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MOULD DESIGN AND MOULD MANUFACTURE

Paper prepared for the Industrial Operations Technology Division

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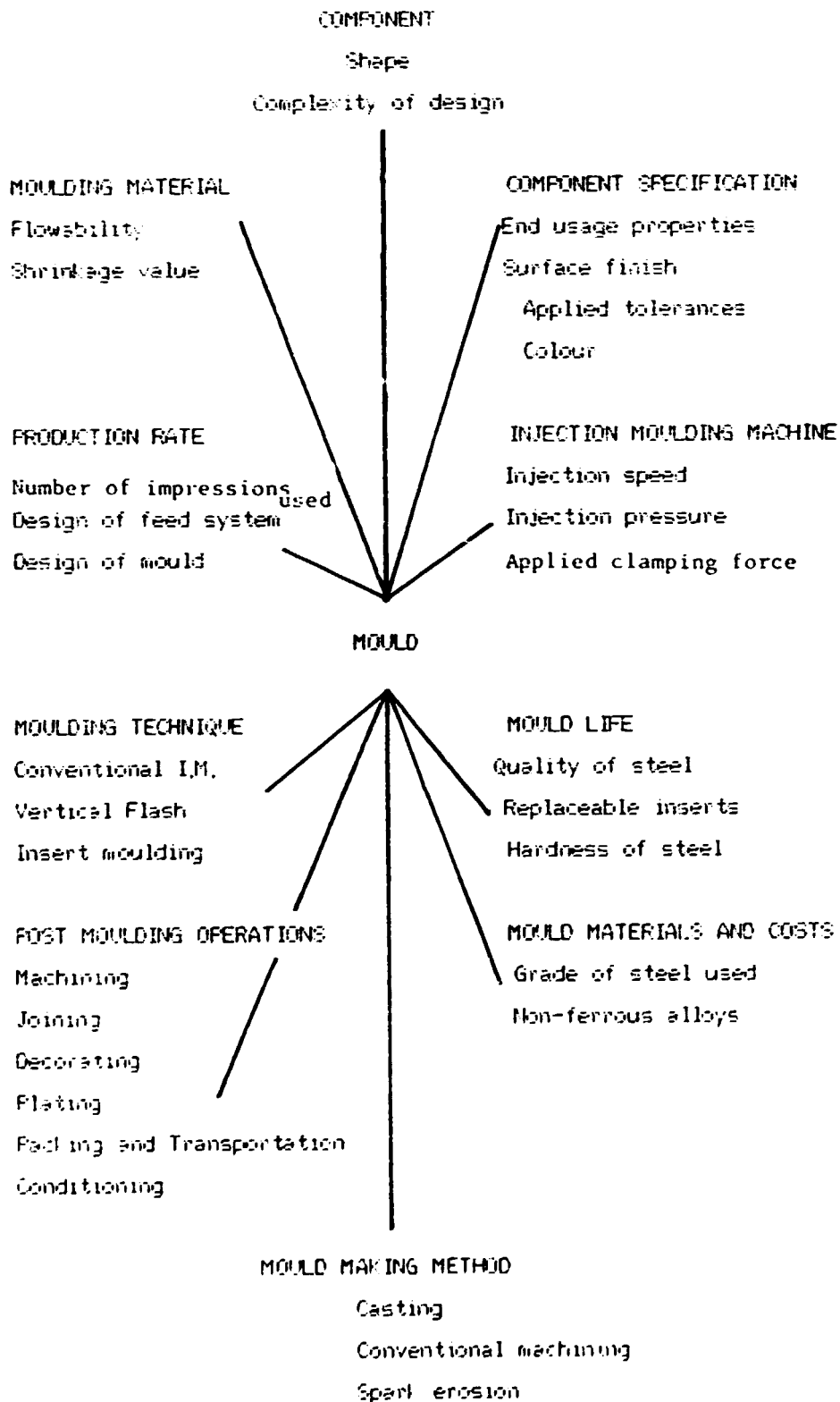
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1. INTRODUCTION

Outside the toolroom and moulding shop, few people realize the importance of the injection mould. Even those connected with production would hesitate to agree that the mould is more important than an injection machine on which it is fitted. Consider a major fire in a moulding shop. Fresh moulding powders can be obtained from the raw material suppliers, and the moulding of such items can be sub-contracted, but nothing can be done normally, about replacing the mould at short notice. The mould has also been called the 'heart' of the injection moulding process, around which other contributing elements are dovetailed in order to achieve the required product. For some important projects, spare moulds are stored away from moulding shops in specially constructed fire-proof stores.

1.1. Inter-dependences: Each mould is different from the other, with the possible exception of duplicate moulds, and at first sight, it might seem difficult to formulate guidelines for mould design. Initially, a number of factors governing the design and construction of an injection mould, should be considered. It is generally conceded that the best design is achieved when the component designer, the mould designer, the tool-maker, the moulder, the raw material supplier and the end-user get around a table, and arrive at the best compromise for the production of the end product. Figure 1 gives the main factors concerned with a mould, although there are minor considerations, such as operator skill, that are involved only occasionally. Every factor has an interaction with at least one, and often many, of the other factors in the influence on mould design.

Figure 1. Interdependence factors



2. THERMOPLASTIC MATERIALS

Because of the importance of this type of material and its relevance to the mould design and manufacturing industry, this report will review various aspects regarding the design and manufacture of injection moulds in order to produce components from thermoplastic materials only.

2.1. Definition of thermoplastics materials: A thermoplastics material may be defined as a plastics material which may be repeatedly heat softened after cooling. In other words, it may be moulded and, if necessary, regranulated and reprocessed. Because plastics materials are degraded by heat, some loss in properties (e.g. colour, mechanical, electrical, etc.) must be expected

2.1.1. Categories of thermoplastics materials: The above materials may be classified or divided into four major types. These are, amorphous, crystalline, thermoplastic elastomer and engineering (speciality materials). Each of these types may be either solid or cellular and may in turn be either reinforced with fibres/fillers or non-reinforced. (A material may fall into more than one category).

2.1.1.1. Amorphous: An amorphous-type thermoplastic is usually a glassy-hard material which in the unfilled state is transparent and rigid. Because the natural colour is usually water-white or a slight yellowish cast, a very wide range of transparent or opaque colours may be produced. Typical materials are: polystyrene (PS); polymethylmethacrylate (PMMA); styrene acrylonitrile (SAN); polycarbonate (PC); cellulotics (CAB, CAP, and CA); these types of materials have low shrinkage values i.e. 0.5 to 0.8%.

2.1.1.2. Crystalline: Crystalline polymers are usually hard and tough but not usually clear because the crystal structures they contain interfere with the passage of light. In the same way that a piece of colourless glass will appear white when crushed, crystalline polymers also appear to be white in their natural condition. Included in this category of materials are the very large-tonnage materials such as:

Polypropylene (PP)
Low density polyethylene (LDPE)
High density polyethylene (HDPE)

(These three materials are commonly called polyolefines because they are derived from a category of material called 'Olefines' and which include ethylene and propylene). Other types of crystalline materials are nylons (polyamides PA6, PA66, PA11/12), polyacetal (POM), polyesters (PBT and PETP). The shrinkage value for these materials ranges from 1 to 3%. The reason for the large value and variance is dependent upon the amount of crystal growth that occurs during the solidification stage when being processed.

2.1.1.3. Crystal growth: The two types of polymers (i.e. amorphous and crystalline) were described briefly, and the difference in the properties of each indicated. With amorphous type polymers, the configuration of chains tends to be random and entangled. Crystalline type polymers have an orderly and symmetrical type structure which enables interchain forces to

develop and thus allow crystal growth to take place. The result is a harder, tougher and opaque polymer. The amount of crystal growth (i.e. crystallinity) is partly controlled by the rate of cooling employed during processing. In general the higher amount of crystallinity required in the product, the slower the cooling rate must be. This allows the polymer chains to move into the required regular order. Fast cooling tends to freeze and prevent chain movement and prohibits crystal growth. Altering the amount of crystallinity alters strength, stiffness, and mould shrinkage. The polymer chemist can change the properties of materials dramatically, e.g. by changing molecular weight and chain branching. Such changes will alter not only the mechanical properties of the material but will change the way in which the material flows into the mould cavity. However, the user, can also change component properties simply by the way in which a given material is handled/processed.

2.1.1.4. Thermoplastic elastomers: These are materials which exhibit properties similar to that of a conventional rubber but which can be readily processed using typical thermoplastic processing equipment. The usage of this type of material is growing extremely rapidly and included in this category are thermoplastic polyurethanes (TPU), styrene butadiene styrene (SBS) and polyether block amide (PEBA) and polyether etherester (PEEL).

2.1.1.5. Engineering materials: The term engineering-type materials covers those plastics which are used in place of metals for load bearing application. Changes have taken place in the terminology used in recent years as a direct result of materials modification. The term used more recently is 'speciality thermoplastics' which encompasses a family of materials that have properties superior to those of the commodity thermoplastics (i.e. polystyrene, polyethylene etc). Such speciality polymers may have specifically or in combination: high heat resistance; low creep and high stiffness. Polymers classified as engineering/speciality materials are:

- Polyetherimide (PEI)
- Polyether-ether-ketone (PEEK)
- Polyvinylidene fluoride (PVDF)
- Polyphenylene oxide (PPO)
- Polyphenylene sulphide (PPS)
- Fluorinated ethylene-propylene (FEP).

2.1.2. Processing of thermoplastics materials: Most techniques for processing thermoplastics rely on heating the plastics material (so as to soften or plasticise it), distorting the heat-softened material (melt) into shape and then setting that shape by heat removal. We have, however, a number of problems because of the inherent nature of such materials. Plastics are based on the element carbon (C) and by definition therefore in the presence of heat and oxygen will react or degrade. They also require large amounts of heat to raise them to their processing temperature (have a high specific heat) and they have a low thermal conductivity. The problem is further complicated by the fact that the viscosity of plastics melts is in general fairly high. Because shaping is required to be carried out quickly shaping pressures can be high.

3. GENERAL PRINCIPLES OF MOULD DESIGN

Some aspects of mould design will be different for each material and where appropriate these will be mentioned in this section. However, there are general rules which should be applied as far as possible.

