will show if, for example, the ring check valve is leaking or damaged

## Melt Pressure.

Melt pressure is measured, or sensed, by a melt pressure transducer which is located within the nozzle. Because of the location of the transducer, such transducers are often referred to as 'nozzle pressure transducers'. Such transducers are useful because they can improve productivity and efficiency (see the section on 'Cavity pressure control'). However, due to the location of the transducer, care must be taken to prevent damage during, for example, the clearing of a blocked nozzle.

## Cavity Pressure.

Cavity pressure may be measured, and monitored, by means of a pressure transducer in direct contact with the melt (ideally located within the injection mold), or from a pressure transducer not in direct contact with the melt. Although, in general, direct pressure sensing is best and should be selected wherever possible, the transducers which are most the popular at the present time are the indirect type. (See the section on 'Cavity pressure control'.) Because of its importance, cavity pressure should be monitored as measuring the mold cavity pressure will provide a profile of pressure rise and drop within the cavity throughout the molding cycle. In turn, such pressure transducer signals can be used to control the injection molding machine: cavity pressure control and monitoring allows quicker set-up, faster production, lower material consumption and fewer rejects.

## Screw Cushion.

Screw cushion is the amount of material which is left in the barrel after injection is completed. The amount of screw cushion is either measured in inches or in millimeters: on small machines it is usually 3mm or 0.12 inches. It is very important to control the amount of screw cushion as it directly affects the amount of pressure that is transmitted from the hydraulic system into the mold. If there is insufficient screw cushion, it is possible to have a gage pressure and yet not have pressure on the material; this is because the screw has come up against restraints or stops. Therefore the screw cushion size should be measured and recorded. Even if the size of the screw cushion cannot be read, on the machine display, then it should still be measured and recorded by the setter/ operator. (If the machine is not fitted with appropriate instruments then, it is useful to fit a ruler to the machine and a display arrow to the injection unit: this will allow a rough measurement of screw displacement speed and screw cushion to be made).

## Injection Speed.

This refers to the speed of mold filling, that is when the screw is acting as a ram. When molding thin sectioned components, high injection speeds (sometimes called "screw displacement rates") are essential in order to fill the molding before freezing occurs. However, a better surface finish is obtained on moldings with thicker sections by using a slower speed. Many molding faults, for example jetting and air trapping, may be avoided by using a range of speeds (that is, programming the injection speed), during the mold filling stage. Even if the mold filling speed is not capable of being read, on the machine display, then it should be measured and recorded by the setter/operator using a stop watch and ruler. However, this will only give an average value and will not show how the speed varies at different points.

## Shear Heat.

Mold filling is often accomplished very quickly, for example, in less than 1 second. To do this high pressures may be required and the effort that is expended is turned into heat as the material is forced or 'sheared' along. This heat is not spread uniformly throughout the material but is highest where the shear rate is the highest: that is, where the layers of material are being sheared one over the other at the highest rate (this is near the surface of the flow channels). This shear heating can be so high that it can cause localized overheating with some materials, for example, with UPVC. Because of shear heating (also caused by high screw rotational speeds), the melt temperature is often greater than the highest set temperature. However, because of practical difficulties, the actual melt temperature is often not measured directly but measured using, for example, an air shot technique.

## Screw Rotational Speed.

The rate at which the screw turns controls how much plastics material/resin is pumped forwards during the cooling part of the cycle. This pumping rate also controls, or affects, mixing, melt temperature and melt temperature variations. Screw speed must be therefore capable of being set accurately, it must be capable of being read accurately and it must be capable of being held to the set value. The injection molding machine must therefore have a display of screw speed and the screw motor must be powerful enough to keep the speed constant. (If the melt temperature is too low or, if the feed form varies, then speed variations will occur). If the injection molding machine does not have a display of screw speed then a rough indication may be obtained by marking the rear end of the screw and timing the rotation, for example, at the beginning and end of the retraction stroke.

## Back Pressure.

This is the pressure that the screw must generate, and exceed, before it can move back. The use of high back pressures can improve color dispersion and material melting, but it is paid for as it increases the screw retraction time, reduces fiber lengths in filled systems and imposes stress on the injection molding machine. Ensure that it is measured, keep as low as possible and in any event, do not exceed 20% of the machines (maximum rated), injection molding pressure.

On some machines it is possible to program the back pressure so as to compensate, for example, for the effective reduction in screw length which occurs during plasticization; such a reduction means less heat imput and therefore a drop in temperature. However, on many machines it is difficult to sensibly set the machine as there is no easy way of measuring the effects of the changes.

## Quality Control.

With components produced by plastics injection molding, it has been found that there is a close correlation between final features of the component (such as weight and size) and production conditions such as cushion size, injection pressure and injection rate. This means that it is possible to check that injection moldings are satisfactory, in many cases, without actually doing any measurements on the actual moldings themselves. During each shot, selected parameters are measured and compared against set, or stored, values. Provided the measured values fall within preselected limits, the injection molding is judged by the control system to be acceptable: If the measured values are outside the set limits then, the injection molding will be either rejected or, if it is only just outside, it may be retained for a second opinion by a qualified person. Machines are now being equipped with a video camera/ computer system, so that each individual molding is compared, upon molding extraction, with a stored image of what is required. That is, each molding is compared against a standard e.g. for size and visual defects.

# MEASUREMENT OF TIE BAR EXTENSION.

The locking force on a toggle operated clamping unit of an injection molding machine is determined by the amount of tie bar stretch (sometimes called tie bar extension). The amount of extension can be as much as 1% of the original length of the tie bar. It is very important to ensure that the length is capable of being measured quickly and easily as incorrect over-setting will, eventually, lead to tie bar failure. Tie bar extension measurement can be carried out in various ways and can, on newer machines, lead to automatic control or regulation, of the clamping force during the injection molding cycle. On modern machines, tie bars are often pre-stressed so as to give better reproducibility.

## Dial Test Indicator.

The dial test indicator (DTI) measures the displacement of a plunger or stylus on a circular dial by means of a rotating pointer. It is from the appearance of this dial that the DTI is familiarly known as a 'clock' or 'dial gauge'. There are two types of dial test indicator and these are as follows.

### PLUNGER TYPE DIAL TEST INDICATOR.

This type relies upon a rack and pinion followed by a gear train to magnify the movement of the plunger to the main pointer. This type of instrument has a long plunger movement and is fitted with a secondary scale and pointer for indicating the number of complete revolutions made by the main pointer.

### LEVER TYPE DIAL TEST INDICATOR.

This type relies upon a lever and scroll system of magnification. It has only a limited range of stylus movement: little more than one complete revolution of the pointer. It is more compact than the plunger type.

### MEASUREMENT OF TIE BAR EXTENSION USING A DTI.

The amount of tie bar extension can be measured by mounting the DTI on a stand so that the end of the spring loaded plunger makes contact with the end (vertical) face of the tie bar. The stand is designed to accommodate 2 or 4 DTI's (i.e. one for each tie bar), so that individual tie bar extensions can be measured simultaneously. Such measurements should be recorded on the mold setting/ record sheet.

## Strain Gage Technique.

A simple strain gage consists essentially of a grid of fine wires (50µm/0.002in in diameter) bonded onto a paper or plastics foil and through which an electric current may be passed. It is found that if the resistor, the grid of wires, is strained, its resistance changes and the amount of change is proportional to the load applied. Four such gages or resistors are grouped together so as to obtain a more sensitive, or higher output, device together with temperature compensation. When a force is applied to the assembly the output alters and this small change may be amplified so that it may be displayed and/or used to initiate a control action.

### THE BENDING MOMENT TECHNIQUE.

The principle of this technique is that the locking or anchor platen remains stationary but deflects, or bends backwards, in the form of an arc, when the locking force is applied to a toggle-lock machine. The formation of the arc creates a 'bending moment' at a point at the base of the platen. This 'moment' may be measured using a strain gage assembly.

A strap is attached to the top and bottom faces of the platen and is designed so that the central section is split to allow the strain gage to be attached to both parts of the strap. As the platen deflects, or arcs, the strain gage detects the amount of movement between the straps and generates a change in an electrical signal. This signal is then amplified and displayed on a VDU, or screen, as a measure of tie bar stretch and of the amount of locking force applied to the mold.

### TIE BAR ATTACHMENT.

The strain gage assembly can be attached directly to a tie bar (for example, by welding) so that when the clamping force is applied, the change in resistance leads to a measure of the clamping force. Such systems are not often seen on production machines.

## Linear Velocity Displacement Transducer.

A linear velocity displacement transducer (LVDT) is a transducer which is used for measuring relatively small amounts of movement in the vertical or horizontal plane. The amount of movement is detected by means of a change in an electrical signal caused by movement of an iron core within a coil: this change is then amplified and converted into a linear measurement. Very accurate readings of tie bar extensions can be obtained when using these devices. Most newer injection molding machines have a linear displacement transducer mounted at the end of, or along, the tie bar so as to measure the tie bar extension when the locking force is applied. The amount of extension is displayed in digital form either on the molding machine's visual display unit (VDU) or on a separate control panel.

## Use of the Tie Bar Extension Value.

Most molding machine manufacturers will supply details regarding the amount of tie stretch that should be used in order to obtain the maximum locking force. On the older type of molding machines, apart from actually measuring the tie bar stretch, there is no other facility to determine the actual locking force being used.

## Tie Bar Extension/Locking Force Graphs.

Newer machines have graphs, displayed on the machine, of tie bar extension value/tonnage lock to enable the molding shop personnel to set the required locking force for a particular design of mold. Because the information is given in this way, molding shop personnel either do not fully understand or, are reluctant to use such data to its maximum effectiveness. Correct usage of such graphs ensures that over-stretching of the tie bar does not occur.

From time to time tie bars break, due to being over-stretched (overstressed), and therefore regular monitoring of the extension values will ensure such breakages do not occur (as a result of preventative action being taken once incorrect or irregular readings occur). By recording the tie bar extension value, one can monitor the wear rate of the toggle linkages/pins/bushes assembly, ensure that the mold is evenly clamped and that an individual, or pair of tie bar(s), are not being subjected to excessive amounts of stretch (stress).

## Automatic Monitoring and Control of the Locking Force.

Automatic regulation of the clamping force (sometimes called clamp force regulation) takes place where an hydraulic motor is attached to the anchor platen of the molding machine. The motor is used to move the platen assembly, in either direction, along the threaded portion of the tie bar, so that the effective tie bar length can be altered without the need of molding shop personnel. Once the initial clamping force has been set, to ensure that a constant locking force is maintained by the machine throughout the production run, the millivolt value from, for example, a strain gauge is monitored each cycle. If the value changes for any reason then the effective tie bar length would be changed accordingly by movement of the platen assembly. This technique is designed to accommodate up to a 10% change in locking force variation from cycle to cycle; if the variation exceeds this value then, the machine will automatically shut down.

# TRANSDUCER CARE.

Everyone would like to know how to extend the life of a melt pressure transducer so as to obtain the greatest number of accurate, reliable, melt pressure measurements from such a unit. By following these tips, you are guaranteed to increase the operating life of your transducer. Now, the pressure transducers used to measure melt pressure can be of two types, direct measuring and indirect measuring (see the section on 'Cavity pressure control'). The tips given will be different for each.

# Melt Pressure Transducer Tips.

This type of transducer screws into the nozzle ( a nozzle pressure transducer) or, into the mold cavity or feed system (direct in-cavity pressure transducer).

## TRANSDUCER MOUNTING

One of the most common causes of damage to melt pressure transducers, is the installation of such units into improperly machined holes. By trying to force a transducer into a too-small, or eccentric hole, the transducer diaphragm will be crushed and the instrument will not function. Dynisco's transducer, mounting hole, machining tool kit (part number 200925) is available to help guarantee the holes are properly sized.

## UNCLEAN MOUNTING HOLES FOR MELT PRESSURE TRANSDUCERS

Once the transducer mounting holes are correctly machined, it is important that they are kept free of any plastic build-up. Before cleaning a machine, carefully remove the transducer from the nozzle to avoid damage. However, once these units are removed, plastic is likely to flow into the mounting holes and harden. If this plastic is not removed, before reinserting the transducer, it is sure to cause extensive damage to the tip of the transducer. An inexpensive cleaning tool kit (part number 200100) has been designed by Dynisco for use in removing this excess plastic and the use of such a kit is strongly recommended.

## INCORRECT POSITION FOR MELT PRESSURE TRANSDUCERS.

If a transducer is also positioned too far back in the mounting hole, room is left for unmelted plastic to build up between the transducer tip and the base of the hole. That is, a dead space has been formed. This unmelted plastic will degrade to carbon and will cause contamination: its presence will also prohibit the transmission of an accurate pressure signal. Conversely, if a transducer is pushed too far into the nozzle, then the tip of the transducer could be damaged by being sheared..

## NOZZLE/BARREL CLEANING.

Cleaning machine nozzles with either a wire brush or a special cleaning compound can ruin the transducer diaphragm. Transducers must be removed before the assembly is cleaned with a wire brush.

## WATER DAMAGE.

Melt transducers are not water tight. Although a transducer's electronic circuitry is designed to withstand the rigors of processing, it will not operate satisfactorily when wet. To avoid damage, make sure there are no leaks in the water cooling system which could result in the transducer being wetted.

### THREAD GALLING.

The friction caused by trying to screw a transducer into a mounting hole, with an incorrect thread size, will damage the transducer's threads and the instrument will then not function properly. The proper, mounting hole dimensions must be used to avoid thread galling: the threads must also be clean before the transducer is inserted and the threads tightened.

### COLD STARTS.

The transducer can be damaged if the heater bands are not left on for a suitable time (a heat soak) before the machine begins operating. Sufficient 'soak time' must be allowed for the residual plastic to return to a molten state. Also, if a transducer is removed from a cold machine, melt and material could adhere to the transducer tip and rip the diaphragm off the unit. Make sure the nozzle is warm before removing the transducer.

### OVER-PRESSURE.

Since Dynisco transducers are built to withstand twice the rated pressure, the machine would have to be operating at an extremely high, and unsafe, pressure level in order for the transducer to fail. However, to avoid the risk of over-pressuring the unit, make sure that you are using a model designed for your operating pressure range.

## Force-Type Transducer Tips.

This type of transducer slides into the mold behind a pin: it is called a slide-type transducer or, a force transducer or, a cavity pressure transducer or, an indirect pressure transducer.

### TRANSDUCER MOUNTING.

One of the most common causes of damage to the slide-type of transducer, is the installation of such units upside down. By trying to force a transducer into the mounting slot in this way, either the transducer or its cable will be damaged. Always double check that the unit has been installed the correct way around and that it has been pushed to its correct depth within the mounting slot. Use the correct mounting tool for this purpose.

### UNCLEAN HOLES AROUND PINS.

Once the pin mounting holes have been correctly machined, it is important that they are kept free of any build-up. The build-up will prevent the pin from moving freely within the pin mounting hole and can cause the pin to stick or bend. Such a build-up may be due to the plastics material itself or it could be due to a build-up of an additive which is being deposited during mold filling. Periodically check the cavity for additive deposition, check the pins for any sign of wear or scoring and see if there is any drift in the pressure readings.

### DAMAGE ON MOLD REMOVAL.

The slide-type of transducer is designed to be used with more than one mold. That is, it is removed from one mold at the end of an injection molding run, the mold is changed and the transducer is inserted in the next mold. Before removing a mold from the machine, carefully remove the transducer from the mold so as to avoid damage to the transducer or to its associated electrical cable. Do not leave the transducer swinging around on its cable but secure it properly, or remove it completely with its cable, so the assembly is not damaged when the mold/platen is moved.

### DAMAGE DURING RUNNING.

If the transducer is removed and not put back then the force transmitting pin can be forced back, during subsequent molding, unless the dummy, or blanking piece, is inserted behind the pin. If the blank is not placed into position, plastics material is likely to flow into the well so formed and harden. If this plastic is not removed completely, before reinserting the transducer, it may cause damage to the tip of the pin and prevent free movement. Always carefully remove such plastics material so as to avoid scoring the pin mounting hole and ensure that the pin is adequately lubricated.

### WATER DAMAGE.

Although slide-type transducers are water resistant it is common sense not to immerse them in water. Make sure there are no leaks in the water cooling system which could result in water penetrating into the clearance between the pin and its mounting hole as this could cause rusting and/or scale formation. Either one of these could cause the pin to bind or stick.

### CORRECT MOLD TEMPERATURES.

The pin/transducer assembly should be checked at the mold temperatures expected to be reached in production. Many such assemblies are used to mold engineering thermoplastics and the mold temperatures used with such materials can be surprisingly high. Check that the pin clearance is adequate at such temperatures.

**OVER-PRESSURE.**

Since Dynisco transducers are built to withstand twice the rated pressure, the machine would have to be operating at an extremely high, and unsafe, pressure level in order for the transducer to fail. However, to avoid the risk of over-pressuring the unit, make sure that you are using a model designed for your operating pressure range.

# MACHINE SETTING.

IT IS VERY IMPORTANT TO REALIZE THAT MACHINE SETTING MUST BE DONE CAREFULLY AND ACCURATELY RECORDED. UNLESS THE INJECTION MOLDING MACHINE IS CAPABLE OF BEING RESET TO THE SAME CONDITIONS, MOLDINGS DIFFERENT TO THOSE PRODUCED DURING THE SETTING OPERATION WILL BE OBTAINED.

Because each machine is different, it is only possible to give a general outline of what needs to be set and recorded. You should examine the following list and then prepare your own setting sheet; this should take into account your own experience and what needs to be recorded for a particular machine/ mold/material combination. You must record all that is essential for identical, injection molding production. Remember, the object of injection molding is to produce identical moldings, of the specified quality, each time and every time,

## Molding Data Record.

Date. Shift. Operator.
Machine setter. Inspector.
Part number.
Description of component.
Material used. Supplier. Grade. %Regrind.

Mold identification.

Machine identification.
  Screw type. Diameter. Screw tip details.
  Nozzle type Diameter. Heater size.

Tools required.

Ancillary equipment required.

Comments.

| THE MACHINE. SETTING. | SET OR TARGET. | ACTUAL OR MEASURED | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| No. of shots | | | | |
| Temperatures in °C or °F | | | | |
| Dryer. | | | | |
| Machine hopper. | | | | |
| Material. | | | | |
| Hopper block. | | | | |
| Hydraulic oil. | | | | |
| Mold-fixed half. | | | | |
| Mold-moving half. | | | | |
| Mold-manifold. | | | | |
| Barrel -throat (Z0) | | | | |
| -rear (Z1). | | | | |
| -middle (Z2). | | | | |
| -middle (Z3). | | | | |
| -front (Z4). | | | | |
| Nozzle (Z5). | | | | |
| Melt. | | | | |
| WATER FLOW RATES in l/s or gal/min. | | | | |
| Mold-fixed half. | | | | |
| Mold-moving half. | | | | |
| Oil cooler. | | | | |
| Hopper block. | | | | |
| PRESSURES in $MNm^{-2}$ or psi. | | | | |
| Maximum oil pressure. | | | | |
| Injection unit (oil). | | | | |
| Clamping unit (oil). | | | | |
| Cores (oil). | | | | |
| Nozzle. | | | | |
| Cavity switch. | | | | |
| Hold. | | | | |
| Back. | | | | |
| CYCLE TIMES in s | | | | |
| Total time. | | | | |

| THE MACHINE. SETTING. | | SET OR TARGET. | ACTUAL OR MEASURED | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| S.F.T. | -injection. | | | | |
| | -hold. | | | | |
| Screw retraction. | | | | | |
| Cooling time. | | | | | |
| Sprue break. | | | | | |
| Mold opening time. | | | | | |
| Pause time. | | | | | |
| Mold closing. | | | | | |
| SPEEDS (in m/s or ft/s). | | | | | |
| Mold closing | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| cores | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| Mold opening | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| cores | -initial. | | | | |
| | -fast . | | | | |
| | -final. | | | | |
| Injection | -initial. | | | | |
| | -fast . | | | | |
| | -final. | | | | |
| Screw rotational speed rpm | | | | | |
| Screw surface speed m/s or ft/min. | | | | | |
| DISTANCES (mm or in). | | | | | |
| Mold closing | -initial | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| cores | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |

| THE MACHINE. SETTING. | | SET OR TARGET. | ACTUAL OR MEASURED | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| Mold opening | -initial. | | | | |
| | -fast . | | | | |
| | -final. | | | | |
| cores | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| Injection | -initial. | | | | |
| | -fast . | | | | |
| | -final . | | | | |
| Screw start. | | | | | |
| Screw speed change. | | | | | |
| Screw stop. | | | | | |
| Screw cushion size (mm or in). | | | | | |
| WEIGHT in g or oz. | | | | | |
| Total shot. | | | | | |
| Component(s) | | | | | |
| Feed system. | | | | | |
| CRITICAL DIMENSIONS in mm or in. | | | | | |

# PRODUCTION INTERRUPTIONS.

Remember, the object of injection molding is to produce identical moldings, of the specified quality, each and every time. So, after any interruption ensure that the machine is running under 'normal' conditions before moldings are checked for the correct quality; this may mean discarding several complete shots even after after the most minor stoppage. Given below is a suitable form which should be used when production stoppages occur.

Name of molded part.
Description.
Mold identification or number.
Relevant component drawing number.
Machine identification or number (on which the mold is installed).
Mold installed by. Date.

Type of thermoplastics material used. Grade.
Color. % Regrind Other additives.

## INTERRUPTIONS.

Date. Time. Operator's/Setter's name.
Reason for production stoppage. Actions taken.

## RESTART DETAILS.

Date. Time. Operator's/Setter's name.
Actions taken.

Mold to be removed on. by the authority of
in order to carry out repairs/modification such as.

Mold removed by. Number of moldings produced.

Mold replaced on by the authority of

Mold set up by. Date. Checked by

Components inspected and cleared for production by.

Date Signed.

# MOLD MOUNTING AND SETTING.

IT IS VERY IMPORTANT TO REALIZE THAT MOLD AND MACHINE SETTING MUST BE DONE CAREFULLY AND ACCURATELY RECORDED. UNLESS THE INJECTION MOLDING MACHINE IS CAPABLE OF BEING RESET TO THE SAME CONDITIONS, MOLDINGS DIFFERENT TO THOSE PRODUCED DURING THE SETTING OPERATION WILL BE OBTAINED. AFTER ANY INTERRUPTION ENSURE THAT THE MACHINE HAS BEEN RESET TO THE PRODUCTION CONDITIONS.
Remember, the object of the injection molding is to produce identical moldings, of the specified quality, each and every time.

MOLD MOUNTING AND SETTING CHART.
Mold identification or number.

Factory or Unit name or number.
Mold manufactured by. Mold maker's ID.
Name of molded part. Drawing number.
Number of impressions in mold. Type of mold.
Type of ejection used on mold.

Ejection spigot diameter. Maximum ejection stroke on mold.

Ejector spigot thread type.
Dimensions of mold (mm or in).
Closed (shut) height. Vertical height. Width of mold.
Weight of mold. Size of eye-bolt used to lift the mold.
Thread type. Diameter of thread.
Location ring diameter.
Sprue bush details.
Flat nozzle. Y/N Radius nozzle Y/N Radius in mm or in.
Mold mounting requirements.
i) Bolts. Thread type. Length. Diameter.
  Cap heads. Y/N Hexagonal. Y/N Number req'd.
ii) Clamps details. ‘ T’ slot type.

iii) Washer details. Type. Thickness. Diameter.
Number req'd.
Mold cooling requirements.
Number of cooling circuits on mold.
Series or parallel type cooling circuitry used for mold.
Are 'snap-on' connectors to be used for mold. Y/N Number req'd.
Size and make of 'snap-on' connectors.
Color coding of cooling pipes.
Red for hot water. Length of pipe. Number req'd.
Blue for cold water. Length of pipe. Number req'd.
White for air. Length of pipe. Number req'd.
Braided steel for oil. Length of pipe. Number req'd.
Ancillary equipment requirements.

Ancillary equipment setting.

Additional tools required.

This mold is usually mounted on machine number.
Can also be used on machine numbers.

Inspect the mold during use every and in particular watch out for

Type of thermoplastics material used Grade.
Color. % Regrind. Additives used.
Total shot weight.
Weight of feed system.
Component weight.

Mold to be removed from machine and overhauled on.
Mold mounted and set by. Date.
Inspected and approved by. Date.

# MOLD MAINTENANCE AND REPAIR.

Name of molded part.
Description.
Mold identification or number.
Relevant component drawing number.
Mold installed on machine number.
Mold installed by. Date.
Type of thermoplastics material used. Grade.
Color. % Regrind. Other additives.

PROCEDURE FORM FOR MOLD REPAIR.
Mold removed from molding machine on
by the authority of Signature.
Removed in order to carry out the following repairs:
i).

ii).

iii).

iv)

Signed and certified by Date.

COMPLETION OF REPAIR.
The following mold modifications have been carried out in order to rectify the stated component and mold faults. Details of the mold modifications are given below:
i).

ii).

iii).

iv).

v).

Comments on mold repairs.

The mold is now suitable for use.
Signed and certified Date

# MOLD REPAIR CHECKLIST.

A standard procedure should be adopted when repairing, maintaining or refurbishing injection molds. To ensure that the mold is in satisfactory working order after repair, a detailed check should be carried out in accordance with the list below. The checklist can be attached to the mold throughout it's duration in the mold repair section.

**HAVE THE FOLLOWING ITEMS BEEN CHECKED?.**

CORES AND CAVITIES.
Checked for water leaks;
Checked for damage on the molding faces;
Surface finish of cores and cavities;
Have the molding faces been protected against corrosion?.

MOLD 'SHUT OUT' FACES.
Damage to the parting line on mold;
Removal of any surface deposit;
Check for flatness of mold plates or inserts;
Check for damage caused by stringing of thermoplastics material from the sprue.

SIDE CORE ASSEMBLY.
Check for straightness of angle pins;
Check for wear on angle pins so that the clearance between the location hole in the side core and pin is not excessive causing scuffing or marks to appear on the molding;
Check for a positive retention of the side cores when in their open position;
Check for any wear on the heel blocks or wear plates;
Check for the correct clearance on the slide retainers;
Check for signs of seizure on the base of the side cores.
EJECTION SYSTEM.
Check for the smoothness of the ejection movement;

Check that the ejection stroke is sufficient for ejection;
Ensure that the sprue puller pin is correctly located ;
Ensure that the ejection system is lubricated with a PTFE based paste;
Check that the ejector blades are suitably supported during the forward and return strokes;
Check that the correct ejection spigot has been fitted (to suit the molding machine it is to fit on);
Check that the ejection return mechanism is operating correctly.

## COOLING SYSTEM.

Check for any water leaks in the cooling arrangement;
Check that the cooling circuit has been correctly connected
up - so as to allow adequate cooling to the mold and to ensure that there are no blockages within the system;
Ensure that the number of the cooling circuit on the mold is the same as specified as on the setting sheet;
Check that the correct 'snap-on' connectors have been used and that they do not get damaged during mold mounting.

## ELECTRICAL HEATING SYSTEM.

Check the cartridge heaters for any failure;
Check all plugs and connector blocks for positive location and tightness of fit;
Check the thermocouples for each nozzle and manifold assembly of the runnerless system.

## UNSCREWING MECHANISM.

Check the position of the cores in relation to the operation of the mold;
Check that the helix spindle has been set correctly - in relation to the mold open and/or close position;
Check that the unscrewing unit has been adequately lubricated and set correctly;
Check that the shear pins have been replaced;
Check that the hydraulic cylinder is aligned with the guide plates so as to prevent premature seizure of the rack during the unscrewing operation.

## ELECTRICAL CIRCUITS ON MOLD.

Check that the microswitches are functioning correctly so as to ensure that the side cores, or additional moving parts of the mold, cannot be operated out of sequence in relation to the operation of the machine.

# START UP PROCEDURES.

One of the most dangerous times during molding is at start up. This is because the machine is being heated and the material may decompose and spit from the nozzle: the operator is involved in getting the machine running satisfactorily and this involves close contact with machinery. So, great care should be taken at start up. In particular nobody should be allowed to stand in front of the nozzle (some barrels can be swung to one side and purged) and the hopper lid should be firmly in place so that the screw cannot be seen (and therefore touched). No unauthorized person should be in the molding area.

## Start Up Preparation.

Obtain advice or, check the records, so that you know what machine settings are needed. Turn the main power switches on and select, or set, the temperature specified. Ensure that the cooling water is on and check that it is flowing through the hopper throat. (If fitted, put on the injection cylinder cooling and turn off the cooling water to the screw). Preheat the hydraulic oil to its operating temperature, for example, 45°C/113°F: this may be done by either, dumping the oil back to tank or, by using a purpose-fitted preheater. Once the machine is at the set temperatures (see WARMING UP) then it should be allowed to equilibrate, or settle down, before any material is introduced into the barrel. This may take 20 minutes so, use the time to prepare for the production run. For example, check that the nozzle/die is clean and that all parts of the mold are clean and operational. Review the production order for color and quantity: check that all necessary tools and equipment are in position. Check that the hopper equipment is clean and is functioning.

## Melt Temperature.

This is as measured in the nozzle or, by extrusion of the material into the air or, by 'shooting' the material into the air. Whatever method is used, great care should be taken during the measurement so as to ensure that, for example, purging of the hot plastic does not cause an accident. This is because a plastic melt is hot enough to cause severe burns, it also adheres to the skin and can be very difficult to remove. Burns are a common injury in injection molding shops. For this reason it is recommended that gloves and face shields are worn when handling hot material or where there is any danger of being splashed with plastic melt, for example, during start-up or purging.

To obtain greater accuracy, when doing an air-shot, the tip of the measuring probe should be pre-heated to the temperature that it is expected to measure. For a given machine, the actual cylinder settings, necessary to achieve this melt temperature, will depend on, for example, the screw rotational speed and the back pressure.

## Warming Up an Empty Machine.

The barrels of thermoplastics machines are most commonly heated by means of electrical resistance heaters. The heat supply to these should be programmed so that overshoot does not occur and so that the heating up time should also be reasonably short. Usually accomplished by using three term control or PID control. With some materials, eg UPVC, overshoot can be very serious as it causes degradation even before molding commences.

Once the machine is at the set temperatures then it should be allowed to equilibrate, or settle down, before any material is introduced into the barrel. (Keep this time as short as is reasonably possible as we do not want to burn the resin by heating the material in the presence of the air which is present in the screw flights). Before starting the molding run check that the set conditions are satisfactory by purging a few pounds of resin out of the nozzle; check its temperature with a melt probe and also check its general appearance.

## Warming Up a Full Mchine.

By ‘full’ we mean that the injection cylinder is full of a plastics material. A cold, full machine sometimes happens through, for example, a power failure or, it could be done deliberately in the case of materials which degrade by the process called oxidation, for example, polyolefins. At the end of an injection molding run, when molding an easily-oxidized material, the machine may be left with material in the barrel so as to prevent oxidation. What we must ensure is that the machine is heated in a safe way so that decomposition of the plastics material does not occur. This is because such decomposition can produce gases under pressure: such pressurised gases can cause serious accidents by, for example, blowing hot material from the nozzle.

Set all temperatures to below the melting temperature of the particular material (resin) e.g 275°F or 135°C for LDPE. Allow the machine to reach, and equilibrate, at these temperatures. Raise the temperature of the nozzle to above the melting temperature of the resin then, raise the temperature of the front zone and the rear zone to above the melting temperature; working towards the center, raise the temperatures of the other zones. Allow the machine to equilibrate (settle down) at these temperatures for a short while before commencing molding.

## Initial Operation and Purging.

Check that the machine is actually at the set temperatures by using a, for example, a digital thermometer fitted with a melt probe. Before starting the actual production run, reduce the screw speed, and the injection speed, to a low value and put a small amount of material/ resin in the hopper. Replace the hopper lid and withdraw the injection unit ('the carriage') from contact with the mold. Check that the set conditions are satisfactory by running a few pounds of material/resin out of the nozzle/die (this will probably mean that the screw must be rotated and then pushed forward i.e. reciprocated). Check the melt temperature with a melt probe, check its general appearance and then dispose of this hot, sticky material in a safe way (by, for example, putting it in a bucket of cold water). When you are satisfied that the material is feeding well, and that the melt looks satisfactory, fill the hopper to the set level. Check that the throat gate (the hopper slide) is open as rotation of the screw in an empty barrel may cause damage to the screw and to the barrel liner. Check that the monitoring equipment is functioning and when material/resin starts to extrude from the nozzle/die, turn on the screw cooling if fitted.

## Commencing Molding (Hand Operation).

Only when a satisfactory melt is being produced, during purging, should injection molding be commenced. Often this is often done under 'hand operation' i.e. the operator initiates each part of the molding cycle by pushing a button so as to achieve the right sequence of operations.

For example, the mold is closed and clamped: at this stage the clamping pressure is checked. The injection unit is brought into contact with the sprue bush (i.e. brought forward) and material is forced into the mold under low speed and pressure. The injection cylinder feed, the pressures and the speeds are gradually increased (injection speed and screw rotational speed) until satisfactory moldings are obtained {see the section entitled **Commencing Molding (Automatic Operation).** Rapid changes often do not save any time as overshooting is often the result. Periodically, check to ensure that the hopper has the required amount of material (may mean checking the level of the plastics material and the colorant supply) and that material is not leaking, or weeping, from around the nozzle. A check is made on the quality of the product and if this is satisfactory then, the molding run is commenced.

## Commencing Molding (Automatic Operation).

Again this is only started when a satisfactory melt is produced during the purging operation

At the end of the purging stage reduce the feed setting to a low value - below that which you would use to fill the mold Commence injection molding on an automatic, or semi-automatic cycle using pre-determined cycle times (although these may be calculated, they are usually based on experience) Adjust the line pressure (first stage pressure), and the injection speed, until the required rate of injection is obtained Gradually increase the feed setting (the amount the screw is allowed to rotate) until the mold is almost full

At this stage of the proceedings the molding should be short but the surface finish should be that required Re-adjust the injection speed if necessary

At the end of the injection stroke the screw/ram should 'bottom' note this position Set the final mold filling pressure (second stage pressure) to that suggested for the particular material usually this is lower than the first stage (but not for some semi-crystalline, thermoplastics materials) Set this second stage pressure to come in, to be actuated, at this point Increase the amount of feed until the screw is approximately 3mm or 0 118 inches (for small machines) away from bottom when injection is complete Increase the second stage pressure until the moldings are free from sinks or voids, allow the machine to equilibrate and then weigh the molding

Increase the second stage pressure until the molding weight no longer increases or, until the molding starts binding or sticking in the mold It may prove necessary to increase the injection time if the molding weight does not settle down to a steady value However, the temptation to overpack the molding must be avoided at all costs and the screw feed must be adjusted to maintain a constant length of screw cushion After each adjustment allow the machine to settle down for approximately 6 shots before making another adjustment Adjust the cooling time until the molding can be ejected without distortion and then adjust the screw rotational speed to fill this time

## Changing Conditions and Dimension Checking.

Once operational, the appearance, color, weight (or selected dimensions) of the product are checked and compared against preset, or specified, values, for example, weight or dimensions Speeds, or settings, are changed until the product conforms to standard It is important to realize that any changes must be well thought out in advance and must be made gradually as, for example, an increase in screw speed causes not only a decrease in screw recovery time but also, an increase in temperature Changes must be made one at a time, the machine must be allowed to settle down and the effect of that change noted otherwise, no one will know what is going on and large amounts of scrap will be produced

## Recording Production Conditions.

It must never be forgotten that the object of injection molding is to produce moldings of the required quality at a specified cost within a specified time To do this it is essential to keep accurate records On many machines this can be done at the press of a button Where this is not possible then, an appropriate record sheet should be completed, and sample moldings retained, for future reference

# SHUTTING DOWN.

It is most important to adopt a sensible shut down procedure as such shut down procedures can save a great deal of time and money If you stop, for example, the material/resin burning, then there is not so much purging out to do and you might even save the cost of a complete shut down and machine clean out

## Temporary Stops.

During a temporary stoppage, periodically purge the cylinder, or barrel, by passing material through the machine and/or by making air shots If the plastic looks discolored then increase the frequency of this purging During a minor repair, the heaters on the injection cylinder should be set to low values, for example 150°C, so as to minimize thermal degradation On more modern machines this procedure may be initiated automatically

## Over-Night Stops.

If a thermally stable plastic (for example, PS) is being injection molded, then for an overnight stop, it is usually only necessary to close the slide at the base of the feed hopper, turn off the cylinder heaters (leave the nozzle heater on) and then purge the cylinder clean by pumping the screw dry When nothing more comes from the nozzle, put any barrel cooling on maximum and when the machine is cool, turn everything off The machine is then ready for reheating

## High Temperature Work.

When high cylinder or barrel temperatures are used, then modify the above procedure slightly so as to prevent thermal decomposition of the material/resin For example, turn off the cylinder heaters (leave the nozzle heater on), put any barrel cooling on maximum and then periodically pump resin through the machine while it is cooling Close the slide at the base of the feed hopper and purge the cylinder clean by pumping the screw dry and/or by making air shots When nothing more comes from the nozzle, and when the machine is cool, turn everything off The machine is then ready for reheating

## Heat Sensitive Materials.

Decomposition, or burning, of the plastic in the injection molding machine will cause color changes and will then result in the subsequent injection moldings being rejected When this happens a complete shut down and clean out may be necessary To prevent this it may be necessary to purge a heat sensitive resin with another, more heat stable, plastic as this will withstand subsequent reheating If material oxidation is a problem then, some molders leave the injection cylinder full of material, for example, PE

## Purge Materials.

Materials which are used to clean the injection cylinder are known as purge compounds may be specially purchased compounds or, may be a resin such as LDPE They are introduced into the cylinder or barrel when the screw has been pumped dry, or free of, the more unstable material e g PVC Before such purge compounds are used, it may be advisable to remove the nozzle assembly as many purge compounds do not melt, or flow, like ordinary resins the nozzle may then be thoroughly cleaned Once the purge compound is coming through, the shut down procedure may then be followed

## Easily Oxidized Materials.

At the end of an injection molding run, when molding an easily-oxidised material (for example, PE) the machine may be left with material in the barrel so as to prevent oxidation This means that the injection cylinder is left full of material (A cold, full machine happens therefore through, for example, a power failure or, it could be done deliberately in the case of materials which degrade by the process called oxidation, for example, polyolefins)

What we must ensure is that the machine is heated in a safe way, when re-started, so that decomposition of the plastics material does not occur This is because such decomposition can produce gases under pressure such pressurised gases can cause serious accidents by, for example, blowing hot material from the nozzle (see 'Heating and heat imput')

## PVC and POM.

Some plastics degrade relatively easily, for example POM and PVC If there has been an emergency shut-down while processing such materials then, before further injection molding is attempted, put the nozzle heater on and only when the plastic is melted in the nozzle, switch on the cylinder heaters Set the cylinder, or barrel temperatures to approximately 140°C/284°F and allow the cylinder to equilibrate at this temperature Then raise the temperature to the processing temperature and purge clean as soon as possible All purgings should be put in a bucket of cold water If a change is being made, from or to, another plastic, then purge with a natural, non-flame retardant grade of PS or PE NEVER mix POM (acetal) and PVC (vinyl) or, follow one with the other without thorough purging with PS or PE

## Check Recommendations.

Always check that you have followed the correct procedure before you turn a machine off or, before you change to another material Material suppliers issue leaflets which give a great deal of information and are readily available Such leaflets should be studied and an 'official shut down procedure' devised from them for each material This should then be placed by the machine so that it is readily available to the machine operator

# CYCLE TIME REDUCTION

The main objective of any molding operation should be the manufacture of components, to a specific quality level, in the shortest period of time In order to maximize the output from a given machine/mold/material combination, detailed investigations are necessary so as to ascertain which area, or areas, of the molding cycle can be reduced so that an increase in output is obtained Some molders have found that by carrying out such studies, as given below, cycle time reductions of up to 30% have been achieved

## Dry Cycle Time of the Molding Machine.

The dry cycle time is the amount of time that the machine needs, in order to complete one cycle when it is operated dry: that is, without any material in the injection cylinder Irrespective of the size and type of injection molding machine, the dry cycle should be known when attempting to improve performance as this helps the molder to determine if a particular molding machine has the ability to produce, and maintain, components at high output levels So before attempting to reduce the time, for individual movements (or operations) of the machine, it should be considered whether a time reduction is possible in view of the machine's condition, age and stated dry cycle time

Table 9 gives typical dry cycle times for a range of molding machines

## The Molding Cycle.

Figure 2 shows, in chart form, the main sections of the molding cycle Each section of the cycle should be considered separately so as to identify the areas where possible time reductions can be made thus often achieving a small time saving for each element Although such savings may be small, when these time increments are added together the net saving can often be significant in terms of an overall percentage reduction

### MOLD CLOSED/MOLD OPEN TIME.

Table 9 gives the fastest possible time for opening and closing the platens on the machine In general most machines use mold close/open times which are slower than the fastest quoted time (e g 100 to 350% slower) This difference is related to the weight/size/complexity, of the mold and to the need for safeguarding of the mold (from damage during the opening and closing operations)

Typical mold close/mold open times are as follows

Conventional two plate molds 1 to $2t_{cm}$,

Complex molds (which involve the use of side cores or unscrewing mechanisms) and multi-plate molds 2 to $3\ 5t_{cm}$,

(where $t_{cm}$ is the time quoted in the machine specification)

If the sum of the collective mold open and close times is greater than 15% of the actual cycle time, then attempts to reduce this time should be made by incorporating modifications to the mold or by the use of a newer type of molding machine The use of the newer design of molding machine allows faster closing and opening speeds to be used in conjunction with low mold closing (mold sensing) pressures prior to the locking force being applied

Quite often shop floor personnel are unaware of the quoted platen speeds, or times, for a particular molding machine, and consequently set the mold open/close times based upon personal experience However, this can lead to long cycles By reducing the collective times by 1 second on a 10 second cycle, an immediate 10% improvement in productivity can be achieved, this improvement is often the difference between a profit and loss situation

## INJECTION TIME.

The injection time (Screw Forward Time or SFT) is broken down into two sections

i) Screw Displacement Time (mold fill time),
ii) Screw Packing Time (mold pack time)

### Screw Displacement Time.

The Screw Displacement Time is the time taken for the molten thermoplastics material to fill the mold (often referred to as the mold fill time) to 95 to 98% completeness For the majority of molded components this time is 3 seconds or less, more typically, fill times of 0 4 to 1 5 seconds are used However, times longer than 3 seconds may be required to produce components of a very high standard Components of this nature are associated with either the optical industry e g acrylic lenses, fascias, prisms etc , or the electronics and automotive industries for the manufacture of computer housings and car bumpers

A slow mold fill time can often be the consequence of a poorly designed mold, e g a wrongly sized feed system or, an incorrectly positioned gate If this is the case then modifications should be made to the mold so as to achieve fill times similar to those given above

### Calculation of the Mold Fill Time.

Most mold fill times are determined by selecting the maximum injection speed possible after consideration of the capabilities of the molding machine and the processing characteristics of the thermoplastics material In some instances, too fast a filling speed adversely affects the mechanical properties of the material and the molded component To overcome this problem, the mold fill time for a given material/mold/machine combination should be calculated A formula proposed by J Bown (reference Injection Molding of Plastics Components by J Bown, Published by McGraw Hill, 1979) is as follows

$$t = \frac{(dw\ P_f/P_{fr})^3}{8[T_x - T_m / T_c - T_m]^3}$$

where t = the mold fill time in seconds,
dw = the minimum wall thickness of the molding in mm,

$P_f$ = the maximum melt flow length from the gate in mm;
$P_{fr}$ = the flow length component wall thickness ratio for the molding material,
$T_c$ = the temperature of the melt in °C or °F;
$T_m$ = the temperature of the mold in °C or °F;
$T_x$ = the heat distortion temperature of the thermo plastics material in °C or °F

In order to simplify the above equation, table 10 gives values for some thermoplastics materials for the expression $[T_x - T_m/T_c - T_m]^3$ The values given, for the above expression, are based upon the use of a general purpose (GP) grade of material If specific grades of polymers, which have considerably different processing characteristics to those of the GP grade, are to be molded then, it is advisable to recalculate the value of V by inserting the actual processing temperatures, intended to be used during the molding operation, in the equation

**Typical Mold Fill Time Calculation**

If a polyacetal (POM) component is to be molded then the mold fill time may be calculated as follows
Wall section of molding = 0 6mm ( 024in),
Flow length of melt in the cavity from the gate = 120 0mm (4 72 in),
Flow length wall thickness ratio for POM is 230 1,
Mold temperature ($T_m$)= 90°C,
Melt temperature ($T_c$) = 205°C,
HDT for polyacetal ($T_x$) =110°C

Then,

$$t = \frac{(dw\ P_f/P_{fr})^3}{8[T_x - T_m/T_c - T_m]^3}$$

$$t = \frac{(0\ 6 \times 120/230)^3}{8[110 - 90/205 - 90]^3}$$

$$t = 0\ 8 \text{ seconds}$$

## THE SCREW PACKING TIME.

The Screw Packing Time is the time when the screw is held almost stationary in its most forward position, so as to apply the necessary injection pressure to the molten material necessary in order to pack the material into the mold cavity during the material solidification stage It should be just long enough to pack the mold with the required amount of material and is therefore directly related to the wall thickness of the molded component and to, the melt and mold temperatures A correct Screw Packing Time results in moldings having an optimum part weight, optimum mold shrinkage, good mechanical properties, a good surface finish and dimensional stability and less of a tendency for sinks and voids to occur within the molding For this reason the Screw Packing Time should always be accurately determined for every material/mold/ machine combination

### SETTING THE SFT.

Calculate the mold fill time Add 0 5 seconds to this and produce say, 5 components at this setting Each of the components produced should then be weighed, and/or measured, and the values noted An average value should be calculated and then, this procedure is repeated for time increases in the SFT (e g 0 5, 1 0, 1 5, 2 0 seconds etc) The time is increased until the average weight, or measurement, of the molding remains constant (this being the correct SFT )

Figure 3 shows a typical graph of component weight against time It can be seen that after 2 5 seconds the component weight remains constant and this is therefore the correct SFT for this particular mold

### INFLUENCE OF GATE SIZE ON THE SFT

For the above procedure to be effective the use of a suitably sized gate, for each molding, is essential The gate aperture should not be so small that the gate freezes off before the mold cavity is fully filled with molten material Alternatively it must not be so large that cool, or semi-solid material, is forced through the gate and into the molding - thus causing stresses and cracking to occur in the gate region For these reasons gate thicknesses (depths) should always be between 0 6t to 1 0t (where t is the component wall thickness)

## Cooling Time

The cooling element of the molding cycle is there to ensure that the molten plastics material in the mold has solidified sufficiently, so that the molding(s) can be ejected without distortion

### INFLUENCING FACTORS.

The time taken for the material to solidify, or set, within a mold is dependent upon many factors, for example, the shape, the wall thickness of the component, the type of material being molded, the design of the cooling circuitry in the mold and the quality requirements of the molded component

This time element is always the longest portion of the molding cycle and is an area where considerable savings can be made

Although it may be calculated, it is usually determined experimentally by, for example, progressively reducing the cooling time until distortion-free moldings are still being consistently produced During the cooling element, sufficient time is needed to retract the screw (sometimes called screw recovery, or dosing time) so as to refill the barrel with material (to replace that injected into the mold) A situation must not arise where the duration of the cooling time is dictated by the screw recovery time If this is the case then the wrong processing conditions, and screw surface speeds, are being used

### Cooling Calculations.

The two major influences that dictate the duration of cooling time are

i) The solidification time for the thermoplastics material being processed, and

ii) The design of the cooling circuitry in the mold

Many molders rely upon the mold designer to specify the type and amount of cooling needed for a given mold and quite often the cooling systems proposed are totally inadequate The amount of cooling capacity required for a mold must be calculated in order to obtain the specified cycle time

By calculating the solidification time for a particular component/material combination, the resultant value can then form the basis of the cooling requirements for a given mold

### Ballman and Shusman Formula

A useful formula, to predict the solidification time, was proposed by Ballman and Shusman (Modern Plastics published by McGraw Hill, 1959) This formula has the merit of being relatively simple and reasonably accurate If the solidification time is called Q then

$$Q = \frac{-D^2 \times \log_e [\, \pi \times (T_x - T_m) \,]}{2\pi\propto \, [\, 4 \, (T_c - T_m) \,]}$$

where $D$ = the maximum thickness of the molding in cm,

$\propto$ = the thermal diffusivity of the thermoplastics material,

$T_c$ = the temperature of the melt in °C or °F,

$T_m$ = the temperature of the mold in °C or °F,

$T_x$ = the heat distortion temperature of the thermoplastics material in °C or °F

$\pi$ = 3 142

The above equation, incorporates various thermal properties and processing conditions In an attempt to simplify calculations, table 10 gives calculated values (for sections of the above formula) for a selection of thermoplastics materials in the form of a constant C By multiplying together the constant C and the maximum wall

thickness, the solidification time is readily determined.
Table 10a gives typical solidification times for a range of thermoplastics materials and wall thicknesses.