3.1. Basic design rules: Each of the following design rules should be considered when commencing to design an injection mould:

- (i) design the mould as a heat exchanger;
- (ii) use a correctly sized feed system;
- (iii) cool the injection moulding uniformly;
- (iv) use adequate mould venting;
- (v) use standard mould parts and accessories wherever possible;
- (vi) use runnerless type moulds where convenient;
- (vii) use pretoughened steels;
- (viii) use computers to assist mould design;
- (ix) make proper allowance for shrinkage;
- (x) design for ease of handling and fixing;
- (xi) design the mould to be insulated;
- (xii) control on moulding cycle time and, on product properties.

3.1.1. Heat exchanger design: If the maximum amount of heat that needs to be removed from each gram of shot (given in Joules (J)) is known, then this figure, may in turn be used to calculate the amount of fluid (usually water) that needs to be circulated through the mould so as to remove the heat carried by the plastic. This is done, for cold runner moulds, 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. To do this, the specific heat of the plastic must also be known: as this changes with temperature, the specific heat over the temperature ranges from melt to mould (the specific heat is quoted in J/kgK) is sometimes used. For hot runner moulds, only the mouldings are considered: assume that all of the heat contained in the components must be removed by the cooling system.

3.1.2. A correctly designed feed system: Typically runner sizes range from 3 to 10mm (0.118 to 0.4in), the most common size being 6mm (0.236in). Runners, like sprues, are usually short in length and generous in diameter as this reduces pressure loss and thus permits the application of adequate follow up pressure. However if they are made too large then excessively long cycles and large material losses result. If they are made too small then, the mould is incapable of being filled and the large amount of pressure which is lost is transferred into heat: heat generation in injection moulding is proportional to the pressure drop in the process. This heat will show up in the regions where the material is being sheared the most, i.e. in the gate regions. Such local temperature rises can be very high and can lead to material degradation. (This is why maximum shear rates are sometimes quoted for plastic materials). It is generally true that, in the injection moulding industry, runners are made too large and gates are made too small.

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

3.1.4. Apply adequate mould venting: The mould must be vented to allow for gas escape: such vents must be placed near weld lines and also near the last areas to be filled. Typical vents are slots 6 to 13mm (0.236 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 mould halves. If a negative pressure device is available it may be possible to vent the mould into the water channels. This can speed up mould filling, reduce component burning and reduce the cycle times.

3.1.5. Use standard components when designing moulds: Use standard mould parts and accessories wherever possible. Many moulds, approximately 85%, are now designed around standardised components as this can speed up the drafting process (the standardised components may be held in a computerised system) and can also reduce mould costs both production costs and maintenance costs. The range of components now offered by some companies e.g. DME, DMS, Hasco Internorm, Uddeform, is now very impressive with items such as the following now being standard:

- a) date stamps for mouldings - useful for quality control and identifying where the product was manufactured, i.e. SPC (Statistical Process Control):
- b) temperature controlled (hot) sprue bushes - for reducing cycle time for mouldings necessitating large sprues:
- c) positive locking on side cores - this has now been integrated with the side core actuator and so simplifies design and operation;
- d) reverse taper nozzles - these are used for large moulds, e.g. in ABS and PC, where there is a need for a central, pin-point gate but a three-plate mould is not wanted. The sprue is ejected pneumatically, in a reverse direction, towards the injection unit:
- e) rapid mould mounting jigs, plates, or clamps, for example, the mould is fitted with studs or tapered pins which locate, and are locked into, holes in the plates:

- f) rapid snap on/snap off couplings - for example, for water, air and for the ejector system:
- g) threaded, and tapered cartridge heaters - these give better control and ease of heater removal in the event of heater failure:
- h) two stage ejection units - useful where side cores are used and fast cycling moulds:
- i) integral side core cams and helix spindle - useful for unscrewing moulds.

3.1.6. Use runnerless type moulds: The use of runnerless moulds is becoming more readily accepted by the moulding industry due to their high success rate. The variety and types of systems available nowadays are numerous and therefore one should discuss in detail, with the hot runner and insulated runner specialists, the requirements/quality of product to be manufactured from a particular polymer. This is necessary in order to ascertain which system will be best suited to a particular job. It is a well known fact that detailed investigations carried out at the design stage, concerning runnerless type moulds, save considerable production problems. When long sprues and/or runners are being moulded, then the use of a runnerless mould can speed up cycle times as the mould opening and closing movements may be shortened considerably: as the sprue and runners are the thickest part of many mouldings, their elimination can also save on cycle time by reducing the mould cooling time. It is well worth considering the use of cast heaters for runnerless-type moulds as they last so much longer than conventional cartridge heaters.

3.1.7. Use pretoughened steels: The majority of injection moulds used nowadays are manufactured from nickel-chrome alloyed steels which are subsequently heat and/or surface treated in order to obtain a surface hardness ranging from 48 to 67 Rockwell C (Rc). Such a hardness is used to prevent damage occurring to the mould surfaces, to obtain a good surface finish and to increase stability/life usage of the mould. Some U.K. and European mouldmakers are beginning to adopt the policy of other foreign counterparts (e.g. from Japan, Portugal and Spain) of using pretoughened steels, without further heat treatment, having a surface hardness of 32 Rc in order to reduce cost and delivery times. One reason for the use of such steels is the improvements and conciseness of control with respect to the mould sensing and closing/locking operation of the moulding machine. This has led to less damage occurring to mould faces when mouldings, or feed systems, become entrapped between the mould halves. However, some mouldmakers are not yet fully convinced that suitable dimensional stability and robustness is achieved for fast cycling, multicavity, production moulds, made from pretoughened steel, and will therefore continue to use hardened moulds until proven otherwise.

3.1.8. The use of computer aided design: The standard or quality of mouldings is ever increasing and the need to accurately predict the materials flow and cooling characteristics within the mould cavity is becoming a necessity. The advent of computer aided mould design has made this task much easier enabling detailed analyses to be carried out for a range of processing conditions and for a range of gating positions. The results of such analyses enables moulds to be designed and manufactured knowing that a successful

component will be produced with the minimum of debugging and that target dates can be met.

3.1.9. Shrinkage allowances: Most plastics components are smaller than the mould used to produce them. Mould shrinkage is not however, the finite shrinkage value as the total shrinkage (TS), experienced by a moulding, is made up of mould shrinkage (MS) and post-moulding shrinkage or, as it is sometimes known, after shrinkage (AS). Mould shrinkage is defined as the change in dimensions between the size of the cavity and the moulding, 24 hours after the moulding is ejected from the mould. Post-moulding shrinkage occurs after the moulding has been aged and is also called environmental shrinkage. To obtain values for mould shrinkage components are produced by injection moulding for thermoplastics materials. After a specified time (eg 2 hours) the dimensions of the moulding are measured at room temperature. The dimensions of the cavity, if not known, are also measured. The mould shrinkage (MS) is given as a percentage by $100 \times L_0 - L_1 / L_0$ where L_0 is the length of the cavity and L_1 is the length of the moulding. Post-moulding shrinkage (AS or PMS) is given as a percentage by $PMS_{48\text{hours}} = 100 \times L_1 - L_2 / L_1$ where L_1 is the length of the original moulding and L_2 is the length measured after 48 hours (or some other time). To convert from volumetric shrinkage (MSv) to linear shrinkage (MSL) use $MSv = -1 + (1 + MSL)$. When moulding shrinkage is used to calculate cavity dimensions then use:- D_c (cavity dimensions) = $D_p + D_p S + D_p S^2$. D_p is the dimensions of the moulding and S is the linear shrinkage. Because shrinkage is so dependent upon the production conditions it is usual to quote a range for each material. The actual value used to size a cavity may need to be obtained by producing a pilot cavity and then, producing components under production conditions. (If a moulding is produced using a conventional cold runner system, which is then changed to a hot runner system, then it will be probably found that slight different shrinkage values are obtained. If these cannot be compensated for by setting/processing changes then the cavity/cores will have to be modified to accommodate the new shrinkage values. For this reason it is good practice to produce the prototype mouldings in an identical manner to the proposed production mouldings.

3.1.10. Design for ease of handling and fixing of the mould: Many moulds seem to be designed without due regard for ease of handling, mounting or fixing. Unless this is done then a lot of valuable production time will be lost while the mould is being fitted to the injection moulding machine i.e. being set up. To save valuable production time it is suggested that:-

- (a) all inlet and outlet cooling connections are clearly stamped/identified on the mould;
- (b) all cooling connections are put on one side of the mould or platen mounted and are designed for rapid coupling;
- (c) cooling connections are sensibly located so that they are accessible (e.g. not located behind tie-bars) and do not hinder mould mounting;
- (d) cooling connections are sensibly located/protected so that they are not damaged during storage, transport or use;
- (e) the mould base plates are of a standard thickness or, the points of mould mounting/fastening are of the same thickness;
- (f) lifting and handling features, for example, eyebolts, straps and clamp sizes;

- (g) having mounted the mould, instruction sheets be made available which are written with the setter in mind and which, not only give precise instructions, but which also state what equipment, services and personnel are needed to get the mould into production.

3.1.11. Use insulation on the backs of moulds: Many moulds, particularly those used for engineering thermoplastics, run at relatively high temperatures, for example 90 - 120 degrees C. If the mould is not insulated then, heat losses to the atmosphere, and to the machine platen, can easily equal those lost by the injection cylinder. So, insulate the mould from the platens and, if possible, insulate the outside surfaces of the mould. If a hot runner mould is being considered then, try and reduce heat exchanges between the hot runner parts and the cold, component-forming parts.

3.1.12. Consider alternatives to steel: Most injection moulds are made from tool steel, even though the length of production run may not warrant or justify the expense involved in manufacturing the mould from tool steel. Many alternative materials and manufacturing methods are suitable for prototype, pre-production or small batch work and their use can lead to worthwhile cost savings in many cases.

3.1.13. Design the component to suit the process: The component must be designed to suit the injection moulding process if the best results, in terms of consistency and speed of production, are to be obtained. Long trouble-free runs are the ideal and these can only be obtained if the material, the machine and the injection mould are all correct and suited one to the other. The component must be designed, and the mould must be made, so that injection mouldings are produced with the minimum of difficulty at the required rate. Components must eject easily, be free of flash and possess the desired dimensional tolerances. In general, component tolerances must be as wide as possible, wall thicknesses must be as thin and as uniform as possible, side walls must be generously tapered and corners rounded. To minimise warping, surfaces must be grooved, corrugated or curved; to ease production, shapes which demand the use of side cores should be avoided as far as is practical.

4. THE PRINCIPLE OF POLYMER FLOW AND ITS EFFECT ON MOULD DESIGN

Plastics materials differ widely in their viscosity, or ease of flow, and the problem is made more difficult by the fact that each material is available in a range of grades each of which also has a different flow behaviour. The position is made even more complicated by the fact that the flow properties of plastics are non-Newtonian (i.e. often called pseudoplastic), and so there is not a linear relationship between pressure and flow. What all this means is that the flow properties cannot be represented meaningfully by one figure and so flow testing over a range of conditions is often performed. However, because of the expense involved in doing such testing, simple tests for example MFR are still used. To demonstrate that plastics materials are pseudoplastic let us consider the values given in Table I, which are for the PA6 (nylon 6) produced by Akzo. These figures clearly show that the three grades quoted have very different viscosities, with the first grade having the lowest viscosity that is, it is the easiest flowing grade. It would be used where mould filling is difficult, or where thin wall sections and/or long flow lengths are involved. The viscosity of all three materials falls as the shear rate is increased, that is, mould filling becomes easier. Raising the melt temperature reduces the amount of injection pressure required to maintain a certain rate of flow. The flowability of a plastics material is usually dependent upon its molecular weight therefore a high viscosity grade should be selected if the components are to be subjected to high mechanical stresses; this is because the high viscosity grades usually have the highest molecular weight and exhibit the best mechanical properties. However in some cases this advice cannot be followed as unacceptable levels of frozen-in strains result. As previously stated easy flow (i.e. low molecular weight) grades are preferred for filling thin walled sections or for use where very smooth surfaces are specified.

4.1. Definition of rheological terms: Rheology is the study of flow. We are interested in the study of flow for a thermoplastics material and therefore it falls under the same category. To make the thermoplastic melt, flow or move, we must apply a stress, also known as shear stress. This makes the plastic flow at a certain rate which is also known as shear rate. Shear stress is given the symbol τ (tau) and shear rate is given the symbol $\dot{\gamma}$ (gamma). If we plot shear stress against shear rate (see fig 2) then, if the plot is a straight line the flow behaviour is referred to as Newtonian. As most plastic melts are non-Newtonian and so the graph is not a straight line and a curve is the result (see fig 3). What this term means is that at high shear rates the materials become in effect easier flowing (reference Table II). As the viscosity μ (eta) of a material is obtained by dividing shear stress by shear rate ($\tau/\dot{\gamma}$) then this means that the viscosity (also known as apparent viscosity) of most plastics falls as the shear rate increases.

Table II
UNITS OF FLOW FOR THERMOPLASTICS MATERIALS

Property	SI units	Imperial units
Shear stress	Nm^{-2}	lbf/in^2 (lbf/in ²)
Shear rate	sec^{-1}	sec^{-1}
Coefficient of viscosity	Nsm^{-2}	lbf/in^2

Flow curves result when viscosity is plotted against shear rate (see figs 4(a) and 4(b)). Once again because of the pseudoplastic nature of plastic melts a curve results. To get a straight line relationship, the log of viscosity is plotted against the log of shear rate and this gives what is called log-log graph. The data given in Table I can also be plotted in this way.

TABLE I. TYPICAL EXAMPLES OF VISCOSITY - SHEAR RATE DATA FOR VARIOUS THERMOPLASTICS MATERIALS

(a) Nylon 6 - (Polyamide 6)

Material	Viscosity (NSM ⁻²) at 1000 sec ⁻¹				Viscosity (NSM ⁻²) at 280°C at increased shear rates			
	240	260	280	300°C	100s ⁻¹	1000s ⁻¹	10,000s ⁻¹	100,000s ⁻¹
Akulon 6	98	78	63	50	197	63	20	6
Low Visc.	149	115	89	69	323	89	25	7
Med. Visc.	394	319	259	210	1220	259	55	12
High Visc.								

(b) Unplasticized PVC - Pipe Formulation

Material	Viscosity (NSM ⁻²) at 1000 sec ⁻¹			Viscosity at (NSM ⁻²) 180°C at increased shear rates (S ⁻¹)				
	170	180	190°C	340	675	1000	1350	2020
No Filler	836	785	684	1952	1137	785	613	426

(c) Polycarbonate

Material	Viscosity (NSM ⁻²) at 1000 sec ⁻¹					Viscosity (NSM ⁻²) at 300°C			
	300°C	320°C	340°C	360°C	10s ⁻¹	100s ⁻¹	1,000s ⁻¹	10,000s ⁻¹	100,000s ⁻¹
Makrolon (Bayer)									
Standard Grade (2800)	420	255	160	100	575	560	420	--	--
Easy Flow (2400)	250	165	105	65	--	325	250	75	--

4.2. Units of viscosity: There are various systems of measurement in use throughout the world. For the purpose of this report, I will use two systems, one of which is used in Europe and the other in the USA. The two systems are SI and Imperial (Tab III). In the SI system the units of stress are Nm^{-2} and units of rate are sec^{-1} so dividing

$$\frac{\text{shear stress}}{\text{shear rate}} = \frac{\text{Nm}^{-2}}{\text{sec}^{-1}} = \frac{\text{Ns}}{\text{m}^2} \quad \text{Nsm}^{-2}$$

In the Imperial system the units of stress are lbf/in^2 and shear rate are sec^{-1} then the viscosity = $\frac{\text{lbfs}}{\text{in}^2}$ or lbfs in^{-2}

4.3. The relationship of polymer flow equations and mould design: In order for this flow information to be used in relation to mould design the designing of a runner system can, for a particular mould, be readily carried out. Secondly the use of computers, in association with standard rheological equations, has enabled flow analyses to be carried out for a particular component which has to be moulded. Such complex analyses have proved extremely beneficial to the mould design and manufacturing industry enabling moulds to work first time without the usual lengthy debugging period after manufacture.

4.3.1. Melt flow along a circular channel: A full round runner used for the feed system on an injection mould may be likened to a pipe, or circular channel, and if the analogy is correct then pressure drop (ΔP) over a specified length of runner, or channel, may be obtained by rearranging Poiseuille's formula. This states that the volumetric flow rate

$$Q = \frac{\text{Pi} \times r^4 \times \Delta P}{8 \times \mu \times L} \quad \text{where Pi} = 3.142$$

where r is the radius of the runner, or channel, μ is the coefficient of viscosity for the specified material and L is the length of the runner of channel. By rearrangement we can obtain

$$\Delta P = \frac{8 \times Q \times \mu \times L}{\text{Pi} \times r^4}$$

$$\text{or} \quad \Delta P = \frac{4 \times Q}{\text{Pi} \times r^3} \times \frac{2 \times L \times \mu}{r}$$

$$\text{where } \gamma = \frac{4 \times Q}{\text{Pi} \times r^3} \text{ and}$$

$$\tau = \frac{\Delta P \times r}{2 \times L}$$

As the apparent shear rate (γ gamma) for a thermoplastic material flowing through a circular channel is $\frac{4 \times Q}{\text{Pi} \times r^3}$ and

we can substitute γ in the equation giving

$$\Delta P = \gamma \times \frac{2 \times L \times \mu}{r}$$

Knowing that shear rate (γ) \times viscosity (μ) = shear stress (τ) (see section 4.1.) then ΔP is the pressure drop of the circular channel (i.e. runner), where L = runner length and r = radius of the runner. Therefore as the thermoplastic material flows along the runner channel it experiences a resistance to flow due to frictional effects and heat loss. The longer the channel, the greater the resistance to flow. As would be expected the magnitude of the pressure drop (resistance) in a runner system is proportional

to the length of the runner and to its diameter. Increasing the length of the runner or decreasing the diameter will increase the pressure drop. Most runners are either full round or trapezoidal. To calculate the pressure drop along a full round runner the use of a Hagan Poiseulle equation, as explained above, is required. For a trapezoidal runner it is usual to use the same equation but assume that the material flows down a circular channel which can just be fitted in the trapezoidal shape.

4.3.2. Runner size calculations: To minimise the amount of pressure loss in the runner system, it is important to keep the runner lengths as short as possible. If this principle is not adhered to, the cavity pressure will be insufficient to maintain the product's specified dimensional tolerances. An approach to calculate runner sizes was undertaken by W.B.Glenn (1980).¹ He showed by use of a calculator, Poiseulle's equation and the relevant rheological data of the moulding material, that correctly sized runners could be easily determined in order to improve productivity and create cost savings. In order for the runner diameter to be calculated, the following points have to be taken into account: (a) The length of the runner branches (which can be taken directly from the proposed mould design); (b) The melt temperature at which the material is to be processed (i.e. moulded): for example a typical melt temperature of 300 degrees C is used for moulding the polycarbonate; (c) The need for a shear rate/viscosity graph for the specified material at the melt temperature to be used; (d) The time taken to fill the mould cavity (or cavities) with molten plastic; most plastics materials are injected into the mould in less than 3 seconds (this is called the cavity fill time). The actual time used is based upon experience and/or information obtained from other moulding runs. Advice on how to predict the cavity fill time is given in a book entitled 'Injection Moulding of Plastic Components' by J.Bown (1979)²; and (e) An allowance for a reasonable pressure drop in the runner system: As most moulding machines are capable of exerting moulding pressures of up to 20,000lb/in² (138MNm⁻²), it is assumed that 5,000lb/in² (34.5MNm⁻²) is needed for mould packing, then this means that 10,000lb/in² (69MNm⁻²) can be reasonably lost in the runner system. This also assumes that the machine, in order to reduce wear, is only operated at 75% of its capacity. This approach forms the basis of Computer Aided Design with respect to the design of the feed system and assessing the flowability of the material, within the mould, during the mould filling stage.

4.4. The flow path/wall thickness ratio: Each type and grade of plastics material will flow a specific distance with respect to the thickness of section it has to flow along: this relationship is expressed as a ratio. If the ratio is quoted as being 180:1 then this means that if the wall thickness of the moulding is 1mm then, the maximum length of flow possible will be approximately 180mm. Because the amount of flow possible is dependent upon wall thickness, the flow ratios may be quoted for a range of wall thicknesses. These values are another way of indicating the ease of flow of a plastics material and are extremely important when deciding the gating position/s for a particular component.