### MOLD OPEN OR DWELL TIME.

At the end of each molding cycle it is necessary to allow sufficient time for the moldings to fall clear from the mold prior to the next cycle commencing. On fully automatic cycles, a delay, or interval timer, is used. For semi-automatic cycles the time period is usually dictated by the proficiency of the molding shop personnel. In general, the mold open time is far too long.

### CALCULATION OF THE MOLD OPEN TIME.

To determine the minimum time setting for the delay or pause timer, the following formula can be used:

$$t_p = \frac{d^{0.5}}{22} \quad \text{or} \quad \frac{\sqrt{d}}{22}$$

where $t_p$ = the time delay in seconds;
$d$ = the distance in cm from the topmost point of the molding, where it fits in the mold, to the bottom edge of the mold.

### WORKED EXAMPLE.

If a box shaped molding has to fall 40cm to become clear of the mold, then the required pause time is:

$$t_p = \frac{d^{0.5}}{22} \quad \text{or} \quad \frac{\sqrt{d}}{22}$$

$$t_p = \frac{\sqrt{40}}{22} \quad = 0.29 \text{ seconds.}$$

## Modifications to Existing Production Molds.

The above procedures were developed to improve the output for existing production molds. In order to achieve such improvements various modifications may be necessary but, in some cases such a modification is not possible because of the initial design. In these situations it may be more profitable to produce a new mold.

# ENDING PRODUCTION.

## End of Production.

At the end of the production run it is all too easy to have the mold taken out of the press as quickly as possible so that the next job can be started immediately. However, it must be remembered that the current mold will need to be used again. So, when a particular,

production run is coming to an end ensure that all relevant people know that the proposed tool (mold) change is imminent so that
(a) the 'new' mold can be checked, cleaned and repaired (if necessary);
(b) pre-assembly, and preheating, of the new mold, prior to mounting, is done as far as possible;
(c) the setting up sheets for the new mold are ready and distributed to the setter and his/her assistant;
(d) the new material, plus additives, are readily available in a moldable form,
(e) production conditions for the new run are available
Ensure that,
(f) the production conditions for the 'old' run have been carefully and accurately recorded,
(g) the setter has inspected the mold still in production so that appropriate repairs can be done before the mold is stored,
(h) all mold defects are recorded in writing so that repairs can be scheduled and future problems avoided;
(i) some moldings are put away with the tool so that, for example, identification of components, such as inserts, is made easier and defects can be readily identified; and,
(j) the mold cooling circuits have been inspected and cleaned

## Insulate the Molds.

Many molds, particularly those used for engineering thermoplastics, run at relatively high temperatures, for example, 80°C/176°F If the mold is not insulated then, heat losses to the atmosphere, and to the machine, can easily equal those lost by the injection cylinder So, insulate the mold from the platens and if possible, insulate the outside surfaces of the mold If a hot runner mold is being considered then, try and reduce heat exchanges between the hot runner parts and the cold, component-forming parts Such measures will reduce energy losses and warming up periods

## Instrument the Mold.

When a mold is out of commission it is always worthwhile spending some time on deciding if that particular mold will run better, or easier, if it is instrumented For example, will the molding operation benefit if rotometers, temperature sensors or pressure sensors are fitted? The opinions of relevant departments should be sought and suitable instruments fitted before the next production run is scheduled

# FAULT FINDING.

(This section is based upon a procedure suggested in "Injection Moulding of Plastic Components" by John Bown Published by McGraw Hill )

A logical and systematic method of dealing with faults is most desirable and many practical molders have their own scheme of operation In compiling such a scheme it is important to ensure that all the terms used are unambiguous and are understood by all concerned Faults should be clearly described and all the possible causes should be examined The effect of the fault should be taken into account and when the cause has been identified the necessary steps should be taken to eliminate it and to prevent its recurrence

A suggested seven-point scheme is as follows

(1) Name the fault This may seem obvious but some faults are given a variety of names For example, "splash marking" is variously referred to as "mica marking", "silvering" or "silver streaking" It is advisable to decide which of the names will be used and to stick to that decision

(2) Describe the fault In describing a fault, a possible cause may be included For example, a "short moulding", i e an incomplete moulding, may be described as "insufficient pressure to fill the mold" or "not enough material to fill the mold" It is a useful exercise to try to describe all the common faults in the simplest possible terms without ascribing any possible cause In this way, the mind is cleared of any possible prejudice for the next stage of the scheme, which is finding the cause of the fault

(3) Find the cause of the fault This may be a lengthy process since it requires consideration of material, machine, mold and process The following guide lines are suggested:

(a) Material Check for grade or type, examine for contamination, and make sure it complies with the manufacturer's specification If the fault is apparent with different lots of the same manufacturer's material, or with material from a different supplier, this indicates the material is not at fault Observe the effect of regrind, with particular reference to any difference of it's processing characteristics to the same virgin material

(b) Machine Check the functioning of all parts of the machine, taking into account anything that could influence pressure, temperature, rate, and time If the fault appears intermittently, this usually indicates a defective operation of the machine, such as temperature fluctuation due to a defective thermocouple If the fault appears in the same place, in a single cavity mold, this indicates that the cause of the problem lies in the injection cylinder assembly (e g back flow valve) or in the regulation of injection

(c) Mold Make sure that the mold is properly set and is at the correct temperature, and that all the parts function smoothly and correctly. If the fault always occurs in the same cavity, or the same cavities of a multi- cavity mold, the fault is usually in the feed system (i.e. runners and gates serving those cavities).

(d) Process. Check that the pressures, temperatures, and times are set as recommended by the materials supplier. If the fault disappears when the mold is shifted to another injection molding machine, the fault is most probably due to the processing conditions used and consistency of production on the original machine. If the fault disappears when the machine is operated by a different person, then the fault may be due to the human element involved in the process. Check the speed and regularity of the molding cycle and the dwell time of opening and closing the safety gate

(4) Determine the effect of the fault. If the fault renders the component unusable or unsaleable it must obviously be rectified. If it is only of minor significance it may be unnecessary to try to eliminate it entirely.

(5) Determine where the responsibility lies. This may only be of academic interest, but if the fault recurs the operator - as well as the material, machine, mold and process - needs to be checked.

(6) Take action to avoid the fault. Failure to take the appropriate action can result in the unnecessary production of faulty moldings and its consequent detrimental effect on the profitability of the project.

(7) Take steps to prevent a recurrence. Make sure that full records are taken of conditions when the fault has been eliminated. Note any repairs and alterations which are made to the mold or the machine and any variations in type, grade or quality of material. If rework (i.e. re-ground scrap) is used, note the proportion and quality.

These steps for dealing with faults may seem superfluous but no fault-finding exercise is complete unless all seven points have been considered. Making faulty moldings, even though they can all be recovered and re-ground, and the material used again, is very uneconomic and is a short route to bankruptcy.

# MOLDING FAULTS AND THEIR REMEDIES.

In every instance of injection molding faults, the defects in a molded component usually originates from one, two or three causes: the operation of the machine, the function of the mold, or the processing behavior of the material. Quite often there is more than one cause contributing to the problem or fault. For each of the faults stated **alphabetically** below, suggested remedies are given under the headings machine, mold and material.

| **FAULT. Black-Brown specks.** | DESCRIPTION. The molding is colored the appropriate shade but specks or streaks are occasionally seen. |
|---|---|
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| Degraded material from the previous production run has solidified in the cylinder, on the screw, in the non-return valve, or possibly in the hot runner manifold. | Use a purging compound or a high molecular weight PMMA to purge the barrel assembly clean. |
| The material gets held up in 'dead spots' or nil flow areas of the cylinder assy, causing it to degrade due to prolonged exposure at high temperatures. | Strip down the barrel and screw assembly and thoroughly clean the surfaces which are in contact with the molten polymer.<br>Check that the nozzle is correctly seated within the barrel assembly.<br>Replace the shut off nozzle with an open or straight through type.<br>Check the non return valve assembly for cracks etc; if necessary replace with a new assembly |
| The material is entering the cavity too fast causing an excessive shearing action to the polymer. | Reduce the injection speed. |
| The melt temperature is too high. | Reduce the melt temperatures by lowering the rear cylinder zones.<br>Check that the flow rate of the cooling medium is sufficient for the hopper block assy and adjust the flow rate if necessary.<br>Reduce the cycle time to increase the material throughput in the barrel assy. |
| Incorrect screw surface speeds and and back pressure are being used causing excessive shearing of the molten material. | Use minimal back pressure and the correct surface speeds. |
| The wrong type of screw design is used for the material being processed. | Use a different screw having a lower compression ratio. |
| **Mold.** | |
| Grease or oil is present in the cavities | Strip down and thoroughly clean the mold, particularly the ejector mechanism. |
| The gates are too small. | Increase the gate size. |
| Wall sections of the component are too narrow for the material to adequately flow along without degrading. | Check for the correctness and uniformity of wall thickness and modify if necessary. |
| Contamination originating from the hot runner mold. | Completely strip down and clean the manifold and nozzle assembly of the hot runner mold. |
| **Material.** | |
| Contamination with small amounts of | Check for the source of the contamination |

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| PVC or another heat sensitive material. | particularly where the material is conveyed in tubes made from PVC. |
| The use of previously, over-heated regrind. | Segregate and critically check the regrind for contamination. |
| Inclusion of burnt particles in the molding material as a result of poor house-keeping and/or drying procedures. | Clean out the drying and/or regranulation units. |
| Insufficient lubricant within the material giving poor flow properties | Add a quantity of an external lubricant. (e.g. add 0.05% to 0.1% of zinc stearate). |
| **FAULT. Black-Brown streaks (see Black-Brown specks for causes and remedies).** | DESCRIPTION. The molding is colored the appropriate shade but specks or streaks are occasionally seen. |
| **FAULT. Brittleness.** | DESCRIPTION. The components breaks on ejection or, are readily broken or cracked during handling. |

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| The melt temperature is too low. | Increase the rear zone and nozzle temperatures on the cylinder.<br>Decrease the screw speed, or adjust the rpm to obtain the correct screw surface speed. |
| The material is degraded in the cylinder resulting in the breakdown of the molecular structure of the material. | Reduce the cylinder temperatures on all zones.<br>Reduce the overall cycle time.<br>Reduce the back pressure.<br>When using a vented barrel assembly, ensure that the exhaust vent is functioning correctly and that the temperatures are set correctly for each zone. |
| The mold filling speed is too slow | Increase the injection speed.<br>Maintain a constant cushion or pressure pad on the machine. |
| **Mold.** | |
| The surface of the mold is too cold. | Increase the mold temperature.<br>Restrict the flow rate of the cooling medium through the mold. |
| The runners and gates are too small creating excessively high shear rates during mold filling. | Use full round runners and increase the size of the runner and gate so as to give acceptable shear rates during mold filling. |
| **Material.** | |
| The components are not properly stress relieved or conditioned. | Anneal the molded parts or, in the case of nylon, immerse in warm water. |
| The component has been inadequately designed to suit the specific material. | Redesign, if possible, the product to strengthen the weaker sections. |
| Too much regrind material is being added. | Reduce the amount of regrind material being blended with the virgin material. |
| Contamination by foreign material. | Inspect the molding material for evidence of contamination.<br>Thoroughly purge the cylinder clean.<br>Strip down and thoroughly clean the hopper or hopper loader assembly. |
| The quality of regranulated material may be poor. | Segregate and critically check all the regranulated material for signs of contamination.<br>Ensure that the reground material is sieved to remove the dust or 'fines'.<br>Check that the regranulation procedure has been strictly followed. |

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| **FAULT. Bubbles (trapped gas).** | DESCRIPTION. If the melt contains gas (volatile matter) then the molding will often contain gas bubbles as a result of |

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| | melt decompression during mold filling. |

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Trapped air in the barrel assembly. | Lower the barrel temperatures especially the rear zones.<br>Increase back pressure.<br>Reduce screw speed.<br>Reduce the amount of decompression (suck-back) used. |
| Insufficient packing pressure. | Increase the injection pressure. |
| The mold filling speed is too fast. | Reduce the injection speed. |
| **Mold.** | |
| Inadequate venting in the mold. | Insert vents in mold or increase the depths of the existing vents. |
| Uneven flow in the mold causing air entrapment. | Use vacuum venting on the mold.<br>Change the position of the gate.<br>Increase the runner diameter. |
| **Material.** | |
| Moisture condensing on the cold material when it is brought into warm atmosphere of the molding shop. | Dry the material.<br>Store the polymer in the molding shop for at least six hours before molding. |

| **FAULT. Burn marks.** | DESCRIPTION. Discolored material (ranging from yellow to black) and which usually appears at the end of the flow path and/or where air is compressed. |
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| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Material is too hot. | Reduce the melt temperature. |
| Mold is being filled too quickly. | Reduce the injection speed. |
| Back pressure is too high. | Reduce the back pressure.<br>Check that the correct screw surface speed is being used. |
| Excessive amount of volatiles in the melt. | Ensure that air is not being drawn into the barrel with the material.<br>Check that the hopper is always filled with material to a constant height. |
| Excessive clamping force being applied to the mold. | Reduce the clamping force slightly. |
| Incorrect purging procedures have been used at the completion of the the previous production run i.e. the material was left to 'cook' in the in the barrel. | Adopt a strict purging procedure for the molding shop. |
| Material remaining in barrel for too long a time. | Decrease the overall cycle time. |
| **Mold.** | |
| The vents in the mold are inadequate or have become blocked. | Inspect and clean the vents.<br>Insert a vent at the point of the burn mark. |
| The molten material surrounds a a pocket of air, in the mold, in such a way that the air becomes trapped. The entrapped air is compressed causing a burn mark to appear as a result of combustion. | Use vacuum venting on the mold.<br>Alter the filling pattern of the mold by reducing the component wall section or creating flow leaders on the component.<br>Change the position of the gate. |
| The gate/s are too small. | Increase the gate depth or width or reduce the gate land. |
| **Material.** | |
| The material has not been thoroughly dried leaving minute traces of moisture. | Dry the material following the correct drying procedure.<br>Use a vacuum or desiccant drier. |

| **FAULT. Component sticking in the mold** | DESCRIPTION. The components or moldings stick in the mold so that difficulty is experienced in component removal. |
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| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Overpacking of material in the mold. | Decrease injection pressure.<br>Reduce shot volume.<br>Cylinder temperature too high. |
| Injection pressure held on for too long a time. | Decrease screw forward time. |
| **Mold.** | |
| Mold surfaces are scratched, porous or marred. | Remove blemishes and polish the mold surface. |
| Insufficient draft angles machined in mold. | Use a minimum draft angle of 0.5 degree per side (the greater the angle the easier the ejection and the faster the cycle). |
| Undercuts are incorrectly designed. | Ensure that undercuts do not have sharp angles and have generous tapers to ease ejection. |
| Components sticking to a highly polished mold surface. | Incorporate venting valves to remove a vacuum which can occur when ejecting components from highly polished surfaces.<br>Also use vents in conjunction with air ejection.<br>Use a matt finish if it is permitted. |
| Inadequate ejection mechanism. | Increase the number of ejectors or replace with a different system. |
| **Material.** | |
| Inadequate lubrication in material. | Use mold release agent if permitted.<br>Add an external lubricant such as zinc stearate (0.05%). |

**FAULT. Crazing.**

DESCRIPTION. The surface of the molding has minute crazes or fractures which on transparent moldings give a white/silver appearance.

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Injection pressure is too high. | Reduce the injection pressure.<br>Reduce the screw forward time. |
| Mold filling speed is too low. | Increase the injection speed. |
| Inhomogeneity of melt occurring. (variations in melt viscosity) | Increase the melt temperature. (increase the temperature of the rear zone on the barrel).<br>Increase the overall cycle time.<br>Increase or profile the back pressure.<br>Transfer the mold to a larger machine having a greater plasticizing capacity. |
| **Mold.** | |
| The component is being highly stressed when ejected from mold. | Incorporate extra ejectors in pins in the mold.<br>Ensure that the ejection movement is uniform and parallel when actuated.<br>Increase the diameter of ejectors if necessary.<br>Reduce the speed ejection movement. |
| The surface of the mold is causing the crazing. | Clean and inspect the mold surface where the crazing exists. |
| The metal inserts are too cold and /or oily. | Degrease and preheat the inserts prior to inserting them into the mold. |
| Traces of oil are getting onto the mold surface from the ejection mechanism. | Strip down, and thoroughly clean the ejection system and check for any leaks on the hydraulic ejector. |
| Water leak in the cavity or core. | Check for any sign of a hairline crack in the cavity, core or mold plate<br>Check for any water leak due to a defective 'O' seal. |
| The gate size is too large causing the molding to be overstressed due to overpacking | Decrease the gate depth. |

| **FAULT. Degradation of the material.** | DESCRIPTION. The moldings, or regions on the molding, are discolored: colors usually darken when degradation occurs and may range range from yellow through orange to black. |
|---|---|
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| The material in the barrel is overheating. | Reduce the melt temperature. |
| The temperature controller is malfunctioning. | Check whether the temperature controller is controlling the correct zone on the barrel.<br>Recalibrate the temperature controller and check for sticking contacts etc. |
| The incorrect thermocouple type has been used. | Check that the type of thermocouple used is the same that is quoted on the temperature controller e.g. Fe Con.<br>Check that all thermocouples are operating satisfactorily. |
| The barrel residence time for the material in the barrel is too long. | Check the throughput time for the material<br>Check that the shot weight is not less than 25% of the machine's shot capacity. If it is, then transfer the mold to a smaller machine. If a smaller machine is unavailable then reduce the barrel temperatures to the lowest value that will still enable components to be produced of the required quality. |
| The material has been left to stand in the barrel during production stoppages. | Ensure that the barrel is purged out leaving the screw in it's most forward position, when any stoppages occur. |
| The material is becoming 'hung up' and degrading in areas within the barrel assembly. | Inspect the barrel assembly and remove any mismatch on mating surfaces. |
| **Mold.** | |
| Shot weight of the mold is too small. | Move the mold to a smaller capacity molding machine. |
| **Material.** | |
| The moisture content in the material is too high. | Use the correct drying procedures |
| The quality of the regrind material is poor or perhaps the regrind is contaminated. | Segregate and critically check all the regranulated material for contamination. |

| **FAULT. Distortion.** | DESCRIPTION. The molding is not an exact replica of the cavity as some parts are deformed, bowed or distorted. |
|---|---|
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| Part is being ejected while still too hot. | Increase the cooling time.<br>Reduce the melt temperature.<br>Increase the overall cycle time.<br>Reduce the mold temperatures. |
| **Mold.** | |
| Undercuts in the mold are too deep. | Reduce the depth of undercut and include radii wherever possible. |
| Ejector pins are too small or too few in number. | Increase the diameter and/or number of ejector pins. |
| Uneven movement of the ejection mechanism. | Check the parallelism and smoothness of movement of the ejection mechanism. |
| The ribs or bosses incorporated in molding are incorrectly designed. | Use the maximum draft possible on the ribs, bosses and webs etc. |
| Poor surface finish on the mold. | Polish the mold surfaces. |

| **FAULT. Flashing of components.** | DESCRIPTION. The component possesses excess material commonly seen as thin webs or fins at the parting line or across molded slots or holes. |
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| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine** | |
| Injection pressure is too high. | Decrease the injection pressure and/or change over earlier from injection pressure to follow-up or hold pressure.<br>Decrease the screw forward time.<br>Decrease the injection speed. |
| Too much material is being injected into the mold. | Reduce the shot size or volume. |
| Material is too hot. | Decrease the melt temperature.<br>Decrease the overall cycle time.<br>Decrease the injection speed until the desired melt temperature is attained. |
| Inadequate or uneven locking force on the machine. | Check for any misalignment or malfunction of the locking unit.<br>Reset the toggles and/or increase the clamp pressure.<br>Check the tie bar stretch.<br>Check the squareness of platens.<br>Check the hydraulic line pressure on clamping unit. |
| Intermittent stops occur during the production run. | Check the molding cycle, particularly the melt temperature, when production is interrupted. |
| **Mold.** | |
| The injection pressure is unevenly distributed across the mold. | The cavity layout should be balanced.<br>Check the wall section of the molded component for consistency and uniformity. |
| Foreign material is acting as a high spot on the mating surface mold. | If flashing occurs on one side of the component, check whether the mating of the surfaces are parallel to each other.<br>Inspect the land areas on the mold, and clean where necessary. Then recheck for flatness with 'engineers' blue. |
| Components in the mold and/or mold surfaces are out of register. | Remove mold, carefully inspect, repair and correct any misalignment to obtain a balanced filling pattern. |
| Projected area is too large. | The total projected area for the mold (i.e. cavities and feed system) is too large for the available clamping force. |
| Inadequate venting forces material from the cavity areas. | Inspect and clean the vents.<br>Enlarge the vents in the mold in increments of 0.0005in or 0.01mm until correct filling of the mold is obtained. |

| **FAULT. Incorrect shrinkage values obtained on the moldings.** | DESCRIPTION. The molding does not display the shrinkage values commonly associated with the material. |
|---|---|

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Injection pressure in the cavity is too low. | Gradually increase the injection pressure, checking the size of the components at each increase, until slight flashing occurs on molding. |
| Insufficient material in the cavity. | Increase the shot volume to obtain the required cushion or pressure pad. |
| Mold temperature is too high. | Reduce the mold temperature. |
| Molding conditions are not optimized. | The incorrect processing conditions are being used (temperatures and pressures etc.).<br>The molding process has not been allowed to stabilize before samples have been taken. |
| Nozzle orifice is too small. | Increase the nozzle orifice diameter. |
| Mold cavity being filled too slowly. | Increase the injection speed or profile the filling speed. |
| Gates in mold are not frozen off. | Increase the screw forward time and measure the samples at each incremental increase. |

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| Variation of the melt temperature within shot volume. | Reduce the screw rotation speed so that screw recovery just finishes before the completion of the cooling time.<br>Increase the back pressure. |
| **Mold.** | |
| Gates are too small or designed incorrectly. | Increase the size of gates and/or reduce the land length. |
| Runner system is incorrectly designed. | Use full round or trapezoidal shaped runners.<br>Increase the size of runner to suit the viscosity or flow properties of the material. |
| Mold cooling circuitry inadequately designed. | Measure the surface temperature at different points of the cavity and relate the actual temperature to the corresponding shrinkage value. If differences are apparent, then redesign the cooling circuit to overcome the problem. |
| **Material.** | |
| Flowability of material is too low. (i.e. too stiff a flow) | Use a polymer of a lower viscosity (i.e. an easier flowing grade). |
| **FAULT. Matt patches on molding:** | DESCRIPTION. The surface of the molding is not of uniform finish and some regions are less glossy than others. |
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| Cold slug from the nozzle. | Check the nozzle seating for dribble.<br>Increase the nozzle temperature.<br>If a shut off nozzle is used check if it is functioning correctly.<br>Counter-ream, or machine, a reverse taper in the orifice of the nozzle so as to ensure that the material separates inside the nozzle itself. |
| Too low a melt temperature. | Increase the melt temperature. |
| The mold filling speed is too fast. | Decrease the injection speed. |
| The component not completely filled. | Increase the shot volume on the machine. |
| Insufficient pressure is applied across the mold surface area. | Increase the injection hold pressure.<br>Increase the effective clamping force. |
| **Mold.** | |
| No provision for a cold slug well. | Machine a cold slug well opposite the sprue bush or deepen the existing cold slug well. |
| The mold temperature is too low | Increase the mold temperature. |
| There are sharp changes in the direction of flow of the material. | Avoid sharp edges in the mold wherever possible. |
| Jetting in the cavity (particularly apparent with filled materials). | Increase the gate aperture or use a tab type gate. |
| Use of release agents. | Avoid the use of release agents. |
| A matt surface in the gate area occurs due to the formation of a cold slug from the hot runner assembly (e.g. Incoe, Seiki spear or Moldmaster systems). | Use a higher nozzle temperature or incorporate a shut off mechanism in the hot runner nozzle. |
| **Material.** | |
| Material contains an excessive amount of lubricant or processing aid. | Carry out molding trials on the different batches of the same material so as to identify if a particular batch is faulty. |
| **FAULT. Silver streaks:** | DESCRIPTION. These are also known as mica marks, bubbles or surface laminations. The surface of the molding has in some places a non-uniform finish and in those areas the surface appears silvery. |

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| The melt temperature is too high | Reduce the barrel temperatures.<br>Reduce the nozzle temperature. |
| The barrel residence time for the material is too long. | Decrease the overall cycle time.<br>The shot capacity is too small for the molding machine. |
| The melt temperature is too low giving erratic mold filling times. | Raise the barrel temperatures.<br>Increase the nozzle temperature.<br>Increase the mold filling speed. |
| Insufficient injection pressure. | Increase the injection pressure. |
| The temperature controllers are inaccurate, giving variability of control. | Check the temperature controllers for accuracy and control. |
| **Mold.** | |
| The mold surface temperature is too low. | Increase the mold temperature.<br>Restrict the flow rate of coolant through the mold. |
| There is a cold slug or an unplasticized section of material in the molding. | Increase the size of the cold slug well.<br>Extend the ends of runner to form additional material traps.<br>Use an electrically heated nozzle and sprue bush. |
| The runners and gates are too small, or too long in length, causing the material to freeze off in the feed. system. | Increase the diameter of the runners and the depth of gate, if necessary. |
| Excessive mold release agent on the surface of the mold. | Thoroughly clean the surface of the mold with white spirit.<br>Restrict the use of release agent, or if necessary change to a non-silicone type of release agent. |
| The component is contaminated by oil or water. | Check for oil or water leaks from the ejection mechanism or from cavity/core. |
| Inadequate venting of the mold. | Check the vents have not been blocked, and increase the depth of vent if necessary. |
| **Material.** | |
| The material is contaminated by another polymer. | Inspect the molding material for evidence of contamination.<br>Thoroughly purge the cylinder clean.<br>Strip down and thoroughly clean the hopper and hopper loader assembly. |
| The quality of the regrind material is inconsistent. | Segregate and critically check all regrind material for contamination etc..<br>Ensure that the regrind has been sieved to remove all the fines or dust.<br>Check that the regranulation procedure has been adhered to. If a procedure is not used within the molding area then install one ensuring that each polymer is segregated and has its own color identity. |
| The material has not been sufficiently dried. | Dry the material for the correct drying time.<br>Use a vacuum or desiccant drier. |
| Volatiles are present in the melt. | Preheat the material prior to molding. |
| Moisture is condensing on the cold material when it is brought into warm atmosphere of the molding shop. | Store the material in the molding area for at least six hours before use. |

**FAULT. Orange peel:**

DESCRIPTION. Flow marks commonly associated in the area around the gate or at the end of flow where the surface has rippled finish.

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine**. | |
| The melt temperature is too low. | Increase the temperature of the front two zones on the cylinder assembly. |
| The mold filling speed is too low | Increase the injection speed. |

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| | Increase the injection pressure. |
| The mold temperature is too low. | Increase the mold temperature. |
| **Mold.** | |
| The runners and gates are too small. | Increase the diameter of the runners and the width of the gate, if necessary |
| **Material.** | |
| The viscosity of material is too high. | Select an easier flowing grade of material. |
| **FAULT. Poor color dispersion.** | DESCRIPTION. The molding is not of uniform color i.e. there are shade variations or colored streaks or patches. |
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| Inadequate mixing of the colorant in the barrel of the molding machine. | Increase the back pressure.<br>Lower the barrel temperatures so as to induce better mixing. |
| **Material.** | |
| Polymer granules are not uniformly covered with the colorant. | Prior to molding, blend the colorant and polymer together in the presence of a wetting agent. |
| The colorant particles are too coarse. | Grind the colorant to obtain a fine powder. |
| The concentration level of the masterbatch is too low. | Use the correct concentration of dry colorant, masterbatch or liquid colorant. |
| Inconsistency of dosage when using liquid colorants. | Check for air locks in the delivery tubing and check if screw slippage is occurring. |
| Variability of the material feed stock. | Remove all the 'fines' or dust when coloring a mixture of virgin and regrind. |
| **FAULT. Poor weld line or knit line strength:** | DESCRIPTION. The moldings contain weld lines and it is at these points that the components fails or breaks on ejection or in service. |
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| Material being too cold at the point of the weld. | Increase the melt temperature.<br>Increase the nozzle temperature.<br>Adjust the screw delay time.<br>Increase the back pressure. |
| The effective cavity pressure is too low. | Increase the injection pressure.<br>Increase the screw forward time.<br>Maintain the correct melt cushion. |
| Material is flowing too slowly or too quickly at the point of the weld. | Adjust the injection speed.<br>Adjust the screw surface speed to give a higher melt temperature. |
| **Mold.** | |
| Use of excessive mold release agent. | Clean the mold; use the mold release agent sparingly or not at all. |
| The mold surface is too cold. | Increase the mold temperature.<br>Restrict the coolant flow rate through the mold. |
| There is insufficient venting in the mold. | Incorporate vents and/or increase the size of vents in the weld line area.<br>Decrease the mold clamp force. |
| The gate/s and runners are too restricted. | Increase the runner diameter.<br>Increase the size of gate and/or shorten the length of the gate land. |
| The weld line is too far from the the gating position | Change the gate position to obtain a different flow pattern in the mold (the distance between the gate and the welded section is too long).<br>Reduce the length of the sprue or incorporate a hot sprue bushing. |
| **Material.** | |
| The material is of a too high a viscosity to fill the mold. | Change to an easier flowing grade of material. |
| **FAULT. Short Shot.** | DESCRIPTION. The molding is incomplete |

as the cavity was not filled with plastics material or, the molding lacks detail.

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Inadequate injection pressure. | Increase the injection pressure. |
| Shortage of material. | Check the level of material in the hopper.<br>Check that the injection stroke is correctly set and alter if necessary. |
| Screw is bottoming at the end of its stroke leaving a zero screw cushion. | Check the non-return valve for excessive wear and for cracks. |
| The cycle time is varying | Check that the cycle is consistent. |
| The cylinder temperature is too low. | Increase the melt temperature.<br>Increase the back pressure. |
| Inadequate injection speed. | Increase the injection speed. |
| The nozzle is partially blocked. | Check the nozzle orifice for foreign or, unplasticized material. |
| The heater bands on the nozzle or the barrel assembly are inoperative. | Check all the heater bands for the correct power output using an ammeter. |
| The injection time is too short. | Increase the screw forward time. |
| Polymer adhering to the walls of the hopper throat | Increase the amount of cooling in the region of the hopper throat or reduce the temperature of the barrel rear zone. |
| The machine capacity is too small (i.e. shot weight or plasticizing capacity). | Use a larger sized molding machine. |
| **Mold.** | |
| The venting is inadequate in the mold. | Check for blockage of the vents. |
| Inadequate filling of the mold. | Increase the runner diameter.<br>Increase the size of gate and/or reduce the land length of the gate.<br>Machine a cold slug well directly opposite the sprue so as to prevent the gates and runners from becoming blocked with unplasticized material. |
| **Material.** | |
| The component wall thickness is too thin for the material to flow. | Use a material with a lower viscosity value (i.e. easier flowing). |
| Too great a flow length for the material to suitably fill the component. | Reposition the gate to reduce the flow length. |

**FAULT. Shot to shot dimensional variations:**

DESCRIPTION. The dimensions, of weight, of a molding run vary beyond the natural production capability expected for that mold/machine/material combination.

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Inconsistent feeding of material into barrel. | Check the hopper throat for blockage.<br>Check that adequate water supply is passing around the hopper throat so as to maintain the correct temperature. |
| Cylinder temperatures are cycling or hunting too broadly. | Check for a defective or loose thermocouple.<br>Check that the correct type of thermocouple is used in conjunction with the temperature controller. |
| Machine capacity is too small. | Check that the shot capacity and plasticizing capacity for the machine and then compare it with the actual shot weight being molded and throughput of the material usage per hour. |
| Inconsistent injection pressure. | Check that a constant melt cushion is maintained each cycle.<br>Check for leakage of the back flow valve and replace if necessary.<br>Check for a faulty feed setting switch. |
| Erratic screw recovery. | Ensure the screw recovery length is identical for each cycle i.e. maximum |

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| | variation of not more than 0.4mm (0.016in). |
| Varying cycle time. | Check for cycle time inconsistency. |
| Inconsistent melt viscosity. | Use back pressure. |
| **Mold.** | |
| Partial blocking of gates. | Check for any sign of gate vestige being left in the gate orifice, particularly with submarine gates. |
| Inconsistent mold temperature control. | Check for temperature variations of the cooling medium used for the mold cooling.<br>Check for blockages in the mold cooling circuitry.<br>Check that the cooling circuit has been connected up correctly. |
| **Material.** | |
| Variations in the material. | Check for variations in the size of feed stock.<br>Ensure that all the fines have been sieved from the regrind material.<br>Check that two different batches of material have not been mixed together. |
| **FAULT. Sink marks:** | DESCRIPTION. Usually associated with marks on the surface (see also voids) and are caused through the material shrinking away from the mold surface. |
| LIKELY CAUSES. | SUGGESTED REMEDIES. |
| **Machine.** | |
| The melt temperature is either too hot or too cold. | Adjust the cylinder temperatures.<br>Adjust the screw speed so as to obtain the correct screw surface speed. |
| Insufficient material in the cavity. | Increase the shot volume.<br>Ensure that the correct cushion or pressure pad is used.<br>Increase the screw forward time.<br>Increase the injection pressure.<br>Increase the injection speed.<br>Check the non-return valve for improper seating, as malfunction can result in the loss of pressure. |
| Excessive thermal contraction of material taking place during the the cooling stage. | Reduce the mold surface temperature. |
| **Mold.** | |
| The feed system is too small. | Increase the runner diameter or gate dimensions (ie. depth, width and length). |
| The moldings are too hot when ejected from the mold | Increase the cooling time.<br>Slowly cool the molded component in warm water immediately after ejection. |
| The wall section of the product is too thick or disproportionately large. | Redesign the component with a thinner and more uniform wall section.<br>Position gate in thickest wall section on the component.<br>Core out the thicker sections on the molding, if possible. |
| The cooling circuitry of the mold is inadequate. | Insert additional cooling in the mold and incorporate thermal pins into thin cores/pins. |
| **FAULT. Smudge mark.** | DESCRIPTION. Flow marks commonly associated in the area around the gate where the surface has a dull, or stippled finish: may also be seen as striations. |
| LIKELY CAUSES. | SUGGESTED REMEDIES |
| **Machine** | |
| The melt temperature is too high. | Reduce the temperature of the front two zones on the cylinder assembly. |
| The mold filling speed is too fast. | Reduce the injection speed.<br>Reduce the injection pressure. |

| | |
|---|---|
| The temperature is too high. | Reduce the mold temperature. |
| **Mold** | |
| There are burns or machining marks in the gate area. | Remove the roughness in the gate area and polish if necessary. |
| **Material** | |
| The viscosity of the material is too low. | Select an easier flowing grade of material. |

| | |
|---|---|
| **FAULT. Sprue sticking:** | DESCRIPTION. On ejection the components may eject easily but the sprue remains caught in the sprue bush. |

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Sprue bushing and nozzle are misaligned. | Re-align the nozzle and sprue bushing. |
| Overpacking of the material in sprue bushing. | Decrease the injection pressure.<br>Decrease the screw forward time. |
| Nozzle temperature is too low. | Increase the temperature of nozzle or use a separate temperature controller to heat the nozzle. |
| The material is not fully solidified in the sprue, particularly with large diameter sprues. | Increase the cooling time, but a better alternative is to replace the sprue bush with one having a smaller sprue. |
| **Mold.** | |
| Burrs on the smaller orifice diameter of the sprue bushing. | Check for burrs which may cause an undercut. Reason for burrs is that the sprue bushing has not been hardened in the nozzle seating area, or that an incorrect radius has been machined on the bushing. |
| Nozzle seating is incorrect. | Remachine nozzle seating using the correct radius (usually 0.5mm less in radius than that used for the nozzle). |
| Nozzle orifice is larger than sprue orifice. | Fit a new nozzle with smaller orifice diameter or increase the diameter of sprue bush orifice. |
| Insufficient taper in the sprue bush. | Increase the angle on sprue bushing to 3 to 5 degrees inclusive. |
| Inadequate sprue puller being used. | Check that the correct type of sprue puller is being used. Wherever possible use a reverse taper-type, sprue puller design or a 'Z' type design for brittle materials, i.e. PS. If a 'Z' type puller is used, check to see that the 'Z' clears the mold during ejection. Insert radii in the corners of the 'Z' puller and between the runner and sprue. |
| Poor surface finish in the sprue bush. | Draw polish the internal surface of sprue. |
| Too small a sprue diameter. | Increase the diameter of the sprue. |

| | |
|---|---|
| **FAULT. Voids.** | DESCRIPTION. Can easily be seen as 'air pockets' in transparent moldings but may still be present in opaque plastics. Associated with thick sections and are often caused by material shrinking away from the center of the molding. |

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Moldings are not completely filled. | Increase the shot volume.<br>Increase the injection pressure.<br>Increase the screw forward time.<br>Reduce the melt temperature.<br>Decrease or increase the injection speed. (for example with amorphous type polymers decrease the speed; for crystalline polymers increase the speed). |
| Malfunction of the non return valve | Check that the non return valve is not cracked or inoperative. |
| **Mold.** | |

| | |
|---|---|
| Too small a gate is being used. | Increase the size of gate so as to prevent premature solidification of the material at the gate. |
| Incorrectly designed and/or sized runner. | Use a full round or trapezoidal type runner.<br>Increase the runner diameter. |
| Wrongly positioned gate. | Change the position of gate so that the material is fed into the thickest section of the molding. |
| The mold temperature is too low. | Increase the mold temperature. |
| Inadequate venting in the mold. | Incorporate vents in the mold or use vacuum venting. |
| The wall thickness in molding is excessive. | Core out thick sections in the molding so as to reduce the wall section. |
| **Material.** | |
| The material contains excessive moisture. | Dry the material for a longer period so as to reduce the moisture level in the material.<br>Use a vacuum or desiccant drier. |

FAULT. Warpage.