¹ GLENN, W.B., "How to Size a Runner System for Efficient Moulding".
Plastics Technology, April 1980, p. 90.

² BOWN, J., "Injection Moulding of Plastic Components", 1979.

TABLE III. SHRINKAGE VALUES FOR A RANGE OF THERMOPLASTICS MATERIALS

THERMOPLASTICS			
Abbreviations	Material	Mould shrinkage in/in or mm/mm	Percentage
ABS	Acrylonitrile-butadi- ene-styrene	0.004-0.007	0.4-0.7
POM	Acetal	0.020-0.035	2.0-3.5
PMMA	Acrylic	0.002-0.010	0.2-1.0
CA	Cellulose acetate	0.003-0.007	0.3-0.7
CAB	Cellulose acetate butyrate	0.002-0.005	0.2-0.5
CP	Cellulose propionate	0.002-0.005	0.2-0.5
EVA	Ethylene vinyl acetate	0.007-0.020	0.7-2.0
FEP	Fluorinated ethylene propylene	0.030-0.060	3.0-6.0
PA6	Nylon 6	0.010-0.015	1.0-1.5
PA66	Nylon 66	0.010-0.020	1.0-2.0
PBT	Polybutylene terephthalate	0.015-0.020	1.5-2.0
-	PBT + 30% glass fibre	0.003-0.008	0.3-0.8
PC	Polycarbonate	0.006-0.008	0.6-0.8
-	PC + 30% glass fibre	0.003-0.005	0.3-0.5
PES	Polyethersulphone	0.006-0.008	0.6-0.8
LDPE	Polyethylene (low density)	0.015-0.040	1.5-4.0
HDPE	Polyethylene (high density)	0.015-0.040	1.5-4.0
PPO	Polyphenylene oxide (modified)	0.005-0.007	0.5-0.7
-	PPO + 30% glass fibre	0.002	0.2
PP	Polypropylene	0.010-0.030	1.0-3.0
PS	Polystyrene (GP)	0.002-0.008	0.2-0.8
TPS	Polystyrene (toughened)	0.002-0.008	0.2-0.8
PTFE	Polytetrafluor- ethylene	0.050-0.100	5.0-10.0
UPVC	Polyvinylchloride (rigid)	0.002-0.004	0.2-0.4
PVC	Polyvinylchloride (plasticised)	0.015-0.050	1.5-5.0
SF	Structural foam	0.006	0.6
PVF	Polyvinylidene fluoride	0.020-0.030	2.0-3.0
SAN	Styrene acrylonitrile	0.002-0.006	0.2-0.6
THERMOPLASTIC ELASTOMERS			
PE/EP(D)M	Rubber reinforced polypropylene	0.010-0.020	1.0-2.0
SBS	Styrene-butadiene-styrene	0.004-0.010	0.4-1.0
TBPO	Thermoplastic polyester ester	0.004-0.016	0.4-1.6
PUR or TPU	Thermoplastic polyurethane	0.005-0.020	0.5-2.0

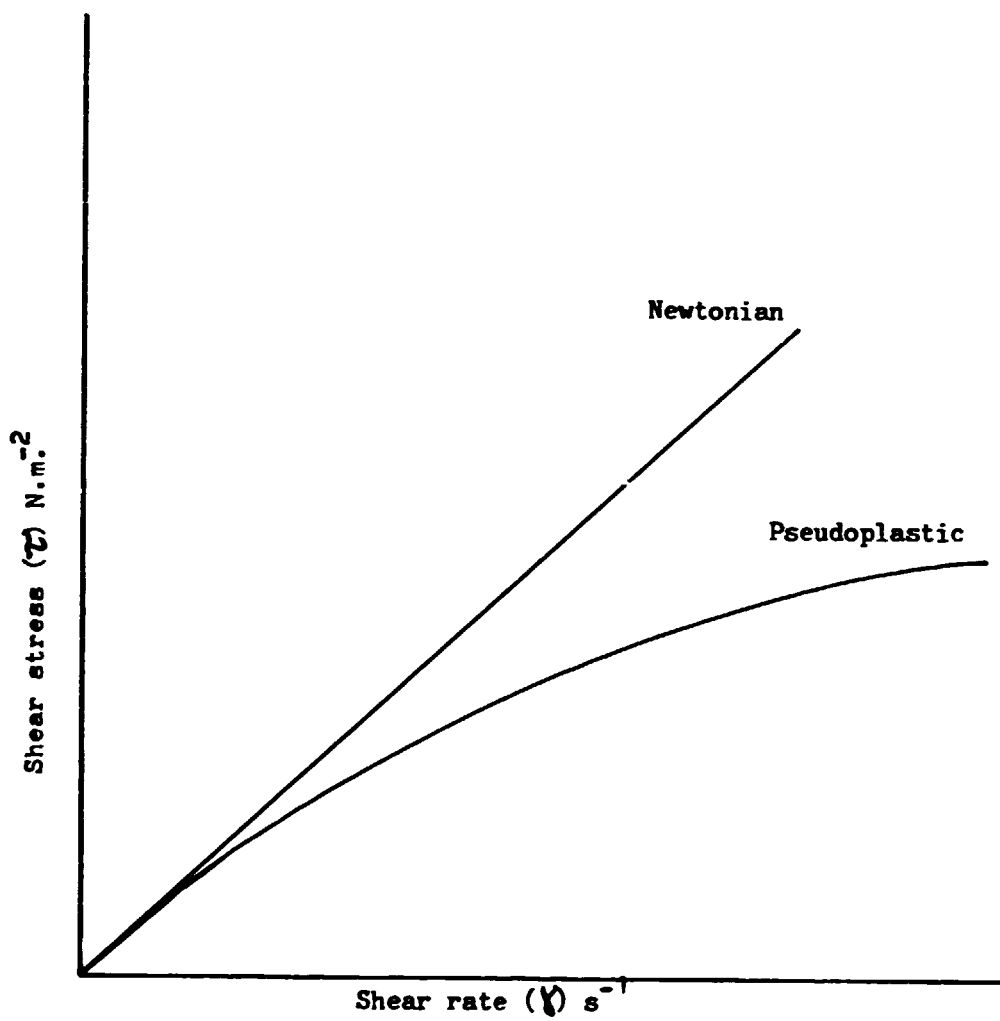


Figure 2. Shear stress - shear rate graph

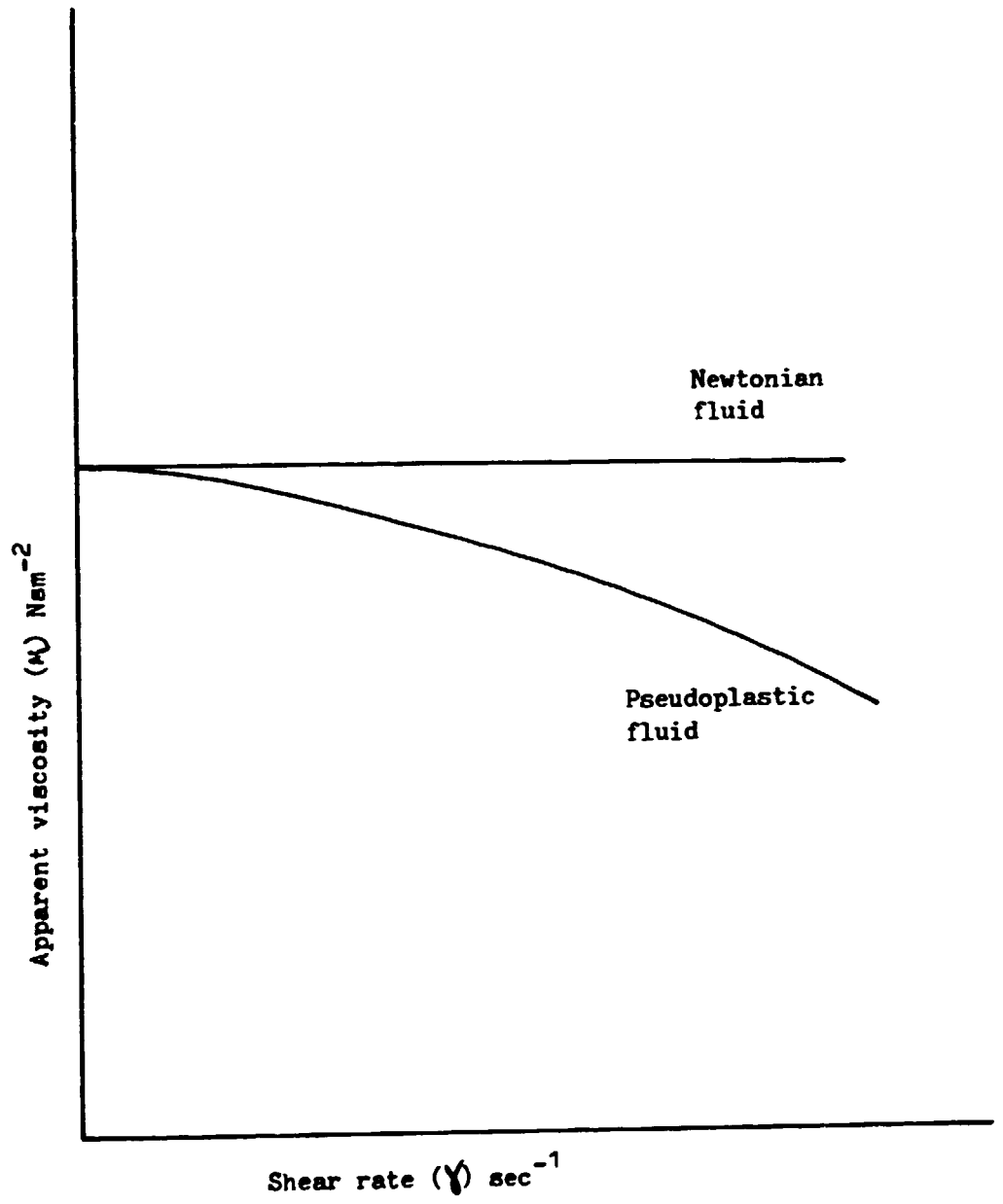


Figure 3. Apparent viscosity - shear rate curve

Figure 4(a). **VISCOSITY/SHEAR RATE GRAPH FOR
ACRYLONITRILE BUTADIENE STYRENE (ABS)**

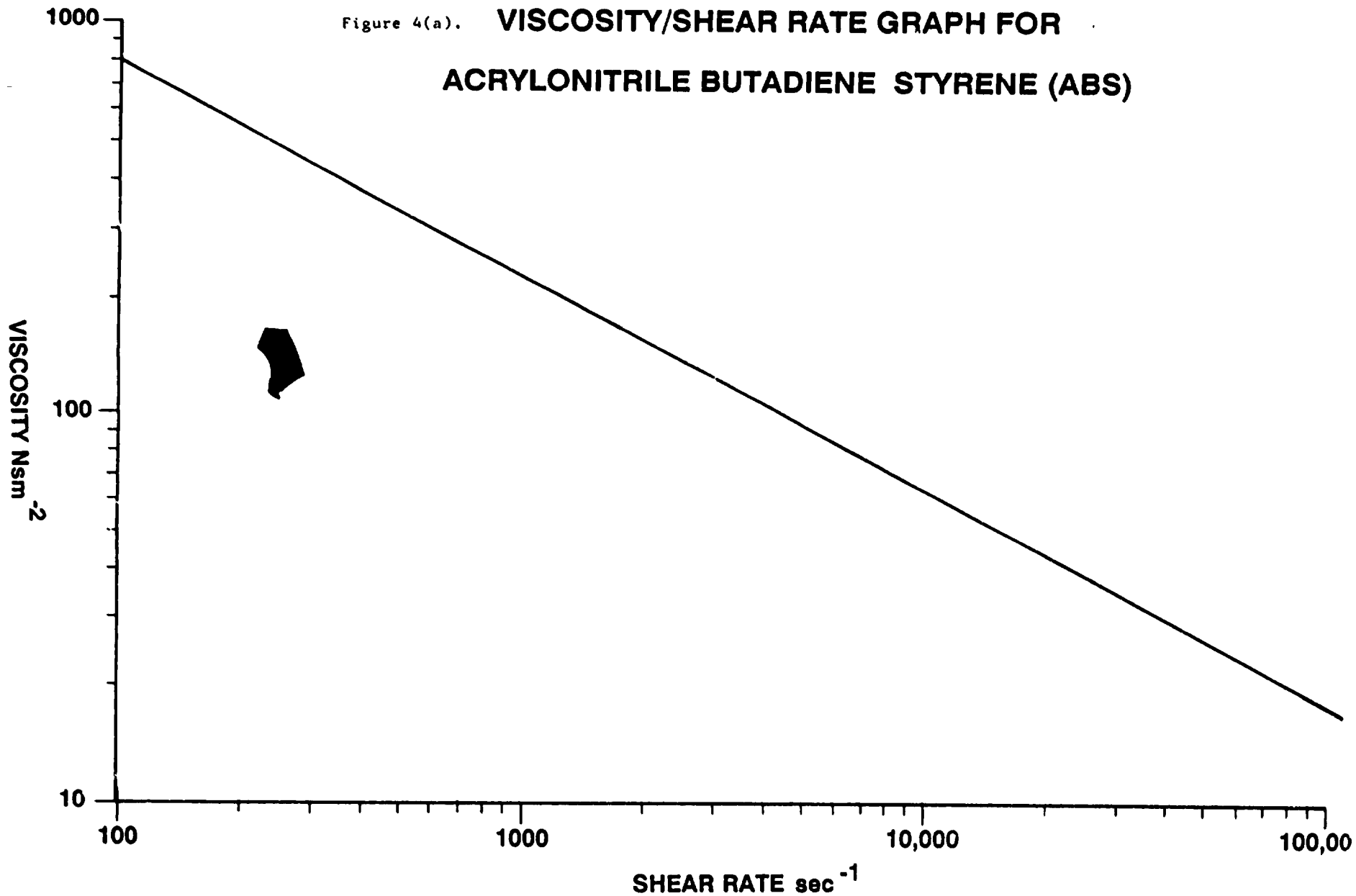
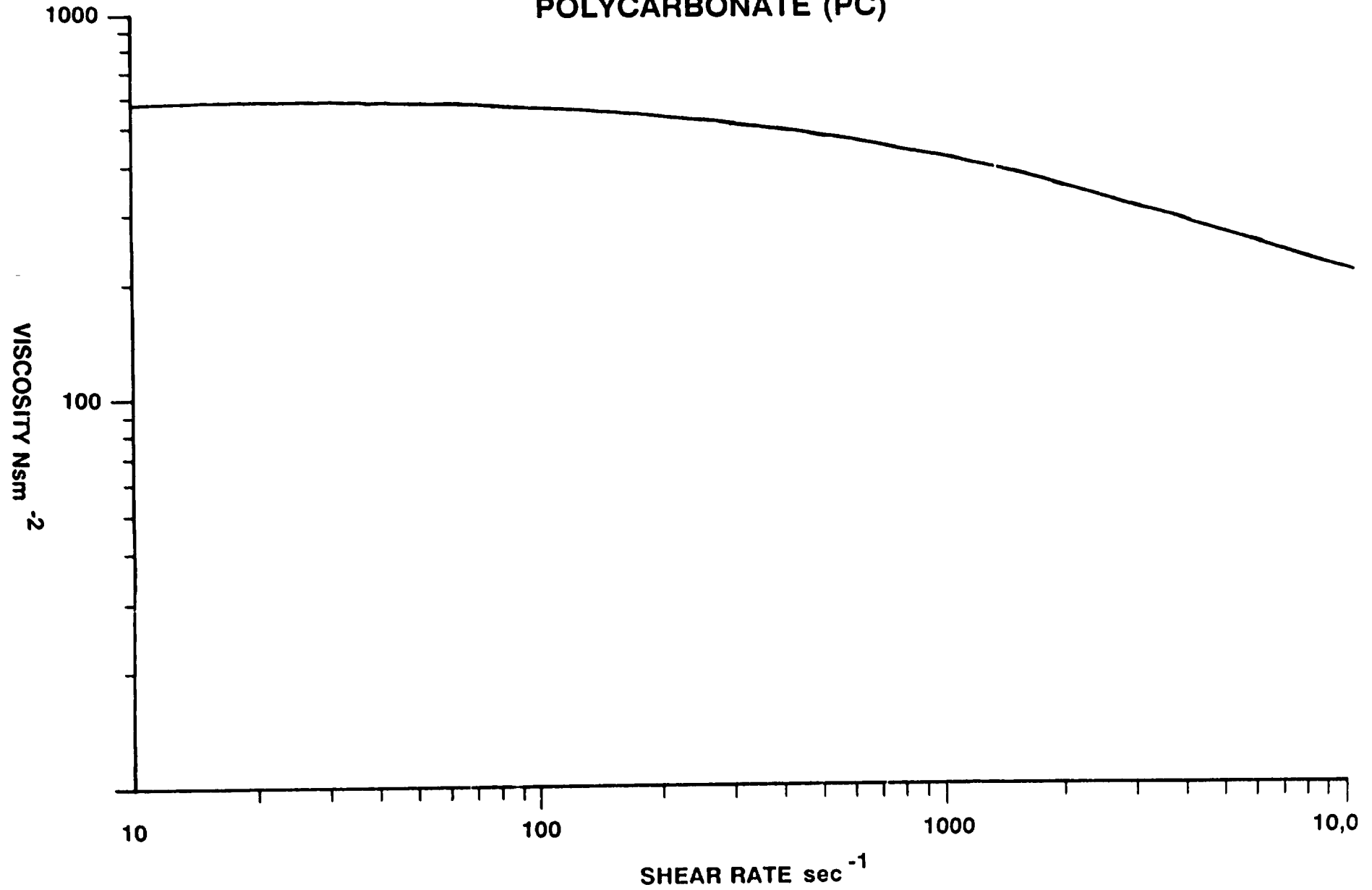


Figure 4(b). **VISCOSITY/SHEAR RATE GRAPH FOR
POLYCARBONATE (PC)**



5. THE DESIGN OF THE FEED SYSTEMS FOR INJECTION MOULDS

5.1 Feed System: A well designed feed system is an essential part of an injection mould as the size and layout of the feed system determines the magnitude of pressure losses during mould filling and shaping phase: heat may also be lost or gained by the polymer composition as it passes through a feed system. The components of a feed system are as follows - (polyacetals,nylons) use shallower tapers on sprues (e.g. 3 to 4 degrees inclusive).

5.1.1. Sprue: In a conventional injection mould, the sprue is used to describe the channel which joins the mould cavity to the nozzle and it is also used to describe the solid material which forms in that channel. The part of the mould which carries this channel is known as the sprue bush or the sprue bushing and it is most important that the fit between the machine nozzle and the sprue bush is a good one. Leakage of polymer at this point increases the likelihood of insufficient pressure during the compaction stage.

5.1.1.1. Sprue dimensions: To assist in machine alignment, the nozzle of the injection moulding machine usually has a rounded tip and this fits into a corresponding recess in the sprue bush. For example, nozzle tip radii of 15mm and 19mm are commonly used: the radius of the sprue bush is usually slightly larger than the corresponding nozzle radius, e.g. by about 0.8mm (0.032in). In order to assist removal, the sprue is usually tapered (with a taper angle of from three to seven degrees) and the diameter of the small end of the sprue (sometimes known as the 'O' dimension) is made larger than the hole in the tip of the nozzle by 1mm. In general, crystallines (polyacetals, nylons) use shallower tapers on sprues (e.g. 3 to 4 degrees inclusive). The diameter of the small end of the sprue could be as small as 1.5mm (0.060in), however for components with a volume of up to 328cm³ (20in³) a 5mm (0.198in) die sprue would be more usual. The diameter of the large end of the sprue should be equal to, or larger than, the diameter of the main runner system so as to ensure that the runner does not seal first and so prevent the application of sufficient dwell pressure. The sprue should blend smoothly into the runner system and it should be polished in the direction of flow as it is found that this provides less resistance to flow and gives easier ejection. To minimise pressure losses and to reduce scrap production, sprues should be kept as short as possible.