DESCRIPTION. The component shape is similar to the cavity but it is a distorted version of the cavity shape.

| LIKELY CAUSES. | SUGGESTED REMEDIES. |
|---|---|
| **Machine.** | |
| Warpage due to excessive internal strains in the molded component. | Reduce the injection pressure.<br>Reduce the screw forward time.<br>Increase the cycle time (particularly the cooling time).<br>Slowly cool the moldings in warm water (38°C or 10°0F) immediately after ejection from the mold (particularly on thick sectioned moldings). |
| The mold filling speed is too low. | Increase the injection speed. |
| There is insufficient material in the cavity. | Increase the shot size. |
| The melt temperature is too low or non homogeneous. | Increase the melt temperature. |
| The moldings are too hot when ejected | Use a cooling jig or fixture. |
| **Mold.** | |
| The mold cooling capacity is inadequate. | Increase the cooling capacity (i.e. flow rate of coolant through the mold).<br>Remove all the scale or deposits from inside the cooling channels. |
| The cooling circuits in the mold are not balanced so as to give a uniform rate of cooling across the molding. | Check the surface temperatures of the mold and if necessary use different temperatures for both halves of the mold.<br>Locate the cooling channel(s) closer to the cavity surface. |
| The gate/s are improperly located and/or designed. | Gate into the thickest section of the molding.<br>Use tab gates wherever possible. (the smaller the gate aperture the greater the warpage). |
| Feed system is too small in size. | Increase the size of runner or sprue. Do not use semi-circular shaped runners. |
| Variations in the wall thickness of molding due to deflection or movement of cores in the mold. | Check for core or cavity misalignment and rectify if necessary. |
| **Material.** | |
| Type of filler used in the material. | Use glass spheres instead of glass strands in glass reinforced materials. |
| The component is improperly designed (i.e. non-uniform thickness and sharp changes in wall section). | Redesign the component using a more uniform wall section and gradual changes in section thickness.<br>Design the component with the material that is to be molded in mind (e.g. the types of gate and the flowability of the material i.e. the wall thickness to flow length ratio). |

**FAULT. Warping. See Warpage.**

# SIMPLE TESTING OF MOLDINGS.

Most tests performed on injection moldings, to judge fitness for use, are of the 'fit and finish' type; that is, if the appearance of the molding is acceptable and if it fits into the finished assembly, then it is satisfactory. Such tests are often perfectly satisfactory and they offer the advantage that, they are simple and cheap to run as they are usually done by the machine operator i.e. by the side of the injection molding machine. Some of the these tests may be modified so that the results can be subjected to statistical analysis. Such analysis can, as the name suggests, help to keep the injection molding process under control.

## Visual Testing of Moldings.

This is often the only test to which injection moldings are subjected. If the machine is running semi-automatically then, the operator inspects every injection molding for color, color dispersion, color uniformity, surface finish (gloss/mattness) and freedom from molding defects such as stringing and silver streaking. (Stringing is caused by material being pulled from the nozzle whereas silver streaking is indicative of wet molding material).

## Weight.

Of all the tests which can be performed alongside an injection molding machine, component weight is now the easiest one to perform. A modern, digital electronic balance needs little, if any, setting up and component weight can be determined very easily and rapidly. Such a determination indicates how well a mold or a particular cavity within a multicavity mold, has filled. Component weight can be readily correlated with the dimensions of a particular component and if required, the digital balance can be fitted with an electronic calculator so that the readings obtained may be statistically analyzed.

If density is specified instead of part weight as a control test, then this is more difficult to perform. Probably the easiest way of performing the measurement is to use two containers each containing a solution of the appropriate density. These solutions are selected so that the molding will sink in one and float in the other.

## Flow Tendency.

The flow tendency, or ease of flow, of a material may be assessed in various ways such as melt flow index, high shear rheometry and spiral flow testing. However, such tests require special equipment to be set aside and so, these tests are not commonly employed in the molding production industry. It is obviously easier to perform the flow test during the molding operation.

One method of assessing a materials flow behavior is by means of a flow tab. This consists of a thin, graduated channel which is say, located at the end of the runner system. During molding the length of the flow tab is noted. If the flow tab length alters, then this is due to either a change in machine settings, operating procedure or material properties.

## Oven Heating.

Many molded components are used at elevated temperatures and for this reason their dimensions may be checked after an oven-heating period. The upper surface temperature should be ascertained and unless otherwise specified, it is suggested that the oven temperature be set 25°C (approximately 50°F) higher than that of the upper surface temperature. The length of time for which the component is in the oven will depend upon its thickness but for most components (e.g. of less than 3 mm/0.118in cross-section) a heating period of 30 minutes is sufficient. Alternatively, formulas used for calculating cooling times may be used to determine the heating-up time or, the time may be measured experimentally by inserting a thermocouple in the thickest part of the molding and then heating the assembly.

Oven heating is also used to determine whether or not a component has excessive molded-in stress. If the orientation stresses within a component change, then its resistance to oven heating will also change. As the orientation stresses increase, then the heat distortion temperature reduces.

## Photoelastic Inspection.

For transparent materials the easiest way of detecting frozen-in stresses is to examine the component through polarized light. Such light is produced when ordinary light passes through certain materials. The crystals which cause polarization are usually carried in sheets of plastic and for the purpose of molding examination, two such sheets are required. One sheet is placed over an ordinary light source (which is polychromatic) and the second sheet is placed on top of the first. The second sheet is rotated until the light passing through the assembly is at a minimum. If the molding is now placed between the two sheets, then a series of colored fringes will be seen; if the number of fringes increases, from one molding to another, then the stress level is also increasing.

## Impact Testing.

The ability to withstand an impact, commonly referred to as toughness, is a very important requirement for many plastics moldings and one which is not often measured satisfactorily by the standard type of test. For this reason it has been suggested that a pendulum type tester be modified so that it can either be used to test small components directly or, so that it may be used to test a molded tab in the case of a large component.

## Simulated End Use Testing.

For components which must meet very critical specifications, recourse is sometimes had to a test which simulates the sort of treatment that a component will experience in use. Such a test may be a dynamic test in which, for example, the component is repeatedly flexed so as to duplicate what the molding will experience in service. Such a test may be performed at two extreme temperatures so that performance may be guaranteed.

# TOLERANCES AND STATISTICS

Successful quality control of a product requires not only that the product meets its specification but, in addition, requires monitoring of the process so as to ensure that adverse changes are not occurring in the process - even though the product is still within specification. If this is not done a situation may arise where, within a short space of time, high reject rates may develop. Such problems may be anticipated by the use of statistical quality control (SQC) methods (also know as statistical process control or SPC). Furthermore, the use of such methods may avoid the acceptance of specification limits that may be difficult to hold in production.

## Testing for Consistency.

While it is the quality of the end-product that is all important clearly it is necessary that the raw materials, and products of intermediate stages, should also be of acceptable quality. For this reason, quality control (QC) should be considered for all stages of production. Extensive testing is expensive but fortunately, in practice, it is often found that a small number of tests can often give a good guide for the consistency of quality. For example, when using polyethylene a check of melt flow rate (MFR or MFI) and density can often provide adequate information on raw material consistency. In the case of injection molding, simple tests such as visual appearance, product weight and oven stability may often be sufficient although for critical applications further testing may be necessary.

## Specification and Tolerance Limits.

The manufacture of a product commonly involves meeting specification limits which have been agreed between purchaser and supplier. For a given product there may be several such limits. One of these could be a particular dimension and for example it may be specified that this should be 100.0 ± 0.2mm (3.937 in ± 0.008), that is to say, the dimension should be between 99.8 and 100.2mm (3.929 and 3.945 in): the value of 100.0mm being known as the nominal value. (It should be noted that the plus and minus deviations need not be equal.)

## Inherent Variations.

Before agreeing to specification limits it is important to appreciate that in a process there is always some natural variation in the product - even when no external modifications have been made to the process: this, for example, could lead to variations in dimensions or weight. These are known as unassigned or inherent variations. Such variations may be analyzed statistically as outlined below.

## Mean and Standard Deviation.

Any such analysis first requires a calculation of the arithmetic mean (or average) and the standard deviation. If we have five numbers (N=5) of a variable X which have values of 5,3.7.4 and 6 then the mean ($\bar{X}$) is obtained by adding up the five numbers (the total of 25 is known as $\sum X$) and dividing by N to give an arithmetic mean or average of 5. The formula used is:
$\bar{X} = \sum X/N$.
By a similar calculation it can be shown that the five numbers 8,0,1,9 and 7, have the same mean but are more widely spread, i.e they have a greater variation. The most useful measure of such a spread is the standard deviation ($\sigma$) which is given by the formula:
$\sigma = \sqrt{[\sum(X-\bar{X})^2/N]}$.

## The Normal or Gaussian Distribution.

It is often found that the inherent variations in a variable quantity closely follow that of the theoretical Gaussian (Normal) distribution. In one form, it may be expressed graphically as a plot of the frequency (f) with which a particular value of the variable occurs against that of the variable (X). This curve is symmetrical and bell shaped and is centered at the arithmetic mean. The greatest concentration of values is around the mean; the further away from this value the lower the frequency. If the mean and standard deviation are known then the Normal curve may be defined. Even in those cases where the plot of **f vs X** does not give a good Gaussian fit, it is found that if a sample of a few individuals is taken, and a sample average calculated ($\bar{X}$), the plot of **f vs $\bar{X}$**, the sample mean, is Gaussian. In this case the true distribution mean, or grand mean, may be given the symbol $\mu$ (and by some writers X with a superimposed double bar that is by X double bar or $\bar{\bar{X}}$).

## Some Normal Distribution Characteristics.

It may be shown that in a Gaussian distribution that;

50% of the results are within $0.6745\sigma$ of the mean,
68.26% are within $1\sigma$,
95% are within $1.96\sigma$,
95.44% are within $2\sigma$,
99.74% are within $3\sigma$, and
99.8% are within $3.09\sigma$ (of the mean).

These limits are a direct consequence of the properties of the Gaussian distribution and are often referred to as the natural tolerance limits

In the case of a distribution of means of samples of size N, 50% of the results are within $0.6745\sigma/\sqrt{N}$ (with the other limits similarly adjusted by the factor $1/\sqrt{N}$). Because it occurs so often the expression $\sigma/\sqrt{N}$ is known as the standard error of the mean.

## Confidence Limits.

It follows from the above that if a large number of samples of size N are taken from a Gaussian distribution, 95% of the samples will lie within the range $\mu \pm 1.96\sigma/\sqrt{N}$ or, put another way, there is a 95% probability that the true mean $\mu$ will lie in the range $\bar{X} \pm 1.96\sigma/\sqrt{N}$. These are sometimes known as the 95% confidence limits. Similarly the expression $\bar{X} \pm 3.09\sigma/\sqrt{N}$ is sometimes referred to as the 99.8% confidence limits.

## Estimating $\sigma$.

The expressions used to obtain confidence limits are only strictly correct if the standard deviation ($\sigma$) is known accurately. In practice we have to estimate this from the standard deviation of a sample and it may be argued, that in this case the best estimate of the standard deviation, as obtained from a sample(s), is given by:

$$s = \sqrt{[\Sigma(X-\bar{X})^2/(N-1)]}$$

## t-Distributions.

When the standard deviation is obtained from a sample (s) then, it is necessary to replace the Gaussian distribution by a series of distributions known as the t-distributions which depend on the sample size as it is found that this gives a more accurate value for the standard deviation. In this case the 95% confidence limits will be given by $\bar{X} \pm t_{0.05} s/\sqrt{N}$. Some values for t at the 95% and 99.9% levels are given in the following table.

| Degrees of Freedom | 1 | 2 | 3 | 4 | 6 | 8 | 10 | ∝ |
|---|---|---|---|---|---|---|---|---|
| t (95%) | 12.71 | 4.30 | 3.18 | 2.78 | 2.45 | 2.31 | 2.23 | 1.96 |
| t (99.9%) | 637.6 | 31.6 | 12.94 | 8.61 | 5.96 | 5.04 | 4.59 | 3.29 |

Degrees of freedom may be defined as any of the independent variables constituting a statistic. In this case, the number of degrees of freedom is equal to N-1.

## Setting Limits.

The product of a process is subject to a measure of variability that is quantified by the natural tolerance limits or confidence limits. It is therefore important to realize that if specification limits are set too closely then, unless changes are made to the process to reduce variability, high wastage or reject rates will occur. Where possible, and where data is available, the supplier and the purchaser should agree to adopt specification limits roughly equal to the 99.8% limits. That is, a spread of approximately six standard deviations about the mean should be adopted. This will give low reject rates, for the particular criterion involved, **providing the average mean value of the property attained during production coincides with the middle value of the specification limit.** Any divergence from this can lead to considerable increases in reject rates.

# ESTIMATING PRODUCTION CAPABILITY.

Before specification limits are agreed it would be advisable to check whether or not a particular injection molding machine is capable of producing moldings whose dimensions fall within these specification limits.

## Production Capability and the SD.

If an injection molding machine is in statistical control then, approximately 68% of all the injection moldings produced have measurements which lie within ±1 standard deviations (SD) of the average, 95% lie within ±2 standard deviations and approximately 99.8% lie within ±3 standard deviations of the average. This means that about 998 injection moldings in every 1,000 produced will have dimensions which can be specified from easily obtained information. One in a thousand will have a dimension which lies below the specified value and one in a thousand will have a dimension which lies above the specified value. So, for many practical purposes the average plus and minus three standard deviations gives the production capability.

What is needed is a method, or methods, which will give a quick way of establishing the natural tolerance limits of the production process (if a more accurate estimate is required see 'CALCULATING PRODUCTION CAPABILITY'). To ensure that a normal distribution curve is followed, the sampling molding run should be divided into small lots so that averages (of say, four individual measurements) are used as it is known that the distribution of averages tends to follow the normal distribution curve (the central limit theory).

## Measurement and Calibration.

i) Decide on the characteristic or dimension which is to be monitored;

ii) Select an appropriate measuring instrument which has the desired degree of sensitivity, for example, a balance capable of weighing to 0.001g;

iii) Check the accuracy of the measuring instrument over the anticipated range, for example, using standard weights;

iv) Calibrate the instrument against the standards and choose another instrument if the first is inaccurate or, not sensitive enough;

v) Draw up a table (see Table 11) capable of accepting the measurements; and

vi) In the case of a multicavity mold initially select one cavity the output of which, will be used for measurement: ensure that this cavity produces readily identifiable, moldings.

## Estimating Tolerance Limits.

i) Set the conditions on the injection molding machine to those used in production;

ii) Allow the molding machine to run (to reach equilibrium or, to settle down) for a suitable period of time; say, for 30 minutes on a small machine;

iii) Once you are satisfied that the machine can produce consist-

ently, acceptable moldings under the set conditions, start collecting the moldings;
iv) Number each molding as it comes from the machine and put it to one side to stabilize. (For many materials this is simply a matter of letting it cool for say, 20 minutes; some moldings may need to be conditioned or annealed).
v) Collect 32 moldings;
vi) After appropriate stabilization perform the measurements; that is, weigh the moldings or, determine the diameter etc.;
vii) Enter the measurements into a suitable table (see table 11) in the order in which they were produced. Work across the columns from left to right so, for example, dimension 1 is in the top left hand box and dimension 2 is in the next box; 5 will then be the first entry in the next row;
viii) For each row perform two calculations. Take the lowest value from the highest value and enter the value so obtained into the range (R) box. Add all four values together, divide by 4 and enter this value into the average ($\bar{X}$ or X bar) box.
ix) Add all of the 8 averages together so as to obtain a grand average total ($\Sigma\bar{X}$). Add all of the 8 ranges together so as to obtain an average range total ($\Sigma R$). Enter these two figures in the appropriate total boxes. Divide each of these totals by 8 (which is n) and tabulate under $\bar{X}$ and $\bar{R}$
x) Multiply the average range by 1.5 and add this figure to the previously obtained average value $\bar{X}$: this then gives the upper limit of production capability which must be tabulated;
xi) Multiply the range by 1.5 and subtract it from the average value $\bar{X}$: this then gives the corresponding lower limit of production capability which also, must be tabulated.
xii) Compare the production capability to the specified tolerances so as to see if the product can be made satisfactorily.
xiii) Repeat for the other cavities.

## Estimating Standard Deviation.

This procedure gives a quick way of establishing the natural tolerance limits of the production process, but if an estimate of the standard deviation for the production run is required, then this may be obtained by multiplying the range by 0.4857. Multiplying this figure by 3 gives the factor previously suggested.
It should be noted that if groups other than 4 are employed during the sampling run, then different factors should be applied. Such factors may be obtained from text books on statistics and for example, in a book written by Neville and Kennedy these factors are listed under the heading “range coefficient d". When the number of samples within each set is 5, the range coefficient is 0.4299.

## Compare the Two Tolerances.

Compare the production capability to the specified tolerances so as to see if the product can be made satisfactorily. Divide the tolerance range by the SD: if the answer is bigger than 6 then, the tolerance range (specified in the design) is big enough to accommodate the natural production range of the machine as this spans 6 standard deviations. However, production may still be difficult if the two ranges do not overlap, or coincide. They may be made to overlap by adjusting the size of the cavities. If, for example, this analysis is done when the tool is being proved then, as cavities are usually made undersized, metal may be removed as appropriate. However, before this is done, a more precise examination should be performed - see 'CALCULATING PRODUCTION CAPABILITY'.

# ESTABLISHING NORMALITY.

If an injection molding machine is in statistical control then, approximately 68% of all the injection moldings produced have measurements which lie within ±1 standard deviations (SD) of the average, 95% lie within ±2 standard deviations and approximately 99.8% lie within ±3 standard deviations of the average. This means that the distribution of measured values is following a normal distribution curve.

## SD and Average Values.

The standard deviation (SD) of the average of a sample, equals the SD of individual components divided by the square root of the sample size. The boundaries of capability of the average of averages (the mean average), are the same as for individual values i.e. the mean average +/- 3SDs. Using average values is more sensitive, more responsive to change, than using individual values.

## Measurement and Calibration.

i) Decide on the characteristic or dimension which is to be monitored;

ii) Select an appropriate measuring instrument which has the desired degree of sensitivity, for example, a balance capable of weighing to 0.001g;

iii) Check the accuracy of the measuring instrument over the anticipated range, for example, using standard weights;

iv) Calibrate the instrument against the standards and choose another instrument if the first is inaccurate or, not sensitive enough, and;

v) Draw up a table capable of accepting the measurements;

vi) In the case of a multicavity mold initially select one cavity the output of which, will be used for measurement: ensure that this cavity produces readily identifiable, moldings.

## The Molding Trial.

i) Set the conditions on the injection molding machine to those used in production;

ii) Allow the molding machine to run (to reach equilibrium or, to settle down) for a suitable period of time; say, for 30 minutes on a small machine;

iii) Once the machine appears capable of producing consistently, acceptable moldings under the set conditions, start collecting the moldings;

iv) Number each molding as it comes from the machine and put it to one side to stabilize. (For many materials this is simply a matter of letting it cool for say, 20 minutes; some moldings may need to be conditioned or annealed).

v) Collect 100 consecutive moldings but then, if possible, allow the machine to continue producing moldings while you do your measurements.

vi) After appropriate stabilization perform the measurements; that is, weigh the moldings or, determine the diameter etc.;

vii) Write down, in order, all the values measured, for example, if weight is the measured value then put down the weight of the first molding on line 1 under column A in Table 12 then, the weight of the next molding on line 1 under column B etc. (the sixth molding will be the first entry on line 2);

vii) Average each set of 5 moldings by adding the measured dimension of A, B, C, D and E and dividing by 5: this gives $\overline{X}$ or X bar;

viii) Take the lowest $\overline{X}$ or, X bar in the table from the highest $\overline{X}$ or, X bar in the table and multiply this number by two;

ix) Use the number calculated in (viii) to put a vertical scale on Fig 4 with the lowest value at the bottom and the highest at the top i.e centrally locate the scale (alternatively plot the results on a QC chart and examine for randomness - see QC WITH AVERAGE AND RANGE CHARTS);

x) Every time a value occurs, put a tick, or cross, on the appropriate line in figure 4 i.e along the horizontal axis: try and keep the ticks, or crosses, the same size;

xi) Examine figure 4: if it looks like a normal distribution curve (i.e. a symmetrical, bell-shaped curve) then the machine has settled down and the information may be used to calculate the natural tolerance limits,

xii) If figure 4 does not look like a normal distribution curve (i e an approximately, symmetrical, bell-shaped curve) then, the machine has not settled down and another set of injection moldings should be collected and measured,

xiii) Repeat (xii) until a normal distribution is obtained i e until it has been established that the injection molding machine is in statistical control

# CALCULATING PRODUCTION CAPABILITY.

A quick way of obtaining an estimate of the production capability is given in the section entitled 'ESTIMATING PRODUCTION CAPABILITY' This section gives a more accurate way of establishing the natural tolerance limits of the production process A calculator with scientific or statistical functions is required if complex calculations are to be avoided Using this procedures then, from a comparatively small sample run, it is possible to calculate the standard deviation (σ or, SD or s) and the average ($\overline{X}$ or X bar) From these two values it turn, one can then estimate what the total spread of values will be on the actual production run

## Measurement and Calibration.

i) Decide on the characteristic or dimension which is to be monitored,

ii) Select an appropriate measuring instrument which has the desired degree of sensitivity, for example, a balance capable of weighing to 0 001g,

iii) Check the accuracy of the measuring instrument over the anticipated range, for example, using standard weights,

iv) Calibrate the instrument against appropriate standards and choose another instrument if the first is inaccurate or, not sensitive enough,

v) Draw up a table capable of accepting the measurements, and,

vi) In the case of a multicavity mold initially select one cavity the output of which, will be used for measurement ensure that this cavity produces readily identifiable, moldings

# Calculating the SD With a Statistical Function Calculator.

If a calculator with scientific or statistical functions is available then this may be used in place of the procedure described under 'ESTIMATING TOLERANCE LIMITS' so as to obtain more accurate information this information may, in turn may be used to construct quality control charts - see the section on QC WITH AVERAGE AND RANGE CHARTS

i) Set the conditions on the injection molding machine to those used in production,

ii) Allow the molding machine to run (to reach equilibrium or, to settle down) for a suitable period of time, say, for 30 minutes on a small machine,

iii) Once the machine appears capable of producing consistently, acceptable moldings under the set conditions, establish that the machine is in statistical control - see the section on ESTABLISHING NORMALITY

iv) Collect 100 consecutive moldings but then, if possible, allow the machine to continue producing moldings while you do your measurements

v) After appropriate stabilization perform the measurements; that is, weigh the moldings or, determine the diameter etc ,

vi) Write down, in order, all the values measured, for example, if weight is the measured value then put down the weight of the first molding on line 1 under column A in Table 12 then, the weight of the next molding on line 1 under column B etc (the sixth molding will be the first entry on line 2);

vii) Average each set of 5 moldings by adding the measured dimension of A, B, C, D and E and dividing by 5: this gives $\overline{X}$ or X bar,

viii) Take the lowest $\overline{X}$ or, X bar in the table from the highest $\overline{X}$ or, X bar in the table and multiply this number by two;

ix) Put the calculator into the statistical mode and then enter each value into the calculator and also enter the number of times it has occurred,

x) Press key 'n' and the sample size (20) will appear,

xi) Press the $\overline{X}$ bar key to obtain the average value of all the 20 values entered and, record this grand average ($\overline{\overline{X}}$ or, X double bar) to say, the third place of decimals,

xii) Press the $\sigma_{n-1}$ key so as to obtain the standard deviation (s) and, record this standard deviation to say, the third place of decimals,

xiii) Check that you have the sample size 'n', the grand average ($\overline{\overline{X}}$ or, X double bar) and the standard deviation (s) before changing the calculator to the non-statistical mode,

xiv) Obtain the production capability of the machine/mold/material,

by subtracting three standard deviations from the average value (xi) and adding three standard deviations to the average, and;
xv) Compare the production capability to the specified tolerances so as to see if the product can be made satisfactorily.

## Calculating Standard Deviation With a Simple Calculator.

The procedure for collecting the data is exactly the same as that in the previous section up until step (xiv). So, after it has been established that the injection molding machine is in statistical control, 100 consecutive moldings are collected and a suitable dimension measured. The results are tabulated as in Table 12. On each of the 20 lines, take the lowest measurement from the highest so as to get the range R. Add up all the ranges ($\Sigma R$) and divide by 20 so as to give $\bar{R}$ or R bar. Multiply $\bar{R}$ or R bar by 0.58. Add up all the averages ($\Sigma \bar{X}$ or $\Sigma$X bar) and divide by 20 so as to give $\bar{\bar{X}}$ or X double bar.
Upper natural tolerance limit = $\bar{\bar{X}}$ or X double bar + 0.58$\bar{R}$ or R bar.
Lower natural tolerance limit = $\bar{\bar{X}}$ or X double bar - 0.58$\bar{R}$ or R bar.

## Compare the Two Tolerances.

Compare the production capability to the specified tolerances so as to see if the product can be made satisfactorily. Divide the tolerance range by the standard deviation: if the answer is bigger than 6 then, the tolerance range (specified in the design) is big enough to accommodate the natural production range of the machine as this spans 6 standard deviations. However, production may still be difficult if the two ranges do not overlap, or coincide. They may be made to overlap by adjusting the size of the cavities. If, for example, this analysis is done when the tool is being proved then, as cavities are usually made undersized, metal may be removed as appropriate.

## Capability Index.

The capability index, or process capability index (PCI), is used to establish the process capabilty with regard to the specified tolerance. PCI equals the total specified tolerance (take the lowest value from the highest value) and then divide by the value of six standard deviations. The minimum acceptible value is one. This capability index has a limitation in that although the range (as measured by the standard deviation) meets the tolerance requirement, the average may not.
To overcome this objection an alternative process capability index (known as PCIK) is used. PCIK is the smaller of the following two

values and must also have a minimum value of one:
(Upper tolerance limit - sample mean value) divided by 3 standard deviations or, (sample mean value - lower tolerance limit) divided by 3 standard deviations.

# QC WITH AVERAGE AND RANGE CHARTS.

Quality control charts (QCC) show how well a process is operating (they are sometimes known as process control charts). They will show if the process is functioning in an acceptable way or if the process has drifted out of control or is about to drift out of control. The tendency of a machine or material to drift out of control, or out of specification, can therefore be spotted before rejects have been produced. It obviously makes sense not to make products which will be subsequently scrapped. However, to get the information required, it is necessary to take samples at predetermined intervals, perform measurements, record the data, plot the measurements on the chart, assess the results and then, take appropriate action.

## Variables and Attributes.

A variable may be considered as a property which arises from measurements and is thus subject to variations. These may be measurements of weight or length, of intelligence, of tensile strength, melt flow rate (MFR) and so on. On the other hand an attribute is a property that either is or is not possessed: for example, pass-fail, go-no go, satisfactory-defect. Quality control systems may be used using either variables or attributes but the procedures used will differ. While attribute testing provides only limited data it is often simpler to carry out and may be adequate for the purpose.

## QC Charts for Sampling by Variables.

To get sensible results it is necessary to keep two charts for each measurement: one which shows the average value ($\bar{X}$ or X bar) of the measurement and another which shows how much variability there is in that particular sample. (The average of 9, 10, 11, 9 and 11 = 50/5 = 10: the average of 6, 10, 14, 8 and 12 also = 50/5 = 10 but, the second set of numbers is obviously more variable). So, unless something is plotted to show variability we could be producing items which vary too much. While the best measure of spread of results is the standard deviation it is easier, and almost as good with small samples, to plot the range (R also known as 'w'). The two charts are known as the Mean chart and the Range chart (Average is sometimes used in place of mean). These two charts, together with the data block, are carried on one sheet and are known as the quality control (QC) chart - see Fig 5.

## Warning and Action Lines.

These are 'limit lines' which are also marked on the process control chart. The horizontal scale is marked off with a time scale, or more strictly speaking sample numbers in order of testing, and the vertical scale is marked off with values of the property being tested. The average chart usually has 5 lines: there is an average value (which is determined during the set-up period), two sets of lines above the average line and two sets of lines below. i.e two sets of tramlines. The first, upper line is known as the Upper Warning Limit (UWL) and the second, upper line is known as the Upper Action Limit (UAL). The first, lower line is known as the Lower Warning Limit (LWL) and the second, lower line is known as the Lower Action Limit (LAL). These lines correspond to probability points on the normal distribution curve and are normally set so that if the product was being produced with the normal variation in values of the property being tested 95% (1 in 20) would lie within the Warning Limits and 99.9% within the Action Limits. Since 1 in 40 of the results might be expected to lie above the upper warning limit and approximately 1 in 1000 above the upper action limit, these limits are sometimes known as the 1 in 40 and 1 in 1000 limits respectively.

## Range Chart Limits.

The range chart usually has 3 lines: there is an average value (which is determined during the set-up period) and a set of two lines above the average line i.e. a set of tramlines. The first, upper line is known as the Upper Warning Limit (UWL) and the second, upper line is known as the Upper Action Limit (UAL). The lower lines {known as the Lower Warning Limit (LWL) and the Lower Action Limit (LAL) may easily be calculated but this is often not done as a smaller range is acceptable.

## Mean Chart Limits.

The warning limits for the mean chart are calculated on the basis that 95% of the results may be expected to be in the range $X \pm 1.96s/\sqrt{N}$. In practice, it is usual to estimate the value of s, the sample standard deviation, from the mean range (i.e the average difference between the highest and lowest value obtained in each sample) using the equation $s = Rd$ where d is a constant dependant on the sample size and R is the mean range. Therefore, the values for the mean warning limits (MWL) will be given by:

$$MWL = M \pm 1.96\bar{R}d/\sqrt{N}$$
$$= M \pm A_W\bar{R}.$$

Where $A_W = 1.96d/\sqrt{N}$ and M is the grand mean of the sample means. The grand mean is often denoted by a capital X with a double bar superimposed ($\bar{\bar{X}}$).

The mean action limits (MAL) are given by $MAL = M \pm A_A\bar{R}$ where $A_A = 3.09d/\sqrt{N}$. Some figures for $A_A$ and $A_W$ are given in the following table.

| Sample size N | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|
| $A_W$ | 1.23 | 0.67 | 0.48 | 0.38 | 0.32 | 0.27 | 0.24 | 0.22 | 0.20 | 0.17 |
| $A_A$ | 1.94 | 1.05 | 0.75 | 0.59 | 0.50 | 0.43 | 0.38 | 0.35 | 0.32 | 0.27 |

## Three Line Charts.

Some average control charts only have three lines on them: the average value, the upper control limit (UCL) line and the lower control limit (LCL) line. The last two lines are obtained by adding three SDs to the average and subtracting three SDs from the average. These give, approximately, 1 in 1,000 limits. In this system, common in the United States, there are no warning limits and it is also common practice to use 5 measurements in a sample i.e N=5. As with the previous system the standard deviation may be estimated from the mean range.

## Range Chart.

In addition to a means chart it is also useful to produce a chart which displays the scatter of results in a sample and in practice a range chart is most commonly used. In this case the range warning limits (RWL) are given by $RWL + D_W\bar{R}$ and the range action limits (RAL) by $RAL = D_AR$. Some values for $D_W$ and $D_A$ are given in the following table.

| Sample size N | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| $D_W$ (upper) | 2.81 | 2.17 | 1.93 | 1.81 | 1.72 | 1.62 | 1.56 | 1.51 |
| $D_W$ (lower) | 0.04 | 0.18 | 0.29 | 0.37 | 0.42 | 0.50 | 0.54 | 0.58 |
| $D_A$ (upper) | 4.12 | 2.99 | 2.58 | 2.36 | 2.22 | 2.04 | 1.94 | 1.87 |
| $D_A$ (lower) | 0.00 | 0.04 | 0.10 | 0.16 | 0.21 | 0.29 | 0.35 | 0.40 |

## Setting Up A QCC

## Measurement and Calibration.

i) Decide on the characteristic or dimension which is to be monitored;

ii) Select an appropriate measuring instrument which has the desired degree of sensitivity, for example, a balance capable of

weighing to 0.001g;
iii) Check the accuracy of the measuring instrument over the anticipated range, for example, using standard weights;
iv) Calibrate the instrument against the standards and choose another instrument if the first is inaccurate or, not sensitive enough;
v) Draw up a table, on the QC chart, capable of accepting the measurements.
vi) Scale the average chart so that the scale has twice the range of values anticipated (take the lowest $\bar{X}$ or, X bar in the table from the highest $\bar{X}$ or, X bar in the table, prepared when the production capability was calculated, and multiply this number by two);
vii) Scale the range chart so that the scale spacing on this chart, has twice the value of those on the average chart (if one scale unit = 0.01mm (0.0004in) on the average chart it will be easier to visualize the result if it = 0.02mm (0.0008in) on the range chart);
viii) Position the nominal value centrally on both scales;
ix) In the case of a multicavity mold, select two cavities the outputs of which, will be used for measurement: select the cavity which produces the largest molding and select the cavity which produces the smallest molding. Ensure that these cavities produce readily identifiable, moldings;
x) Ensure that the sample size selected is consistent i.e. the same as used for limit line calculation, for example, 5, and;.
xi) Allocate a different color, for data plotting, to each shift.

## Sampling and Plotting.

It is assumed that the production capability of the machine has been assessed (see Calculating Production Capability).
i) Only take samples from a machine which has reached equilibrium i.e it has settled down);
ii) Only when the machine appears capable of producing consistently, acceptable moldings, under the set conditions, start collecting the moldings;
iii) Enter the sampling time, or other identification, in the data block;
iv) Number each molding as it comes from the machine and put it to one side to stabilize. (For many materials this is simply a matter of letting it cool for say, 20 minutes; some moldings may need to be conditioned or annealed);
v) Perform the measurement on each annealed molding and enter the results in the appropriate box (in the data block);
vi) Calculate the average and the range for each sample and enter these results into their boxes on the data block;
vii) Plot the range value and the average value on the chart and connect, by means of lines, to the previous points so that patterns and trends may be visualized;

viii) Check the calculations and also check that the points have been plotted correctly, for example, that the range point and the average point are, in line;
ix) Repeat the sampling and plotting if the first is out of specification, and;
x) Note when the next sample is due.

## Actions.

Always check that the points have been plotted correctly and that the measuring system is accurate: frequent checking and calibration of this is essential.

If the points have a random scatter and if they lie between the warning limits (below the warning limit for the range chart) then there is nothing to worry about. If a point is plotted between the warning and the action line (on either chart) then, the process may have changed. Check by taking another sample immediately. If that second point is below the warning line then, assume that the process is satisfactory but keep it under observation. However, if two successive points are between the warning and the action lines then, it must be assumed that the process is out of statistical control. What caused this to happen (an assignable cause such as someone 'twiddling') must be found and put right. The output produced since that point was plotted must be segregated until it can be proved that it is acceptable.

(For a point to fall outside a warning limit a 1 in 40 chance must have paid off; for two, successive points to fall outside such limits a 1 in 1600 chance must have paid off i.e 1 in 40 times 1 in 40).

If a point lies outside an action line then, the reason must be found immediately as the process is almost certainly out of statistical control. Again, as in all cases when the process is out of statistical control, component segregation and examination is necessary.

If seven points in a row on one side of the average occur then, it may be assumed that a process shift or trend has begun and corrective action must be considered. If seven points in a row are consistently increasing or, consistently decreasing, then, it may be assumed that a process shift or trend has begun and corrective action must be considered.

Compare the shifts one with another (easy with color plotting) so as to see if any techniques developed by one, can be taught to another.

# MACHINE DEVELOPMENTS AND STATISTICAL PROCESS CONTROL (SPC).

At first glance injection molding machines do not seem to have changed very significantly over the past few years. The basic machines look roughly the same but what has changed dramatically is the way that they are controlled and/or operated. This is because of the application of microprocessor technology: the microprocessor and improved hydraulics seem to have happened at the same time and the advent of one has helped the other.

## Cartridge Valves.

Cartridge valves have brought big improvements to injection molding, as they operate faster (about five times faster), allow higher flows and close off more quickly than spool valves. Such valves are smaller and as they fit inside a manifold (about 3/4 of the valve is inside a block) then, oil leaks are reduced. This makes for a tidier, safer molding shop and saves on contamination. In many molding shops, oil contamination (of the moldings and of the environment) is a very serious problem and so this feature is not to be dismissed lightly. Such valves cannot normally make for a closed loop system: their use does, however, result in very good reproducibilty from shot-to-shot and from run-to-run.

## Open and Closed Loop Control.

A process is said to be in closed loop control if, when a command is given, the control system monitors what happens and re-adjusts the strength of the response, if necessary, so as to achieve what is desired. Open loop control is the term given to a control system which does not monitor what happens when a control command is given.

## Types of Closed Loop.

The term closed loop is often applied, in injection molding, to the hydraulic system e.g. to injection, or mold filling speed or, to injection pressure. If closed loop control is specified for speed then, it is easier, and cheaper, to do this with a loop which 'closes' at the hydraulic valve: the oil flow rate through, or across, the valve is monitored and controlled. On larger machines, it maybe worth monitoring and controlling linear screw speed but, where the stroke is relatively small (e.g 100mm/3.9in or less) then, valve monitoring is preferred. CPC is often used for pressure control.

(See the section on Velocity pressure transfer.)

## SPC and Closed Loop.

Some users of statistical process control (SPC), or statistical quality control (SQC), systems do not like existing closed loop as they believe that what we have at the present is not good enough: For example, they believe that a closed loop system can introduce, more problems than it solves. What this means is that the relationship, or cross coupling, between each of the process parameters does not allow the process to be effectively controlled by changing one process parameter such as the injection pressure. What is needed with closed loop control is the application of an artificial intelligence to the machine so that the effect of any changes can be predicted and assessed.

## SPC and Open Loop.

Results from numerous experiments show that, at present, SPC can only be effectively used on molding machines which have open loop control. The open loop process can be effectively monitored and any deviation to the molding process can be readily identified. This information enables the SPC software package to analyze the current data and accurately predict when the machine will produce components which would be outside the specified tolerance limits.

## Setting and Monitoring.

This is the area which has obviously developed as the microprocessor has developed, and has been applied, to molding machines. The use of microprocessors has made setting and monitoring easier. Memories are available for machine and tool setting so that, for example, automatic tool setting, and changing, is not only possible but is feasible. A host of additional features can be easily put onto the machine at low cost e.g programmed air ejection can be fitted at a comparatively low cost. Safety is another area that has benefited from the application of the microprocessor so that a modern injection molding machine is safer than the one it replaces.

## JIT Production.

The ability to reclaim faulty moldings, and the feed system, produced during the molding of thermoplastic materials, is very often a mixed blessing as it can lead to the attitude that the production of faulty moldings does not matter. It is said that it does not matter because the injection moldings can be ground up and used again. They can be reclaimed but there is a lot of wasted time and effort: it costs an awful lot of money to keep an injection molding machine running, so it makes sense to try and get it right, first time. If this is done, then just in time production, is possible: this is often abbreviated to JIT.

## Microprocessor Controls.

The reliability and built-in fault finding of microprocessor-based controllers are now well established and few companies would think of buying a machine with electro-mechanical controls and relays. However, to get the speed of response required, it is necessary to use more than one microprocessor as microprocessors work to a program and it takes time to work through that program. Because of this time delay, each microprocessor may be dedicated to one machine function (for example, core pulling, fault diagnosis etc.). Each of these microprocessors is connected to a master computer: the master is therefore connected to slaves.

Even the simple temperature controller is now able to communicate with the control system of the injection molding machine and with other computers. The master computer is capable of, for example, setting the temperature, altering the control characteristics, or terms, of the temperature controller and then accepting the actual temperature for record purposes.

## Automatic Quality Control.

Because of the power of the microprocessor, it is now relatively easy to incorporate features on an injection molding machine so that verification of product quality during an injection molding shot is possible. Verification of product quality at the point of manufacture can be documented in statistical process control (SPC) records. The average, or set, value of a monitored value may be automatically displayed, on a VDU, together with appropriate control limits, for example, an upper control limit and, a lower control limit. During the actual molding cycle, the data is gathered and displayed on the VDU. Production drifts, or trends, can therefore be easily spotted and, out-of-specification moldings rejected completely or, diverted for inspection.

# SETTING UP STATISTICAL PROCESS CONTROL (SPC).

For quality assurance and/or quality control systems to work effectively it is essential that everyone in the injection molding factory is totally dedicated to the concept of quality. Before any strategy is implemented, or documents prepared, there must be commitment from senior management and, discussions with key people throughout the organization. Those responsible for implementing the quality strategies, must be provided with the correct equipment, with clear and precise directions, the duties of everyone involved must be publicized and the effect of their contribution on the quality of the end-product/service must be defined.

## QA and TQM.

Quality assurance (QA) aims for zero defects and for getting the job right first time. The emphasis is on preventing defects and on building in quality at every stage, right from the initial design stage. The impetus for improvement must come from the top of the organization and then it must involve everyone from the directors down to the shopfloor personnel. Such total quality management (TQM) requires a change of attitude and a commitment on the part of everyone to zero errors/defects and to supplying products which meet the customers requirements. All departments in an organization must be so committed - stores, purchasing etc., as well as the production department. Ideally, the function of a quality control (QC) department would then be to simply reassure everyone that the quality was being maintained.

## Quality Control Inspectors.

Quality control inspectors are usually essential and such people must be regarded as members of the team and not, people who are to be shunned or avoided. The inspectors must be trained in quality control (QC)/statistical process control (SPC) techniques and have attended formal courses so that they can interpret the QC/SPC data effectively. QC/SPC will only work if the people who analyze the data, do so correctly and, if they act sensibly, to correct faults, after information analysis.

## JIT Production.

It costs an awful lot of money to keep an injection molding machine running, so it makes sense to try and get it right, first time. If this is done, then just in time production, is possible (this is often abbreviated to JIT). Not only is money saved but so is production time and energy. The energy which is used to power the injection molding machine, is turned into heat. A great deal of this heat finds its way into the surroundings where it causes thermal pollution: thermal pollution is one of the world's great problems.

## QC with Average and Range Charts.

Quality control charts (QC) show how well a process is operating (they are sometimes known as process control charts). They will show if the process is functioning in an acceptable way or, if the process has drifted out of control or, if the process is about to drift out of control. The tendency of a machine to drift out of control can therefore be spotted before rejects have been produced. After all, it makes sense not to produce components which will be subsequently scrapped. However, to get the information required, it is necessary to take samples, or measurements, at predetermined intervals, perform measurements, or comparisons, record the data, plot the measurements on the chart, assess the results and then, take appropriate action.

## Implementing SPC.

It is suggested that a manual data collection and interpreting system be tried before a computer-based system is installed. Once the concept has been tried and proved then, the information so gathered may be used to define what precisely is wanted.

i) Liase with your customer so as to ensure that the correct characteristics are being subjected to SPC control;
ii) Ensure that all personnel are involved, committed and have the right training;
iii) Carry out production capability analysis (see the section on Calculating production capability) so as to establish that the process can consistently meet the customers requirements:
iv) If necessary modify the injection molds or, the injection molding technique until correct production capability is obtained;
v) Ensure that the computer software will handle and, give the information which is required;
vi) Once both you and the customer are satisfied with the production process then, enter the SPC details into the SPC computer i.e. put it on a floppy disc;
vii) Decide, after consultations with the customer, on the frequency of checks which are to be carried out by the SPC inspectors;
viii) Ensure that the SPC inspectors enter the information into the SPC computer as specified or, that the measuring instruments enter the information directly into the SPC computer;
ix) Display the information and then retain the information against a production run identification; and,
x) Assess the results and then, take appropriate action.

## Process Monitoring.

Many moldings are judged by color, surface finish and feel (handle): these parameters are not easily measured on-line and cannot be measured until the component has been produced. On-line measurement and control, presents problems of detection, quantifying differences from a standard and in many cases, relating these differences to easily controllable, process variables. Temperature and pressure, and temperature and pressure profiles, are relatively easy to measure during an actual production run and for this reason are being used to judge molding quality.

## Automatic Quality Control.

Because of the power of the microprocessor, it is now relatively easy to incorporate features on an injection molding machine so that verification of product quality during an injection molding shot is possible. Verification of product quality at the point of manufacture can be documented in statistical process control (SPC) records. The average, or set, value of a monitored value may be automatically displayed, on a VDU, together with appropriate control limits, for example, an upper control limit and a lower control limit. During the actual molding cycle, the data is gathered and displayed on the VDU. Production drifts, or trends, can therefore be easily spotted and, out-of-specification moldings rejected completely or, diverted for inspection.

## Typical On-Line System

To monitor on-line, the system designer must identify what needs to be monitored and then equip the machine with appropriate transducers. A melt thermocouple, in the nozzle, may be needed, and a thermocouple in the mold may be required. Pressure transducers in both the mold and the hydraulic line are also usually required: a linear displacement transducer, to measure linear screw movement, is also usually required. The output from these transducers is monitored and if the signal from one transducer, or from a combination of several, is different from previously set limits then various quality control (QC) actions may be taken if selected. In one such injection molding, machine-based system, seven parameters (one is peak cavity pressure) are set and monitored; injection speed and hydraulic pressure profiles are also set and monitored. If the set limits are exceeded, or not met, then the control system judges that the particular injection molding is unlikely to be acceptable. Various control strategies can then be implemented, for example, an alarm sounds and the injection molding is diverted to an inspection area. If the number of rejects exceeds a certain preset, percentage then, the machine will stop once that percentage is exceeded.

## PVT Systems.

If an injection molding machine is equipped with appropriate transducers, and if the machine is also equipped with the right software and computer then, the operator can implement PVT control. The idea behind this is relatively simple: it is that pressure (P), volume (V) and temperature (T) are inter-related. As the molding cools in the cavity then, the holding pressure may be progressively reduced so as produced components free from over-packing (and therefore with reduced stress levels). Because of the rapid, and large, volume change which occurs when a semi-crystalline, thermoplastics material cools within the injection mold, some authorities believe that such PVT programs are not suitable for highly crystalline, hard materials such as POM, PA6 and PA66. It is commonly suggested that a consistent, high packing pressure be applied to such materials.

## Use of Robots.

Where robots are used for molding removal then, a robot measuring system (for example, based on the measurement of weight, size, color etc.) may be used to judge the component. The information that the robot measuring system generates may be transmitted to the microprocessor control system and used for QC charts: on-line QC, based on molding measurements, is therefore relatively easy.

# SETTING AND MACHINE REPRODUCIBILITY.

On many modern injection molding machines, machine setting is incredibly easy: a data carrier (a cassette/a card) is used to transfer machine settings so that manual setting is eliminated. Many people believe that this means that the molding machine is then set to exactly the same values as those used on a previous run but, this is not so for the following reasons. (If the machine does not have a data transfer system, then machine setting errors, introduced by manual setting, must also be considered).

## Machine Differences.

When an injection molding machine is built, certain latitudes are allowed, for example, a bar may be specified as being 2,000 +/- 1mm. This means that it can either be 1,999 or, 2,001 or, any length in between these two values. As injection molding machines are built up from many different components, each with a production tolerance, then no two machines are exactly the same: the settings derived from one machine will not produce identical components on another machine.

## Re-Setting Tolerances.

If the settings were originally derived from the same machine then, even if a data carrier is used, exactly the same production conditions will not be obtained when the injection molding machine is re-set. Machine setting, although it can be very close to an original value, is not absolutely precise and will have to be fine-tuned. These inconsistencies arise for many reasons and one of them is again the allowed production tolerances. It must not be forgotten that on many machines all the settings/parameters, necessary to control the production operation, are not capable of being set: a change beyond the setting capability may have occurred

## Mold Changes.

An injection mold has a very hard life: on fast cycling machines the two mold halves may open, close and clamp once every second. Parting surfaces may therefore, easily be damaged: this is a change beyond the setting capability. Water is usually circulated through the mold, in order to remove the heat carried in by the plastics material, and if the cooling channels change (for example, through 'furring') then the mold will not be in the same original condition: it will not have the same heat removal capacity. Mold surface temperature should be measured and circulation of the heat transfer medium (usually water) should be adjusted to get the same heat removal rate. The action of mold filling, particularly for heavily filled materials, causes wear to occur and again this means that the mold will not be in the same original condition. This again, is an example of a change beyond the setting capability.

## Temperature Changes.

A modern injection molding machine appears to have an abundance of temperature control systems or circuits. Because of this abundance, the temperature control or monitoring is often thought to be sufficient. This view should be treated with caution as often the following are ignored: oil temperature, hopper block/feed flange temperature, mold surface temperature and material temperature. Significant, material temperature variations can occur, particularly if the molding machine is fed incorrectly from a dryer, for example, by not allowing sufficient residence time in the drying unit.

## Sensor and Melt Temperature Changes.

The control system relies on sensors for the information it needs to control the molding operation. Such sensors measure distances/speeds, temperatures and pressures. Once again these units have production tolerances, and operational tolerance, and so variations can occur. (For example, a pressure measuring device may be calibrated at room temperature and used at a higher temperature.) The location and condition of the thermocouples are particularly important but are often ignored so that significant temperature differences occur.

A frequent source of error is melt temperature variations caused by injection cylinder variations: such variations could arise because the molding machine is badly sited, for example, in an inconsistent, draughty location. Machines should be in sheltered locations and anything which is heated or cooled excessively, should be lagged or insulated. For example, the molds used for engineering plastics are often run at relatively high temperatures and should be insulated from the platens so as to save on energy losses: this is often not done.

## Material Changes.

Most injection molding materials are produced or synthesized in processes referred to as 'polymerization'. This again means that variations may occur and such variations can be quite large. The ease of flow of the material can therefore change by a considerable amount from one batch of a material to another (because of blending it does not usually change within a batch). Simple tests such as melt flow rate/index may not be capable of picking up the changes although the machine will. High shear rate rheometry may be the only answer.

## Feed Form.

The injection molding machine can be fed with plastics (resins) or compounds in various forms: the feed may be fine powder, regranulated material or, pellets. If the material is available in more than one feed form, then feeding problems will probably be encountered if a mixture of feed forms is used. In terms of feeding efficiency, spherical granules (of approximately 3mm/0.118in diameter) are the most efficient. Fine powder is usually the worst, followed by regranulated material, then by cube cut granules and then by lace cut granules (granules made by chopping strands with a circular cross-section). For many good and valid reasons injection molding machines are often fed with a mixture of plastics material (may be in ore than one form) and masterbatch. The use of such a mixture can however, cause production problems. The usual problem is one of color shade differences between different machines; another is separation of the masterbatch from the plastic in the hopper.

## Material Condition Changes.

Even if the material fed to the machine is identical in chemical composition and feed form then, variations can and do occur. Such variations arise because the water content of the material may change and/or because the heat content of the material may change. As mentioned before, material temperature (if fed from a dryer) can easily change because of a lack of residence time in the dryer. This will also affect the water content. Material temperature affects flow but so does a comparatively low, water content. A higher water content usually makes it easier but, the presence of water/moisture, introduces molding faults such as silver streaking and/or brittleness.

## Effect of Additives.

Some materials can speed up (they catalyze) chemical changes, for example, traces of copper cause a rapid change in hot polypropylene (PP). What this means is that the addition of any material to a material/resin should be done with care and only done when it is proved that addition will not cause an undesirable change. This means that every additive should have been tested and only tested additives used in production. What this means is that if a pigment or color masterbatch has been specified then, there must be no substitution with another until the new material has been tested and approved.

## Ruthless Rejection.

When faulty moldings, and feed systems, are scheduled for reclamation then they should be looked after very carefully and only those parts which are free from contamination and color changes should be used. This is because it is common practice to blend virgin (new) material with reclaimed material (regrind) and if the reclaimed material is contaminated, then a lot more reject material is produced. If unchecked the problem can quickly get out of hand. So, ruthlessly reject any moldings or any feed system which is suspected of being contaminated.i.e. only reclaim good quality material.

## Variability.

By making deliberate changes to machine settings, the output (the components or moldings) of an injection molding machine will be changed. An easy way of showing this is to weigh the components: changes in weight can be correlated, or assigned, to deliberate changes in machine settings. Such intentional changes are called 'assignable variations'. However, even when a machine is running under constant conditions, i.e. it has 'settled down' and no deliberate changes are made, changes still occur. This is an 'inherent variation' and is so called because it cannot be attributed to a single cause: could be caused by material variations, machine variations, environment variations or operator variations. Inherent variation is also known as 'inherent variability' or as 'intrinsic variability' or as 'instantaneous variability'. Statistics may be used to determine how accurately a machine/material/mold/operator combination can produce components i.e. they can answer production capability questions and, what is more such questions can be answered relatively easily.

# PROJECTED AREA AND CLAMPING FORCE.

The projected area of a molding is the largest area that can be seen if the molding is viewed from the direction of the clamp force application. The total projected area for a multicavity, injection mold is given by the area of one cavity multiplied by the numbers of cavities in the mold plus the area of the feed system.

## Information Required.

To calculate the total projected area, for a given multi-impression mold, it is necessary to know the following:-

a The dimensions of one impression in the mold;
b. The number of impressions in the mold;
c. The layout of the impressions in the mold;
d. The dimensions of the feed system, i.e. the diameter and length of runner branches.

## Area of the Runner System.

The total area of the runner system is obtained by adding the sum of all the areas for each section of the runner configuration. The area for each section is the largest area seen when viewed from the direction of the clamp force application. For small moldings (of approximately less than 5g/0.2oz) the area, and the weight, of the feed system can be the same as, or even greater than, than that for the components. In these circumstances, the runner layout should be very carefully designed so as to minimize the amount of material in the runner and the runner projected area.

## Gate Considerations.

The area of the gate is not usually considered because of its very small size. However, if a film, fan, ring, diaphragm or tab-type gate is used then the area should be included in the total projected area value.

## Parting Line Determination.

To calculate the projected area of a molding, the split or parting line for the component has to be decided upon. Once this decision is made, then the component can then be arranged so that it is viewed from the direction of clamp force application or, in the line of extraction from the mold (i.e. its plan view).

## Clamping Force.

To determine the clamping force, calculate the total projected area for the mold and then multiply this area by the required clamping pressure. The clamping pressure will vary for each thermoplastics material: Table 14 gives typical clamping pressures for a range of thermoplastic materials. The applied clamp force must be sufficiently high so as to ensure that the mold remains fully closed during the filling and packing stages.

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# SIMPLE PROJECTED AREA AND CLAMPING FORCE CALCULATIONS.

In many cases it is possible to obtain a good idea of the clamping force required from a relatively simple calculation. To do this, the projected area of the component must be calculated and a suggested clamping pressure must be known. This procedure will be illustrated using a typical injection molding. Figure 6 shows the proposed mold layout for a cover molding: the total projected area can be calculated as follows:-

i. Projected area of impressions;
ii. Projected area of feed system.

## Projected Area of Impressions.

The number of impressions in the mold = 6. Therefore the total projected area for 6 impressions = 6 x (6 x 4) = 144 cm$^2$ (0.0144 m$^2$) or 6 x (2.36in x 1.57in) = 22.23in$^2$.

## Projected Area of Feed System.

Details of the dimensions for the runner system can be found in Figure 6. To simplify matters the area of the feed system can be broken down into various sections, e.g, primary and secondary.

**PROJECTED AREA OF PRIMARY RUNNER.** The area for the primary runner section equals it's length multiplied by it's breadth. That is, L x 2R, which equals 5.2 x 0.6cm. = 3.12cm$^2$ (3.12 x 10$^{-4}$m$^2$), or 2.5in x 0.236in = 0.484in$^2$.

The number of primary runner branches is 3, hence the total area for the primary runner is 3.12 x 3 which equals 9.36cm$^2$ (9.36 x 10$^{-4}$m$^2$) or 0.4842 x 3 = 1.452in$^2$.

**PROJECTED AREA OF SECONDARY RUNNERS.** The area for the secondary runner can be also be broken down into three sections (see Figure 6) where sections 1 and 3 are semi-circles. The area of a semi circle is $\pi R^2/2$. As there are two semi circles, the area $= 2 \times \pi R^2$

Section 2 is a rectangle: the area is (L - 2R) x (2R or D). Therefore the area of the secondary runner $= \pi R^2 + (L-2R) \times D$ (where R = 0.3cm or 0.118in) which equals $\pi \times (0.3)^2 + ((3.7 - 0.6) \times 0.6) = 2.14\text{cm}^2$ or $(2.14 \times 10^{-4}\text{m}^2)$ or $\pi \times (0.118)^2 + ((1.457 - 0.236) \times 0.236) = 0.3318\text{in}^2$.

The number of secondary runner branches is 3, hence the total projected area for the secondary runner system is 2.14 x 3 which equals $6.42\text{cm}^2$ or $(6.42 \times 10^{-4}\text{m}^2)$ or $0.3318\text{in}^2 \times 3 = 0.9954\text{in}^2$.

**TOTAL PROJECTED AREA.** The total projected area of the mold can be obtained by adding:-

i. The total projected of impressions = $144.00\text{cm}^2$ plus,
iia. The total area of primary runner = $9.36\text{cm}^2$ plus,
iib. The total area of secondary runner = $6.42\text{cm}^2$
This equals $159.78\text{cm}^2$ $(0.01598\text{m}^2)$; or,
i. The total projected of impressions = $22.23\text{in}^2$ plus,
iia. The total area of primary runner = $1.452\text{in}^2$ plus,
iib. The total area of secondary runner = $0.9954\text{in}^2$
This equals $24.6774\text{in}^2$;

## Calculation of Clamping Force.

Table 14 gives typical clamping pressure values for a range of thermoplastic materials. To compensate for any changes in the material's melt viscosity, as a result of batch to batch variation, it should be assumed that the higher of the two values may need to be used. The clamping force needed to produce the polycarbonate covers can be calculated where the material pressure for PC (i.e. 46.3 to 77.2 $\text{MNm}^{-2}$ or 3 to 5 tons/in$^2$) is multiplied by the total projected area for the mold (i.e. $0.01598\text{m}^2$ or $24.6774\text{in}^2$).

Therefore, the clamping force needed is,

$$0.01598\text{m}^2 \times 77.2\ \text{MNm}^{-2} \text{ which equals } 1.235\text{MN}.$$

As 1N = 0.1kg and 1MN = $1 \times 10^6$N then to convert to metric tonnes use the following, $\dfrac{1.235 \times 10^6 \times 0.1}{1000} = 123.5$ tonnes;

or 24.774 x 5 = 123.87 tons.

The machine needed would be approximately, one capable of exerting a clamping force of 130 to 135 tonnes or, 130 to 135 tons.

# ACCURATE METHOD OF CALCULATING THE CLAMPING FORCE.

The main problem with the simple methods suggested for calculating clamping force, is that the formula does not take into account the length or distance which the material has to flow in the mold (i.e. the position of the gate), the thickness of the component wall section and the flow behavior of the chosen thermoplastics material. For these reasons, simple methods can only be used as an approximation of the clamping force. A more accurate clamping force value can be calculated using typical graphs and formulae. See Table 15 and Figure 7.

## Influence of Gate Position.

To demonstrate the importance of the position of the gate, the clamping force required for a polycarbonate cover molding will be calculated for two different types of gates and gate position.

**(a) SUBMARINE GATE.** The submarine gate is positioned half way down the 2.6cm (4.213in) dimension and 0.5cm (0.197in) from one end of the component (see Figure 9). (This type of gate is used so that the gate scar will not be readily seen and so that the component will be automatically degated from the feed system when ejected from the mold). The cover molding, as shown in Figure 8, has a wall section of 1.0mm (0.039in). With the gate position shown in Figure 9, the maximum flow length of material from the gate to the last point of fill in the mold is approximately 107mm (4.213in). Hence the flow length to wall thickness ratio for the above gating position 107/1 = 107:1 (4.213/0.039 = 107:1).

### Viscosity Factors for Thermoplastics Materials.

Each thermoplastics material is given a flowability rating or viscosity factor value. The viscosity value for materials such as PS, PP and PE is 1 and the other materials have been rated according to their stiffness of flow as compared to PP, PS and PE. For instance PC is much more stiffer flowing than PS and therefore PC will have a higher viscosity factor value see Table 15. To cater for long or short material flow lengths in the mold, the value for the viscosity factor is given in range form, the higher value being used for long flow lengths.

**Cavity Pressure.** The resultant cavity pressure obtained from Figure 7 is 250bar (i.e. at a 1mm wall section and a flow length to wall thickness ratio of 107:1). A safety factor of 30% is added to the predicted cavity pressure i.e. 250 + (0.3 x 250) = 325bar. The flow factor for PC as compared to PS is 1.7 to 2.0 (see Table 15). As the flow length is relatively long it is advisable to use the factor of 2. Therefore the cavity pressure of 300 x 2 = 650bar or 9425psi or 4.21tsi or 65,000 kN/m$^2$.

**Clamp Force per Impression for the Submarine Gate.**

As 1cm$^2$ = 0.0001m$^2$ then the clamping force per impression
= 24 x 0.0001 x 65,000
= 156.0kN
= 15.60 tonnes (or 15.60 tons)

**Clamp Force for the Runner.**

The projected area of the runner system is 15.78cm$^2$
therefore the clamping force for the feed system is:
15.78 x 0.0001 x 65,000
= 102.6kN
= 10.26 tonnes (or 10.26 tons)

(b) **PIN GATE.** The second type of gate is a pin gate, which is centrally positioned on the top face, see Figure 9. The reason for its use is to prevent the formation of flow lines occurring on the center section and outer walls. As the gate position has been altered, a shorter material flow length is now obtained. The material flow length (Sf) is now 56mm or 5.6cm (2.205in), compared to the value (i.e. 10.7cm or 4.213in) which was used for the submarine gate. The resultant flow length to wall thickness ratio is 56/1 = 56:1 or 2.205/0.039 = 56:1.

**Clamping Force per Impression for the Pin Gate.**

The resultant cavity pressure obtained from Figure 7 is 180bar (i.e. at a 1mm wall section and a flow length : wall thickness ratio of 56:1). Again a safety factor of 30% is added to the cavity pressure i.e. 180 + (0.3 x 180) = 240bar. The flow factor for PC as compared to PS is 1.7 to 2.0 (seeTable 15). As the flow length is shorter a factor of 1.7 can be used. Therefore the cavity pressure of 240 x 1.7 = 408bar or 5916psi or 2.64tsi or 40,800 kN/m$^2$.

The clamping force per impression =
24 x 0.0001 x 40,800
= 97.9kN or 9.79 tonnes (or 9.79 tons)
or, 2.362in x 1.574in x 2.64tsi
= 9.81tons

## Total Clamping Force Required for Each Gate-Type.

The revised clamping force value for each gate is as follows:

**SUBMARINE GATE.** The total clamping force for the six polycarbonate cover moldings when using the submarine gate equals the clamping force for each impression x 6 (number of impressions) + clamping force for feed system. That is, 15.65 x 6 + 10.26 = 104.16 or 105 tons

**PIN GATE.** The total clamping force for six impressions is, 9.79 x 6 + 10.26 = 69 tons (The type of mold required to permit the use of a centrally positioned pin gate is of the multi-plate or runnerless type design. Both designs do not require any additional projected area to cater for the feed system as in the case with the submarine type gate).

## Comparison of Clamping Forces.

It can be seen that the total clamping force can vary dramatically depending upon the position of gate. Therefore calculations, using the above procedure, should be carried out during the mold design stage and not when the mold has been manufactured. The size of injection molding machine needed to produce the PC covers with the submarine gate requires an additional 34% locking force capacity than that needed with the pin type gate. This means that the product and operating costs will be much higher for the former mold design; giving a lower overall profit margin than that of the latter.

# SPECIFYING THE CLAMP FORCE CAPACITY.

Once the clamping force value for a given mold has been calculated the clamping force capacity of the injection molding machine should then be determined. To ensure that the correct size of molding machine (in terms of sufficient locking force capacity) is selected it is important to introduce a safety, or wear factor, in the clamping force calculations.

## Safety or Wear Factor.

To compensate for wear problems (for example, in the form of worn hydraulic seals and/or enlarged clearances between toggle bush and linkage pin) and also, to prevent the machine running at its maximum capacity, a safety factor of approximately 10% is included in the locking force calculations (e.g. 1.1 times the calculated locking force value). That is, the clamping force capacity of the selected molding machine should always be approximately 10% greater in value than the calculated clamping force value.

## Revised Clamping Force for the Polycarbonate Covers.

The actual size of molding machine needed to produce the polycarbonate covers shown in figure 6, and calculated in previous sections, is as follows:

i. using the submarine type gate.
$1.1 \times 105 = 116$ tonnes;
ii. using the pin type gate
$1.1 \times 69 = 76$ tonnes.

The range of locking force capacities of injection molding machines vary from supplier to supplier and therefore the actual size of molding machine used to produce the cover moldings would be the exact, or the next highest capacity, to the calculated value. For example, a 120/125 tonne locking capacity machine and an 80/85 tonne locking capacity machine respectively, should be selected.

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# DIRECT HYDRAULIC LINE PRESSURE CALCULATIONS.

In order to calculate the hydraulic line pressure that is required to exert a specific clamping force on a direct hydraulic (thrust) type machine, it is necessary to find the diameter of the main, clamping ram. This value is usually quoted in the machine's instruction or service manual, for example a typical 120 tonne direct hydraulic locking force machine, would have a ram diameter of 280mm (28cm) or 11.024in.

**CALCULATION OF LINE PRESSURE.** The clamping force ($C_f$) for a direct hydraulic clamping unit is, the pump delivery pressure (sometimes called main line pressure) ($P_p$) x the area of the piston/ram head of the hydraulic cylinder ($A_{hc}$).

i.e. $P_p \times A_{hc} = C_f$

$A_{hc} = \pi D^2/4$ where D is the diameter of the ram head

**WORKED EXAMPLE.** The necessary hydraulic line pressure to exert a clamping force of 110 tonnes for a direct hydraulic clamping unit, having a main ram diameter of 28cm (11.024in) is as follows:

Given $P_p \times A_{hc} = C_f$

As $A_{hc} = \pi D^2/4$ (where D is the diameter of ram head) then,

$A_{hc} = \pi \times 28 \times 28/4$

$A_{hc} = 615.8$cm2; or,

$A_{hc} = \pi \times 11.024 \times 11.024/4$

$A_{hc} = 95.448\text{in}^2$;

Therefore, $P_p \times 615.8 = 120$ (the effective clamping force), or

$P_p \times 95.448 = 120$.

Line pressure is commonly quoted in either $\text{kgcm}^{-2}$ or, in psi. So, if we want $\text{kgcm}^{-2}$ then we we must multiply tonnes by a 1000 as there are 1000kg in a metric tonne (2205lb).

Then $P_p = \dfrac{120 \times 1000}{615.8}$

$P_p = 194.9\text{kgcm}^{-2}$ or,

$P_p = \dfrac{120 \times 2205}{95.448}$

$P_p = 2{,}772.2$psi.

## Advantage of Calculating Line Pressure.

Once the required line pressure for a given machine/mold combination has been calculated then, quite often, operational costs can be reduced because the hydraulic line pressure can be adjusted to the calculated value. It has also been found that by conserving energy, in the form of line pressure reductions, additional savings in maintenance costs have also been achieved. When the locking force is applied by means of toggles, a reduction of the hydraulic line pressure is not recommended as a reduction in the clamping force is achieved by altering the stretch on the tie bar.

## Pump Pressure Values.

The line pressure used for an injection molding machine depends, for example, upon the size of machine and the number, and type, of pump/s used. Typical values for the most popular types of pumps are as follows:

Gear type pump: 1200 to 1400 psi (83 to 97 bar).
Vane type pump: 2000 to 2320 psi (138 to 160 bar).
Piston type pump: up to 5000 psi (345 bar).

# CALCULATION OF TIE BAR EXTENSION.

The locking force on a toggle operated, clamping unit is determined by the amount of tie bar stretch that occurs (sometimes called tie bar extension). The amount of extension can be as much as 1% of the original length of the tie bar.

## Clamping Force Generation.

Most injection molding machines have as their prime source of power an electric motor which drives a hydraulic pump(s). When this fluid is fed to a ram or cylinder (hydraulic actuator) then movement is generated: if there is resistance to movement force is generated. Because of the application of force to the mold, the tie bars stretch (the tie bars stretch on any injection molding machine.) On toggle lock machines, the toggles act like levers and stretch the tie bars: when the toggles/levers are fully extended, and in line at the end of their stroke, it is the stored elasticity in the tie bars which holds the mold halves together.

## Formula for Tie Bar Extension Calculations.

The amount of tie bar stretch can be calculated using the following formula:-

$$e = \frac{\text{Clamping force} \times L}{n \times a \times E.}$$

(With such formulas it is essential to use units which are consistent or compatible so that sensible answers are achieved.)

e is the extension of the bar;

L is the effective, or active, length of the bar in, for example, cm. It is the distance between the tie bar nuts over which the extension is being obtained;

n is the number of tie bars used on the molding machine;

a is the cross-sectional area of the tie bar in cm2 (D is the diameter of the tie bar);

and, E is the tensile modulus of elasticity for the tie bar steel (e.g. EN9 which is usually $2.1 \times 10^6$kgf/cm$^2$ ($2.1 \times 10^{11}$Nm$^{-2}$) or $30 \times 10^6$psi).

The diameter (D) of the tie bar for each machine will be quoted in the machine's manual. The effective length (L) of the tie bar will change according to the thickness of the mold and position of the locking unit along the tie bar.

## Tie Bar Extension Calculation.

A typical diameter of the tie bar used on a 125/150 tonne toggle-lock molding machine is 70mm (7cm) or 2.756in. The effective, or active, length of the tie bar is not known as this length is related to the mold height and hence the actual value of (L) can only be measured on the machine itself. However, to complete the example it will be assumed that the effective length of the tie bar is 80% of the total tie bar length. Say 210cm x 80% (or 0.8) which equals 168cm (1680mm), or 82.677 x 0.8 = 66.142in.Given the above data, the amount of tie bar extension to exert a clamping force of 150 tonnes on a 4 tie bar toggle-lock molding machine is as follows: (150 tonnes = 150,000kg)

$$e = \frac{150 \times 1{,}000 \times 168}{4 \times a \times 2.1 \times 10^6.}$$

$$e = \frac{252 \times 10^5}{8.4 \times 10^6 \times a}$$

$$e = 3/a$$

As $$a = \pi D^2/4 = \frac{\pi \times 7 \times 7}{4} = 38.48\text{cm}^2$$

then, $$e = \frac{3}{38.4} = 0.078\text{cm.}$$

Or, $$e = \frac{150 \times 2240 \times 66.142}{4 \times a \times 30 \times 10^6.}$$

$$e = \frac{22.224 \times 10^6}{4 \times 30 \times 10^6 \times a}$$

$$e = 0.1852/a$$

As $$a = \pi D^2/4 = \pi \times 2.756 \times 2.756/4$$

$$= 5.966\text{in}^2.$$

Then, $$e = \frac{0.1852}{5.966} = 0.031\text{in.}$$

## Use of Tie Bar Extension Value.

Most molding machine manufacturers will supply details regarding the amount of tie stretch that should be used in order to obtain the maximum locking force. On the older type of molding machines, apart from actually measuring the tie bar stretch, there is no other facility to determine the actual locking force being used. Newer machines have graphs, displayed on the machine, of tie bar extension value/tonnage lock to enable the molding shop personnel to set the required locking force for a particular design of mold.

# CALCULATE THE COOLING REQUIREMENTS FOR A MOLD.

When calculating the cooling requirements for a given mold the use of a simple procedure should be followed. The one suggested is as follows:

i. Calculate the shot weight of the molding;
ii. Calculate the heat content for the mold each cycle;
iii. Calculate the flow rate of the cooling medium through the mold;
iv. Select the diameter of cooling channel to be used; and,
v. Calculate the number of cooling channels required, in the mold, to accommodate the required cooling medium, flow rate.

To illustrate the above procedure, the cooling requirements will be calculated for the mold producing polycarbonate (PC) cover moldings, as shown in figure 8.

## Calculate the Shot Weight of the Molding.

As there are no existing sample cover moldings available, in order to determine the total shot weight of the molding (i.e. six PC cover moldings + the weight of the feed system) the total shot volume will need to be calculated. Once this value is found then, by multiplying the shot volume by the material's density the shot weight can be determined. The total shot volume of the molding equals the volume of one impression x number of impressions in mold + volume of feed system. To simplify matters, the volume of the component and the feed system will be considered separately:

**Volume (vol) of component :**

Vol of top $= 6 \times 4 \times 0.2 = 4.8\ \text{cm}^3$
Vol of short sides $= (4 \times 2.4 \times 0.2) \times 2$
$= 3.84\ \text{cm}^3$
Vol of long sides $= (5.6 \times 2.4 \times .2) \times 2$
$= 5.38\text{cm}^3$
Vol of tube section $= \pi \times (1.15 + 1) \times (1.15 - 1) \times 3.4$
$= 3.44\text{cm}^3$
Vol of component $= 4.8 + 3.84 + 5.38 + 3.44$
$= 17.46\text{cm}^3$.

Or,

Vol of top $= 2.362 \times 1.575 \times 0.079\text{in}$
$= 0.294\text{in}^3$
Vol of short sides $= (1.575 \times 0.945 \times 0.079) \times 2$
$= 0.235\text{in}^3$

Vol of long sides $= (2.205 \times 0.945 \times 0.079) \times 2$
$= 0.329\text{in}^3$
Vol of tube section $= \pi \times (0.453 + 0.394) \times (0.453 - 394) \times 1.339$
$= 0.210\text{in}^3$
Vol of component $= 0.294 + 0.235 + 0.329 + 0.210$
$= 1.068\text{in}^3$.

### Volume of the feed system :

Vol of primary runner $= \pi R^2 L$
where R is the radius of runner and L is the runner branch length.
$= \pi \times 0.3 \times 0.3 \times 5.2$
$= 1.47\text{cm}^3$.

The number of primary runners is 3, therefore the volume for the primary runner $= 3 \times 1.47 = 4.41\text{cm}^3$.

Vol of secondary runner $= \pi R^2 L + 4/3 \pi R^3$

$$= \frac{\pi \times 0.3 \times 0.3 \times 3.1 + 4 \times \pi \times 0.3^3}{3}$$

$= 0.877 + 0.113$
$= 0.99\text{cm}^3$

The number of secondary runners is 3, therefore the volume for the secondary runner $= 3 \times 0.99 = 2.97\text{cm}^3$.

The total volume for the runner system is the volume of the primary plus the volume of the secondary $= 4.41 + 2.97$
$= 7.38\text{cm}^3$.

Or,

Vol of primary runner $= \pi R^2 L$
where R is the radius of runner and L is the runner branch length.
$= \pi \times 0.118 \times 0.118 \times 2.047$
$= 0.0895\text{in}^3$

The number of primary runners is 3, therefore the volume for the primary runner $= 3 \times 0.0895 = 0.269\text{in}^3$.

Vol of secondary runner $= \pi R^2 L + 4/3\, \pi R^3$

$$= \frac{\pi \times 0.118 \times 0.118 \times 1.2204 + 4 \times \pi \times 0.118^3}{3}$$

$= 0.0534 + 0.00688$
$= 0.0603\text{in}^3$

The number of secondary runners is 3, therefore the volume for the secondary runner $= 3 \times 0.0603 = 0.180\text{in}^3$.

The total volume for the runner system is the volume of the primary plus the volume of the secondary $= 0.269 + 0.180$
$= 0.449\text{in}^3$.

Note: Excluded from the above calculations is the volume of the sprue and gate. These are omitted as a hot sprue bushing is to be used for this mold: also the sizes of the gates used to produce the cover molding are relatively small (i.e. 0.5mm (0.020in) in length, 2mm (0.079in) deep and 4mm (0.157in) wide). If the volume of the gate is calculated then this equals 0.05 x 0.2 x 0.4 = .004cm$^3$, or 0.020 x 0.079 x 0.157 = 0.000248in$^3$: therefore due to its very small value it can be neglected. However, if large gates (e.g film, fan, ring or tab type) are used, then the volume of these must be included. If a conventional sprue is to be used then the formula to determine its volume is $\pi h/3\ (R^2 + R.r + r^2)$

Where R = the radius of sprue at runner junction,
r = the radius of sprue at nozzle entry,
and, h = the vertical height of the sprue.

### The total shot volume and weight.

The total shot volume equals the number of components x vol. of one component + the total volume of the feed system;

= 6 x 17.46 + 7.38
= 104.76 + 7.38
= 112.14cm$^3$

The total shot weight = the total shot volume of the molding times the density of the material (1.21g/cm$^3$). This equals,

= 112.14 x 1.21
= 135.7g.

Or,

= 6 x 1.068 + 0.449
= 4.998 + 0.449
= 6.857in$^3$

The total shot weight = the total shot volume of the molding times the density of the material (0.7008oz/cu.in). This equals,

= 6.857 x 0.7008
= 4.80oz.

## Calculate the Heat Content to be Removed Each Cycle.

Table 7 indicates the amount of heat energy that needs to be removed per gram for a range of thermoplastics materials. For this example the material is PC and the amount of heat energy needed to be removed per gramme is 369 Joules (158.78Btu/lb). The estimated cycle time for the cover molding is 20s and therefore the amount of heat that needs to be removed per cycle is as follows:

$$q = \frac{\text{the total shot weight (g) x heat energy to be removed (J/g)}}{\text{cycle time (s)}}$$

Where q = (135.69 x 369)/20

Therefore, q = 2503.5 J/s, or 2.504 kJ/s, or 2.504kW.

$$\text{Or, } q = \frac{\text{total shot weight (lb) x heat energy to be removed (Btu/lb)}}{\text{cycle time (s)}}$$

Where $$q = \frac{4.81 \times 158.78}{16 \times 20}$$

Therefore, q = 2.375 Btu/s or 8549.78 Btu/h or 2.505 kW.

## Calculate the Flow Rate of the Cooling Medium.

Use the formula Q = q/Cp ΔT.

Where Q = the flow rate of the cooling medium required;

q = the amount of heat which is to be removed each cycle (from the plastics material);

Cp = the specific heat of the cooling medium, for example, it is 4.186kJ/kg°C for water; and,

ΔT = the temperature difference between the inlet and outlet temperatures of the cooling fluid, for example, 4°C (7.2°F) is a commonly accepted value.

As the specified mold temperature for PC is 90°C (194°F) then the minimum quantity (i.e. flow rate) of water required to maintain a mold temperature of 90 +/- 2°C, or 194 +/- 3.6°F is:

Q = 2.504/4.186 x 4
= 0.149 liters/second.
= 540 liters/hour or 1141.6 US pints/hour.

## Select the Diameter of the Cooling Channel.

The recommended cooling channel diameters, and the distance from the cavity, can be found in Figure 10. A suggested diameter for the cooling channel (to be used for the mold to produce the polycarbonate covers) is 10mm (0.394in) and the spacing between each cooling channel is 20mm (0.787in).

## Calculate the Number of Cooling Channels.

The formula for calculating the total cooling channel length is:

$$L = \frac{2 \times s \times q}{K \times \pi \times D \times \Delta T.}$$

Where, s = the distance between each cooling channel in meters;

q = the calculated heat content needed to be removed from the plastics material in J/s;

K = the thermal conductivity value for the mold material, for example, where the type of steel used for the mold had a 5% Cr. content then K = 40W/m°C;

D = the diameter of the cooling channel in meters;

ΔT = the temperature difference from melt to mold for the plastics material.

Then $$L = \frac{2 \times 20 \times 10^{-3} \times 2.5 \times 10^{3}}{40 \times \pi \times 10 \times 10^{-3} \times (300-90)}$$

$$L = 0.379\text{m or } 1.24\text{ft.}$$

The total calculated length of the cooling channel is therefore 0.379m (1.24ft) and this length of cooling channel must be accommodated in a cooling system configuration designed to suit, for example, the type of ejection used to extract the component from the mold. If the cooling channels were designed to run lengthwise along the component therefore, as the longest length of the component is 60mm (0.06m or 2.36in or 0.196 ft)), the number of cooling channels needed in total is:

0.379/0.06 = 6.32

or, 1.24/0.196 = 6.32

Therefore the minimum number of cooling channels required for each half is 3.

## The Minimum Cooling Requirements for a Mold.

The above formulae enables the mold designer to calculate the minimum cooling circuitry requirements for any mold. Any additional cooling circuitry can only improve the cycle time. In the case of the mold to produce the polycarbonate cover moldings, the cooling circuitry should have a minimum of 3 cooling channels (preferably more) in each half. Any additional cooling incorporated, for example, in the center of the core pin which forms the cylinder section, will prevent any heat build-up taking place and allow the component to be ejected distortion-free.

---

## UNIT CONVERSION.

LENGTH.

| | | | | | |
|---|---|---|---|---|---|
| Knowing | GAUGE | multiply by | 0.254 | to get | MICRONS . |
| Knowing | THOU | multiply by | 25.4 | to get | MICRONS . |
| Knowing | INCHES | multiply by | 25.4 | to get | MILLIMETERS . |
| Knowing | FEET | multiply by | 0.305 | to get | METERS . |
| Knowing | YARDS | multiply by | 0.914 | to get | METERS . |
| Knowing | MICRONS | multiply by | 3.937 | to get | GAGE . |
| Knowing | MM | multiply by | 0.0394 | to get | INCHES . |
| Knowing | CM | multiply by | 0.3937 | to get | INCHES . |
| Knowing | METERS | multiply by | 1.094 | to get | YARDS . |
| Knowing | METERS | multiply by | 3.28 | to get | FEET . |

AREA.

| | | | | | |
|---|---|---|---|---|---|
| Knowing | SQUARE INCHES | multiply by | 645 | to get | SQUARE MM . |
| Knowing | SQUARE FEET | multiply by | 0.093 | to get | SQUARE METERS . |
| Knowing | SQUARE YARDS | multiply by | 0.8354 | to get | SQUARE METERS . |
| Knowing | SQUARE MM | multiply by | 0.0016 | to get | SQUARE INCHES . |

| | | | |
|---|---|---|---|
| Knowing | SQUARE METERS | multiply by 10.76 to get | SQUARE FEET . |

### VOLUME.

| | | | |
|---|---|---|---|
| Knowing | CUBIC INCHES | multiply by 16,387 to get | CUBIC MMs |
| Knowing | CUBIC INCHES | multiply by 16.39 to get | CUBIC CMs. |
| Knowing | CUBIC FEET | multiply by 0.0284 to get | CUBIC METERS . |
| Knowing | CUBIC CMs | multiply by 0.061 to get | CUBIC INCHES . |
| Knowing | CUBIC METERS | multiply by 35.3 to get | CUBIC FEET . |
| Knowing | US LIQUID PINTS | multiply by 0.833 to get | BRITISH IMP. PINTS . |
| Knowing | US LIQUID PINTS | multiply by 0.473 to get | LITERS . |
| Knowing | BRITISH IMP. PINTS . | multiply by 1.201 to get | US LIQUID PINTS |
| Knowing | LITERS | multiply by 2.114 to get | US LIQUID PINTS . |
| Knowing | LITERS | multiply by 61.024 to get | CUBIC INCHES . |

### WEIGHT.

| | | | |
|---|---|---|---|
| Knowing | OUNCES | multiply by 28.3 to get | GRAMS. |
| Knowing | GRAMS | multiply by 0.0353 to get | OUNCES. |
| Knowing | POUNDS | multiply by 0.452 to get | KILOGRAMS . |
| Knowing | TONS | multiply by 0.907 to get | METRIC TONNES . |
| Knowing | KILOGRAMS | multiply by 2.205 to get | POUNDS . |
| Knowing | METRIC TONNES | multiply by 1.103 to get | TONS . |

### PRESSURE AND STRESS.

| | | | |
|---|---|---|---|
| Knowing | PSI | multiply by 0.0069 to get | MPa . |
| Knowing | MPa | multiply by 145 to get | PSI . |
| Knowing | MPa | multiply by 10 to get | BAR . |
| Knowing | BAR | multiply by 1.013 to get | ATMOSPHERES . |
| Knowing | BAR | multiply by 14.50 to get | PSI . |

### SPEED.

| | | | |
|---|---|---|---|
| Knowing | FEET/MINUTE | multiply by 0.0051 to get | METERS/SECOND . |
| Knowing | FEET/MINUTE | multiply by 0.305 to get | METERS/MINUTE . |
| Knowing | METERS/SECOND | multiply by 197 to get | FEET/MINUTE . |
| Knowing | METERS/MINUTE | multiply by 3.28 to get | FEET/MINUTE . |

### DENSITY.

Knowing POUNDS/CUBIC FOOT multiply by 16 to get KILOGRAM/CUBIC METER

Knowing KILOGRAMS/CUBIC METER multiply by 0.06243 to get POUNDS/CUBIC FOOT.

Knowing GRAMS/CUBIC CENTIMETER multiply by 0.58 to get OUNCES/CUBIC INCH.

Knowing OUNCES/CUBIC INCH multiply by 1.73 to get GRAMS/CUBIC CENTIMETER.