5.1.1.2. Reverse taper sprues: The use of a reverse tapered sprue is where a single component is fed directly from the sprue. Removal of the sprue from a mould takes place during mould opening as the sprue is severed or detached from the moulding. As the moulding is ejected in the normal way, the sprue is ejected by using a blast of compressed air through a valve or sleeve surrounding the sprue and blown out from the mould in the direction of the nozzle. Another way to remove sprues from a moulding is to machine a hook onto the end of the nozzle so that when the injection carriage is withdrawn from the mould, the sprue is broken from the component. Sprue removal can be performed either manually or automatically (pneumatically).

5.1.1.3. Cold slug well: The theory of the cold slug well is to prevent solidified or unplasticised material at the nozzle exit being introduced into the cavity. However, this does not always happen as traces of unplasticised segments can often be seen as positions in the runner system, indicating that the segments have been removed from the slug well and carried

along by the flow of molten material. The major use for the slug well is to act as a sprue puller. Various types of sprue pullers are used for different types of plastics. As a rule the most popular type for:

(i) Ductile materials (PP, Nylons (PA6 and PA66) and POM) is the reverse taper (see fig.5):

(ii) Brittle materials (PS, PMMA and SAN) is the 'Z' type sprue puller (see fig.6): and

(iii) 3 plate moulds is ball nosed or inverted taper type (see fig.7).

5.2. Runners: Once again this term is used to describe two separate items:

(i) It is used to describe the channel in the mould which connects the sprue bush to the gate: and

(ii) It is also used to describe the set polymer which is formed in that channel. The solid runner system may be ejected when the mould opens or may remain within the mould in a semi-fluid state (runnerless moulding). There are two features which a mould designer should consider when deciding on the runner system for a particular mould.

5.2.1. Runner cross-section: The basis of good runner design is that the runner should be of sufficient cross-sectional area to permit maximum pressure transfer but possess minimal contact on its outer surface in order to reduce heat transfer or loss. The ratio of the cross sectional area to the circumference (periphery) indicates the effectiveness of the runner design. The higher the value the greater the effectiveness. It has been found that the full round and modified square runner designs (i.e. trapezoidal) are the most efficient types (see figs 8(a) and 8(b)).

5.2.1.1. Full round runners: In every mould the runner should be designed to fill the mould quickly and uniformly and therefore be kept as short as possible. The diameter of the runner system usually lies within the range 3mm to 10mm (0.118 to 0.394in), e.g. for nylons (PA6 and PA66)/polyacetals 3 to 5mm (0.118 to 0.198in) and for PVC/PSU up to 10mm (0.394in). In general, runner sizes are not greater than 6mm (0.236in) diameter, unless used for specific materials such as PC, PVC, PSU, etc. When the runner is going to be reground, so that it may be reused, then its diameter should be kept small, then this will restrict mould filling speed and cause very high pressure losses. The fully round runner is expensive to machine, as it must be cut in each half of the moulds where a sliding action occurs across the parting line. Where the fully round runner is expensive or inconvenient to use, then the trapezoidal runner is used.

5.2.1.2. Trapezoidal runners: The advantage of a trapezoidal shaped runner is that it need only be cut into one mould half. Provided it is dimensioned correctly, it is almost as good as the full round runner. A very generous radius should be given to the corners in the base: if possible, the shape of the base should be semi-circular. The side walls should be tapered by about 5 to 10 degrees (see fig 9) as this will ease ejection. Such runners are often used with three plate moulds as with this type of mould the runner is retained on one plate and then stripped away during part ejection.

5.2.2. Runner layout: The runners should be laid out so that sharp corners, or sharp changes in direction are avoided: on a multi-cavity mould the runner system should be laid out so that the flow path between each cavity and the sprue is of the same length.

5.2.2.1. Balanced runner layout: When the flow path length is identical then the system is called a balanced runner mould. It is relatively easy to design a balanced runner layout when the number of cavities equals an exponential power of two, i.e. 2.4.6.8.16.32 etc. (see fig 10), the exception being for circular layouts. The feed system in a balanced runner mould provides each cavity with the best chance of feeding simultaneously and undergoing the same pressures. Its uses, therefore, should result in components which are identical. When uneven filling occurs in a balanced runner system, then the rate of filling in the 'slow' cavity may be conveniently increased by removing metal from the gate land, i.e. keeping the cross-section constant but reducing the gate length. Alternatively (Glenn 1980, see footnote 1 chapter 4) the runner diameter may be altered so that the pressure drop at each cavity is the same.

5.2.2.2. Unbalanced runner layouts: If runner layouts are designed so that unequal flow lengths are apparent (see fig 11), the impressions close to the sprue will fill quickly under high pressure whereas the impressions further away from the sprue will fill later under a lower pressure. The above configuration will result in mouldings being produced of different sizes and properties from the same mould. In order to reduce the component variability, runner balancing or gate balancing is incorporated into the design. It is usual to balance the gate land in preference to runner size. However, with the use of CAD many runner designs are now modified by varying the runner dimensions (i.e. diameter).

5.2.3 Streamlining of material flow through runners: As previously stated, the absence of sharp corners in runners will greatly assist the filling characteristics of material (see fig 12). It is therefore preferable to use radii or radial sweeps at junctions of runners, instead of the original 'T' design. There is a great reluctance, by the moulding industry, to adopt the radial sweep design because of increased mouldmaking costs and manufacturing time. Technically it is a far better type of design and this has been proven by processors who use this technique when processing thermosetting, thermally unstable or highly viscous polymers. Another point is the position of gate relative to the cross-section of a runner. When the plastic melt flows through a channel the maximum velocity and temperature of a material is achieved at the centre of the flow (i.e. core). The material at the edges of the channel solidifies and acts as an insulant to the centre core. The position of the gate should be selected so that it is in line with the centre of the runner so that it is able to receive material from the centre core. This can readily be achieved with a full round runner. However, it is not possible to fulfil this requirement with the trapezoidal design and glass filled materials, e.g. delamination.