Knowing SPECIFIC GRAVITY multiply by 62.4 to get POUNDS/CUBIC FOOT.

| | | | |
|---|---|---|---|
| Knowing | SPECIFIC GRAVITY | multiply by 16.39 to get | GRAMS/CUBIC INCH. |
| Knowing | SPECIFIC GRAVITY | multiply by 0.58 to get | OUNCES/CUBIC INCH. |
| Knowing | SPECIFIC GRAVITY | multiply by 0.036 to get | POUNDS/CUBIC INCH. |

### ENERGY, QUANTITY OF HEAT AND WORK.

| | | | |
|---|---|---|---|
| Knowing | FOOT POUNDS | multiply by 1.356 to get | JOULES . |
| Knowing | BTUS | multiply by 1.056 to get | KILOJOULES . |
| Knowing | BTUS | multiply by 778.2 to get | FOOT POUNDS . |
| Knowing | JOULES | multiply by 0.738 to get | FOOT POUNDS . |
| Knowing | KILOJOULES | multiply by 0.9478 to get | BTUS . |
| Knowing | KILOJOULES | multiply by 1000 to get | JOULES . |
| Knowing | CALORIES | multiply by 4.184 to get | JOULES . |

### POWER.

| | | | |
|---|---|---|---|
| Knowing | FOOT POUNDS/S | multiply by 1.356 to get | WATTS . |
| Knowing | HORSEPOWER | multiply by 745.7 to get | WATTS . |
| Knowing | HORSEPOWER | multiply by 550 to get | FOOT POUNDS/S. |
| Knowing | KILOWATTS | multiply by 737.6 to get | FOOT POUNDS/S. |
| Knowing | KILOWATTS | multiply by 1.341 to get | HORSEPOWER |

# TEMPERATURE CONVERSION TABLE.

| Centigrade | Starting Value | Fahrenheit |
|---|---|---|
| -18 | **0** | 32 |
| -12 | **10** | 50 |
| -7 | **20** | 68 |
| -1 | **30** | 86 |
| 4 | **40** | 104 |
| 10 | **50** | 122 |
| 16 | **60** | 140 |
| 21 | **70** | 158 |
| 27 | **80** | 176 |
| 32 | **90** | 194 |
| 38 | **100** | 212 |
| 43 | **110** | 230 |
| 49 | **120** | 248 |
| 54 | **130** | 266 |
| 60 | **140** | 284 |
| 66 | **150** | 302 |
| 71 | **160** | 320 |
| 77 | **170** | 338 |
| 82 | **180** | 356 |
| 88 | **190** | 374 |
| 93 | **200** | 392 |
| 99 | **210** | 410 |
| 104 | **220** | 428 |
| 110 | **230** | 446 |
| 116 | **240** | 464 |
| 121 | **250** | 482 |
| 127 | **260** | 500 |
| 132 | **270** | 518 |
| 138 | **280** | 536 |
| 143 | **290** | 554 |
| 149 | **300** | 572 |
| 154 | **310** | 590 |
| 160 | **320** | 608 |
| 166 | **330** | 626 |
| 171 | **340** | 644 |
| 177 | **350** | 662 |
| 182 | **360** | 680 |
| 188 | **370** | 698 |
| 193 | **380** | 716 |
| 199 | **390** | 734 |

| Centigrade | Starting Value | Fahrenheit |
|---|---|---|
| 204 | **400** | 752 |
| 210 | **410** | 770 |
| 216 | **420** | 788 |
| 221 | **430** | 806 |
| 227 | **440** | 824 |
| 232 | **450** | 842 |
| 238 | **460** | 860 |
| 243 | **470** | 878 |
| 249 | **480** | 896 |
| 254 | **490** | 914 |
| 260 | **500** | 932 |
| 266 | **510** | 950 |
| 271 | **520** | 968 |
| 277 | **530** | 986 |
| 282 | **540** | 1004 |
| 288 | **550** | 1022 |
| 293 | **560** | 1040 |
| 299 | **570** | 1058 |
| 304 | **580** | 1076 |
| 310 | **590** | 1094 |
| 316 | **600** | 1112 |
| 321 | **610** | 1130 |
| 327 | **620** | 1148 |
| 332 | **630** | 1166 |
| 338 | **640** | 1184 |
| 343 | **650** | 1202 |
| 349 | **660** | 1220 |
| 354 | **670** | 1238 |
| 360 | **680** | 1256 |
| 366 | **690** | 1274 |
| 371 | **700** | 1292 |
| 377 | **710** | 1310 |
| 382 | **720** | 1328 |
| 388 | **730** | 1346 |
| 393 | **740** | 1364 |
| 399 | **750** | 1382 |
| 404 | **760** | 1400 |
| 410 | **770** | 1418 |
| 416 | **780** | 1436 |
| 421 | **790** | 1454 |

# LIST OF BOOKS

The following books are recommended for additional reading so as to broaden the knowledge and understanding of injection molding technology.

| **Author** | **Title** | **Publisher** |
|---|---|---|
| BRAUN, D. | Simple methods for the identification of plastics | Hanser Publishers |
| BRYDSON, J. | Plastics Materials | Newnes Butterworths |
| BRYDSON, J. | Flow Properties of Polymer Melts | George Godwin |
| BERNHARDT, E.C. (ed) | Processing of Thermoplastics Materials | Chapman & Hall |
| DUBOIS, J.H. &<br>DRIBBLE, W.T. | Plastics Mold Engineering Handbook | Van Nostrand Reinhold Co. |
| GASTROW, H. | Injection Moulds | Hanser Publishers |
| MENGES, G. | Mold Making and Design | Hanser Publishers |
| PYE, R. | Injection Mould Design for Thermoplastics (3rd edition) | George Godwin (Longman Group) |
| ROFF, W.J. &<br>SCOTT, J.R. | Fibres, Films, Plastics and Rubbers | Newnes Butterworths |
| ROSATO, D.V. &<br>ROSATO, D.V. | Injection Molding Handbook | Van Nostrand Reinhold Co. |
| SEYMOUR, R.B. | Modern Plastics Technology | Reston Pub. Co. Inc. |
| TURNER, S. | Mechanical Testing of Plastics | George Godwin |
| WHELAN, A. | Injection Moulding Materials | Elsevier Applied Science |
| WHELAN, A. | Injection Moulding Machines | Elsevier Applied Science |
| WHELAN, A. &<br>CRAFT, J.L. | Developments in Injection Moulding - 1 | Elsevier Applied Science |
| WHELAN, A. &<br>CRAFT, J.L. | Developments in Injection Moulding - 2 | Elsevier Applied Science |
| WHELAN, A. &<br>GOFF, J.P. | Developments in Injection Moulding - 3 | Elsevier Applied Science |

| | | |
|---|---|---|
| WHELAN, A. & GOFF, J.P. | Injection Molding of Engineering Thermoplastics | Van Nostrand Reinhold Co. |
| WHELAN, A. & GOFF, J.P. | Injection Molding of Thermoplastics Materials - 1 | Van Nostrand Reinhold Co. |
| WHELAN, A. & GOFF, J.P. | Injection Molding of Thermoplastics Materials - 2 | Van Nostrand Reinhold Co. |
| WHELAN, A. & GOFF, J.P. | Molding of Thermosetting Plastics | Van Nostrand Reinhold Co. |

# Table 1. SOME NAMES AND ABBREVIATIONS OF PLASTICS AND ELASTOMERS.

| **Common name.** | **Abbreviation.** |
|---|---|
| Acetal | POM |
| Acetal copolymer | POM-K or POM-CO |
| Acetal homopolymer | POM-H |
| Acrylate styrene acrylonitrile. | ASA or AAS |
| Acrylate modified styrene acrylonitrile. | ASA or AAS |
| Acrylic acid ester rubber or, acrylate rubber acrylic rubber. | ACM |
| Acrylic ester acrylonitrile copolymer rubbers. | ANM |
| Acrylic ester butadiene rubber. | ABR |
| Acrylic rubber. | ACM |
| Acrylonitrile butadiene rubber or nitrile butadiene rubber or, butadiene acrylonitrile rubber.. | NBR |
| Acrylonitrile butadiene styrene. | ABS |
| Acrylonitrile styrene/chlorinated polyethylene. | ACS |
| Acrylonitrile methyl methacrylate. | AMMA |
| Acrylonitrile styrene/EPR rubber or, acrylonitrile ethylene propylene styrene. | AES |
| Alkylene sulphide rubber | ASR |
| Alpha methyl styrene. | AMS |
| Atactic polypropylene. | APP or PP-A |
| Bromobutyl rubber or, halogenated isobutene-isoprene rubber. | BIIR |
| Butadiene acrylonitrile rubber.. | NBR |
| Butadiene rubber or, cis-1,4-polybutadiene rubber or, polybutadiene rubber | BR |
| Butadiene rubber based on a cobalt catalyst. | Co-BR |
| Butadiene rubber based on a lithium catalyst | Li-BR |
| Butadiene rubber based on a neodynium catalyst | Nd-BR |
| Butadiene rubber based on a nickel catalyst | Ni-BR |
| Butadiene styrene block copolymer | BDS |
| Butyl rubber | IIR |
| Bulk molding compound. | BMC |
| Casein formaldehyde. | CF |
| Cellulose acetate . | CA |
| Cellulose acetate butyrate . | CAB |
| Cellulose acetate propionate. | CAP |
| Cellulose nitrate. | CN |
| Chlorinated polyethylene | CPE or CM |
| Chlorinated polyvinyl chloride | CPVC or PVC-C |
| Chlorobutyl rubber or, | |

| | |
|---|---|
| halogenated isobutene-isoprene rubber. | CIIR |
| Chloro-polyethylene or, chlorinated polyethylene. | CM or CPE or PE-C |
| Chloroprene acrylonitrile copolymer or rubber. | NCR |
| Chloroprene rubber or, polychloroprene rubber | CR |
| Chloroprene rubber with reactive groups | X-CR |
| Chlorosulphonated polyethylene | CSM |
| Chlorotrifluoroethylene ethylene copolymers. | ECTFE |
| Cis-polyisoprene or, cis-1,4-polyisoprene | IR |
| Coumarone indene resins. | CIR |
| Deproteinated natural rubber. | DP-NR |
| Diallyl phthalate. | DAP |
| Diallyl isophthalate. | DAIP |
| Dough molding compound. | DMC |
| Elastomeric alloy melt processable rubber | EA-MPR |
| Elastomeric alloy thermoplastic vulcanizate | EA-TPV |
| Emulsion butadiene rubber. | E-BR |
| Emulsion styrene butadiene rubber. | E-SBR |
| Emulsion synthetic rubber. | E-SR |
| Epichlohydrin ethylene oxide allylglycidyl copolymer or rubber | ETER |
| Epichlohydrin ethylene oxide copolymer or, epichlohydrin ethylene oxide rubber | ECO |
| Epichlohydrin homopolymer rubber. | CO |
| Epichlohydrin rubber | CHR or CO or ECO or ETER |
| Epoxidized natural rubber. | ENR |
| Epoxy or, epoxide | EP |
| Epoxy or, epoxide, with glass fiber | EP GF |
| Ethyl cellulose | EC |
| Ethylene acrylate rubber or, ethylene acrylate copolymer. | EAM |
| Ethylene acrylic acid. | EAA |
| Ethylene propylene diene monomer or, ethylene propylene diene terpolymer. | EPDM or EP(D)M |
| Ethylene propylene monomer (an EPR copolymer). | EPM |
| Ethylene propylene rubber | EPR or EPDM or EP(D)M |
| Ethylene tetrafluoroethylene copolymer). | ETFE |
| Ethylene vinyl acetate. | EVA |
| Ethylene vinylacetate rubber or, ethylene vinylacetate copolymer. | EVM |
| Ethylene vinyl alcohol. | EVOH or EVAL |

| | |
|---|---|
| Ethylidene norbornene (rubber). | ENB |
| Expanded polystyrene | EPS or PS-E or XPS or PS-X |
| Fibre reinforced epoxy or epoxide. | FREP or EP-FR |
| Fibre reinforced plastic. | FRP |
| Fluorinated ethylene propylene copolymer. | FEP or TFE-HFP |
| Fluorinated rubber or, fluoro rubber. | FPM or FKM |
| Fluorosilicone rubber or, fluoro silicone rubber. | FVQ or FMQ |
| Glass mat reinforced plastic. | GMT |
| Granular polyester molding compound | GPMC |
| Halogenated isobutene-isoprene rubber or, halogenated isobutylene-isoprene rubber. | BIIR or CIIR or XIIR |
| High density polyethylene | HDPE or PE-HD |
| High impact polystyrene. | HIPS or TPS or IPS |
| Highly substituted nitrile rubber | HSN |
| Hydrogenated nitrile rubber | H-NBR or ENM or HSN |
| Isobutene-isoprene rubber or, isobutylene-isoprene rubber. | IIR |
| Isoprene acrylonitrile copolymer or rubber. | NIR |
| Isoprene rubber. | IR |
| Linear low density polyethylene. | LLDPE or PE-LLD |
| Liquid crystal polymer. | LCP |
| Liquid silicone rubber | LSR |
| Low density polyethylene. | LDPE or PE-LD |
| Low nitrogen natural rubber | LN-NR |
| Medium density polyethylene. | MDPE or PE-MD |
| Melamine formaldehyde. | MF |
| Melamine phenol formaldehyde. | MPF |
| Melt processable rubber. | MPR or EA-MPR |
| Methyl methacrylate, styrene/polybutadiene. | MBS |
| Methyl silicone rubber | MQ |
| Natural rubber | NR |
| Nitrile butadiene rubber or, acrylonitrile butadiene rubber. | NBR |
| Nitrile rubber PVC blends | NBR/PVC |
| Nitrile butadiene rubber with reactive groups. | X-NBR |

| | |
|---|---|
| Nitroso rubber | AFMU |
| Oil extended butadiene rubber | OE-BR |
| Olefin thermoplastic elastomer. | TPO |
| Oriented polyethylene terephthalate | OPET |
| Oriented polypropylene | OPP |
| Oriented polystyrene | OPS |
| Oriented polyvinyl chloride | OPVC |
| Perfluoroalkoxy copolymers. | PFA |
| Phenol formaldehyde. | PF |
| Phenylene ether copolymer. | PEC |
| Plasticized polyvinyl chloride. | PPVC or<br>PVC-P |
| Polyacrylonitrile. | PAN |
| Polyamide. | PA |
| Polyamide 6 or nylon 6. | PA 6 |
| Polyamide 11 or nylon 11. | PA11 |
| Polyamide 12 or nylon 12. | PA12 |
| Polyamide 66 or nylon 66. | PA66 |
| Polyamide 610 or nylon 610. | PA610 |
| Polyamide-imides. | PAI |
| Polyaryl amide. | PAA 6 or<br>PAMXD6 |
| Polybenzimidazole | PBI |
| Polybutadiene rubber | BR |
| Polybutylene. | PB |
| Polybutylene terephthalate. | PBT |
| Polycarbonate. | PC |
| Polychloroprene rubber or,<br>chloroprene rubber | CR |
| Polychlorotrifluorethylene. | PCTFE |
| Polychlorotrifluorethylene rubber. | CFM |
| Polyether block amide or,<br>thermoplastic copolyether | PEBA<br>or TPE-A |
| Polyether ether ketone. | PEEK |
| Polyether ester elastomer | PEEL or<br>COPE or<br>YPBO or<br>TEEE |
| Polyether imide | PEI |
| Polyether ketone. | PEK |
| Polyether ketone ketone. | PEKK |
| Polyether sulfone or polysulfone. | PES or PSU |
| Polyethylene. | PE |
| Polyethylene-high density. | HDPE or<br>PE-HD |
| Polyethylene-linear low density. | LLDPE or<br>PE-LLD |
| Polyethylene-low density. | LDPE or<br>PE-LD |

| | |
|---|---|
| Polyethylene-medium density. | MDPE or PE-MD |
| Polyethylene-very low density. | VLDPE or PE-VLD |
| Polyethylene terephthalate. | PET |
| Polyethylene terephthalate glycol. | PETG |
| Polyfluorphosphazene rubber | PNF |
| Polyimides. | PI |
| Polymethyl methacrylate (acrylic). | PMMA |
| Polynorbornene (rubber) | PNR |
| Polyoctenamer rubber | TOR |
| Polyoxymethylene or, acetal or, polyformaldehyde. | POM |
| Polyphenylene ether. | PPE |
| Polyphenylene oxide (modified). | PPO or PPO-M or PPE |
| Polyphenylene sulfide. | PPS |
| Polyphenylene sulfide sulfone. | PPPS |
| Polyphenylene sulfone. | PPSU |
| Polypropylene. | PP or PPR |
| Polypropylene copolymer. | PP-K or PP-CO |
| Polypropylene homopolymer. | PP-H |
| Polypropylene oxide. | PPOX |
| Polysiloxane rubber (acronyms contain Q). | Q |
| Polystyrene | PS or GPPS |
| Polysulphide rubber | T or TM |
| Polytetrafluorethylene. | PTFE |
| Polyurethane | PUR |
| Polyurethane rubber | AU or EU |
| Polyvinyl acetate. | PVA or PVAC |
| Polyvinyl alcohol. | PVAL |
| Polyvinyl carbazole. | PVCZ |
| Polyvinyl chloride. | PVC |
| Polyvinyl chloride acetate copolymer. | PVCA |
| Polyvinyl pyrolidone. | PVP |
| Polyvinylidene chloride copolymers. | PVDC |
| Polyvinylidene fluoride. | PVDF |
| Polyvinyl fluoride. | PVF |
| Propylene oxide rubber | PO or GPO |
| Propylene oxide-allylglycidyl ether rubber | GPO |
| Rubber modified polypropylene. | RRPP or RMPP or PP/EPDM. |
| Rubber reinforced polypropylene. | RRPP or RMPP or PP/EPDM. |

| | |
|---|---|
| Rubber reinforced polypropylene - with crosslinked rubber. | TPO-XL(an EA-TPV or TPV). |
| Sheet molding compound. | SMC |
| Silicone plastics. | SI |
| Silicone rubber (acronyms contain Q). | Q |
| Silicone rubber containing fluoro groups. | FVQ |
| Silicone rubber containing methyl groups | MQ |
| Silicone rubber containing vinyl groups. | VMQ |
| Solution butadiene rubber | L-BR |
| Solution styrene butadiene rubber | L-SBR |
| Standardized natural rubber from China. | CNR |
| Styrene acrylonitrile copolymer | SAN |
| Styrene-butadiene rubber | SBR or, GRS |
| Styrene butadiene styrene block copolymer. | SBS or TPE-S |
| Styrene ethylene-butylene styrene block copolymer or styrene olefin thermoplastic elastomer | SEBS or TPE-S |
| Styrene isoprene styrene block copolymer. | SIS or TPE-S |
| Styrene acrylonitrile copolymer. | SAN |
| Styrene butadiene block copolymer. | BDS or SBB |
| Styrene butadiene styrene block copolymer - a thermoplastic elastomer (TPE-S). | SBS |
| Styrene butadiene styrene block copolymer - a saturated thermoplastic elastomer. | SEBS |
| Styrene maleic anhydride | SMA |
| Synthetic polyisoprene. | IR |
| Technically classified natural rubber | TSR |
| Tetrafluorethylene-ethylene copolymers. | ETFE |
| Thermoplastic olefin elastomer | TPE-O or EPDM/PP |
| Thick molding compound. | TMC |
| Thermoplastic copolyether or, polyether block amide | TPE-A or PEBA |
| Thermoplastic elastomer (or rubber). | TPE or TPR |
| Thermoplastic elastomer - amide based. | TPE-A |
| Thermoplastic elastomer - olefin based. | TPE-O |
| Thermoplastic elastomer - styrene based. | TPE-S |
| Thermoplastic elastomer - urethane based. | TPE-U |
| Thermoplastic ether ester (COPE or PEEL) thermoplastic copolyester | TP-EE or TPE-E or Y-BPO |
| Thermoplastic ethylene propylene rubber - a TPE | TPE-EPDM or TP-EPDM |

| | |
|---|---|
| Thermoplastic ethylene vinyl acetate elastomer - a TPE | TPE-EVA or<br>TP-EVA |
| Thermoplastic fluoro elastomers | TEP-FKM |
| Thermoplastic isoprene rubber | Y-IR |
| Thermoplastic natural rubber - a TPE. | TPE-NR or<br>TP-NR |
| Thermoplastic nitrile butadiene rubber or, thermoplastic nitrile butadiene elastomer. | TPE-NBR or<br>TP-NBR or<br>Y-NBR |
| Thermoplastic polyolefin. | TPO or<br>TPE-O |
| Thermoplastic polyolefin- with crosslinked rubber | TPE-OXL or<br>TPO-XL |
| Thermoplastic polyurethane. | TPU or<br>TPE-U |
| Thermoplastic rubber (or elastomer). | TPR or TPE |
| Thermoplastic styrene butadiene rubber | Y-SBR or<br>TPE-SBR |
| Thermoplastic vulcanizate (a TPE). | TPV or<br>EA-TPV |
| Ultra low density polyethylene. | ULDPE or<br>VLDPE or<br>PE-VLD |
| Unplasticized polyvinyl chloride. | UPVC or<br>PVC-U |
| Unsaturated polyester. | UP |
| Unsaturated polyester, with glass fiber. | UP-GF (PMC,<br>DMC or SMC) |
| Urea formaldehyde. | UF |
| Urethane rubber based on polyesters | AU |
| isocyanate crosslinkable | AU-I |
| peroxide crosslinkable | AU-P |
| Urethane rubber based on polyethers | EU |
| Very low density polyethylene. | VLDPE or<br>ULDPE<br>PE-VLD |
| Vinyl chloride ethylene. | VCE |
| Vinyl chloride ethylene vinyl acetate | VCEVA |
| Vinyl chloride vinyl acetate | VCVA |
| Vinyl ester resins | VE |
| Vinyl pyridine copolymer or rubber | VP |
| Vinylidene chloride, acrylonitrile copolymers | VCA |

## Table 2A. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| | SETTING CONDITIONS | UNITS | ASA | ABS | BDS |
|---|---|---|---|---|---|
| 1 | Temperatures. | °F. | | | |
| | Barrel rear. | | 410 to 446 | 356 to 464 | 374 to 410 |
| | Barrel middle. | | 446 to 482 | 356 to 446 | 374 to 419 |
| | Barrel front. | | 464 to 536 | 410 to 536 | 410 to 464 |
| | Nozzle. | | 464 to 536 | 410 to 500 | 419 to 464 |
| 2 | Melt temperature. | °F. | | | |
| | Range. | | 491 to 509 | 428 to 500 | 374 to 446 |
| | Recommended. | | 500 | 482 | 428 |
| 3 | Mold temperature. | °F. | | | |
| | Range. | | 104 to 176 | 140 to 194 | 50 to 140 |
| | Recommended. | | 140 | 140 | 95 |
| 4 | Heat content. | | | | |
| | Heat removal. | Btu/lb. | 173 | 159 | 157 |
| | Specific heat | Btu/lb°F. | 535 | 546 | 523 |
| 5 | Material drying. | | | | |
| | Temperature. | °F. | 176 to 185 | 176 to 185 | 140 |
| | Time. | h. | 2 to 4 | 2 to 4 | 1 |
| 6 | Pressures (max). | psi. | | | |
| | Injection. | | 21,750 | 21,750 | 21,750 |
| | Hold. | | 10,850 | 10,850 | 10,850 |
| | Back. | | 2,175 | 2,175 | 2,175 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Slow to fast | Fast |
| | Screw rotational. | ft/s. | 1.97 to 2.13 | 1.80 to 2.13 | 2.30 to 2.46 |
| 8 | Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 | Clamping pressure. | ton/in². | 2.5 to 4 | 2.5 to 4 | 2.5 to 4 |
| 1 | Temperatures. | °C. | | | |
| | Barrel rear. | | 210 to 230 | 180 to 230 | 190 to 210 |
| | Barrel middle. | | 230 to 250 | 180 to 240 | 190 to 215 |
| | Barrel front. | | 240 to 280 | 210 to 260 | 210 to 240 |
| | Nozzle. | | 240 to 280 | 210 to 260 | 215 to 240 |
| 2 | Melt temperature. | °C. | | | |
| | Range. | | 250 to 265 | 220 to 260 | 190 to 230 |
| | Recommended. | | 260 | 250 | 220 |
| 3 | Mold temperature. | °C. | | | |
| | Range. | | 40 to 80 | 60 to 90 | 10 to 60 |
| | Recommended. | | 60 | 60 | 35 |
| 4 | Heat content. | | | | |
| | Heat removal. | J/g. | 402 | 369 | 364 |
| | Specific heat | J/kg K. | 2010 | 2050 | 1968 |
| 5 | Material drying. | | | | |
| | Temperature. | °C. | 80 to 85 | 80 to 85 | 60 |
| | Time. | h. | 2 to 4 | 2 to 4 | 1 |
| 6 | Pressures (max). | MN/m². | | | |
| | Injection. | | 150 | 150 | 150 |
| | Hold. | | 75 | 75 | 75 |
| | Back. | | 15 | 15 | 15 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Slow to fast | Fast |
| | Screw rotational. | m/s. | 0.6 to 0.65 | 0.55 to 0.65 | 0.7 to 0.75 |
| 8 | Screw cushion. | mm. | 3 | 3 | 3 |
| 9 | Clamping pressure. | MN/m². | 39 to 62 | 47 to 62 | 31 to 62 |

# Table 2B. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITIONS | UNITS | CA/CAB/ CAP | FEP | HIPS/TPS |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 284 to 320 | 599 to 626 | 320 to 374 |
| Barrel middle. | | 311 to 347 | 626 to 662 | 356 to 446 |
| Barrel front. | | 365 to 401 | 653 to 698 | 410 to 536 |
| Nozzle. | | 180 to 200 | 345 to 370 | 210 to 280 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 320 to 446 | 572 to 716 | 392 to 518 |
| Recommended. | | 410 | 662 | 464 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 104 to 176 | 392 to 464 | 50 to 176 |
| Recommended. | | 122 | 392 | 68 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 117 | 103 | 186 |
| Specific Heat | Btu/lb°F. | 452 | 426 | 524 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 131 to 185 | 302 | 149 to 158 |
| Time. | h. | 3 to 4 | 2 to 4 | 3 to 4 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 21,750 |
| Hold. | | 10,875 | 10,875 | 10,875 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Slow to fast | Slow | Fast |
| Screw rotational. | ft/s. | 1.48 to 1.64 | 0.67 to 0.82 | 2.29 to 2.62 |
| 8 Screw cushion. | in. | 0.118 | not req'd | 0.118 |
| Clamping pressure. | tons/in$^2$. | 1 to 2 | 5 | 1 to 2 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 140 to 160 | 315 to 330 | 160 to 190 |
| Barrel middle. | | 155 to 175 | 330 to 350 | 180 to 230 |
| Barrel front. | | 185 to 205 | 345 to 370 | 210 to 280 |
| Nozzle. | | 180 to 200 | 345 to 370 | 210 to 280 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 160 to 230 | 300 to 380 | 200 to 270 |
| Recommended. | | 210 | 350 | 240 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 40 to 80 | 200 to 240 | 10 to 80 |
| Recommended. | | 50 | 200 | 20 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 272 | 240 | 433 |
| Specific Heat | J/kg K. | 1700 | 1600 | 1970 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 55 to 85 | 150 | 65 to 70 |
| Time. | h. | 3 to 4 | 2 to 4 | 3 to 4 |
| 6 Pressures (max). | MN/m$^2$. | | | |
| Injection. | | 150 | 150 | 150 |
| Hold. | | 75 | 75 | 75 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Slow to fast | Slow | Fast |
| Screw rotational. | m/s. | 0.45 to 0.5 | 0.2 to 0.25 | 0.7 to 0.8 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m$^2$. | 15 to 31 | 77 | 15 to 31 |

# Table 2C. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION | UNITS | PA6 | PA66 | PA11/PA12 |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 428 to 464 | 527 to 536 | 410 to 464 |
| Barrel middle. | | 446 to 500 | 518 to 545 | 446 to 500 |
| Barrel front. | | 446 to 518 | 509 to 545 | 464 to 518 |
| Nozzle. | | 428 to 500 | 500 to 536 | 464 to 518 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 446 to 536 | 500 to 554 | 464 to 572 |
| Recommended. | | 482 | 536 | 500 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 140 to 194 | 68 to 212 | 86 to 212 |
| Recommended. | | 176 | 176 | 140 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 224 | 265 | 210 |
| Specific Heat | Btu/lb°F. | 814 | 818 | 649 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 176 to 221 | 187 to 221 | 185 |
| Time. | h. | 12 to 16 | 5 to 12 | 3 to 5 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 14,500 |
| Hold. | | 10,875 | 21,750 | 7,250 |
| Back. | | 2,175 | 1,450 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Fast | Med to fast |
| Screw rotational. | ft/s. | 1.31 to 1.64 | 0.98 to 1.31 | 0.98 to 1.64 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/in². | 4 to 5 | 4 to 5 | 1 to 1.5 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 220 to 240 | 275 to 280 | 210 to 240 |
| Barrel middle. | | 230 to 260 | 270 to 285 | 230 to 260 |
| Barrel front. | | 230 to 270 | 265 to 285 | 240 to 270 |
| Nozzle. | | 230 to 280 | 260 to 280 | 240 to 300 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 230 to 280 | 260 to 290 | 240 to 300 |
| Recommended. | | 250 | 280 | 260 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 60 to 90 | 20 to 100 | 30 to 100 |
| Recommended. | | 80 | 80 | 60 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 520 | 615 | 488 |
| Specific Heat | J/kg K. | 3060 | 3075 | 2440 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 80 to 105 | 85 to 105 | 85 |
| Time. | h. | 12 to 16 | 5 to 12 | 3 to 5 |
| 6 Pressures (max). | MN/m². | | | |
| Injection. | | 150 | 150 | 100 |
| Hold. | | 75 | 150 | 50 |
| Back. | | 15 | 10 | 20 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Fast | Med to fast |
| Screw rotational. | m/s. | 0.45 to 0.5 | 0.3 to 0.4 | 0.3 to 0.5 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m². | 62 to 77 | 62 to 77 | 15 to 23 |

# Table 2D. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION | UNITS | PBT | PC | PEBA |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 419 to 446 | 527 to 572 | 338 to 482* |
| Barrel middle. | | 437 to 482 | 545 to 599 | 392 to 518* |
| Barrel front. | | 401 to 446 | 545 to 599 | 428 to 554* |
| Nozzle. | | 383 to 419 | 536 to 590 | 428 to 554* |
| 2 Melt temperature. | °F. | | | |
| Range. | | 428 to 500 | 428 to 608 | 364 to 428 (S) |
| Recommended. | | 464 to 473 | 572 | 419 to 464 (H) |
| 3 Mold temperature. | °F. | | | |
| Range. | | 68 to 230 | 176 to 248 | 68 to 104 |
| Recommended. | | 140 | 194 | 86 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 122 | 158 | 224 |
| Specific Heat | Btu/lb°F. | 418 | 466 | 638 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 248 to 302 | 248 | 158 to 176 |
| Time. | h. | 2.5 to 5.5 | 2 to 4 | 2 to 6 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 18,850 | 26,100 | 14,500 |
| Hold. | | 10,440 | 17,400 | 10,875 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Med to fast | Med to fast |
| Screw rotational. | ft/s. | 0.98 to 1.15 | 0.98 to 1.64 | 1.64 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/in$^2$. | 3 to 4.5 | 3 to 5 | 1 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 215 to 230 | 275 to 300 | 170 to 250* |
| Barrel middle. | | 225 to 250 | 285 to 315 | 200 to 270* |
| Barrel front. | | 205 to 230 | 285 to 315 | 220 to 290* |
| Nozzle. | | 195 to 215 | 280 to 310 | 220 to 290* |
| 2 Melt temperature. | °C. | | | |
| Range. | | 220 to 260 | 280 to 320 | 185 to 220 (S) |
| Recommended. | | 240 to 245 | 300 | 215 to 240 (H) |
| 3 Mold temperature. | °C. | | | |
| Range. | | 20 to 110 | 80 to 120 | 20 to 40 |
| Recommended. | | 60 | 90 | 30 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 283 | 368 | 520 |
| Specific Heat | J/kgK. | 1570 | 1750 | 2400 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 120 to 150 | 120 | 70 to 80 |
| Time. | h. | 2.5 to 5.5 | 2 to 4 | 2 to 6 |
| 6 Pressures (max). | MN/m$^2$. | | | |
| Injection. | | 130 | 200 | 100 |
| Hold. | | 72 | 120 | 75 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Med to fast | Med to fast |
| Screw rotational. | m/s. | 0.3 to 0.35 | 0.3 to 0.5 | 0.5 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m$^2$. | 47 to 68 | 47 to 77 | 15 |

* - low values for softer grades (H) - hard grade (S) - soft grade.

# Table 2E. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| | SETTING CONDITION | UNITS | PEEL | PEEK | PE-HD |
|---|---|---|---|---|---|
| 1 | Temperatures. | °F. | | | |
| | Barrel rear. | | 356 to 428 | 644 to 662 | 320 to 392 |
| | Barrel middle. | | 392 to 473 | 680 to 698 | 338 to 446 |
| | Barrel front. | | 410 to 500 | 698 to 716 | 428 to 536 |
| | Nozzle. | | 392 to 464 | 698 to 716 | 410 to 518 |
| 2 | Melt temperature. | °F. | | | |
| | Range. | | 383 to 491 | 680 to 716 | 401 to 536 |
| | Recommended. | | 428 to 437 | 698 | 428 to 500 |
| 3 | Mold temperature. | °F. | | | |
| | Range. | | 50 to 158 | 320 to 338 | 50 to 140 |
| | Recommended. | | 122 | 329 | 68 |
| 4 | Heat content. | | | | |
| | Heat removal. | Btu/lb. | 132 | 118 | 344 |
| | Specific Heat | Btu/lb°F. | 479 | 356 | 968 |
| 5 | Material drying. | | | | |
| | Temperature. | °F. | 194 to 248 | 302 | 149 |
| | Time. | h. | 10 | 3 | 3 |
| 6 | Pressures (max). | psi. | | | |
| | Injection. | | 21,750 | 21,750 | 21,750 |
| | Hold. | | 10,875 | 14,500 | 10,875 |
| | Back. | | 2,175 | 2,175 | 2,175 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Fast | Fast |
| | Screw rotational. | ft/s. | 1.31 | 1.64 | 2.46 to 2.62 |
| 8 | Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 | Clamping pressure. | tons/in$^2$. | 3 | 1 to 2 | 1.5 to 2.5 |
| 1 | Temperatures. | °C. | | | |
| | Barrel rear. | | 180 to 220 | 340 to 350 | 160 to 200 |
| | Barrel middle. | | 200 to 245 | 360 to 370 | 170 to 230 |
| | Barrel front. | | 210 to 260 | 370 to 380 | 220 to 280 |
| | Nozzle. | | 200 to 240 | 370 to 380 | 210 to 270 |
| 2 | Melt temperature. | °C. | | | |
| | Range. | | 195 to 255 | 360 to 380 | 205 to 280 |
| | Recommended. | | 220 to 255 | 370 | 220 to 260 |
| 3 | Mold temperature. | °C. | | | |
| | Range. | | 10 to 70 | 160 to 170 | 10 to 60 |
| | Recommended. | | 50 | 165 | 20 |
| 4 | Heat content. | | | | |
| | Heat removal. | J/g. | 306 | 275 | 800 |
| | Specific Heat | J/kg K. | 1800 | 1340 | 3640 |
| 5 | Material drying. | | | | |
| | Temperature. | °C. | 90 to 120 | 150 | 65 |
| | Time. | h. | 10 | 3 | 3 |
| 6 | Pressures (max). | MN/m$^2$. | | | |
| | Injection. | | 150 | 150 | 150 |
| | Hold. | | 75 | 100 | 75 |
| | Back. | | 15 | 15 | 15 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Fast | Fast |
| | Screw rotational. | m/s. | 0.4 | 0.5 | 0.75 to 0.8 |
| 8 | Screw cushion. | mm. | 3 | 3 | 3 |
| 9 | Clamping pressure. | MN/m$^2$. | 47 | 15 to 31 | 23 to 39 |

# Table 2F. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION | UNITS | PE-LD | PE-LLD | PES |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 248 to 392 | 266 to 392 | 635 to 662 |
| Barrel middle. | | 320 to 446 | 284 to 446 | 644 to 680 |
| Barrel front. | | 392 to 536 | 320 to 536 | 653 to 688 |
| Nozzle. | | 410 to 518 | 320 to 518 | 671 to 707 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 356 to 536 | 320 to 536 | 662 to 716 |
| Recommended. | | 374 to 446 | 320 to 464 | 680 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 50 to 140 | 50 to 140 | 284 to 320 |
| Recommended. | | 86 | 104 | 302 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 246 | 234 | 104 |
| Specific Heat | Btu/lb°F. | 856 | 853 | 446 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 149 | 149 | 275 to 302 |
| Time. | h. | 3 | 3 | 3 to 4 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 29,000 |
| Hold. | | 10,850 | 10,850 | 17,400 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Fast | Fast |
| Screw rotational. | ft/s. | 2.3 to 2.46 | 2.3 to 2.46 | 0.66 to 0.98 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 to 0.236 |
| 9 Clamping pressure. | tons/in². | 1 to 2 | 1 to 2 | 5 to 10 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 120 to 200 | 130 to 200 | 335 to 350 |
| Barrel middle. | | 160 to 230 | 140 to 230 | 340 to 360 |
| Barrel front. | | 200 to 280 | 160 to 280 | 345 to 365 |
| Nozzle. | | 210 to 270 | 160 to 270 | 355 to 375 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 180 to 280 | 160 to 280 | 350 to 380 |
| Recommended. | | 190 to 230 | 160 to 240 | 360 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 10 to 60 | 10 to 60 | 140 to 160 |
| Recommended. | | 30 | 40 | 150 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 572 | 545 | 242 |
| Specific Heat | J/kg K. | 3180 | 3206 | 1150 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 65 | 65 | 135 to 150 |
| Time. | h. | 3 | 3 | 3 to 4 |
| 6 Pressures (max). | MN/m². | | | |
| Injection. | | 150 | 150 | 200 |
| Hold. | | 75 | 75 | 120 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Fast | Fast | Fast |
| Screw rotational. | m/s. | 0.7 to 0.75 | 0.7 to 0.75 | 0.2 to 0.3 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 to 6 |
| 9 Clamping pressure. | MN/m². | 15 to 31 | 15 to 31 | 77 to 154 |

# Table 2G. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION. | UNITS | PET/PETP | PMMA | POM-H |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 518 to 554 | 302 to 410 | 329 to 338 |
| Barrel middle. | | 518 to 563 | 338 to 446 | 338 to 392 |
| Barrel front. | | 518 to 572 | 356 to 527 | 356 to 410 |
| Nozzle. | | 518 to 572 | 356 to 527 | 338 to 410 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 509 to 563 | 410 to 518 | 374 to 419 |
| Recommended. | | 527 | 464 | 410 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 248 to 284 | 140 to 194 | 104 to 248 |
| Recommended. | | 275 | 140 | 194 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 131 | 147 | 161 |
| Specific Heat | Btu/lb°F. | 580 | 505 | 798 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 275 to 329 | 167 | 230 |
| Time. | h. | 2 to 4 | 2 to 4 | 2 to 3 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 21,750 |
| Hold. | | 10,875 | 10,875 | 10,875 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Med to fast | Slow to med | Fast |
| Screw rotational. | ft/s. | 0.66 to 1.15. | 1.15 to 1.31 | 1.64 to 1.97 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/$in^2$. | 4 to 6 | 2 to 4 | 4 to 5 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 270 to 290 | 150 to 210 | 165 to 170 |
| Barrel middle. | | 270 to 295 | 170 to 230 | 170 to 200 |
| Barrel front. | | 270 to 300 | 180 to 275 | 180 to 210 |
| Nozzle. | | 270 to 300 | 180 to 275 | 170 to 210 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 265 to 295 | 210 to 270 | 190 to 215 |
| Recommended. | | 275 | 240 | 205 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 120 to 140 | 60 to 90 | 40 to 120 |
| Recommended. | | 135 | 60 | 90 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 305 | 342 | 345 |
| Specific Heat | J/kg K. | 2180 | 1900 | 3000 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 135 to 165 | 75 | 110 |
| Time. | h. | 2 to 4 | 2 to 4 | 2 to 3 |
| 6 Pressures (max). | MN/$m^2$. | | | |
| Injection. | | 150 | 150 | 150 |
| Hold. | | 75 | 75 | 75 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Med to fast | Slow to med | Fast |
| Screw rotational. | m/s. | 0.3 to 0.35 | 0.35 to 0.4 | 0.5 to 0.6 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/$m^2$. | 62 to 92 | 31 to 62 | 62 to 77 |

# Table 2H. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION. | UNITS | POM-CO | PPO-M | PPS |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 329 to 338 | 410 to 482 | 536 to 572 |
| Barrel middle. | | 338 to 392 | 428 to 500 | 572 to 626 |
| Barrel front. | | 356 to 410 | 482 to 554 | 599 to 680 |
| Nozzle. | | 338 to 410 | 464 to 527 | 581 to 644 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 347 to 428 | 500 to 572 | 572 to 680 |
| Recommended. | | 419 | 536 | 608 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 104 to 248 | 140 to 230 | 275 to 320 |
| Recommended. | | 194 | 176 | 275 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 146 | 187 | 166 |
| Specific Heat | Btu/lb°F. | 798 | 577 | 553 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 230 | 212 | 302 |
| Time. | h. | 2 to 3 | 2 | 3 to 6 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 24,650 | 26,100 | 20,300 |
| Hold. | | 24,650 | 20,300 | 14,500 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Med to fast | Fast | Med to fast |
| Screw rotational. | ft/s. | 1.64 to 1.97 | 0.98 to 1.31 | 0.98 to 1.31 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/in$^2$. | 4 to 5 | 2 to 3 | 2 to 3 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 165 to 170 | 210 to 250 | 280 to 300 |
| Barrel middle. | | 170 to 200 | 220 to 260 | 300 to 330 |
| Barrel front. | | 180 to 210 | 250 to 290 | 315 to 360 |
| Nozzle. | | 170 to 210 | 240 to 275 | 305 to 340 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 175 to 220 | 260 to 300 | 300 to 360 |
| Recommended. | | 215 | 280 | 320 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 40 to 120 | 60 to 110 | 135 to 160 |
| Recommended. | | 90 | 80 | 135 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 375 | 434 | 385 |
| Specific Heat | J/kg K. | 3000 | 2170 | 2080 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 110 | 100 | 150 |
| Time. | h. | 2 to 3 | 2 | 3 to 6 |
| 6 Pressures (max). | MN/m$^2$. | | | |
| Injection. | | 170 | 180 | 140 |
| Hold. | | 170 | 140 | 100 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Med to fast | Fast | Med to fast |
| Screw rotational. | m/s. | 0.5 to 0.6 | 0.3 to 0.4 | 0.3 to 0.4 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m$^2$. | 62 to 77 | 31 to 47 | 31 to 47 |

# Table 2I. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| | SETTING CONDITION | UNITS | PP | GPPS | PSU |
|---|---|---|---|---|---|
| 1 | Temperatures. | °F. | | | |
| | Barrel rear. | | 374 to 446 | 302 to 356 | 563 to 671 |
| | Barrel middle. | | 392 to 464 | 356 to 446 | 581 to 689 |
| | Barrel front. | | 428 to 510 | 410 to 482 | 590 to 698 |
| | Nozzle. | | 428 to 518 | 410 to 536 | 608 to 716 |
| 2 | Melt temperature. | °F. | | | |
| | Range. | | 392 to 527 | 392 to 482 | 662 to 716 |
| | Recommended. | | 464 | 401 | 680 |
| 3 | Mold temperature. | °F. | | | |
| | Range. | | 86 to 176 | 50 to 176 | 212 to 302 |
| | Recommended. | | 120 | 68 | 212 |
| 4 | Heat content. | | | | |
| | Heat removal. | Btu/lb. | 240 | 170 | 188 |
| | Specific Heat | Btu/lb°F. | 779 | 524 | 306 |
| 5 | Material drying. | | | | |
| | Temperature. | °F. | 176 | 158 | 275 to 302 |
| | Time. | h. | 2 to 3 | 2 to 3 | 3 to 4 |
| 6 | Pressures (max). | psi. | | | |
| | Injection. | | 26,100 | 21,750 | 26,100 |
| | Hold. | | 21,750 | 10,850 | 17,400 |
| | Back. | | 2,175 | 2,175 | 2,175 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Fast | Fast |
| | Screw rotational. | ft/s. | 2.46 to 2.62 | 2.46 to 2.62 | 0.66 to 0.98 |
| 8 | Screw cushion. | in. | 0.118 | 0.118 | 0.118 to 0.236 |
| 9 | Clamping pressure. | tons/in$^2$. | 1 to 2.5 | 1 to 2 | 5 to 10 |
| 1 | Temperatures. | °C. | | | |
| | Barrel rear. | | 190 to 230 | 150 to 180 | 295 to 355 |
| | Barrel middle. | | 200 to 240 | 180 to 230 | 305 to 365 |
| | Barrel front. | | 220 to 270 | 210 to 250 | 310 to 370 |
| | Nozzle. | | 220 to 270 | 210 to 280 | 320 to 380 |
| 2 | Melt temperature. | °C. | | | |
| | Range. | | 220 to 275 | 200 to 250 | 350 to 380 |
| | Recommended. | | 240 | 225 | 360 |
| 3 | Mold temperature. | °C. | | | |
| | Range. | | 30 to 80 | 10 to 80 | 100 to 150 |
| | Recommended. | | 50 | 20 | 100 |
| 4 | Heat content. | | | | |
| | Heat removal. | J/g. | 557 | 394 | 436 |
| | Specific Heat | J/kg K. | 2930 | 1970 | 1675 |
| 5 | Material drying. | | | | |
| | Temperature. | °C. | 80 | 70 | 135 to 150 |
| | Time. | h. | 2 to 3 | 2 to 3 | 3 to 4 |
| 6 | Pressures (max). | MN/m$^2$. | | | |
| | Injection. | | 180 | 150 | 180 |
| | Hold. | | 150 | 75 | 120 |
| | Back. | | 15 | 15 | 15 |
| 7 | Speeds. | | | | |
| | Injection. | | Fast | Fast | Fast |
| | Screw rotational. | m/s. | 0.75 to 0.8 | 0.7 to 0.8 | 0.2 to 0.3 |
| 8 | Screw cushion. | mm. | 3 | 3 | 3 to 6 |
| 9 | Clamping pressure. | MN/m$^2$. | 15 to 39 | 15 to 31 | 77 to 154 |

# Table 2J. SETTING GUIDELINES FOR UNFILLED MATERIALS.

| SETTING CONDITION | UNITS | PVDF | SAN | TPU/PUR |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 320 to 410 | 302 to 356 | 320 to 392 |
| Barrel middle. | | 356 to 464 | 356 to 446 | 338 to 428 |
| Barrel front. | | 374 to 500 | 410 to 536 | 356 to 437 |
| Nozzle. | | 482 to 554 | 410 to 536 | 365 to 455 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 356 to 572 | 392 to 518 | 356 to 446* |
| Recommended. | | 464 to 500 | 446 to 500 | 383 to 428* |
| 3 Mold temperature. | °F. | | | |
| Range. | | 86 to 248 | 104 to 176 | 59 to 158 |
| Recommended. | | 140 | 140 | 86 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 154 | 152 | 120 |
| Specific Heat | Btu/lb°F. | 478 | 523 | 439 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 176 | 158 to 167 | 176 |
| Time. | h. | 2 to 4 | 3 to 4 | 3 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 26,100 |
| Hold. | | 10,875 | 10,875 | 17,400 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Slow | Fast | Fast |
| Screw rotational. | ft/s. | 0.33 to 0.66 | 1.8 to 2.13 | 0.66 to 0.98 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/in². | 1 | 2.5 to 3 | 0.5 to 2.5 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 160 to 210 | 150 to 180 | 160 to 200 |
| Barrel middle. | | 180 to 240 | 180 to 230 | 170 to 220 |
| Barrel front. | | 190 to 260 | 210 to 280 | 180 to 225 |
| Nozzle. | | 250 to 290 | 210 to 280 | 185 to 235 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 180 to 300 | 200 to 270 | 180 to 230* |
| Recommended. | | 240 to 260 | 230 to 260 | 195 to 220* |
| 3 Mold temperature. | °C. | | | |
| Range. | | 30 to 120 | 40 to 80 | 15 to 70 |
| Recommended. | | 60 | 60 | 30 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 359 | 354 | 280 |
| Specific Heat | J/kg K. | 1796 | 1968 | 1650 |
| 5 Material drying. | | | | |
| Temperature. | OC. | 80 | 70 to 75 | 80 |
| Time. | h. | 2 to 4 | 3 to 4 | 3 |
| 6 Pressures (max). | MN/m². | | | |
| Injection. | | 150 | 150 | 180 |
| Hold. | | 75 | 75 | 120 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Slow | Fast | Fast |
| Screw rotational. | m/s. | 0.1 to 0.2 | 0.55 to 0.65 | 0.2 to 0.3 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m². | 31 | 39 to 47 | 7.8 to 39 |

* dependent upon grade i.e. Shore 78 to 85 A grade = 383°F (195°C), Shore 50 to 74 D grade = 428°F (220°C).

# Table 2K. SETTING GUIDELINES FOR UNFILLED MATERIALS

| SETTING CONDITION | UNITS | UPVC | PPVC | EVA |
|---|---|---|---|---|
| 1 Temperatures. | °F. | | | |
| Barrel rear. | | 284 to 320 | 284 to 320 | 266 to 320 |
| Barrel middle. | | 302 to 338 | 320 to 356 | 302 to 356 |
| Barrel front. | | 338 to 374 | 338 to 374 | 356 to 410 |
| Nozzle. | | 356 to 419 | 356 to 401 | 374 to 428 |
| 2 Melt temperature. | °F. | | | |
| Range. | | 365 to 401 | 329 to 392 | 284 to 437 |
| Recommended. | | 374 to 392 | 374 to 392 | 374 to 392 |
| 3 Mold temperature. | °F. | | | |
| Range. | | 86 to 140 | 86 to 122 | 59 to 104 |
| Recommended. | | 104 | 104 | 77 |
| 4 Heat content. | | | | |
| Heat removal. | Btu/lb. | 125 | 125 | 242 |
| Specific Heat | Btu/lb°F. | 484 | 484 | 833 |
| 5 Material drying. | | | | |
| Temperature. | °F. | 149 | 149 | 122 to 140 |
| Time. | h. | 2 to 3 | 2 | 8 |
| 6 Pressures (max). | psi. | | | |
| Injection. | | 21,750 | 21,750 | 21,750 |
| Hold. | | 10,875 | 10,875 | 10,875 |
| Back. | | 2,175 | 2,175 | 2,175 |
| 7 Speeds. | | | | |
| Injection. | | Slow | Slow to med | Slow |
| Screw rotational. | ft/s. | 0.49 to 0.66 | 0.49 to 0.66 | 1.64 to 1.80 |
| 8 Screw cushion. | in. | 0.118 | 0.118 | 0.118 |
| 9 Clamping pressure. | tons/in$^2$. | 2 to 3 | 1.5 to 3 | 1 to 2.5 |
| 1 Temperatures. | °C. | | | |
| Barrel rear. | | 140 to 160 | 140 to 160 | 130 to 160 |
| Barrel middle. | | 150 to 170 | 150 to 170 | 150 to 180 |
| Barrel front. | | 170 to 190 | 170 to 190 | 180 to 210 |
| Nozzle. | | 180 to 215 | 180 to 205 | 190 to 220 |
| 2 Melt temperature. | °C. | | | |
| Range. | | 185 to 205 | 175 to 200 | 140 to 225 |
| Recommended. | | 190 to 200 | 190 to 200 | 190 to 200 |
| 3 Mold temperature. | °C. | | | |
| Range. | | 30 to 60 | 30 to 50 | 15 to 40 |
| Recommended. | | 40 | 40 | 25 |
| 4 Heat content. | | | | |
| Heat removal. | J/g. | 291 | 291 | 563 |
| Specific Heat | J/kg K. | 1820 | 1820 | 3130 |
| 5 Material drying. | | | | |
| Temperature. | °C. | 65 | 65 | 50 to 60 |
| Time. | h. | 2 to 3 | 2 | 8 |
| 6 Pressures (max). | MN/m$^2$. | | | |
| Injection. | | 150 | 150 | 150 |
| Hold. | | 75 | 75 | 75 |
| Back. | | 15 | 15 | 15 |
| 7 Speeds. | | | | |
| Injection. | | Slow | Slow to Med | Slow |
| Screw rotational. | m/s. | 0.15 to 0.2 | 0.15 to 0.2 | 0.5 to 0.55 |
| 8 Screw cushion. | mm. | 3 | 3 | 3 |
| 9 Clamping pressure. | MN/m$^2$. | 31 to 47 | 23 to 47 | 15 to 38.5 |

# Table 3. SOME ABBREVIATIONS AND TRADE NAMES OF PLASTICS.

| Abbreviation | Common name. | Common trade names or, trade marks. |
|---|---|---|
| ABS | Acrylonitrile butadiene styrene | Cycolac; Lustran. |
| AMS | Alpha methyl styrene | Elite HH. |
| ASA | Acrylonitile styrene acrylonitrile (AAS) | Luran S. |
| BDS | Butadiene styrene block copolymer | K resin; Styrolux. |
| BMC | Bulk moulding compound | Freemix; Norsomix. |
| CA | Cellulose acetate | Cellidor; Tenite. |
| CAB | Cellulose acetate butyrate | Cellidor; Tenite. |
| CAP | Cellulose acetate propionate | Cellidor; Tenite. |
| CF | Casein formaldehyde | Erinoid; Lactoid. |
| CN | Cellulose nitrate | Celluloid; Xylonite. |
| COPE | Polyether ester elastomer | Arnitel; Hytrel. |
| CP | Cellulose propionate (CAP) | Cellidor; Tenite. |
| CPE | Chlorinated polyethylene (PE-C). | Bayer CM; Tyrin CM. |
| CPVC | Chlorinated polyvinyl chloride (PVC-C). | Lucalor. |
| DAP | Diallyl phthalate | |
| DAIP | Diallyl isophthalate. | |
| DMC | Dough moulding compound | Beetle DMC; ERF DMC. |
| EA-MPR | Elastomer alloy melt processable rubber | Alcryn. |
| EA-TPV | Elastomer alloy thermoplastic vulcanizate | Lomod; Santoprene. |
| EP | Epoxide or epoxy (cured) | Araldite. |
| ETFE | Tetrafluorethylene-ethylene copolymers | Tefzel. |
| EVA | Ethylene vinyl acetate copolymer | Evatane. |
| EVAL | Ethylene vinyl alcohol copolymer. | Clarene; Eval. |
| EVOH | Ethylene vinyl alcohol copolymer. | Clarene; Eval. |
| FEP | Fluorinated ethylene propylene (TFE-HFP) | Teflon FEP. |
| GPMC | Granular polyester moulding compound | Freeflo; Impel. |
| HDPE | High density polyethylene (PE-HD) | Lupolen HD; Rigidex. |
| HIPS | High impact polystyrene (TPS or IPS) | Lustrex; Polystyrol. |
| LCP | Liquid crystal polymer | Vectra; Xydar. |
| LDPE | Low density polyethylene (PE-LD) | Alathon; Hostalen LD. |
| MDPE | Medium density polyethylene (PE-MD) | Fortiflex. |
| MF | Melamine formaldehyde | Melmex; Melopas. |
| MPR | Melt processable rubber | Alcryn. |
| PA | Polyamide or nylon. | |
| PA 6 | Polyamide 6 or nylon 6 | Akulon K; Ultramid. |
| PA 11 | Polyamide 11 or nylon 11 | Rilsan B. |
| PA 12 | Polyamide 12 or nylon 12 | Rilsan A; Grilamid. |
| PA 46 | Polyamide 46 or nylon 46 | Stanyl. |
| PA 66 | Polyamide 66 or nylon 66 | Maranyl; Zytel. |
| PA 610 | Polyamide 610 or nylon 610 | Brulon; Perlon N. |
| PAA 6 | Polyaryl amide or, poly-m-xylene-adipamide (PA MXD6) | Ixef. |
| PAN | Polyacrylonitrile | Acrilan; Barex; Orlon. |
| PBI | Polybenzimidazole | Celazole. |
| PBT | Polybutylene terephthalate | Pocan; Valox. |
| PC | Polycarbonate. | Lexan; Makrolon. |
| PCTFE | Polychlorotrifluorethylene. | Hostaflon C2; Kel-F. |
| PE | Polyethylene | Alathon; Lupolen. |
| PEBA | Polyether block amide | Pebax. |
| PEEK | Polyether ether ketone | Victrex PEEK; |
| PEEL | Polyether ester (YPBO) | Arnitel; Hytrel. |

| | | |
|---|---|---|
| PE-HD | Polyethylene-high density | Lupolen HD; Rigidex HDPE. |
| PEI | Polyether imide | Ultem. |
| PEK | Polyether ketone | Hostatec. |
| PEKK | Polyether ketone ketone | (from DuPont) |
| PE-LD | Polyethylene- low density | Alathon; Lupolen. |
| PE-MD | Polyethylene- medium density | Fortiflex. |
| PE-VLD | Polyethylene- very low density | Norsoflex. |
| PET | Polyethylene terephthalate | Arnite A; Techster E. |
| PES | Polyether sulphone | Victrex. |
| PMC | Polyester molding compound | Aropol; Norsomix. |
| PF | Phenol formaldehyde | Bakelite; Sternite. |
| PI | Polyimide | Vespel. |
| PMMA | Polymethyl methacrylate (acrylic) | Diakon; Plexiglas. |
| PMMA-T | Toughened acrylic | |
| POM | Polyoxymethylene or, acetal or, polyformaldehyde. | Delrin; Hostaform. |
| POM-H | Acetal homopolymer. | Delrin and Delrin II. |
| POM-CO | Acetal copolymer. | Hostaform; Ultraform. |
| PP | Polypropylene | Profax; Propathene. |
| PPE | Polyphenylene ether (see PPO). | |
| PPO | Polyphenylene oxide-usually modified polyphenylene oxide (PPO-M) | Luranyl; Noryl. |
| PPS | Polyphenylene sulphide | Fortron; Ryton. |
| PPPS | Polyphenylene sulphide sulphone | Ryton S. |
| PPVC | Plasticised polyvinyl chloride (PVC-P). | Solvic; Vinnol. |
| PS | Polystyrene (GPPS) | Lustrex; Polystyrol. |
| PSU | Polysulphone | Udel. |
| PTFE | Polytetrafluorethylene | Fluon; Teflon. |
| PVC | Polyvinyl chloride | Corvic; Geon. |
| PVDC | Polyvinylidene chloride copolymers | Saran. |
| PVDF | Polyvinylidene fluorride. | Dyflor; Kynar; Solef. |
| PVF | Polyvinyl fluoride. | Tedlar. |
| SAN | Styrene acrylonitrile copolymer | Lustran SAN; Tyril. |
| SMC | Sheet moulding compound | ERF SMC; Flomat. |
| UPVC | Unplasticised polyvinyl chloride (PVC-U) | Corvic; Geon. |
| RMPP | Rubber modified polypropylene (PP/EPDM) | Uniroyal TPR; Keltan. |
| RRPP | Rubber reinforced polypropylene (PP/EPDM) | Uniroyal TPR; Keltan. |
| SBS | Styrene butadiene styrene block copolymer | Cariflex TR; Solprene. |
| SEBS | Styrene butadiene styrene block copolymer (saturated) | Cariflex. |
| TPE | Thermoplastic elastomer rubber) | |
| TP-EE | Thermoplastic elastomer - ether ester | Arnitel; Hytrel. |
| TP-EPDM | Thermoplastic elastomer - based on EPDM. | |
| TP-EVA | Thermoplastic elastomer - based on EVA. | |
| TP-NBR | Thermoplastic elastomer - based on NBR. | |
| TPO | Thermoplastic polyolefin | Propathene OTE; Vistaflex. |
| TPO-XL | Thermoplastic polyolefin rubber-crosslinked (rubber) | Levaflex; Santoprene. |
| TPR | Thermoplastic rubber (elastomer) | |
| TPU | Thermoplastic polyurethane | Elastollan; Estane. |
| TPV | Thermoplastic elastomer or rubber-crosslinked (rubber) | Lomod; Santoprene. |
| UF | Urea formaldehyde | Beetle; Scarab. |
| VE | Vinyl ester resins. | |
| VLDPE | Very low density polyethylene | Norsoflex. |

# Table 4. SOME TRADE NAMES, ABBREVIATIONS AND SUPPLIERS OF POLYMERS AND POLYMER COMPOUNDS.

| Trade name/ Trade marks | Abbreviation | Supplier |
|---|---|---|
| A-C | Low mol wt. PE | Allied Signal Imc. |
| A-Clyn | Low mol wt. ionomers | Allied Signal Imc. |
| Acrylite | PMMA | Canada Colors & Chemicals |
| Adpro | PP | Advanced Global Polymers |
| A-Fax | PP-A | Himont |
| Akulon K | PA 6 | Akzo Engineering Plastics |
| Akulon M | PA 6 | Akzo Engineering Plastics |
| Alathon | PE-HD | DuPont |
| Alcoryl | ABS | Rhone Poulenc |
| Alcryn | EA-TPV or TPE | DuPont |
| Algoflon | PTFE | Enimont |
| Altulite | PMMA | Altulor |
| Amoco HDPE | PE-HD | Amoco |
| Apec | Polyester PC | Bayer |
| Appryl | PP | Appryl |
| Apscom | Thermoplastics compounds | Akzo Engineering Plastics |
| Araldite | EMC or EP | Ciba Geigy |
| Ardel | Polyarylate | Amoco |
| Arnite A | PET | Akzo Engineering Plastic |
| Arnitel | PEEL or COPE | Akzo Engineering Plastics |
| Arnite T | PBT | Akzo Engineering Plastics |
| Aropol | PMC | Ashland Chemical Co. |
| Arylon T | ABS/PSU | USS Chemicals |
| Ashlene | PA 66 | Ashley Polymers Inc |
| Azdel | GMT/PP | GEP(General Electric Plastics) |
| Azloy | GMT/PC/PBT | GEP(General Electric Plastics) |
| Azmet | GMT/PBT | GEP(General Electric Plastics) |
| Bakelite | PF | Bakelite/Sterling Moulding Materials |
| Bakelite Polyester Alkyd | GPMC | Sterling Moulding Materials |
| Bapolan | PS | BASF/Bamberger |
| Bapolan | HIPS | BASF |
| Bapolene | HDPE & PP | Bamberger |
| Barex | PAN | Sohio |
| Barex | PAN | Standard Oil |
| Basopor | UF | BASF |
| Bayblend | ABS/PC | Bayer |
| Bayer CM | CPE | Bayer |
| Baycomp | Fiber filled thermoplastics | Baycomp |
| Baygal | Encapsulating resins | Bayer |
| Baymidur | Encapsulating resins | Bayer |
| Baypren | CR | Bayer |
| Beetle | UF | BIP Chemicals/Cyanamid |
| Beetle DMC | DMC | BIP Chemicals |
| Beetle nylon 6 | PA 6 | BIP Chemicals |
| Beetle nylon 66 | PA 66 | BIP Chemicals |

| | | |
|---|---|---|
| Beetle PET | PET | BIP Chemicals |
| Bergamid A | PA 66 | Bergmann |
| Bergamid B | PA 6 | Bergmann |
| Bergacell | CA | Bergmann |
| Bexloy | Engineering thermoplastics for cars | DuPont |
| Buna AP | EPM/EPDM | Bunawerke Huls |
| Buna CB | BR | Bayer |
| Buna EM | SBR | Bunawerke Huls |
| | | |
| Cabelec | PP (conductive) | Cabot Plastics |
| Cadon | SMA | Monsanto |
| Cadon 300 | Impact modified SMA (used with PVC) | Monsanto |
| Calibre | PC | Dow |
| Caprolan | TPU | Elastogran/BASF |
| Capron | PA 6 | Allied Corp |
| Carbaicar | UF | S A Aicar |
| Carbopol | Acrylic acid polymer | BF Goodrich |
| Carboset | Acrylic polymer | BF Goodrich |
| Carinex | HIPS | Shell |
| Cariflex | TPE (SBS) | Shell |
| Celanese Nylon | PA 66 | Hoechst/Hoechst Celanese |
| Celanex | PBT | Hoechst/Hoechst Celanese |
| Celazole | PBI | Hoechst/Hoechst Celanese |
| Cellidor | CA & CAP | Albis |
| Celsir | UF resins | SIR |
| Celstran | Long fibre filled thermoplastic | Hoechst/Hoechst Celanese |
| Cellobond BP | PF | BP Chemicals |
| Centrex | ASA or AAS | Monsanto |
| Clarene | EVOH or EVAL | Solvay |
| Corton | PP mineral filled | Poly Pacific Pty |
| Corvic | PVC | EVC |
| Crastine | PBT | Ciba Geigy |
| Craston | PPS | Ciba Geigy |
| Crystic | UP | Scott Bader |
| Crystic Impreg | GMC | Scott Bader |
| Cycolac | ABS | Monsanto |
| Cymel | MF | Cyanamid |
| | | |
| DAP 5000 | DAP | Synres Amoco |
| DAIP 6000 | DAIP | Synres Amoco |
| Daplen | LDPE: HDPE: PP | Chemie Linz |
| Delrin | POM-H | DuPont |
| Delrin II | POM-H | DuPont |
| DER | EP | Chemroy Canada |
| Desmopan | TPU | Bayer |
| Dexel and Dexel S | CA | Courtaulds Speciality Plastics |
| Dexflex | TPO | Dexter Plastics |
| Diakon | PMMA | ICI |
| Dialac | ASA | Mitsubishi |
| Dion | UP | Fiberglass |
| Dowlex | PE-LD | Dow Chemicals |
| Dowlex | PE-LLD | Dow Chemicals |
| DSM Nyrim | Reaction injection moulding (RIM) PA | DSM RIM Nylon |
| Duracryn | TPE/TPV | DuPont |
| Dural | reinforced UPVC | Dexter Plasics |
| Duralex | PVC/PU/NBR alloy | Dexter Plasics |
| Duralon | PA 11 | Thermoclad |
| Durapol | PMC | Isola Werke |
| Durez | PF | Occidental/Canadian Oxy Chemicals |

| | | |
|---|---|---|
| Durez | DAP | Occidental |
| Durolon | PC | Atochem |
| Dutral | PS | Enimont |
| Dutral FLX | TPE/TPV | Enimont |
| Dyflor | PVDF | Dynamit Nobel |
| Dyflor | PVDF | Kay Fries |
| Dytron XL | TPE (DV) | Monsanto |
| Dynaform | RRPP | Dynamit Nobel |
| Dynaset | PF | Reichold |
| | | |
| Ecdel | COPE or PEEL | Eastman Chemicals |
| Eccomold | EP | Emmerson and Cuming |
| Ecolyte II & IV | PE | Ecoplastics/Eco Chemicals |
| Ecolyte | Photodegradable TP | Ecoplastics/Eco Chemicals |
| Ecolyte S | PS | Ecoplastics/Eco Chemicals |
| Edister | ABS | Enimont |
| Edister | HIPS | Enimont |
| Edister | PS | Enimont |
| Elastar | TPE (based on NBR-XL/PVC) | |
| Elastollan | TPU | Elastogran/BASF |
| Elastopreg | GF/GMT laminates | BASF/Elastogran |
| Elite HH | AMS | Monsanto |
| Elvanol | EVAL | DuPont |
| Elvax | EVA copolymer | DSM |
| Empee PP | PP | Monmouth Plastics |
| Envex | Reinforced PI | Rogers Corp |
| Epoester | EP resins | SIR |
| Epolan | ABS | Industrial Resistol |
| Epolene | Maleated PP | Eastman Chemicals |
| Epon | EP | Shell |
| Eponac | EP | SPREA |
| Eposir | EP resins | SIR/Kingsley & Keith |
| ERF DMC | DMC | ERF |
| ERF SMC | SMC | ERF |
| Ertalan | cast PA | Erta |
| Escorene | PE-LLD | Exxon |
| Estane | TPU | Goodrich |
| Estamid | PEBA/TPE | Dow |
| Esterform | PMC | Chromos Ro-Polimeri |
| ETA | TPE | Republic Plastics |
| Europrene N | NBR | Enimont |
| Europrene S | NBR/PVC | Enimont |
| Europrene SOL T | TPE (SBS) | Enimont |
| Eval | EVOH or EVAL | Kuraray/EVAL Co |
| Evatane | EVA | Atochem |
| Exxelor | Plastics modifiers | Exxon |
| | | |
| Fenochem | PF | Chemiplastica Spa |
| Fenoform | PF | Chromos Ro-Polimeri |
| Ferrolene | PP | Ferro |
| Ferropak | PP mineral filled | Ferro |
| Fibiter | PBT | Enimont |
| Flomat | SMC | Freeman Chemicals |
| Foraflon | PVDF | Atochem |
| Fortiflex | PE-MD | Soltex Polymer Corp |
| Fortiflex | PE-HD | Soltex Polymer Corp |
| Fortilene | PP | Soltex Polymer Corp |
| Fortron | PPS | Hoechst/Hoechst Celanes |
| Freeflow | GPMC | Freeman Chemicals |
| Flowmat | SMC | Freeman Chemicals |
| | | |
| Gaflex | COPE or PEEL | Hoechst//Hoechst Celanese |
| Gedex | PS | Orkem |
| Gedex | HIPS/TPS | Orkem |

| | | |
|---|---|---|
| Geloy | ASA | General Electric Plastics/GEP |
| Genal | PF | General Electric Plastics/GEP |
| Geolast | TPV or NBR-TPV | Monsanto |
| Geon | PVC | BF Goodrich |
| Glilax | PEBA/TPE | Dianippon |
| Grilamid | PA12 | EMS-Grilon (EMS-Chemie)/ Emser Industries |
| Grilon | PA 6 | EMS-Grilon (EMS-Chemie)/ Emser Industries |
| Grilon T | PA 66 | EMS-Grilon (EMS-Chemie)/ Emser Industries |
| Grivory | Amorphous EP | Emser Ind. |
| Halar | ECTFE | Ausimont |
| Halon | PTFE | Ausimont |
| Haysite | PMC | Haysite Reinforced Plastics |
| Hercules HPR | PE-HD of high molecular weight | Hercules |
| Hetron | PMC | Ashland Chemical Corp. |
| Hostaform | POM-CO | Hoechst/Hoechst Celanese |
| Hostadur | PBT | Hoechst/Hoechst Celanese |
| Hostaflon FEP | FEP | Hoechst/Hoechst Celanese |
| Hostalen | PE-HD | Hoechst/Hoechst Celanese |
| Hostalen GUR | PE-UHMW | Hoechst/Hoechst Celanese |
| Hostalen PPPP | | Hoechst/Hoechst Celanese |
| Hostalen PP | reinforced PP | Hoechst/Hoechst Celanese |
| Hostapren | PE-C | Hoechst/Hoechst Celanese |
| Hostalit | PVC | Hoechst/Hoechst Celanese |
| Hostalit Z | PVC-HI | Hoechst/Hoechst Celanese |
| Hostatec | PEK | Hoechst/Hoechst Celanese |
| Huntsman Polystyrene | PS | Huntsman |
| Hytrel | PEEL or COPE | DuPont |
| Idemitsu Polycarbonate | PC | Idemitsu Petro Chem. |
| Illandur | PMC | Dr. Illing |
| Impel | GPMC | Scott Bader |
| Impet | PET | Hoechst/Hoechst Celanese |
| Indopol | Polybutenes | Amoco |
| Innovex | PE-LLD | BP |
| Isomin | MF | Perstorp |
| Ixef | PAA 6 | Laporte/Solvay |
| Iztavil | PVC | Polimeros De Mexico |
| Kadel | Polyketone | Amoco |
| Kamax | Acrylic imides | Rohm and Haas |
| Kane Ace | CPVC | Kaneka/E W Seward Ltd. |
| Kane Ace B | MBS | Kaneka/E W Seward Ltd. |
| Kane Ace PA | Acrylic proc. aid | Kaneka/E W Seward Ltd. |
| Kane Ace XEL | Cross linked PVC | Kaneka/E W Seward Ltd. |
| Kelburon | RRPP/TPE | DSM (Dutch State Mines) |
| Kelrinal | CM rubber | DSM (Dutch State Mines) |
| Keltan TP | RRPP/TPE | DSM (Dutch State Mines) |
| Keltan | EP(D)M | DSM (Dutch State Mines) |
| Kelprox | TPE | DSM (Dutch State Mines) |
| Keltaflex | TPE/TPV | DSM (Dutch State Mines) |
| Kematal | POM-C | Hoechst/Hoechst Celanese |
| Kerimid | PI | Rhone Poulenc |
| Keripol | PMC | Pheonix |
| K F | PVDF | Kureha |
| Kinel | PI | Rhone Poulenc |
| Kodapek PET | PET | Eastman Chemicals |
| Kodar PETG | PET-K or, PET-C | Eastman Chemicals |

| | | |
|---|---|---|
| Kostil | SAN | Enimont |
| Kraton TR | TPE (SBS) | Shell |
| K resin | BDS | Phillips |
| Kynar | PVDF | Penwalt |

| | | |
|---|---|---|
| Lacovyl | PVC | Atochem |
| Lacqrene | PS | Atochem |
| Lacqrene | HIPS | Atochem |
| Lacqtene HD | PE-HD | Atochem |
| Lacqtene HX and LX | PE-LLD | Atochem |
| Ladene | PE-LLD | Sabic |
| Legupren | UP | Bayer |
| Leguval | UP resins | Bayer |
| Lekutherm | EP | Bayer |
| Levaflex | TPO-XL | Bayer |
| Levapren | EVA/PVC | Bayer |
| Lexan | PC | GEP(General Electric Plastics) |
| Linpac Polystyrene | PS | Linpac |
| Lomod | COPE or PEEL | GEP |
| Lotader | Co & terpolymers | Orkem (was CdF Chemie) |
| Lotrene | PE-LD | Orkem |
| Lotrex | PE-LLD | Orkem |
| Lucalen | EA | BASF |
| Lucalor | CPVC | Atochem/Orgavyl |
| Lucobit | ECB | BASF |
| Lucolene | PVC compounds | Atochem |
| Lucorex | PVC compounds | Atochem |
| Lucovyl | PVC | Atochem |
| Lucryl | PMMA | BASF |
| Lupolen | PE-LD | BASF |
| Lupolen HD | PE-HD | BASF |
| Luranyl | PPO-M or PPE/HIPS | BASF |
| Luran | SAN | BASF |
| Luran S | ASA | BASF |
| Lustran | ABS | Monsanto |
| Lustran | SAN | Monsanto |
| Lustran Elite HH | AMS | Monsanto |
| Lustran Ultra ABS | ABS (high gloss) | Monsanto |
| Lustrex | PS | Monsanto |
| Lustrex | HIPS | Monsanto |
| Luran | SAN | BASF |
| Luran S | ASA or AAS | BASF |

| | | |
|---|---|---|
| Magnum | ABS | Dow |
| Makroblend | PC/PBT | Bayer |
| Makrolon | PC | Bayer |
| Maranyl | PA 66 | ICI/LNP |
| Marlex | PE-HD | Phillips |
| Melaicar | MF | S A Aicar |
| Melamine moulding compounds | MF | Perstop Ferguson |
| Melmex | MF | BIP |
| Meloplas | MF | Ciba Geigy |
| Melsprea | MF | SPREA |
| Menzolit | PMC | Menzolit Werke |
| Merlin | PC | Mobay |
| Merlon | PC | Bayer |
| Metton | A liquid moulding resin | Shell/Hercules |
| Miapol | UP resin | Mia Chemical |
| Mindel | PSU (filled) | Amoco Chemicals |
| Minlon | PA 66 (filled) | DuPont |
| Moldsite | PF | SPREA |
| Moplen RO | PE-HD | Enimont |
| Moplen SP | RRPP | Enimont |

| | | |
|---|---|---|
| Morthane | TPU | Morton Thiokol Inc. |
| MultiSperse | Elastomeric dispersions | Croxton & Garry |
| Naycar-A | PA 66 | Polymer Trading |
| Naycar-B | PA 6 | Polymer Trading |
| Neoflon | FEP | Daikin |
| Neonite | EMC or EP long | Ciba Geigy<br>glass fiber filled |
| Neste HDPE | PE-HD | Neste |
| Neste LD | PE-LD | Neste |
| Neste LPLD | PE-LLD | Neste |
| Neste PS | HIPS | Neste |
| Nestorite | PF | Perstorp |
| Nike | CN | Punda Inc. |
| Norchem | PE-HD, PE-LLD & PP | Enron/Delong Prochem |
| Norlin | PE-LLD | Northern Petrochemicals |
| Norpol | UP | Jotun Polymer |
| Norsomix | DMC/PMC | Orkem (CdF Chimie) |
| Norsoflex | VLDPE | Orkem (CdF Chimie) |
| Nortuff | PP | Norchem Inc |
| Norvinyl | PVC | Norsk Hydro |
| Noryl | PPO-M | GEP(General Electric Plastics) |
| Noryl GTX | PPO-M/PA | GEP(General Electric Plastics) |
| Novamid | PA | Mitsuibishi |
| Novablend | PVC | Novatec |
| Novapol HD | PE-HD | Novacor Chemicals |
| Novapol LD | PE-LD | Novacor Chemicals |
| Novex | PE-LD | BP Chemicals |
| Novodur | ABS | Bayer |
| Novolen | PP | BASF |
| Nuloy | PA 6 | Terlon Polimeros |
| Nydur | PA 6 & PA 66 | Mobay |
| Nylafil | Filled PA | Wilson Fibrefil |
| Nylon | PA | e.g. DuPont |
| Nypel | PA 6 | Allied Signal Inc. |
| Oppanol | PIB | BASF |
| Orgalloy R | PA 6/PP or PA 66/PP | Atochem |
| Orgamide | PA 6 | Atochem |
| Orgasol | PA powder | Atochem |
| Orgater | PBT | Atochem |
| Oroglas | PMMA | Rohm and Haas |
| Palatal | UP | BASF |
| Paraloid | Impact modifiers | Rohm and Haas |
| Parr | DAP | US Prolam Inc. |
| Paxon | PE-HD | Allied |
| Pax-Purge | Purge compounds | Canada Color & Chemicals |
| Pebax | PEBA | Atochem |
| Pemex | LDPE | Petroleos Mexicanos |
| Pekema | PVC | Punda Inc |
| Pekevic | PVC | Neste Oy |
| Perbunan N | NBR | Bayer |
| Petlon | PET | Bayer/Mobay |
| Petra | PET | Allied Signal Inc. |
| Petrothene | PE-HD | USI/Quantum |
| Petrothene | PE-LLD | USI/Quantum |
| Pevikon | PVC | Norsk Hydro |
| Pibiflex | PEEL or COPE | Dutral/Montedison |
| Pibiter | PBT | Dutral/Montedison |
| Plasticlean | Purging compound | W S Wood Assoc. |
| Plaskon | EP | Plaskon Molding Div. |
| Plaskon DAP | DAP | Plaskon Molding Div. |
| Plenco | PF, MPF & UP | Plastics Engineering Co. |

| | | |
|---|---|---|
| Plexiglas | PMMA | Rohm and Haas |
| Pocan | PBT | Bayer/Mobay |
| Polloplas | UF | Dynamit Nobel |
| Polyclear | PET | Hoechst/Hoechst Celanese |
| Polychem | DAP | Budd Co. |
| Polycol | PVC | Atochem |
| Poly DAP | DAP | US Prolam Inc. |
| Polyfort | PP filled | Schulman Inc |
| Polykemi | PC | Atochem |
| Polyloy | PA 6 | Illing |
| Polyloy | PA 66 | Illing |
| Polymer E | LDPE | Asia Polymer Corp |
| Polyset | EP | Morton Chemical Div. |
| Polystyrol | PS | BASF |
| Polystyrol | PS | Norsk Hydro |
| Polystyrol | HIPS | BASF |
| Polystyrol | HIPS | Norsk Hydro |
| Polystyron | PS | Svenska |
| Polyvest | Polybutadiene | Huls |
| Prevex | PPO-M or PPE | Borg Warner |
| Primax | PE-UHMW | Air Products and Chemicals. |
| Procom | PP compounds | ICI |
| Profax | PP | Himont/Hercules |
| Progilite | PF | Rhone Poulenc |
| Proloy | EP | GEP(General Electric Plastics) |
| Propathene OTE | RRPP | ICI |
| Pulse | ABS/PC | Dow |
| Quimcel | CN | Punda Inc. |
| Radel | PSU | Amoco |
| Radlite | GMT | Azdel Europe |
| Ravikral | ABS | Enichem |
| Resarit | PMMA | Resart |
| ResarthermPMC | | Resart |
| Resilon | PVC | Canadian General-Tower |
| Resin 18 | AMS | Amoco |
| Rexene | PP | El Paso |
| Rigidex HDPE | PE-HD | BP |
| Rilsan A | PA 12 | Atochem |
| Rilsan | PA 11 | Atochem |
| Riteflex | PEEL or COPE | Hoechst/Hoechst Celanese |
| Ronfalin | ABS | DSM (Dutch State Mines) |
| Ronfaloy | ABS alloy | DSM (Dutch State Mines) |
| Ronfaloy E | ABS/EP(D)M | DSM (Dutch State Mines) |
| Ronfaloy V | ABS/PVC | DSM (Dutch State Mines) |
| Rovel | Styrene based material | Dow |
| Royalene | EPDM | Uniroyal |
| Rutaform | MF | Sterling Moulding Materials |
| Rutaform Polyester | GPMC | Sterling Moulding Materials |
| Rutamid 6 | PA 6 | Bakelite |
| Rutamid 66 | PA 66 | Bakelite |
| Rynite | PET | DuPont |
| Ryton | PPS | Phillips Chemicals |
| Ryton S | PPPS | Phillips Chemicals |
| Saran | PVDC or PVdC | Dow |
| Santoprene | TPO-XL an EA-TPV | Monsanto |
| Scarab | UF | BIP |
| Scarnol | EVOH or EVAL | Nippon Gobsei |
| Sclair | PE-LLD | DuPont |
| Sclairlink | Cross linkable PE | DuPont |
| Selar | amorphous PA | DuPont |
| Sinvet | PC | Enimont |
| Sirester | UP resins | SIR (Societa Italiana Resine) |
| Sirfen | PF resins | SIR (Societa Italiana Resine) |

| | | |
|---|---|---|
| Sirfen X | PF | SIR (Societa Italiana Resine) |
| Siritle | UF | SIR (Societa Italiana Resine) |
| SMA Resins | SMA | Sartomer |
| Siritle | UF | SIR (Societa Italiana Resine) |
| Soarnol | EVOH | Atochem |
| Solef | PVDF | Laporte |
| Solef | PVDF | Solvay |
| Sol T | SBS & SIS | Enimont |
| Stamylan HD | PE-HD | DSM (Dutch State Mines) |
| Stamylan LD | PE-LD | DSM (Dutch State Mines) |
| Stamylan P | PP | DSM (Dutch State Mines) |
| Stamylex | PE-LLD | DSM (Dutch State Mines) |
| Stamyroid | modified amorphous PP | DSM (Dutch State Mines) |
| Stanyl | PA 46 | DSM (Dutch State Mines) |
| Stapron S | rubber modified SMA | DSM (Dutch State Mines) |
| Statoil | | |
| Statoil polyethylene | PE-HD | Statoil |
| LDPE | PE-LD | Statoil |
| Sternite | PF | Sterling Moulding Materials |
| Sternite | PS | Sterling Moulding Materials |
| Sternite | HIPS | Sterling Moulding Materials |
| Styrolux | BDS | BASF |
| Styron | PS | Dow |
| Styron | HIPS | Dow |
| Supec | PPS | GEP(General Electric Plastics) |
| Supraplas | EP | Sud West Chemie |
| Suramin | UF and MF resins | SIR (Societa Italiana Resine) |
| Surlyn | Ionomer resins | DuPont |
| Tancin | PP | Washington Penn Plastics |
| Technyl B | PA 66 | Rhone Poulenc |
| Techster E | PET | Rhone Poulenc |
| Techster T | PBT | Rhone Poulenc |
| Tecolit | PF | Toshiba Chemical Products |
| Tedur | PPS | Bayer |
| Teflon FEP | FEP | DuPont |
| Teflex | FEP | Nitechim |
| Tenite | CA | Eastman Chemical |
| Tenite | CAB | Eastman Chemical |
| Tenite | CP or CAP | Eastman Chemical |
| Tenite polyethylene | PE-LD | Eastman Chemicals |
| Terblend S | ASA/PC | BASF |
| Terluran | ABS | BASF |
| Therban | NBR or HNBR | Bayer |
| Thermocomp | PES/PSU | LNP Plastics |
| Thermocomp | Filled PA | LNP Plastics |
| Torlon | PAI | Amoco |
| Toyobo MXDA | PAMXD6 | Toyobo |
| Trefsin | TPE/TPV | Exxon |
| Triax | PA/ABS alloys | Monsanto |
| Trithene | LDPE | Petroquimica Triunfo |
| Trithera | EVA | Petroquimica Triunfo |
| Trogamid T | amorphous PA | Huls |
| Tyril | SAN | Dow |
| Tyrin | CPE | Dow |
| Udel | PSU | Amoco Chemicals |
| Ugikral | ABS | Orkem |
| Ultem | PEI | GEP(General Electric Plastics) |
| Ultrablend | PBT/PC | BASF |
| Ultrablend S | PBT/ASA | BASF |
| Ultradur | PBT | BASF |
| Ultraform | POM-K | BASF |
| Ultralen | PET | BASF |
| Ultrapek | PEK | BASF |

| | | |
|---|---|---|
| Ultraplas | MF | Dynamit Nobel |
| Ultramid | PA 6 | BASF |
| Ultramid A | PA 66 | BASF |
| Ultramid C | PA copolymers | BASF |
| Ultramid S | PA 610 | BASF |
| Ultranyl | PPO-M/PA or PPE/PA | BASF |
| Ultrason E | PES | BASF |
| Ultrason S | PSU | BASF |
| Ultrax | Liquid crystal polymers (LC) | BASF |
| Urochem | UF | Chemiplastica Spa |
| Uroplast | UF | Sterling Moulding Materials |
| Urtal | ABS | Enichem |
| Valox | PBT | GEP(General Electric Plastics) |
| Vandar | Thermoplastic alloys. | Hoechst//Hoechst Celanese |
| Vectra | LCP | Hoechst/Hoechst Celanese |
| Vedril | PMMA | Enimont |
| Versamid | PA | |
| Verton | Long fibre filled thermoplastic | ICI |
| Vespel | PI | DuPont |
| Vestamid | PA 12 | Huls |
| Vestoblend | PPE/PA | Huls |
| Vestodur | PBT | Huls |
| Vestolen A | PE-HD | Huls |
| Vestolen P | PP | Huls |
| Vestolit | PVC | Huls |
| Vestopal | UP | Huls |
| Vestoplast | amorphous PO | Huls |
| Vestopren | EPM | Huls |
| Vestoran | PPO-M or PPE | Huls |
| Vestyron | PS | Huls |
| Vibrin | UP resins | Fiberglass |
| Viclan | PVDC/PVC | ICI |
| Victrex | PEEKPEEK | ICI |
| Victrex PES | PES | ICI |
| Vinoflex | PVC | BASF |
| Vinuran | PVC modifiers | BASF |
| Vipla | PVC | European Vinyl Corp. |
| Vista | PVC | Vista Chemicals |
| Vistalon | EPDM | Exxon |
| Vitalon | PA 46 | Trade name used in Japan for Stanyl |
| Vitax | ASA | Hitachi Chemicals |
| Voltalef | PCTFE | Atochem |
| Vydox | PTFE | DuPont |
| Vydyne | PA | Monsanto |
| Vydyne R | PA 66 (reinforced) | Monsanto |
| Vynite | PVC/NBR | Alpha Chemical & Plastics |
| Vythene | PVC/PU | Alpha Chemical & Plastics |
| Wacker Chemie | PE-HD | Wacker Polyathylen |
| Welite | PBT | Wellman Inc. |
| Wellamid | PA 6 & PA 66 | Wellman Inc. |
| Welpet | PET | Wellman Inc. |
| Xantar | PC | DSM (Dutch State Mines) |
| Xenoy | PC/PBT | GEP(General Electric Plastics) |
| Xydar | LCP | Amoco |
| Zytel | PA 66 | DuPont |
| Zytel ST | PA 66 super tough | DuPont |

# Table 5. SOME MELTING POINTS AND SOFTENING POINTS OF PLASTICS.

| | PMMA. | | PVC. | | PP. | |
|---|---|---|---|---|---|---|
| | °F | (°C) | °F | (°C) | °F | (°C) |
| VST at 50°C and 10N. | 238 | (114) | 185 | (85) | 274 | (134) |
| HDT at 120°C and 1.8MPa. | 207 | (97) | 147 | (64) | 153 | (67) |
| HDT at 120°C and 0.45MPa | 223 | (106) | 158 | (70) | 261 | (127) |
| Glass transition temperature. | 221 | (105) | 176 | (80) | -9 | (-23) |
| Melting point. | - | | - | | 338 | (170) |

# Table 6. DRYING CONDITIONS.

| Abbreviation | Water absorption % | Hot air drying Temp. °F | (°C) | Hours | Dessicant drying Temp. °F | (°C) | Hours |
|---|---|---|---|---|---|---|---|
| ASA | >0.1 | 176-185 | (80-85) | 2 to 4 | 194 | (90) | 2 to 3 |
| ABS | 0.2 to 0.35 | 158-176 | (70-80) | 2 to 4 | 167 | (75) | 2 |
| BDS | 0.08 | 140 | (60) | 1 to 1.5 | 140 | (60) | 0.5 |
| CA | 4.5 to 6.0 | *131-185 | (55-85) | 3 to 4 | 185 | (85) | 1 to 2 |
| CAB | 2.2 | *131-185 | (55-85) | 3 to 4 | 185 | (85) | 1 to 2 |
| CAP | 2.8 | *131-185 | (55-85) | 3 to 4 | 185 | (85) | 1 to 2 |
| FEP | 0.01 | 302 | (150) | 2 to 4 | 302 | (150) | 2 to 3 |
| HIPS | 0.08 | 158 | (70) | 2 to 3 | 158 | (70) | 1 to 2 |
| PA 6 | 1.6 | 176 | (80) | 16 | 221 | (105) | 12 |
| PA 66 | 1.5 | 185 | (85) | 16 | 221 | (105) | 12 |
| PA 11 | 0.4 | 185 | (85) | 5 to 6 | 185 | (85) | 3 |
| PA 12 | >0.4 | 185 | (85) | 5 to 6 | 185 | (85) | 3 |
| PBT | 0.08 | 248-302 | (120-150) | 3 to 5 | 275 | (135) | 2 to 3 |
| PC | 0.16 | 248 | (120) | 2 to 4 | 248 | (120) | 2 |
| PEBA (hard grades) | 0.5 | 176 | (80) | 4 | 176 | (80) | 3 PEBA |
| (soft grades) | 2.5 | 158 | (70) | 6 | 158 | (70) | 4 |
| PEEL (GP grades) | 1.5 | 248 | (120) | 10 | 248 | (120) | 2 to 4 |
| PEEL (high perf'mce) | 0.6 | 194 | (90) | 10 | 194 | (90) | 2 to 4 |
| PEEK | 0.5 | 302 | (150) | 3 | 302 | (150) | 2 to 3 |
| PE-HD | <0.01 | 149 | (65) | 3 | 176 | (80) | 1 to 1.5 |
| PE-LD | <0.2 | 149 | (65) | 3 | 176 | (80) | 1 to 1.5 |
| PE-LLD | <0.2 | 149 | (65) | 3 | 185 | (85) | 1 to 1.5 |
| PES | 0.6 | 275-302 | (135-150) | 3 to 4 | 275 | (135) | 2 to 3 |
| PET Amorphous | 0.03 | **131-275 | (55-135) | 4 | 275 | (135) | 2 |
| PET Crystalline | 0.03 | 275 | (135) | 4 | 275 | (135) | 2 |
| PMMA | 0.3 | 167 | (75) | 2 to 4 | 194 | (90) | 3 to 4 |
| POM-H | 0.4 | 230 | (110) | 2 to 3 | 230 | (110) | 1 to 2 |
| POM-CO | 0.22 | 230 | (110) | 2 to 3 | 230 | (110) | 1 to 2 |
| PPO-M | 0.1 | 212 | (100) | 2 | 212 | (100) | 2 |
| PPS | <0.05 | 302 | (150) | 6 | 302 | (150) | 3 |
| PP-H and PP-CO | <0.2 | 149 | (65) | 3 | 185 | (85) | 1 to 1.5 |
| PS (GPPS) | 0.08 | 158 | (70) | 2 to 3 | 158 | (70) | 1 to 2 |
| PSU | 0.3 | 275-302 | (135-150) | 3 to 4 | 275 | (135) | 2 to 4 |
| PVDF | 0.05 | 176 | (80) | 2 to 4 | 176 | (80) | 2 to 4 |
| SAN | 0.25 | 167-176 | (75-80) | 3 to 4 | 185 | (85) | 1.5 |
| TPU/PUR | 0.3 | 176 | (80) | 3 | 176 | (80) | 1 |
| UPVC | <0.2 | 149 | (65) | 3 | 176 | (80) | 1 to 1.5 |

* The temperature at which the material is dried at is dependent upon the material's flow characteristics i.e. soft flow materials 131°F to 154°F (55°C to 68°C) and hard flow materials 158°F to 185°F (70°C to 85°C).