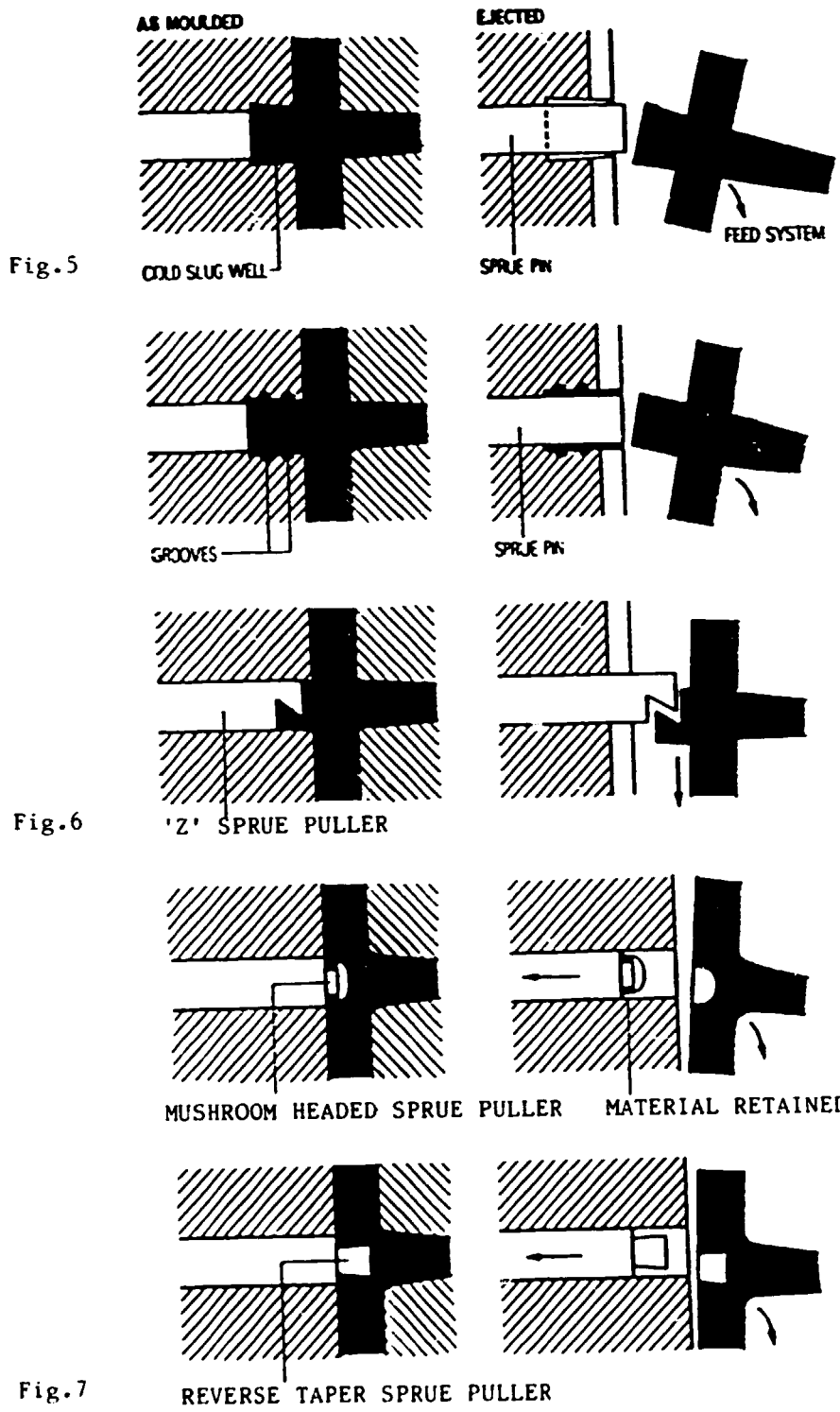


Fig.5

Fig.6

Fig.7

Figure 5. Reverse taper cold slug well type sprue puller

Figure 6. Grooved and 'Z' type cold well sprue puller

Figure 7. Mushroom headed and reverse tapered pin types of cold slug well

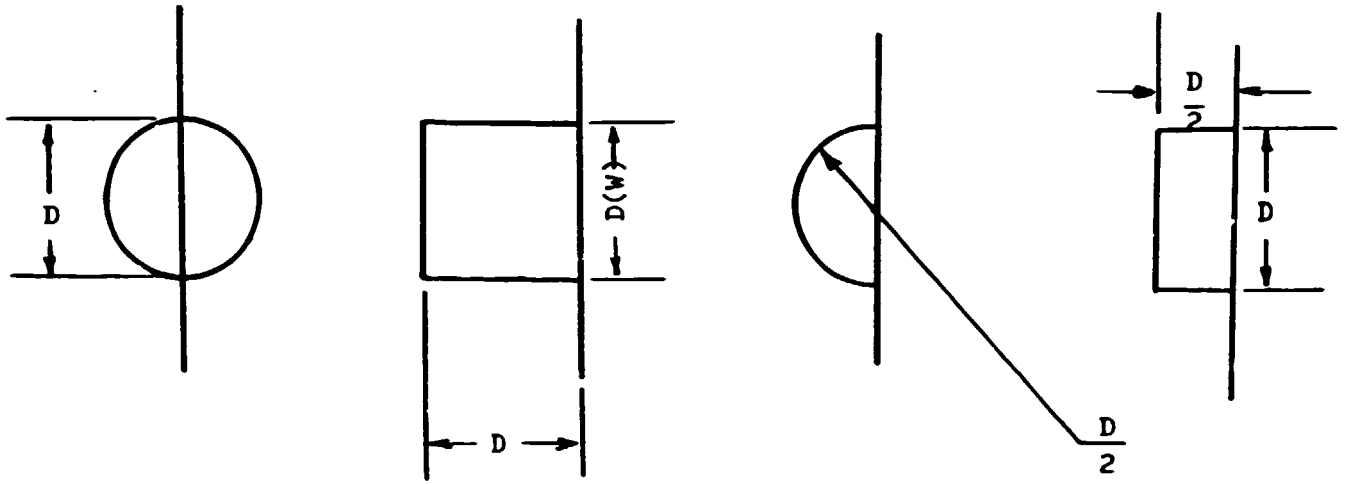
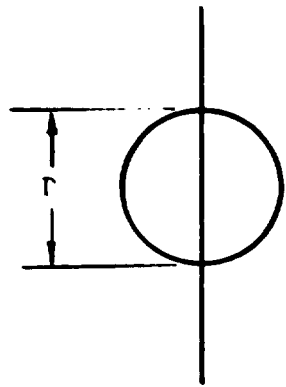
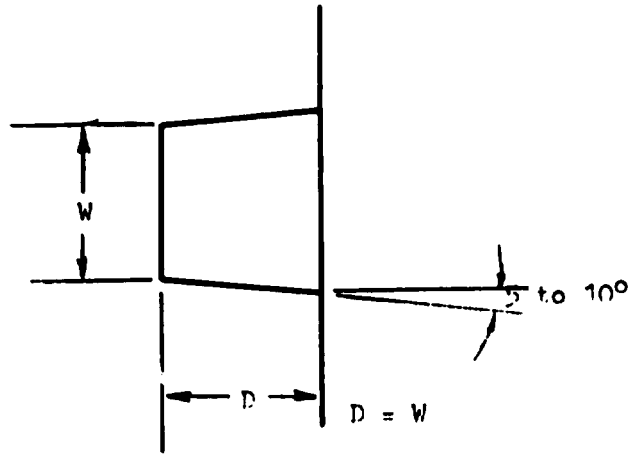


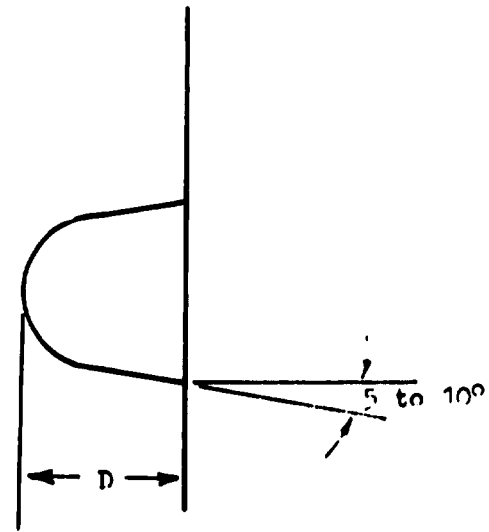
Figure 8(a). Runner cross sections



Circular



Trapezoidal



Modified Trapezoidal

Figure 8(b). Runner cross sections

Figure 9. Modified trapezoidal runner section

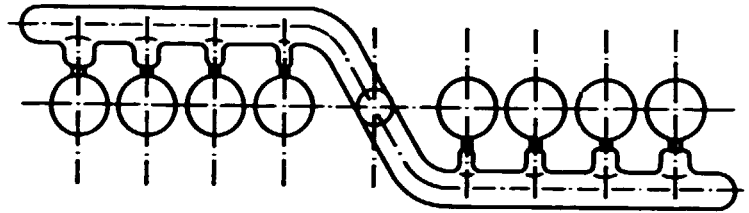
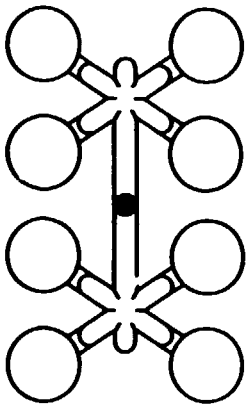


Figure 10. Balanced runner layout Figure 11. Unbalanced runner layout

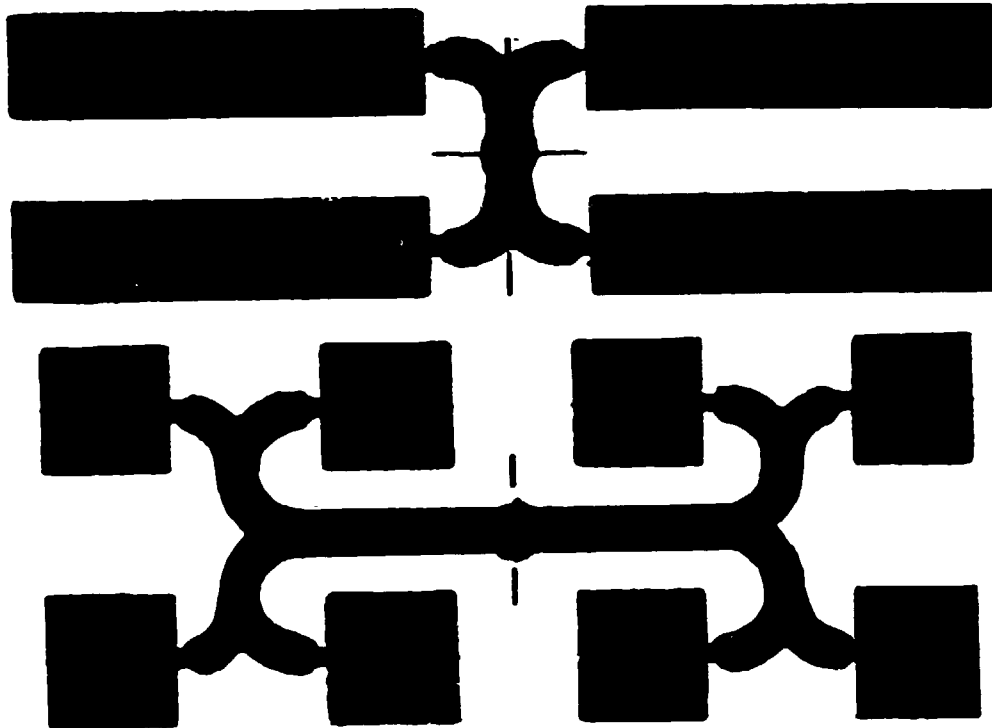


Figure 12. Runner layouts using radii at each intersection

6. THE DESIGN AND TYPES OF GATING SYSTEMS USED FOR INJECTION MOULDS

In order to produce consistent mouldings of a high quality, the mould designer must select the correct size and type of gate, in conjunction with a suitably sized runner system, for a particular material-product combination. The types and sizing of a feed system have been explained in section 5.0.

6.1. Definition of gate: The gate is the restriction in the runner immediately before the cavity, i.e. it is where the molten material enters the mould.

6.2. Gate function: One of the major functions of the gate is to permit easy separation of the component from the runner system, and if the gate is made small enough this may be done automatically during the ejection part of the cycle. The gate must also permit sufficient material to enter the mould so that components with the required dimensions are produced. In order to compensate for shrinkage it is often necessary to pack additional material into the mould during the dwell part of the cycle and this can only be done if the gate remains open - ideally the gate should freeze when the cavity is fully packed. As the gate is usually the thinnest part of the moulding, it responds, or changes, to the mould temperature more quickly than any other part of the moulding. It must also not be forgotten that polymers exhibit pseudoplastic flow behaviour, i.e. the faster they are sheared, the less viscous they become. What this means is that the use of small, or restricted, gates provides a means of generating large shear rates, e.g. up to 1 million reciprocal seconds (10^6s^{-1}). At high shear rates the viscosity of the polymer melt is very much lower than it is at low shear rates but 'die swell' will probably not occur as a critical shear rate has been exceeded.

6.3. Gate location: The gate should be located so that easy and therefore economical separation of the component from the runner system is obtained to prevent jetting, the gate should be located so that the incoming plastics material impinges on an obstruction within a short distance, e.g. 6mm (0.236in). (The use of programmed injection speed can, however, eliminate this requirement). As far as possible the material should enter the cavity at the point where the wall thickness of the component is greatest; as the gate area is commonly a highly stressed area the gate should not be located in a position which will be exposed to stress in service. Aesthetic reasons may also restrict gate location areas to hidden or masked parts of the moulding. If the flowing melt stream is divided, e.g. by a core, then when the melt recombines a weld line and/or burning may result. The burning occurs as a result of compressing trapped gases (e.g. air) and suitable mould venting will alleviate this; venting the mould will also help to improve the strength of the weld. If possible, the gate should be located so that, if a weld has to be produced, the divided melt is recombined as quickly as possible i.e. the weld is located as close to the gate as possible. Where part of a component is required to have the best 'see-through' properties then that part should not be located in a region remote from the gate. Some components, e.g. large mouldings, are made via more than one gate (for example, four or eight or bumper or automobile facia mouldings) as this shortens the flow length and results in a lower clamping pressure requirement. However, unless there are very good reasons for their use, multiple gates should not be used.

6.4. Gate size: Because of a lack of suitable information (e.g. material temperature, viscosity, mould filling times) gate sizes are not normally calculated but are usually obtained by experiment and/or experience. The gate is, therefore, usually made deliberately small (e.g. 50% of part thickness) and then metal is removed, after sampling, in order to achieve the desired filling rate and/or pattern. One of the biggest dangers with this approach is that the final gate size will be rather small and this will result in mouldings of poor surface finish, non-uniform shrinkage and which are highly stressed: this can result in later failure.