** Some grades cannot be dried at > 60°C.

## Table 7. HEAT CONTENTS OF SOME MOLDING MATERIALS.

| Material Abb. | Melt Temp °C | (°F) | Mold Temp °C | (°F) | Difference °C | (°F) | Specific Heat $JKg^{-1}K^{-1}$ | Heat to be Removed J/g | (Btu/lb) |
|---|---|---|---|---|---|---|---|---|---|
| FEP | 350 | (662) | 220 | (428) | 130 | (234) | 1600 | 240 | (103) |
| PES | 360 | (680) | 150 | (302) | 210 | (378) | 1150 | 242 | (104) |
| CA | 210 | (410) | 50 | (122) | 160 | (288) | 1700 | 272 | (117) |
| CAB | 210 | (410) | 50 | (122) | 160 | (288) | 1700 | 272 | (117) |
| CP | 210 | (410) | 50 | (122) | 160 | (288) | 1700 | 272 | (117) |
| PEEK | 370 | (698) | 165 | (329) | 205 | (369) | 1340 | 275 | (118) |
| PET | 240 | (464) | 60 | (140) | 180 | (324) | 1570 | 283 | (131) |
| PETP(C) | 275 | (527) | 135 | (275) | 140 | (252) | 2180 | 305 | (131) |
| PEEL | 220 | (428) | 50 | (122) | 170 | (306) | 1800 | 306 | (132) |
| PMMA | 240 | (464) | 60 | (140) | 180 | (324) | 1900 | 342 | (147) |
| POM | 205 | (401) | 90 | (194) | 115 | (207) | 3000 | 345 | (148 to 161) |
| SAN | 240 | (464) | 60 | (140) | 180 | (356) | 1968 | 354 | (152) |
| BDS | 220 | (428) | 35 | (95) | 185 | (333) | 1968 | 364 | (157) |
| PC | 300 | (572) | 90 | (194) | 210 | (378) | 1750 | 368 | (158) |
| ABS | 240 | (464) | 60 | (140) | 180 | (324) | 2050 | 369 | (159) |
| PPS | 320 | (608) | 135 | (275) | 185 | (333) | 2080 | 385 | (166) |
| PS | 220 | (428) | 20 | (68) | 200 | (360) | 1970 | 394 | (170) |
| ASA/AAS | 260 | (500) | 60 | (140) | 200 | (360) | 2010 | 402 | (173) |
| HIPS | 240 | (464) | 20 | (68) | 220 | (396) | 1970 | 433 | (186) |
| PPO | 280 | (536) | 80 | (176) | 200 | (360) | 2170 | 434 | (187) |
| PSU | 360 | (680) | 100 | (212) | 260 | (500) | 1675 | 436 | (188) |
| PETP(A) | 265 | (509) | 20 | (68) | 245 | (441) | 1970 | 483 | (207) |
| PA 11/12 | 260 | (500) | 60 | (140) | 200 | (360) | 2440 | 488 | (210) |
| PA 6 | 250 | (482) | 80 | (176) | 170 | (306) | 3060 | 520 | (224) |
| LDPE | 210 | (410) | 30 | (86) | 180 | (324) | 3180 | 572 | (246) |
| PA 66 | 280 | (536) | 80 | (176) | 200 | (360) | 3075 | 615 | (265) |
| PP | 240 | (464) | 50 | (122) | 190 | (374) | 2790 | 670 | (240) |
| HDPE | 240 | (464) | 20 | (68) | 220 | (396) | 3640 | 801 | (344) |

## Table 8. TRANSDUCER PRESSURE RANGE

| Pin Dia. mm (in) | Transducer Range from 0 to 450 N (Permissible cavity pressure, in bar (or psi), that can be used over the selected transducer range) | |
|---|---|---|
| 1.5 (0.059) | 700 to 2,500 | (10,150 to 36,250) |
| 2.0 (0.079) | 400 to 1,400 | (5,800 to 20,300) |
| 2.5 (0.098) | 300 to 900 | (4,350 to 13,050) |
| 3.0 (0.118) | 200 to 640 | (2,900 to 9,280) |
| 4.0 (0.158) | 120 to 350 | (1,740 to 5,075) |
| 5.0 (0.197) | 80 to 230 | (1,160 to 3,335) |
| 6.0 (0.236) | 30 to 160 | (435 to 2,320) |
| 8.0 (0.315) | 20 to 90 | (290 to 1,305) |
| 10.0 (0.394) | - | - |
| 12.0 (0.472) | - | - |

| Pin Dia. | Transducer Range from 0 to 1100 N |
|---|---|

| mm (in) | (Permissible cavity pressure, in bar (or psi), that can be used over the selected transducer range) | |
|---|---|---|
| 1.5 (0.059) | Not available | |
| 2.0 (0.079) | 1,100 to 3,500 | (15,950 to 50,750) |
| 2.5 (0.098) | 700 to 2,250 | (10,150 to 32,625) |
| 3.0 (0.118) | 400 to 1,660 | (5,800 to 24,070) |
| 4.0 (0.158) | 270 to 880 | (3,915 to 12,760) |
| 5.0 (0.197) | 180 to 560 | (2,610 to 8,120) |
| 6.0 (0.236) | 130 to 390 | (1,885 to 5,655) |
| 8.0 (0.315) | 80 to 220 | (1,160 to 3,190) |
| 10.0 (0.394) | 0 to 140 | (0 to 2,030) |
| 12.0 (0.472) | 0 to 100 | (0 to 1,450) |

Example: With an ejector pin diameter of 4mm (0.158in) and a cavity pressure of 500 bar (7250psi) the correct range for the required transducer should be from 0 to 1100N.

| Pin Dia.<br>mm (in) | Transducer Range from 0 to 2,500 N<br>(Permissible cavity pressure, in bar or (psi), that can be used over the selected transducer range) | |
|---|---|---|
| 1.5 (0.059) | Not available | |
| 2.0 (0.079) | Not available | |
| 2.5 (0.098) | Not available | |
| 3.0 (0.118) | 1,100 to 3,500 | (15,950 to 50,750) |
| 4.0 (0.158) | 600 to 1,950 | (8,700 to 28,725) |
| 5.0 (0.197) | 380 to 1,250 | (5,510 to 18,125) |
| 6.0 (0.236) | 280 to 880 | (4,060 to 12,760) |
| 8.0 (0.315) | 150 to 480 | (2,175 to 6,960) |
| 10.0 (0.394) | 100 to 310 | (1,450 to 4,495) |
| 12.0 (0.472) | 80 to 220 | (1,160 to 3,190) |

| Pin Dia.<br>mm (in) | Transducer Range from 0 to 4500 N<br>(Permissible cavity pressure, in bar (or psi), that can be used over the selected transducer range) | |
|---|---|---|
| 1.5 (0.059) | Not available | |
| 2.0 (0.079) | Not available | |
| 2.5 (0.098) | Not available | |
| 3.0 (0.118) | Not available | |
| 4.0 (0.158) | 1,100 to 3,500 | (15,950 to 50,750) |
| 5.0 (0.197) | 700 to 2,240 | (10,150 to 32,480) |
| 6.0 (0.236) | 490 to 1,560 | (7,150 to 22,620) |
| 8.0 (0.315) | 270 to 880 | (3,915 to 12,760) |
| 10.0 (0.394) | 160 to 560 | (2,320 to 8,120) |
| 12.0 (0.472) | 120 to 400 | (1,740 to 5,800) |

| Pin Dia.<br>mm (in) | Transducer Range from 0 to 10,000 N<br>(Permissible cavity pressure, in bar (or psi), that can be used over the selected transducer range) | |
|---|---|---|
| 1.5 (0.059) | Not available | |
| 2.0 (0.079) | Not available | |
| 2.5 (0.098) | Not available | |
| 3.0 (0.118) | Not available | |
| 4.0 (0.158) | Not available | |
| 5.0 (0.197) | Not available | |
| 6.0 (0.236) | 1,050 to 3,470 | (15,225 to 50,315) |
| 8.0 (0.315) | 530 to 1,950 | (7,685 to 28,275) |
| 10.0 (0.394) | 100 to 1,250 | (1,450 to 18,125) |
| 12.0 (0.472) | 260 to 870 | (3,770 to 12,615) |

# Table 9. DRY CYCLE TIMES FOR A TYPICAL RANGE OF MOLDING MACHINES (ACCORDING TO EUROMAP 6A).

| Locking Force. tonnes | Dry Cycle Time. seconds | Dry Cycle Time (without nozzle retraction). seconds | Platen open & closing times. seconds |
|---|---|---|---|
| **Toggle Machines** | | | |
| 40 | 1.40 | 1.00 | 0.50 |
| 60 | 1.60 | 1.20 | 0.60 |
| 85 | 1.75 | 1.32 | 0.66 |
| 100 | 1.80 | 1.40 | 0.70 |
| 125 | 1.44 to 1.80 | 0.80 to 1.50 | 0.40 to 0.75 |
| 150 | 1.90 | 1.15 to 1.55 | 0.58 to 0.78 |
| 175 | 2.10 | 1.40 to 1.80 | 0.70 to 0.90 |
| 210 | 2.20 | 1.50 | 0.75 |
| 250 | 2.60 to 2.90 | 2.00 to 2.25 | 1.00 to 1.12 |
| 300 | 2.80 | 2.20 | 1.10 |
| 350 | 3.00 | 2.25 | 1.12 |
| 420 | 2.60 to 3.00 | 2.00 to 2.25 | 1.00 to 1.12 |
| 560 | 2.75 to 3.00 | 2.00 to 2.40 | 1.00 to 1.20 |
| 750 | 3.69 | 3.00 | 1.50 |
| 1000 | 4.80 to 7.00 | 3.80 to 6.00 | 1.90 to 3.00 |
| 1250 | 4.80 to 7.20 | 3.80 to 6.00 | 1.90 to 3.00 |
| 1600 | 8.00 to 11.25 | - | - |
| 1800 | 8.00 to 11.25 | - | - |
| 2500 | 11.25 to 20.00 | - | - |
| 3000 | 12.00 to 20.00 | - | - |
| 3600 | 12.00 to 20.00 | - | - |
| **Hydraulic Machines** | | | |
| 60 | 1.38 | - | - |
| 90 | 1.64 | - | - |
| 120 | 1.71 | - | - |
| 150 | 1.89 | - | - |
| 200 | 2.57 | - | - |
| 250 | 2.77 | - | - |
| 350 | 3.00 | - | - |
| 420 | 3.00 | - | - |
| 500 | 3.60 | - | - |
| 650 | 5.54 | - | - |
| 800 | 6.00 | - | - |

# Table 10a. DATA FOR CALCULATING MOLD FILL AND SOLIDIFICATION TIMES FOR SOME MATERIALS.

| Material Abb. | Temps. Melt °C | Mold °C | Thermal Diffusivity $cm^2sec^{-1}/°C$ | HDT °C | $\frac{Tx - Tm}{Tc - Tm}$ (V) | $\frac{1}{2\pi}\log_e\frac{[\pi \times V]}{[4]}$ ($V^3$) | (C) |
|---|---|---|---|---|---|---|---|
| ABS | 240 | 60 | $1.70 \times 10^{-3}$ | 95 | 0.19 | 0.007 | 178 |
| CA | 210 | 50 | $1.04 \times 10^{-3}$ | 98 | 0.30 | 0.027 | 221 |
| CAB | 210 | 30 | $1.27 \times 10^{-3}$ | 78 | 0.36 | 0.046 | 205 |
| PA 6 | 260 | 90 | $0.98 \times 10^{-3}$ | 180 | 0.52 | 0.140 | 145 |
| PA 66 | 285 | 90 | $1.01 \times 10^{-3}$ | 180 | 0.46 | 0.097 | 160 |
| PC | 300 | 90 | $1.47 \times 10^{-3}$ | 130 | 0.19 | 0.007 | 206 |
| PE-HD | 240 | 20 | $0.74 \times 10^{-3}$ | 92 | 0.33 | 0.036 | 290 |
| PEI | 380 | 140 | $1.50 \times 10^{-3}$ | 200 | 0.25 | 0.016 | 173 |
| PE-LD | 220 | 20 | $1.15 \times 10^{-3}$ | 45 | 0.13 | 0.002 | 316 |
| PES | 360 | 150 | $1.00 \times 10^{-3}$ | 203 | 0.25 | 0.016 | 259 |
| PMMA | 240 | 50 | $1.09 \times 10^{-3}$ | 102 | 0.27 | 0.020 | 226 |
| POM-CO | 210 | 90 | $0.70 \times 10^{-3}$ | 155 | 0.54 | 0.157 | 192 |
| POM-H | 220 | 90 | $0.71 \times 10^{-3}$ | 160 | 0.54 | 0.157 | 192 |
| PP | 240 | 40 | $0.85 \times 10^{-3}$ | 107 | 0.34 | 0.039 | 247 |
| GPPS | 220 | 20 | $1.60 \times 10^{-3}$ | 85 | 0.33 | 0.036 | 134 |
| HIPS | 220 | 20 | $1.60 \times 10^{-3}$ | 85 | 0.33 | 0.036 | 134 |
| PPO-M | 280 | 80 | $1.53 \times 10^{-3}$ | 130 | 0.33 | 0.036 | 140 |
| PSU | 360 | 120 | $1.00 \times 10^{-3}$ | 181 | 0.25 | 0.016 | 259 |
| PPVC | 180 | 20 | $1.16 \times 10^{-3}$ | 60 | 0.25 | 0.016 | 223 |
| SAN | 240 | 60 | $1.20 \times 10^{-3}$ | 107 | 0.26 | 0.018 | 210 |
| UPVC | 180 | 20 | $0.70 \times 10^{-3}$ | 82 | 0.39 | 0.059 | 269 |

# Table 10b. TYPICAL SOLIDIFICATION TIMES (IN SECONDS) FOR A RANGE OF WALL THICKNESSES

| Material |  |  | Wall Thickness in mm |  |  |  |
|---|---|---|---|---|---|---|
| Abbreviation | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 |
| ABS | 1.8 | 7.0 | 15.8 | 28.2 | 44.0 | 63.4 |
| CA | 2.2 | 8.8 | 19.9 | 35.4 | 55.3 | 79.6 |
| CAB | 2.1 | 8.2 | 18.5 | 32.8 | 51.3 | 73.8 |
| PA 6 | 1.5 | 5.8 | 13.1 | 23.2 | 36.3 | 52.2 |
| PA 66 | 1.6 | 6.4 | 14.4 | 25.6 | 40.0 | 57.6 |
| PC | 2.1 | 8.2 | 18.5 | 32.8 | 51.5 | 74.2 |
| PE-HD | 2.9 | 11.6 | 26.1 | 46.4 | 72.5 | 104.4 |
| PEI | 1.7 | 7.2 | 16.1 | 27.7 | 43.4 | 62.3 |
| PE-LD | 3.2 | 12.6 | 28.4 | 50.1 | 79.0 | 113.8 |
| PES | 2.6 | 10.4 | 23.3 | 41.4 | 64.8 | 93.2 |
| PMMA | 2.3 | 9.0 | 20.3 | 36.2 | 56.5 | 81.4 |
| POM-CO | 1.9 | 7.7 | 17.3 | 30.7 | 48.0 | 69.2 |
| PP | 2.5 | 9.9 | 22.3 | 39.5 | 61.8 | 88.9 |
| PS | 1.3 | 5.4 | 12.1 | 21.4 | 33.5 | 48.4 |
| HIPS | 1.3 | 5.4 | 12.1 | 21.4 | 33.5 | 48.4 |
| PPO-M | 1.4 | 5.6 | 12.6 | 22.4 | 35.0 | 50.4 |
| PPVC | 2.2 | 8.9 | 20.1 | 35.7 | 55.8 | 80.3 |
| PSU | 2.6 | 10.4 | 23.3 | 41.4 | 64.8 | 93.2 |
| SAN | 2.1 | 8.4 | 18.9 | 33.6 | 52.5 | 75.6 |
| UPVC | 2.7 | 10.7 | 24.2 | 43.0 | 67.3 | 96.8 |

Note: The above calculated values are those needed for the material to cool to the mold temperature. However, in many cases it is the time taken for the material to cool to just below the HDT (heat distortion temperature) which determines if the component can be ejected from the mold in a distortion free condition. Therefore the above values can be considered as maximum values.

# Table 11. ESTIMATION OF NATURAL TOLERANCE LIMITS.

| **Set** | **Measured values** | | | | **Total** | **Range** |
|---|---|---|---|---|---|---|
| **No.** | **A** | **B** | **C** | **D** | **$\overline{X}$ (X bar)** | **R** |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| Totals | | | | | $\Sigma X$ | $\Sigma R$ |

The average of the averages = $\overline{\overline{X}}$ or, X double bar = $\Sigma X/8$ =
Average range = $\overline{R}$ or, R bar = $\Sigma R/8$ =
Then, 1.5 times $\overline{R}$ or, R bar =
This component can be produced with an average value of
Upper natural tolerance limit = $\overline{\overline{X}} + 1.5\overline{R}$ which equals
Lower natural tolerance limit = $\overline{\overline{X}} - 1.5\overline{R}$ which equals

# Table 12. CALCULATION OF NATURAL TOLERANCE LIMITS.

| Set | Measured values | | | | | Total | Average | Range |
|---|---|---|---|---|---|---|---|---|
| No. | A | B | C | D | E | $\Sigma X$ | $\overline{X}$ (X bar) | R |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| 16 | | | | | | | | |
| 17 | | | | | | | | |
| 18 | | | | | | | | |
| 19 | | | | | | | | |
| 20 | | | | | | | | |

Highest value measured = . Lowest value measured = .
Difference =
Total of all the averages = $\Sigma X$ ($\Sigma\overline{X}$ bar) =
The average of the averages = $\overline{X}$ or, X double bar = $\Sigma\overline{X}/20$ =
Standard deviation = . Three standard deviations = .
This component can be produced with an average value of $\Sigma X/20$ =
Upper natural tolerance limit = $\overline{X}$ or X double bar + 3SD =
Lower natural tolerance limit = $\overline{X}$ or X double bar - 3SD =

Check your calculation by adding up all the ranges ($\Sigma R$) and dividing by 20 so as to give $\overline{R}$ or R bar.
Multiply $\overline{R}$ or R bar by 0.58.
Upper natural tolerance limit = $\overline{\overline{X}}$ or X double bar + 0.58$\overline{R}$ or R bar =
Lower natural tolerance limit = $\overline{\overline{X}}$ or X double bar - 0.58$\overline{R}$ or R bar =

# Table 13. FACTORS FOR THE CALCULATION OF LIMIT LINE POSITIONS AND SD.

| Sample | Average factors | | | Range factors | | | R bar to SD |
|---|---|---|---|---|---|---|---|
| Size | $A_W$ | $A_A$ | $A_{CL}$ | $D_W$ | $D_A$ | $D_{CL}$ | d |
| 2 | 1.229 | 1.937 | 1.88 | 2.87 | 4.12 | 3.27 | 1.128 |
| 3 | 0.668 | 1.054 | 1.02 | 2.17 | 2.98 | 2.57 | 1.693 |
| 4 | 0.476 | 0.758 | 0.73 | 1.93 | 2.57 | 2.28 | 2.059 |
| 5 | 0.377 | 0.594 | 0.58 | 1.81 | 2.34 | 2.11 | 2.326 |
| 6 | 0.316 | 0.498 | 0.48 | 1.72 | 2.21 | 2.00 | 2.534 |
| 7 | 0.274 | 0.432 | 0.42 | 1.66 | 2.11 | 1.92 | 2.704 |
| 8 | 0.244 | 0.384 | 0.37 | 1.62 | 2.04 | 1.86 | 2.807 |
| 9 | 0.220 | 0.347 | 0.34 | 1.58 | 1.99 | 1.82 | 2.970 |
| 10 | 0.202 | 0.317 | 0.31 | 1.56 | 1.93 | 1.78 | 3.078 |

$\bar{R}$ or R bar (mean sample range) = d x SD.
Upper limits = X or $\bar{\bar{X}}$ double bar + A x $\bar{R}$ or R bar.
Lower limits = X or $\bar{\bar{X}}$ double bar - A x $\bar{R}$ or R bar.

# Table 14. CLAMPING FORCE REQUIREMENTS FOR SOME THERMOPLASTIC MATERIALS

| Material Abbreviation | Tons.in$^{-2}$ (or tsi.) | MNm$^{-2}$ (or MN/m$^2$) |
|---|---|---|
| ASA | 2.5 to 4.0 | 38.6 to 61.8 |
| ABS | 2.5 to 4.0 | 38.6 to 61.8 |
| BDS | 2.0 to 3.0 | 30.9 to 46.3 |
| BDS (thin walls) | 3.0 to 4.0 | 46.3 to 61.8 |
| CA | 1.0 to 2.0 | 15.4 to 30.9 |
| CAB | 1.0 to 2.0 | 15.4 to 30.9 |
| CAP | 1.0 to 2.0 | 15.4 to 30.9 |
| FEP | 5.0 | 77.2 |
| HIPS | 1.0 to 2.0 | 15.4 to 30.9 |
| HIPS (thin walls) | 2.5 to 3.5 | 38.6 to 54.0 |
| PPVC | 1.5 to 2.5 | 23.2 to 38.6 |
| PA 6 | 4.0 to 5.0 | 61.8 to 77.2 |
| PA 66 | 4.0 to 5.0 | 61.8 to 77.2 |
| PA 11 | 1.5 to 2.0 | 23.2 to 30.9 |
| PA 12 | 1.5 to 2.0 | 23.2 to 30.9 |
| PBT | 3.0 to 4.5 | 46.3 to 69.5 |
| PC | 3.0 to 5.0 | 46.3 to 77.2 |
| PEBA (hard grades) | 2.0 | 30.9 |
| PEBA (soft grades) | 1.5 to 2.0 | 23.2 to 30.9 |

| | | |
|---|---|---|
| PEEL | 2.0 to 3.0 | 30.9 to 46.3 |
| PEEK (unreinforced) | 2.0 to 4.0 | 30.9 to 61.8 |
| PEEK (reinforced) | 4.0 to 6.0 | 61.8 to 92.6 |
| PE-HD | 1.5 to 2.5 | 23.2 to 38.6 |
| PE-HD (long flows) | 2.5 to 3.5 | 38.6 to 54.0 |
| PE-LD | 1.0 to 2.0 | 15.4 to 30.9 |
| PE-LLD | 1.0 to 2.0 | 15.4 to 30.9 |
| PES | 6.0 to 10.0 | 92.6 to 154.4 |
| PES (easy flow) | 4.0 to 6.0 | 61.8 to 92.6 |
| PET Amorphous | 2.0 to 2.5 | 30.9 to 38.6 |
| PET Crystalline | 4.0 to 6.0 | 61.8 to 92.6 |
| PMMA | 2.0 to 4.0 | 30.9 to 61.8 |
| POM-H | 3.0 to 5.0 | 46.3 to 77.2 |
| POM-CO | 3.0 to 5.0 | 46.3 to 77.2 |
| PPO-M (unreinforced) | 2.0 to 3.0 | 30.9 to 46.3 |
| PPO-M (reinforced) | 4.0 to 5.0 | 61.8 to 77.2 |
| PPS | 2.0 to 3.0 | 30.9 to 46.3 |
| PP-H | 1.5 to 2.5 | 23.2 to 38.6 |
| PP-CO | 1.5 to 2.5 | 23.2 to 38.6 |
| PP-H/CO (long flows) | 2.5 to 3.5 | 38.6 to 54.0 |
| PS (GPPS) | 1.0 to 2.0 | 15.4 to 30.9 |
| PS (GPPS) (thin walls) | 3.0 to 4.0 | 46.3 to 61.8 |
| PSU | 6.0 to 10.0 | 92.6 to 154.4 |
| PSU (easy flow) | 4.0 to 6.0 | 61.8 to 92.6 |
| PVDF | 2.0 | 30.9 |
| SAN | 2.5 to 3.0 | 38.6 to 46.3 |
| SAN (long flows) | 3.0 to 4.0 | 46.3 to 61.8 |
| TPU/PUR (easy flow) | 0.5 to 1.5 | 7.7 to 23.2 |
| TPU/PUR | 1.5 to 2.5 | 23.2 to 38.6 |
| UPVC | 2.0 to 3.0 | 30.9 to 46.3 |

**CONVERSION FACTORS.**

To change t.s.i. to $MNm^{-2}$ then multiply t.s.i. x 15.44 = $MNm^{-2}$.
To change t.s.i. to $kgf.cm^{-2}$ then multiply t.s.i. x 157.5 = $kgf.cm^{-2}$.
To change to $MNm^{-2}$ to $kgf.cm^{-2}$ then multiply $MNm^{-2}$ x 10.2

## Table 15. VISCOSITY FACTOR FOR A RANGE OF THERMPOPLASTICS MATERIALS.

| VISCOSITY FACTOR | THERMOPLASTICS MATERIALS. |
|---|---|
| 1.0 | PE, PP, PS. |
| 1.2 to 1.4 | Nylons (PA6 or PA66), POM. |
| 1.3 to 1.5 | Cellulosics. |
| 1.3 to 1.5 | ABS, ASA, SAN. |
| 1.5 to 1.7 | PMMA. |
| 1.7 to 1.9 | PC, PES, PSU. |

# Table 16. APPROXIMATE PRICE OF MATERIALS RELATIVE TO A GENERAL GRADE OF ABS (GPABS = 1.00)

| **Full Name** | **Abb.** | **Natural Compound** | |
|---|---|---|---|
| Acetal | POM | Homopolymer | 1.20 |
| | | Copolymer | 1.19 |
| | | Super tough grade | 1.61 |
| Acrylonitrile butadiene styrene | ABS | GP grade | 1.00 |
| | | Heat resistant grade | 1.05 |
| | | High impact grade | 1.02 |
| | | Transparent grade | 1.22 |
| Acrylate styrene acrylontrile | ASA | GP grade | 1.03 |
| | | Heat resistant | 0.99 |
| | | High impact | 1.03 |
| Butadiene styrene copolymer | BDS | GP grade | 0.85 |
| | | Easy flow | 0.85 |
| Cellulose acetate | CA | GP grade | 1.13 |
| Ethylene vinyl acetate | EVA | GP grade (5% VA content) | 0.35 |
| Fluorinated ethylene propylene | FEP | Standard grade | 8.90 |
| High density polyethylene | HDPE | Easy flow grade | 0.35 |
| | | Medium flow grade | 0.35 |
| | | GP grade | 0.35 |
| | | Stiff flow grade | 0.36 |
| High impact polystyrene | HIPS/TPS | GP grade | 0.44 |
| | | Heat resistant | 0.44 |
| | | Transparent | 0.67 |
| Linear low density polyethylene | LDPE | GP grade | 0.35 |
| Low density polyethylene | LDPE | Easy flow grade | 0.35 |
| | | Medium flow grade | 0.35 |
| | | Stiff flow grade | 0.35 |
| Nylon 6 | PA 6 | Standard grade | 1.44 |
| | | 30% reinforced grade | 1.48 |
| Nylon 66 | PA 66 | Standard grade | 1.46 |
| | | 30% reinforced grade | 1.51 |
| Nylon 11/12 | PA 11/12 | Standard grade | 2.64 |

| | | | |
|---|---|---|---|
| Plasticized polyvinyl chloride | PPVC | GP grade | 0.34 to 0.38 |
| | | Medical grade | 0.51 to 0.63 |
| Polyarylamide | PAMXD6 | 30% reinforced grade | 1.73 |
| | | 50% reinforced grade | 1.54 |
| | | High impact grade | 1.84 |
| Polybutylene terephthalate | PBT | Standard grade | 1.20 |
| | | 30% reinforced grade | 1.50 |
| Polycarbonate | PC | Standard grade | 1.49 |
| | | 30% reinforced grade | 1.74 |
| Polyetherimide | PEI | Standard grade | 7.30 |
| | | 10% reinforced grade | 7.30 |
| | | 20% reinforced grade | 7.30 |
| Polyether ether ketone | PEEK | Standard grade | 22.30 |
| | | 20% reinforced grade | 20.02 |
| Polyethylene terephthalate | PETP | 30% reinforced grade | 1.10 |
| | | Mineral and glass reinforced grade | 1.10 |
| | | Super tough grade | 1.50 |
| | PETG | Standard grade | 1.00 |
| Polyphenylene oxide | PPO-M | Standard grade | 1.30 |
| | | 30% reinforced grade | 1.60 |
| Polyphenylene sulphide | PPS | 40% reinforced grade | 3.70 |
| | | Mineral and glass reinforced grade | 2.40 |
| Polypropylene | PP | Homopolymer GP grade | 0.34 |
| Polystyrene | PS/GPPS | GP grade | 0.42 |
| Polyvinylidene flouride | PVDF | Standard grade | 5.24 |
| Rubber modified polypropylene | PP-EPDM | Easy flow grade Copolymer | 0.35 |
| | | GP grade | 0.37 |
| | | Automotive bumper grade | 0.57 |
| Styrene acrylonitrile | SAN | GP grade | 0.75 |
| | | Heat resistant | 0.85 |
| | | 35% reinforced | 0.92 |
| Sulphone polymers | PSU | Standard grade | 4.00 |
| | | 30% reinforced grade | 3.30 |
| | | Standard grade of mindel | 2.30 |
| Unplasticized polyvinyl chloride | UPVC | Pipe fitting grade | 0.48 |
| | | High performance grade | 0.65 |

# Table 17. DENSITIES AND APPROXIMATE COSTS OF MATERIALS

| Abbreviation | Specific Gravity | Specific volume cc/g | oz/cu in | Approx. Cost p/g | c/cu in |
|---|---|---|---|---|---|
| ABS | 1.07 | 0.935 | 0.619 | 0.209 | 5.864 |
| ASA | 1.07 | 0.935 | 0.619 | 0.214 | 6.004 |
| CA | 1.26 to 1.30 | 0.769 to 0.794 | 0.728 to 0.752 | 0.236 | 7.797 to 8.044 |
| CAB | 1.15 to 1.21 | 0.826 to 0.870 | 0.665 to 0.670 | 0.276 | 8.322 to 8.756 |
| CAP | 1.18 to 1.23 | 0.813 to 0.847 | 0.682 to 0.711 | 0.276 | 8.539 to 8.901 |
| EVA | 0.926 to 0.95 | 1.05 to 1.08 | 0.54 to 0.55 | 0.72 to 0.99 | 17.48 to 24.66 |
| FEP | 2.12 | 0.472 | 1.226 | 1.64 | 91.17 |
| GPPS | 1.04 to 1.06 | 0.943 to 0.962 | 0.601 to 0.613 | 0.088 | 2.399 to 2.446 |
| HDPE | 0.94 to 0.965 | 1.04 to 1.06 | 0.54 to 0.56 | 0.72 to 0.76 | 17.74 to 19.23 |
| HIPS | 1.05 to 1.08 | 0.952 to 0.926 | 0.607 to 0.624 | 0.092 | 2.533 to 2.605 |
| LDPE | 0.92 | 1.09 | 0.53 | 0.72 to 0.74 | 17.36 to 17.85 |
| LLDPE | 0.90 to 0.94 | 1.06 to 1.11 | 0.52 to 0.54 | 0.86 | 20.29 to 21.19 |
| PA 6 | 1.13 | 0.885 | 0.653 | 0.27 | 8.00 |
| 30% GF | 1.35 | 0.741 | 0.780 | 0.30 | 10.62 |
| PA 11 | 1.04 | 0.962 | 0.601 | 0.49 | 13.36 |
| PA 12 | 1.02 | 0.980 | 0.590 | 0.49 | 13.36 |
| PA 66 | 1.15 | 0.870 | 0.665 | 0.27 | 8.14 |
| 30% GF | 1.35 | 0.741 | 0.780 | 0.31 | 10.97 |
| PAMXD6 | | | | | |
| 30% GF | 1.42 | 0.704 | 0.821 | 0.32 | 11.92 |
| PBT | 1.31 | 0.763 | 0.757 | 0.25 | 8.59 |
| PC | 1.21 | 0.826 | 0.700 | 0.27 | 8.57 |
| 30% GF | 1.43 | 0.699 | 0.827 | 0.33 | 12.43 |
| PEI | 1.27 | 0.787 | 0.734 | 1.03 | 34.30 |
| PEEK | 1.30 | 0.769 | 0.752 | 41.27 | 1406.72 |
| PES | 1.37 | 0.730 | 0.792 | 1.02 | 36.64 |
| PET-A | 1.34 | 0.746 | 0.775 | 0.18 | 6.32 |
| PET-C | 1.38 | 0.725 | 0.798 | 0.21 | 7.60 |
| PMMA | 1.18 | 0.847 | 0.682 | 0.165 | 5.105 |

| | | | | | |
|---|---|---|---|---|---|
| POM-H | 1.43 | 0.699 | 0.827 | 0.22 | 8.25 |
| POM-K | 1.41 | 0.709 | 0.815 | 0.22 | 8.13 |
| PP | 0.90 | 1.11 | 0.52 | 0.71 to 0.77 | 16.75 to 18.17 |
| PP-EPDM | 0.86 to 0.90 | 1.11 to 1.16 | 0.50 to 0.52 | 1.20 | 27.05 to 28.31 |
| PPO-M | 1.06 | 0.943 | 0.613 | 0.23 | 6.39 |
| PPS 40% GF | 1.60 | 0.625 | 0.925 | 0.68 | 28.53 |
| PSU | 1.24 | 0.806 | 0.717 | 0.74 | 24.06 |
| PVDF | 1.78 | 0.562 | 1.029 | 0.97 | 45.28 |
| PPVC | 1.25 to 1.65 | 0.61 to 0.80 | 0.72 to 0.95 | 0.70 to 1.32 | 22.94 to 57.11 |
| SAN | 1.08 | 0.926 | 0.624 | 0.157 | 4.446 |
| UPVC | 1.34 to 1.45 | 0.69 to 0.75 | 0.77 to 0.84 | 0.99 to 1.36 | 34.78 to 51.70 |

As plastics materials are bought by weight and sold by volume (in the form of moldings) then, any material with a low density, or specific gravity (SG), has a tremendous advantage. Often therefore, the cost per unit volume is more important than the cost per unit weight. To convert to the cost in cents per cubic inch (c/cu in), multiply the cost per pound (lb) in cents by the SG and then, by 0.0361. Note that, the density in g/cc has the same numerical value as the SG.

To obtain density in oz/cu in. multiply g/cc by 0.5781.

To obtain density in lbs/cu in. multiply g/cc by 0.0361.

The conversions from one currency to another were obtained by assuming that there are 1.60 dollars to the pound sterling.

That is, \$1.60 = £1.00, or 160 cents = 100 pence (p) or 1.60c = 1p.

So, for example, to convert from p/g to c/g multiply the p/g by the currency conversion factor, for example, 1.60 in this case.

To convert from p/g to c/cu.in: first convert to p/lb by multiplying by 454 (454g = 1lb), then to obtain c/lb multiply p/lb by, the currency conversion factor, for example, 1.60 in this case. To convert the cost in cents per cubic inch (c/cu in), multiply the cost per pound (lb) in cents (c) by the SG and then, by 0.0361.

That is:

p/g x 454 x 1.60 x 0.0361 x SG = c/cu.in

p/g x 26.22 x SG = c/cu in.

# Table 18a. MATERIAL PROPERTIES

| | Property | Units | ASTM | SAN<br>Unfilled | SAN<br>20% GF | ASA<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 10,000-12,000 | 15,000-18,000 | 4,000-5,000 |
| 2 | Elongation at break | % | D638 | 2-3 | 1.2-1.8 | 20-40 |
| 3 | Tensile yield strength | psi | D638 | 10,000-12,000 | - | 5,200-6,000 |
| 4 | Compressive strength | psi | D695 | 14,000-15,000 | 17,000-15,000 | 21,000 |
| 5 | Flexural strength | psi | D790 | 11,000-15,000 | 20,000-23,000 | 6,000-8,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 480-560 | 1,200-1,700 | - |
| 7 | Compressive modulus | $10^3$psi | D695 | 530-580 | - | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 500-580 | 1,000-1,300 | 200-250 |
| 9 | Izod impact strength | 'a' | D256A | 0.4-0.6 | 1.0-3 | 8.0-10.0 |
| 10a | Hardness - Rockwell | | D785 | R85 | R12 | R85 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 65-68 | 20-40 | 60 |
| 12a | HDT 264psi | °C | D648 | 101-104 | 99-110 | 85-88 |
| | | °F | D648 | 215-220 | 210-230 | 185-190 |
| 12b | HDT 66psi | °C | D648 | 104-107 | 104 | 93-99 |
| | | °F | D648 | 220-225 | 220 | 200-210 |
| 13 | Thermal conductivity | 'c' | C177 | 3 | 6.6 | - |
| 14 | $T_g$ - when amorphous | °C | - | 120 | 120 | - |
| | | °F | - | 248 | 248 | - |
| 14b | $T_m$ - when crystalline | °C | - | - | - | - |
| | | °F | - | - | - | - |
| 15 | Linear shrinkage | in/in | D955 | 0.004-0.007 | 0.001-0.003 | 0.004-0.007 |
| 16 | Specific gravity | - | D792 | 1.06-1.08 | 1.22-1.4 | 1.06-1.07 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.15-0.25 | 0.1-0.2 | 0.03 |
| 17b | Saturation water abs | % | D570 | 0.5 | 0.7 | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 425 | 500 | - |

**Notes**

| | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| **'d'** | water absorption tests performed with 0.125 in specimines |

# Table 18b. MATERIAL PROPERTIES

| | Property | Units | ASTM | ABS<br>Unfilled | ABS<br>20% GF | PMMA<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 4,400-7,500 | 10,500-13,000 | 7,000-11,000 |
| 2 | Elongation at break | % | D638 | 5-73 | 2-3 | 2-10 |
| 3 | Tensile yield strength | psi | D638 | 2,600 | - | - |
| 4 | Compressive strength | psi | D695 | 2,000-12,000 | 13,000-14,000 | 10,000-18,000 |
| 5 | Flexural strength | psi | D790 | 5,500-13,000 | 14,000-17,500 | 10,500-19,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 150-400 | 700-900 | 300-50 |
| 7 | Compressive modulus | $10^3$psi | D695 | 140-540 | 800 | 350-450 |
| 8 | Flexural modulus | $10^3$psi | D790 | 175-400 | 650-800 | 300-450 |
| 9 | Izod impact strength | 'a' | D256A | 3-9 | 1.0-1.3 | 0.3-0.6 |
| 10a | Hardness - Rockwell | | D785 | R85-115 | R107 | M65-105 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 80-110 | 20 | 50-90 |
| 12a | HDT 264psi | °C | D648 | 93-104 | 99-104 | 71-99 |
| | | °F | D648 | 200-220 | 210-220 | 160-210 |
| 12b | HDT 66psi | °C | D648 | 99-104 | 104-110 | 77-110 |
| | | °F | D648 | 210-220 | 220-230 | 170-230 |
| 13 | Thermal conductivity | 'c' | C177 | - | 4-5 | 4-6 |
| 14 | $T_g$ - when amorphous | °C | - | 90-115 | 100-110 | 85-105 |
| | | °F | - | 194-239 | 212-230 | 185-221 |
| 14b | $T_m$ - when crystalline | °C | - | - | - | - |
| | | °F | - | - | - | - |
| 15 | Linear shrinkage | in/in | D955 | 0.004-0.008 | 0.001-0.002 | 0.004-0.007 |
| 16 | Specific gravity | - | D792 | 1.01-1.07 | 1.18-1.22 | 1.17-1.2 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.2-0.4 | 0.19 | 0.1-0.3 |
| 17b | Saturation water abs | % | D570 | - | - | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 350-500 | 450 | 400-500 |

**Notes**

| | |
|---|---|
| 'a' | foot pounds per inch of notch: 0.125 in specimines used |
| 'b' | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| HDT | stands for heat deflection temperature, or deflection temperature under flexural load |
| 'c' | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| 'd' | water absorption tests performed with 0.125 in specimines |

# Table 18c. MATERIAL PROPERTIES

| | Property | Units | ASTM | CA<br>Unfilled | CAB<br>20% GF | CAP<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 2,000-9,000 | 2,500-7,000 | 2,000-8,000 |
| 2 | Elongation at break | % | D638 | 5-70 | 40-90 | 30-100 |
| 3 | Tensile yield strength | psi | D638 | - | - | - |
| 4 | Compressive strength | psi | D695 | 3,000-8,000 | 2,000-7,500 | 2,500-7,000 |
| 5 | Flexural strength | psi | D790 | 2,000-16,000 | 2,000-9,500 | 3,000-11,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | - | 50-200 | 50-200 |
| 7 | Compressive modulus | $10^3$psi | D695 | - | - | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 1,000-4,000 | 100-300 | 120-350 |
| 9 | Izod impact strength | 'a' | D256A | 1-8 | 1-11 | 0.5-N.B. |
| 10a | Hardness - Rockwell | | D785 | R35-125 | R30-117 | R10-120 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 80-180 | 110-170 | 110-170 |
| 12a | HDT 264psi | °C | D648 | 43-93 | 43-93 | 43-110 |
| | | °F | D648 | 110-200 | 110-200 | 110-230 |
| 12b | HDT 66psi | °C | D648 | 49-99 | 54-110 | 66-121 |
| | | °F | D648 | 120-210 | 130-230 | 150-250 |
| 13 | Thermal conductivity | 'c' | C177 | 4-8 | 4-8 | 4-8 |
| 14 | $T_g$ - when amorphous | °C | - | - | - | - |
| | | °F | - | - | - | - |
| 14b | $T_m$ - when crystalline | °C | - | 230 | 140 | 190 |
| | | °F | - | 446 | 284 | 374 |
| 15 | Linear shrinkage | in/in | D955 | 0.003-0.01 | 0.003-0.009 | 0.003-0.009 |
| 16 | Specific gravity | - | D792 | 1.22-1.34 | 1.15-1.22 | 1.18-1.23 |
| 17a | Water abs. in 24h | (d) % | D570 | 1.7-6.4 | 1-2 | 1-3 |
| 17b | Saturation water abs | % | D570 | - | - | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 250-600 | 250-400 | 400-450 |

**Notes**

| | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| **'d'** | water absorption tests performed with 0.125 in specimines |

# Table 18d. MATERIAL PROPERTIES

| | Property | Units | ASTM | ABS<br>Medium Impact | ABS<br>Heat Resistant | FEP<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 5,500-8,000 | 5,000-7,500 | 2,700-3,500 |
| 2 | Elongation at break | % | D638 | 5-25 | 3-30 | 250-330 |
| 3 | Tensile yield strength | psi | D638 | 5,000-6,400 | 4,300-6,800 | - |
| 4 | Compressive strength | psi | D695 | 1,800-12,500 | 7,200-10,000 | 2,200 |
| 5 | Flexural strength | psi | D790 | 7,000-13,000 | 9,500-13,000 | - |
| 6 | Tensile modulus | $10^3$psi | D638 | 300-400 | 300-358 | 50 |
| 7 | Compressive modulus | $10^3$psi | D695 | 200-450 | 190-440 | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 310-400 | 300-400 | 80-95 |
| 9 | Izod impact strength | 'a' | D256A | 3-6 | 2-7 | No break |
| 10a | Hardness - Rockwell | | D785 | R107-R115 | R100-115 | - |
| 10b | Hardness - Shore | | D2240 | - | - | D60-D65 |
| 11 | Thermal expansion | 'b' | D696 | 80-100 | 60-93 | - |
| 12a | HDT 264psi | °C | D648 | 93-104 | 104-115 | - |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 100-107 | 110-119 | 160 |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | - | 4.5-8 | 6 |
| 14 | $T_g$ - when amorphous | °C | - | 102-115 | 110-115 | - |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | - | - | 275 |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.004-0.008 | 0.004-0.009 | 0.03-0.06 |
| 16 | Specific gravity | - | D792 | 1.02-1.06 | 1.05-1.08 | 2.12-2.17 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.20-0.45 | 0.2-0.45 | <0.01 |
| 17b | Saturation water abs | % | D570 | - | - | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 300-500 | 300-500 | 500-600 |

| Notes | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| **'d'** | water absorption tests performed with 0.125 in specimines |

# Table 18e. MATERIAL PROPERTIES

| | Property | Units | ASTM | PA 12 (Dry) | PA 66 (Dry) | PA 66 Conditioned |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 7,300-9,000 | 12,000 | 11,000 |
| 2 | Elongation at break | % | D638 | 250-350 | 50-60 | 150-300 |
| 3 | Tensile yield strength | psi | D638 | 5,800-6,100 | 8,000 | 6,500 |
| 4 | Compressive strength | psi | D695 | - | 15,000 | - |
| 5 | Flexural strength | psi | D790 | 7,600-8,100 | 17,000 | 6,100 |
| 6 | Tensile modulus | $10^3$psi | D638 | 180 | 230 | 500 |
| 7 | Compressive modulus | $10^3$psi | D695 | - | - | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 120-190 | 420 | 185 |
| 9 | Izod impact strength | 'a' | D256A | 1.7-6.7 | 0.6-1.0 | 0.9-2.0 |
| 10a | Hardness - Rockwell | | D785 | R105-109 | R119 | M83 |
| 10b | Hardness - Shore | | D2240 | D72-75 | - | - |
| 11 | Thermal expansion | 'b' | D696 | 61-100 | 80 | 80 |
| 12a | HDT 264psi | °C | D648 | 50-55 | 74 | - |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 145-150 | 245 | - |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 5.2-7.3 | 5.8 | 5.8 |
| 14 | $T_g$ - when amorphous | °C | - | 125-155 | - | - |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | 176-179 | 265 | 265 |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.003-0.015 | 0.008-0.015 | 0.008-0.015 |
| 16 | Specific gravity | - | D792 | 1.01-1.02 | 1.13-1.15 | 1.13-1.15 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.25-0.23 | 1.0-2.8 | 1.0-2.8 |
| 17b | Saturation water abs | % | D570 | 0.75-0.9 | 8.5 | 8.5 |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 450 | 600 | - |

**Notes**

| | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of 10-6 in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are 10-4 cal-cm/sec-cm2 |
| **'d'** | water absorption tests performed with 0.125 in specimines |

## Table 18f. MATERIAL PROPERTIES

| | Property | Units | ASTM | PA 6<br>Dry | PA 6<br>Conditioned | PA 11<br>Dry |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | - | - | 8,000 |
| 2 | Elongation at break | % | D638 | 30-100 | 300 | 300 |
| 3 | Tensile yield strength | psi | D638 | 11,700 | 7,500 | - |
| 4 | Compressive strength | psi | D695 | 13,000-16,000 | - | - |
| 5 | Flexural strength | psi | D790 | 15,700 | 5,800 | - |
| 6 | Tensile modulus | $10^3$psi | D638 | 380 | 100 | 185 |
| 7 | Compressive modulus | $10^3$psi | D695 | - | 250 | 180 |
| 8 | Flexural modulus | $10^3$psi | D790 | 390 | 140 | 150 |
| 9 | Izod impact strength | 'a' | D256A | 0.6-1.0 | 3.0 | 1.8 |
| 10a | Hardness - Rockwell | | D785 | R119 | - | R108 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 80-83 | - | 100 |
| 12a | HDT 264psi | °C | D648 | 68-85 | - | 54 |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 185-191 | - | 150 |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 5.8 | - | 8 |
| 14 | $T_g$ - when amorphous | °C | - | - | - | - |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | 210-220 | 210-220 | 189-194 |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.005-0.015 | 0.005-0.015 | 0.012 |
| 16 | Specific gravity | - | D792 | 1.12-1.14 | 1.12-1.14 | 1.03-1.05 |
| 17a | Water abs. in 24h | (d) % | D570 | 1.3-1.9 | 1.3-1.9 | 0.3 |
| 17b | Saturation water abs | % | D570 | 8.5-10 | 8.5-10 | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 400 | - | 425 |

**Notes**

**'a'** foot pounds per inch of notch: 0.125 in specimines used

**'b'** thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C

**HDT** stands for heat deflection temperature, or deflection temperature under flexural load

**'c'** the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$

**'d'** water absorption tests performed with 0.125 in specimines

## Table 18g. MATERIAL PROPERTIES

| | Property | Units | ASTM | PBT Unfilled | PC Unfilled | PEEK Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 8,200 | 9,500 | 10,200-15,000 |
| 2 | Elongation at break | % | D638 | 50-300 | 110 | 30-150 |
| 3 | Tensile yield strength | psi | D638 | 8,200-8,700 | 9,000 | 13,200 |
| 4 | Compressive strength | psi | D695 | 8,600-14,000 | 12,000 | 18,000 |
| 5 | Flexural strength | psi | D790 | 12,000-16,700 | 13,500 | 16,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 280-435 | 345 | - |
| 7 | Compressive modulus | $10^3$psi | D695 | - | 350 | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 330-400 | 340 | 560 |
| 9 | Izod impact strength | 'a' | D256A | 0.6-1.0 | 14-16 | 1.6 |
| 10a | Hardness - Rockwell | | D785 | M68-78 | M70 | - |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 60-93 | 68 | 50 |
| 12a | HDT 264psi | °C | D648 | 50-85 | 132 | 160 |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 116-191 | 138 | - |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 4.2-6.9 | 4.7 | - |
| 14 | $T_g$ - when amorphous | °C | - | - | 140-150 | - |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | 220-267 | 334 | 334 |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.009-0.022 | 0.005-0.007 | 0.011 |
| 16 | Specific gravity | - | D792 | 1.3-1.4 | 1.2 | 1.31 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.08-0.09 | 0.15 | 0.1-0.14 |
| 17b | Saturation water abs | % | D570 | 0.4-0.5 | 0.32 | 0.5 |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 420-550 | 380 | - |

**Notes**

| | |
|---|---|
| 'a' | foot pounds per inch of notch: 0.125 in specimines used |
| 'b' | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| HDT | stands for heat deflection temperature, or deflection temperature under flexural load |
| 'c' | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| 'd' | water absorption tests performed with 0.125 in specimines |

# Table 18h. MATERIAL PROPERTIES

| | Property | Units | ASTM | PEI<br>Unfilled | PES<br>20% GF | PET<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 14,000 | 17,400-20,000 | 7,000-10,500 |
| 2 | Elongation at break | % | D638 | 10-60 | 2-3.5 | 30-300 |
| 3 | Tensile yield strength | psi | D638 | 15,200 | 18,000-19,000 | - |
| 4 | Compressive strength | psi | D695 | 20,000 | 19,500-24,000 | 11,000-15,000 |
| 5 | Flexural strength | psi | D790 | 21,000 | 24,500-27,700 | 14,000-18,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 380-430 | 850 | 400-600 |
| 7 | Compressive modulus | $10^3$psi | D695 | 420 | - | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 430-480 | 850-880 | 350-450 |
| 9 | Izod impact strength | 'a' | D256A | 1.0-1.2 | 1.2-1.7 | 0.25-0.7 |
| 10a | Hardness - Rockwell | | D785 | M109 | M98 | M94-101 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 47-56 | 23-32 | 65 |
| 12a | HDT 264psi | °C | D648 | 195-200 | 208-218 | 21-38 |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 206-210 | 210-216 | - |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 1.6 | - | 3.3-3.6 |
| 14 | $T_g$ - when amorphous | °C | - | 216 | 220-225 | 73-80 |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | - | - | 245-265 |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.005-0.007 | 0.002-0.006 | 0.021-0.25 |
| 16 | Specific gravity | - | D792 | 1.27-1.33 | 1.51 | 1.29-1.4 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.25 | 0.15-0.4 | 0.1-0.2 |
| 17b | Saturation water abs | % | D570 | 1.25 | 1.65-2.1 | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 480 | 375-500 | - |

**Notes**

**'a'** foot pounds per inch of notch: 0.125 in specimines used

**'b'** thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C

**HDT** stands for heat deflection temperature, or deflection temperature under flexural load

**'c'** the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$

**'d'** water absorption tests performed with 0.125 in specimines

# Table 18i. MATERIAL PROPERTIES

| | Property | Units | ASTM | POM-H Unfilled | POM-K Unfilled | PPO-M Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 9,700 | - | 7,800-9,500 |
| 2 | Elongation at break | % | D638 | 13-75 | 40.74 | 50-60 |
| 3 | Tensile yield strength | psi | D638 | 9,500-12,000 | 8,800-10,400 | 6,500-9,000 |
| 4 | Compressive strength | psi | D695 | 16,000-18,000 | 16,000 | 12,000-16,500 |
| 5 | Flexural strength | psi | D790 | 13,800 | 13,000 | 8,300-14,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 520 | 410-464 | 340-380 |
| 7 | Compressive modulus | $10^3$psi | D695 | 670 | 450 | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 380-430 | 370-450 | 325-400 |
| 9 | Izod impact strength | 'a' | D256A | 1.2-2.2 | 0.8-1.4 | 4-6 |
| 10a | Hardness - Rockwell | | D785 | M93 | M78-90 | R118 |
| 10b | Hardness - Shore | | D2240 | - | - | - |
| 11 | Thermal expansion | 'b' | D696 | 100 | 61-85 | 33-77 |
| 12a | HDT 264psi | °C | D648 | 126 | 85-120 | 80-130 |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | 166 | 154-166 | 110-138 |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 5.6 | 5.4 | 3.8-5.2 |
| 14 | $T_g$ - when amorphous | °C | - | - | - | 100-140 |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | 175-181 | 163-175 | - |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.018-0.025 | 0.018-0.025 | 0.005-0.008 |
| 16 | Specific gravity | - | D792 | 1.42 | 1.41 | 1.06-1.1 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.25-0.4 | 0.02-0.21 | 0.06-0.12 |
| 17b | Saturation water abs | % | D570 | 1.42 | 0.65-0.8 | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 500 | 500 | 400-700 |

**Notes**

| | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| **'d'** | water absorption tests performed with 0.125 in specimines |

# Table 18j. MATERIAL PROPERTIES

| | Property | Units | ASTM | PPS<br>40% GF | PVdF | PSU30%GF<br>Unfilled |
|---|---|---|---|---|---|---|
| 1 | Tensile strength | psi | D638 | 17,700-23,000 | 5,200-7,500 | 14,800 |
| 2 | Elongation at break | % | D638 | 1-4 | 12-100 | 1.5 |
| 3 | Tensile yield strength | psi | D638 | - | 6,000-8,400 | - |
| 4 | Compressive strength | psi | D695 | 21,000-26,000 | 10,900-14,000 | 19,000 |
| 5 | Flexural strength | psi | D790 | 22,000-32,000 | 9,700-13,700 | 20,000 |
| 6 | Tensile modulus | $10^3$psi | D638 | 1,100 | 220-420 | 1,340 |
| 7 | Compressive modulus | $10^3$psi | D695 | - | 304-420 | - |
| 8 | Flexural modulus | $10^3$psi | D790 | 1,750 | 290-420 | 1,050 |
| 9 | Izod impact strength | 'a' | D256A | 1.1-1.5 | 3 | 1.1 |
| 10a | Hardness - Rockwell | | D785 | R123 | R83 | M90-100 |
| 10b | Hardness - Shore | | D2240 | - | D80 | - |
| 11 | Thermal expansion | 'b' | D696 | 21-45 | 70-142 | 25 |
| 12a | HDT 264psi | °C | D648 | 250-263 | 88-116 | 177 |
| | | °F | D648 | | | |
| 12b | HDT 66psi | °C | D648 | - | 138 | 182 |
| | | °F | D648 | | | |
| 13 | Thermal conductivity | 'c' | C177 | 6.9-10.7 | 2.4-3.1 | - |
| 14 | $T_g$ - when amorphous | °C | - | 88 | -20 to -30 | 190 |
| | | °F | - | | | |
| 14b | $T_m$ - when crystalline | °C | - | 275-291 | 175-178 | - |
| | | °F | - | | | |
| 15 | Linear shrinkage | in/in | D955 | 0.002-0.004 | 0.02-0.03 | 0.001-0.003 |
| 16 | Specific gravity | - | D792 | 1.6-1.67 | 1.78 | 1.46 |
| 17a | Water abs. in 24h | (d) % | D570 | 0.03-0.06 | 0.3 | - |
| 17b | Saturation water abs | % | D570 | - | - | - |
| 18 | Dielectric str. - short time and with 0.125 in samples | v/mil | D149 | 360-450 | 260-280 | - |

**Notes**

| | |
|---|---|
| **'a'** | foot pounds per inch of notch: 0.125 in specimines used |
| **'b'** | thermal expansion means the coefficient of thermal expansion with units of $10^{-6}$ in/in°C |
| **HDT** | stands for heat deflection temperature, or deflection temperature under flexural load |
| **'c'** | the units of thermal conductivity are $10^{-4}$ cal-cm/sec-cm$^2$ |
| **'d'** | water absorption tests performed with 0.125 in specimines |

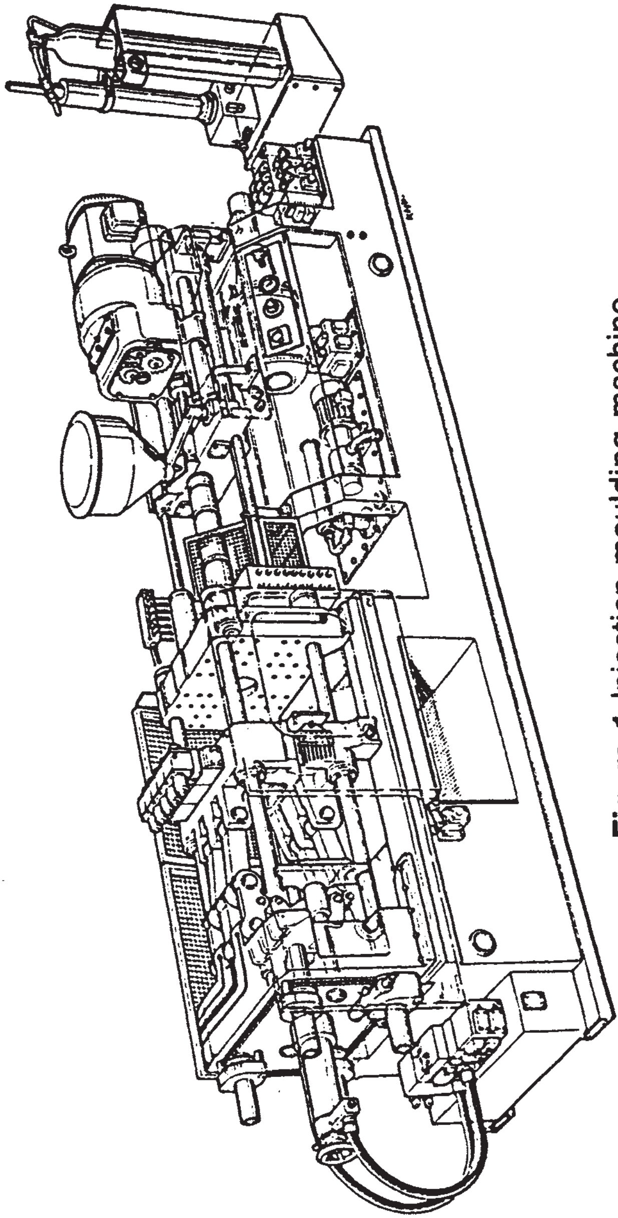
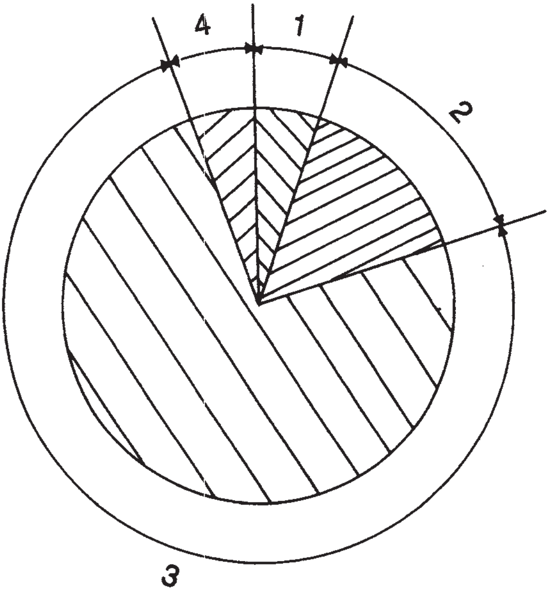


**Figure 1** Injection moulding machine (courtesy Mannesmann Demag Hamilton)

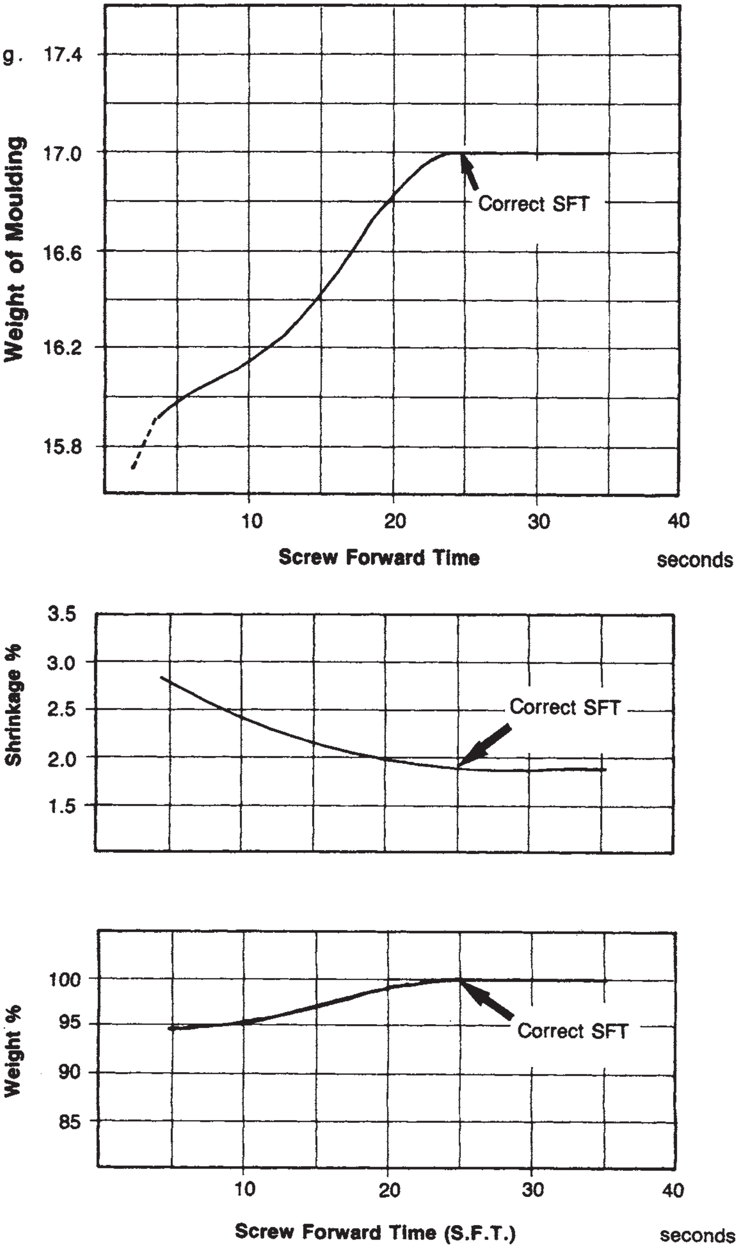
**Figure 2** Moulding cycle breakdown

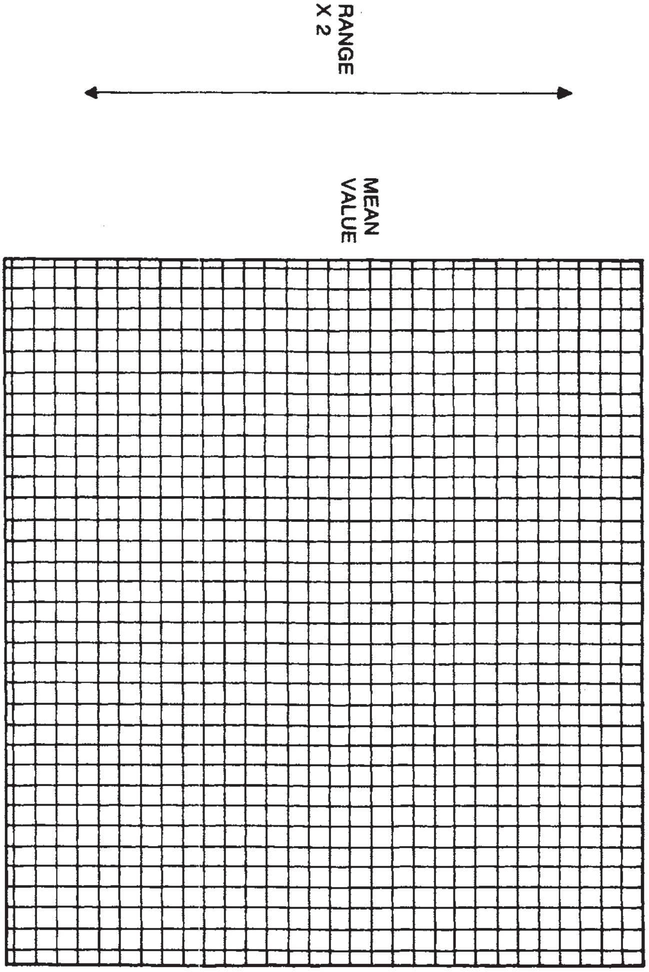


| **SECTIONS** | **% OF TOTAL CYCLE** |
|---|---|
| 1 MOULD CLOSE | 1 – 5% (4) |
| 2 INJECTION TIME | 5 – 25% (15) |
| 3 COOLING TIME | 50 – 85% (75) |
| 4 COMPONENT EJECTION AND MOULD OPEN TIME | 5 – 10% (6) |

FIGURES IN BRACKETS ARE TYPICAL VALUES

**Figure 3** Relationship between component weight and SFT





Enter the individual values in the appropriate empty box closest to the left hand vertical axis.

Figure 4 Check on normal distribution

# **Figure 5** Process control chart

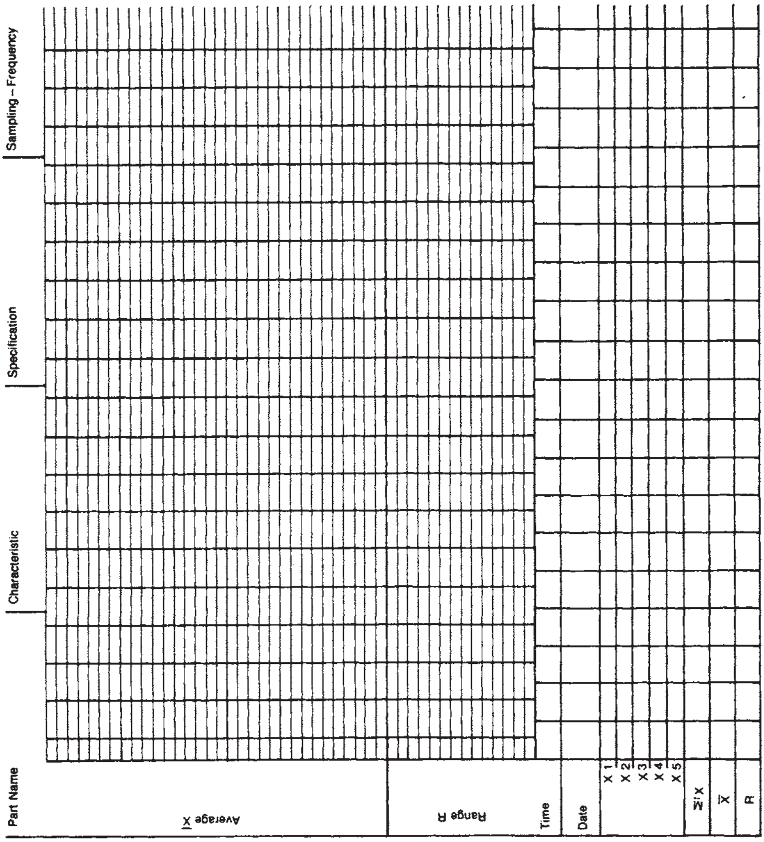
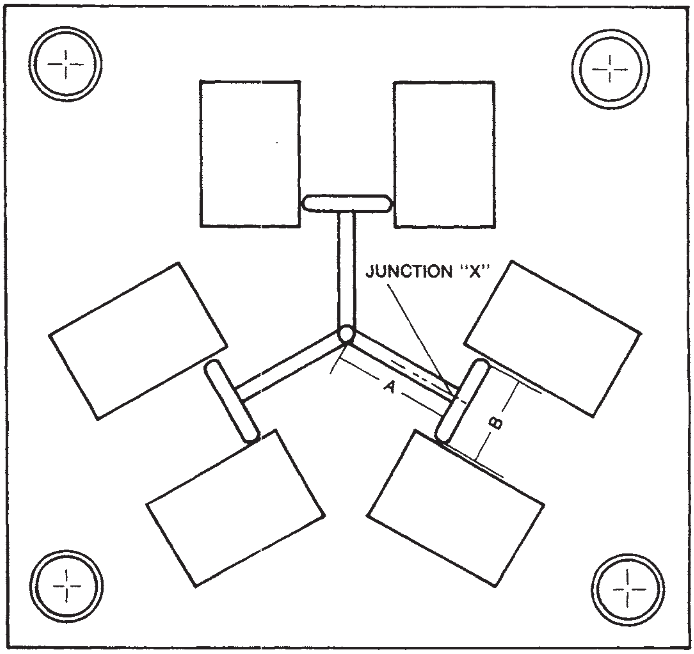


**Figure 6** Proposed mold layout for cover molding



RUNNER LENGTH
A = 5.2cm (Primary)
B = 3.7cm (Secondary)
RUNNER DIAMETER = 6mm

## SECONDARY RUNNER SECTION

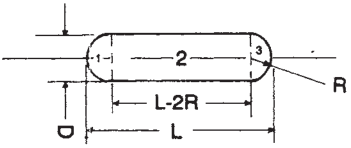


**Figure 7** Mold cavity pressure:
Wall thickness graph

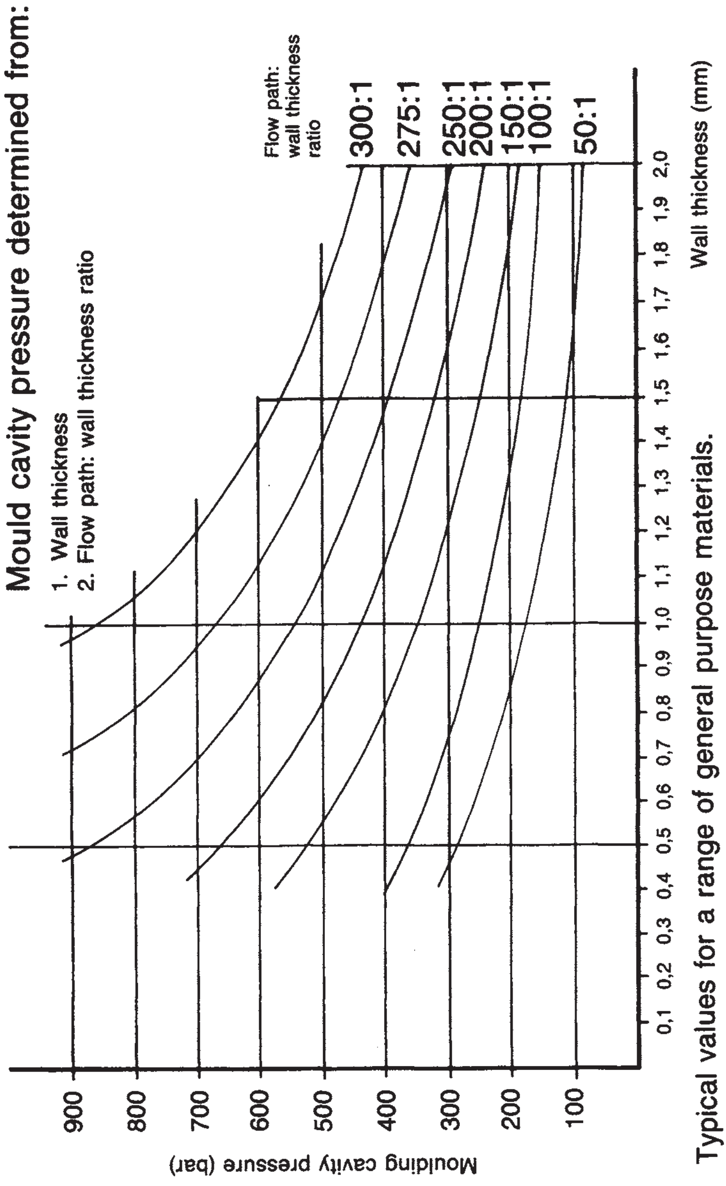


**Figure 8** Diagram of a cover molding

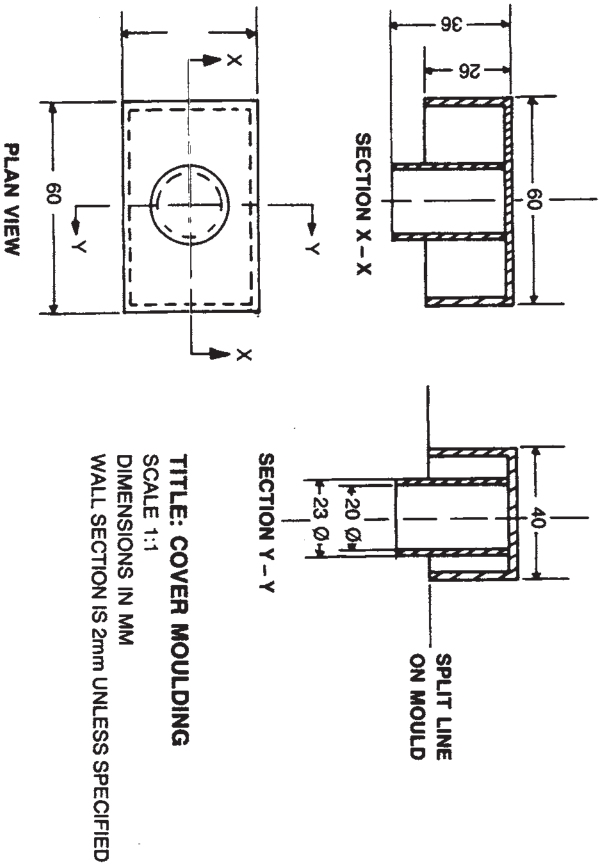


**Figure 9** Diagram of a cover molding showing different gating positions

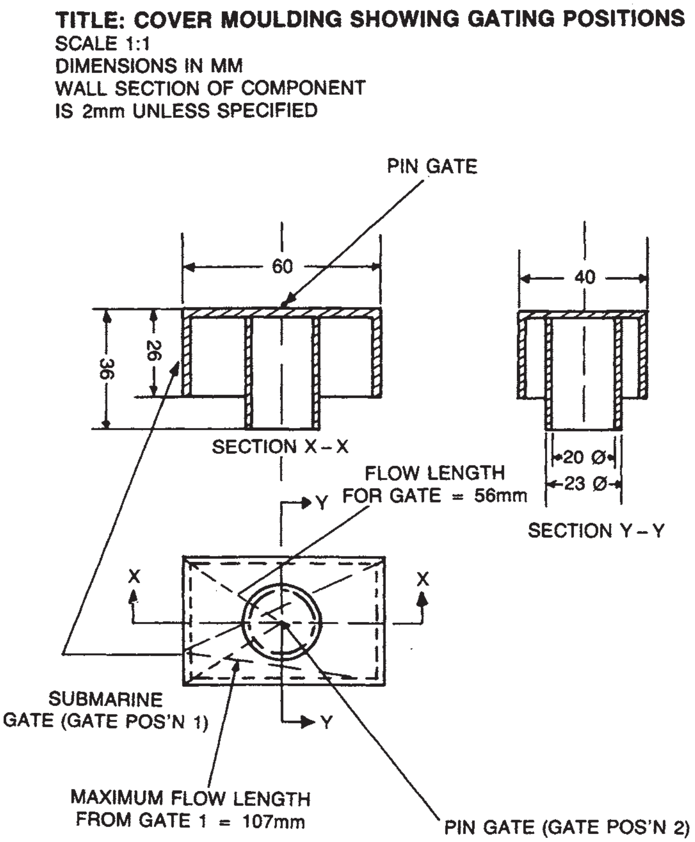
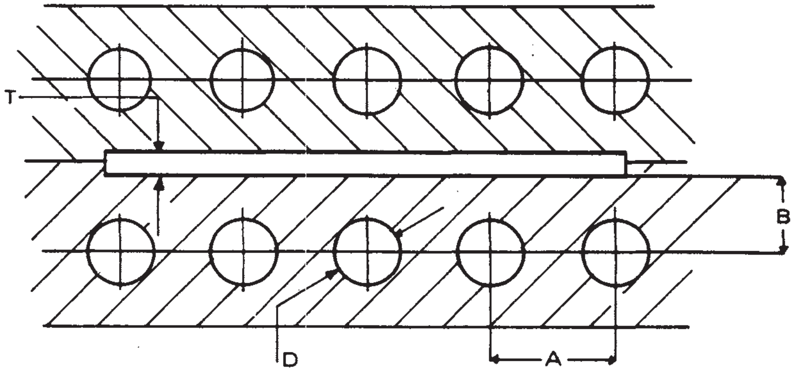


**Figure 10** Recommended cooling channel diameters and distances for various component wall sections



| Part thickness mm 'T' | Channel diameter mm 'D' |
|---|---|
| 2 | 8 – 10 |
| 4 | 10 – 12 |
| 5 | 12 – 15 |

Dimension 'B' (part wall – channel centre):
'D' x 2 – 3 (maximum)
Dimension 'A' (channel spacing): 'D' x 3 (maximum)
Extracted from: Venting and Cooling by JB Smith

**Figure 11** Dimensional drawings of Dynisco transducers
(all dimensions in inches)

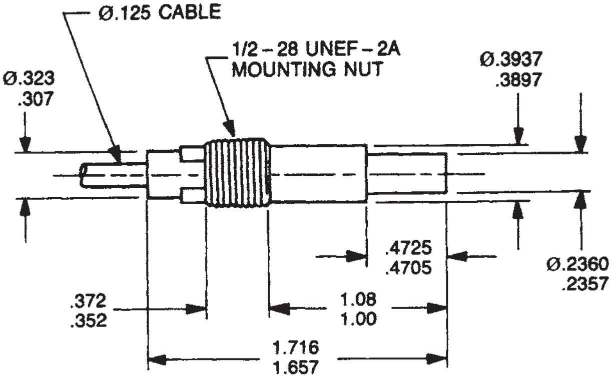


**Figure 11a** Direct cavity presure transducer PT449
(with free turning captive nut)

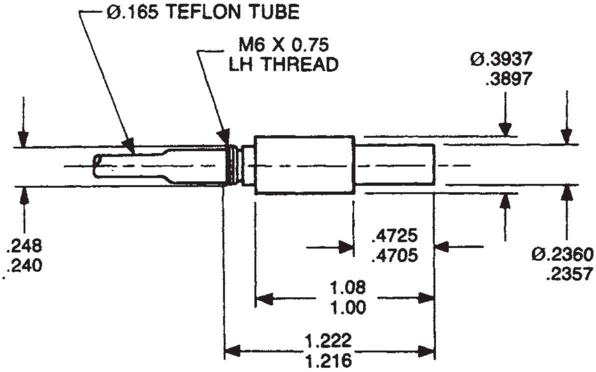


**Figure 11b** Direct cavity pressure transducer PT449
(with free turning captive nut removed for compressive sleeve mounting)

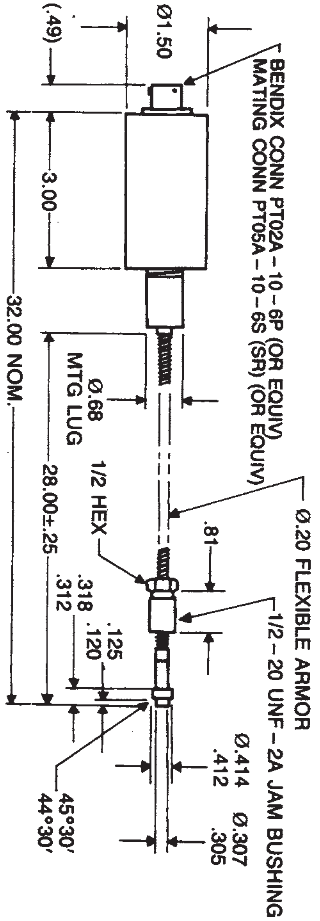


Figure 11c Nozzle pressure tranducer (PT465XL)

**Figure 12** Installation details for Dynisco transducers (all dimensions in inches)

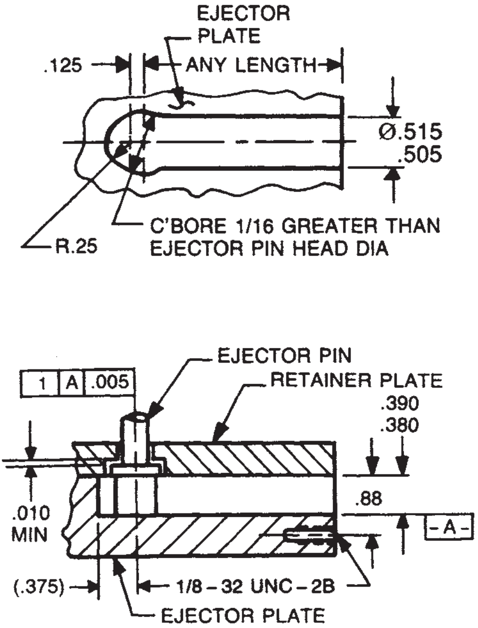


**Figure 12a** Indirect pressure transducer FT444 DH

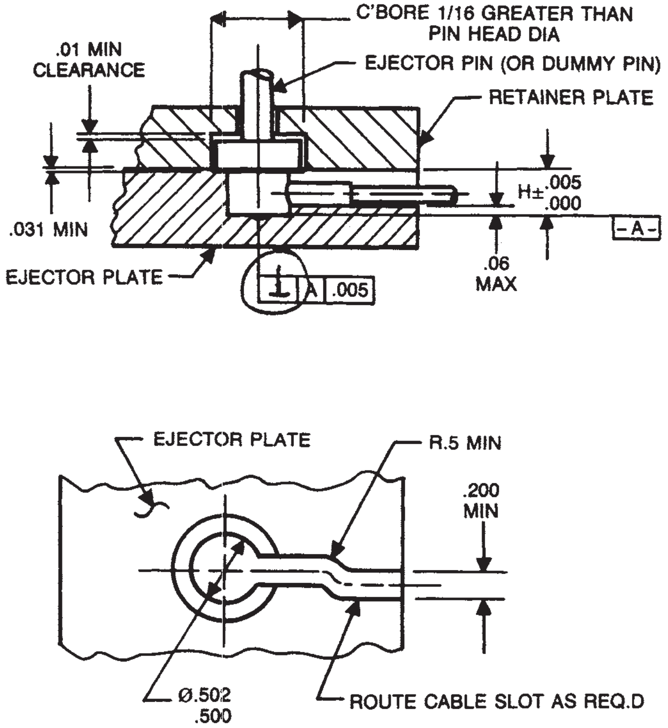


**Figure 12b** Indirect pressure transducers FT445 H, FT446 H and FT446 HM

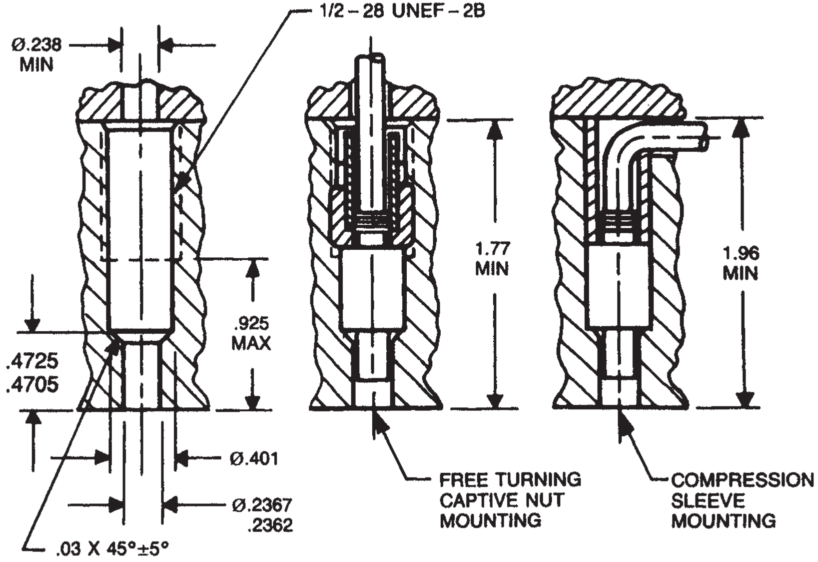
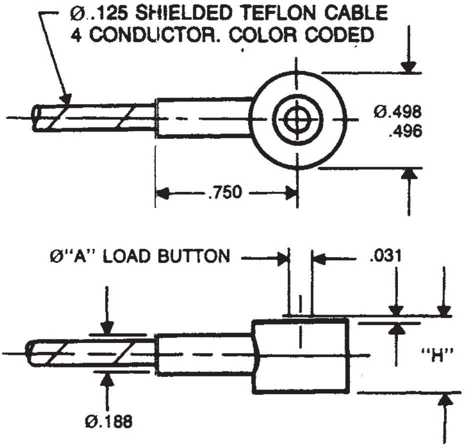


**Figure 12c** Direct cavity pressure transducer PT449



| RANGE (PSI) | Ø"A" | "H" |
|---|---|---|
| 0 – 50 | .125 | .375 |
| 0 – 100 | | |
| 0 – 250 | | |
| 0 – 550 | | |
| 0 – 1000 | | |
| 0 – 2200 | .156 | .438 |

**Figure 12d** Indirect cavity pressure transducers FT445H, FT446H and FT446HM

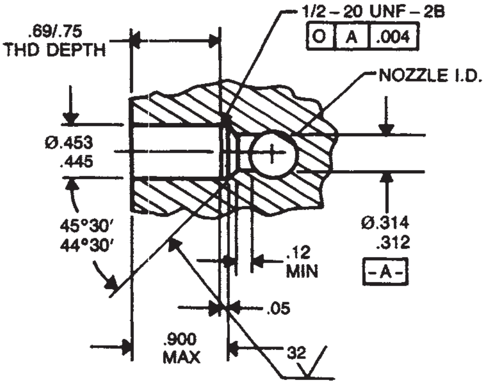


**Figure 12e** Mounting Hole dimensions for nozzle pressure transducer PT465XL