6.5. Types of gate: Many different types, or styles, of gate are used within the feed system. If the gate seriously interferes with material flow then it may be known as a 'restricted' gate: conversely where there is no serious flow obstruction, the gate may be known as an 'unrestricted' gate.

6.5.1. Sprue gate: The term 'sprue gate' means that the sprue is joined directly to the moulding (see fig 13), e.g. at the base of a bowl or bucket. Such a gate is commonly used for large single-impression mouldings as it is relatively easy to machine or make, gives symmetrical mould filling and the large scar (which is produced when the gate is removed) is hidden in use. However, it is often found that parts made with a sprue gate fail in service by cracking in the gate region. This is because the gate is so large that over-packing can easily occur and this over-packing causes stress in the gate area. If too much material is packed into the mould (in an effort to compensate for shrinkage) then most of the extra material will be concentrated and compressed in the gate area; it is this compressed material which generates the stress. To help alleviate this problem it is beneficial to include a slight thickening of the base beneath the sprue: this is gradually blended back into the wall over a large diameter. Some mouldings are made with a reverse taper sprue as in such cases the opening action of the mould causes the sprue gate to be separated from the component: the sprue may then be removed from the mould in various ways, e.g. by means of a hooked nozzle, or compressed air.

6.5.2. Pin-point gate: When a reverse taper sprue is used, the cavity may be fed, in effect, via a small well restricted gate. When the gate is small (e.g. 1 mm/0.039in) and circular it is known as a pin point gate and such gates are commonly found on mouldings using a three-plate mould or on runnerless type moulds. For example, simple thin-walled mouldings (e.g. beakers) are sometimes made using multiple-impression three-plate moulds and in such cases the cavities are fed via central pin-point gates in the base of the cavity. Sub-sprues connect the gates to the main runner system. Pin point gates (pin gates) (see fig 14) need to be fed with a generous runner system as otherwise premature freezing will occur. The diameter of the gate used lies within the range 0.2 to 2mm (0.008 to 0.078in): above 2mm (0.078in) dia the gate may be difficult to break during mould opening. The gate should be designed so that when it is broken it breaks cleanly and does not block the gate cavity. A parallel gate land should not be used: the gate should taper or flare into the cavity. This type of gate provides ease of finishing and can cause very high shear rates to be generated. Because of the pseudoplastic nature of the polymers, this means that there is a reduction in material viscosity and mould filling becomes easier. Such high shear rates have been employed so as to allow long thin cavities to be filled. The major disadvantages of three-plate gating are runner ejection difficulties, runner entanglement during conveying and regrinding, more runner to be reground

(compared to edge gating) and more complex mould design and operating sequences. In view of the facts, three-plate moulds have been replaced by runnerless type moulds, however there are certain materials (i.e. some flame retardant grades) which still require the use of three-plate moulds due to their susceptibility to thermal degradation.

6.5.3. Side or edge gate: This type of gate is commonly used with multi-impression moulds as it allows the usage of two-plate tools (see fig 15). The gate usually has the same type of cross section as the runner system (i.e. round or trapezoidal) and its size is dependent upon the shape and thickness of the moulding. This type of gate is also known as a 'standard' gate. As usual with gate design, it is recommended that initially the gates be made deliberately small so that they may be opened up after moulding trials. This is because it is easier to remove metal than it is to put it back. The short shots produced during the moulding trials should be used to indicate which gates need modification or balancing. This may be done by increasing the cross sectional area of the gate or by decreasing the land length of the gate. The former alters both the shear rate and pressure drop whereas the latter only reduces pressure drop and has the virtue of being more accurate. For example, a gate may only require a very slight adjustment to enable the cavity to fill, and on a land length of 1.5mm (0.06in) may mean a removal of about 3%. Removal of the same amount of metal on the diameter of a round gate will alter the pressure drop by about 12%.

6.5.4. Submarine gate: A submarine gate (or tunnel gate) feeds the plastics material into the side of the component (see fig 16). A runner carries the plastics material down below the parting line of the mould and feeds it, via a cone-shaped gate, into the cavity. The gate is usually located in the moving half of the mould and, when the mould opens, the gate is sheared by the ejection action. Such gates are usually only used for small components and their diameters may range from 0.5 to 2mm (0.02 to 0.078in); the size employed depends on the material being moulded, for example, the materials ease of flow and its strength in shear. The gate should be as short as possible and a generous taper must be employed. In order to reduce the land length for a submarine gate, various designs have been used:

i) The conventional type of submarine gate: This uses angles of 30° and 45° to the walls of the moulding. The shallower the angle of the gate, the greater is the restriction to the material flow. In an attempt to reduce this problem a spherical section added above, or adjacent to, the gate entry, so that a land length similar to that of an edge gate (i.e. 0.7-1.0mm/0.028 to 0.039in) is achieved (see fig 17).

ii) A modified submarine gate: This is in the form of a truncated cone (see fig 18). The gate is designed so that the upper edge of the cone forms the characteristic oval shape of the gate, but in a horizontal plane. The advantage with this type of gate is that the depth area of shear is considerably less than that of the conventional type. These gates are particularly useful where zero or minimal gate vestige is required. If a tunnel or submarine gate is used on a heavy-sectioned component then surface marking may result as it may not be possible to make the material impinge on an opposing mould surface. Short mouldings may not eject properly and gate blockage may result. During ejection the shearing action causes material movement or flexing in the gate area to occur and this can cause the gate region to wear, particularly if a heavily filled plastics material is being processed. Because of stress concentration effects, the gate region can

constitute a potential source of weakness to the finished moulding and failure in service may, therefore, occur through a fault developing in the gate region. If the gate diameter is small then this type of gate is sometimes referred to as a 'pin point submarine' gate (see figs 19(a) and 19(b)). Tunnel gates with a curved axis are sometimes referred to as 'winkle' gates. Although such gates may be useful (in the production of buttons, bobbins, compact disc cases, etc.) they are more difficult to make and so their usage is comparatively restricted.

6.5.5. Fan gate: A fan type gate is a wide gate which is formed by opening or 'fanning' the runner out so that it blends into the component being moulded (see fig 20). The gate cross-section is still relatively small, or restricted, so that finishing is comparatively easy. The fan gate helps to spread the material into the cavity and can thus help to minimise weld lines: it is used on components having flat thin sections, e.g. boxes, lids. To minimise pressure drops the land length of the gate should be kept as small as possible providing that adequate strength of the mould metal in this area can be maintained.

6.5.6. Flash gate: This type of gate is also known as a 'film' gate and is a slit which can extend along the complete side of the component (see figs 21(a) and 21(b)). Initially, the gate thickness would be uniform but if it was found that the mould was not filling with the same rate at all points then metal would be removed from the gate at the slow-filling areas. For example, the gate land length could be reduced. A significant factor with the film type gate is the position of the sprue-runner entry with respect to the film gate itself. Conventional designs tend to fall into 3 categories:

- (i) centre fed film gates:
- (ii) side fed film gates: or.
- (iii) centre fed with fan shaped introductory section.

i) With the centre fed type the contour, or shape, of the gate must be designed so that the gate depth at the centre is smaller than at the ends (see fig 22). By profiling the gate depth it ensures that the correct distribution of melt flow takes place across the entire gate land. Use of a centre fed, film gate without the gap profiling causes the molecular orientation/flow distribution to be in the form of a fan (see fig 23) and not in the form of a parallel flow front, which is usually expected of a film gate.

ii) With this type of gate, the contour of the gate is such that the gate depth decreases along its length, so as to evenly distribute the flow.

iii) With this type of gate the main emphasis is to either profile the gate depth as in (i) or profile the depth of the fan section so that the material reaches the extremities at the same time as the centre. The reduction in gate depth for all types is dependent upon the length and depth of gate, but generally the gap adjacent to the runner entry is 70% smaller than the full depth. However, modifications may need to be carried out, depending upon the types of materials being moulded. Such gates work best with a full round runner system and with the gate carried in each mould half. By feeding the material in this way, i.e. along the parting line of the mould, distortion and non-uniform surface shrinkage are minimised. It has also been

found that a more uniform filling pattern will be obtained if the runner extends beyond the gate. e.g. by about 6mm (0.236in). These gates have been used for large flat components as this helps to minimise distortion. Film gates have also been used for fibre-filled materials and for metallic-coloured materials as this type of gate helps to eliminate unsightly flow or weld lines.

6.5.7. Tab gate: To mould large flat or curved surfaces, particularly in transparent materials where flow marks should be reduced to a minimum, it is sometimes expedient to feed through a side gate into a tab at the side of the cavity (see fig 24). This system, known as a 'tab gate' helps to obviate 'jetting' by creating turbulent flow in the tab, immediately opposite this small side gate³. After the moulding operation, the tab may be removed from the component: as the area adjacent to the gate is usually highly stressed, tab-gate removal can also improve component reliability.

6.5.8. Ring gate: This type of gate is used in the production of cylindrical mouldings and, as its name implies, the runner circles the cavity at its normal dimensions (see fig 25 and footnote 3). Ring gates have been used for hollow cylindrical parts, such as pen barrels, as it is found that air-trapping is minimised due to the uniform material flow that is obtained. This gate may be considered to be a circular film gate.

6.5.9. Diaphragm gate: A diaphragm gate is sometimes used in the production of components which contain holes, e.g. telephone handsets, pump membranes, etc. The runner feeds into a thick section, which almost covers the hole, and then the material flows through a thin restricted slit (which extends completely around the circumference of the hole) into the cavity (see fig 26). After moulding, removal of the sprue and circular runner system creates the hole which is required. Provided that the mould is adequately vented, air-traps and weld lines are not usually a problem when this type of gate is employed. This type of gate is also known as a disc gate.

6.5.10. Spider gate: This type of gate may be considered as an alternative to the diaphragm gate mentioned above as, again, it is used in the production of hollow cylindrical components (see fig 27). The material feeds into the side of the component via a number of legs or spokes and, as a result, welds are produced in the finished component. Although such welds may be of adequate strength, their presence may cause a surface blemish with certain materials, e.g. filled compositions or non concentricity of circular bores.

³ Imperial Chemical Industries Plc. - The Principles of Injection Moulding. Technical Service Note G.103. 1978.

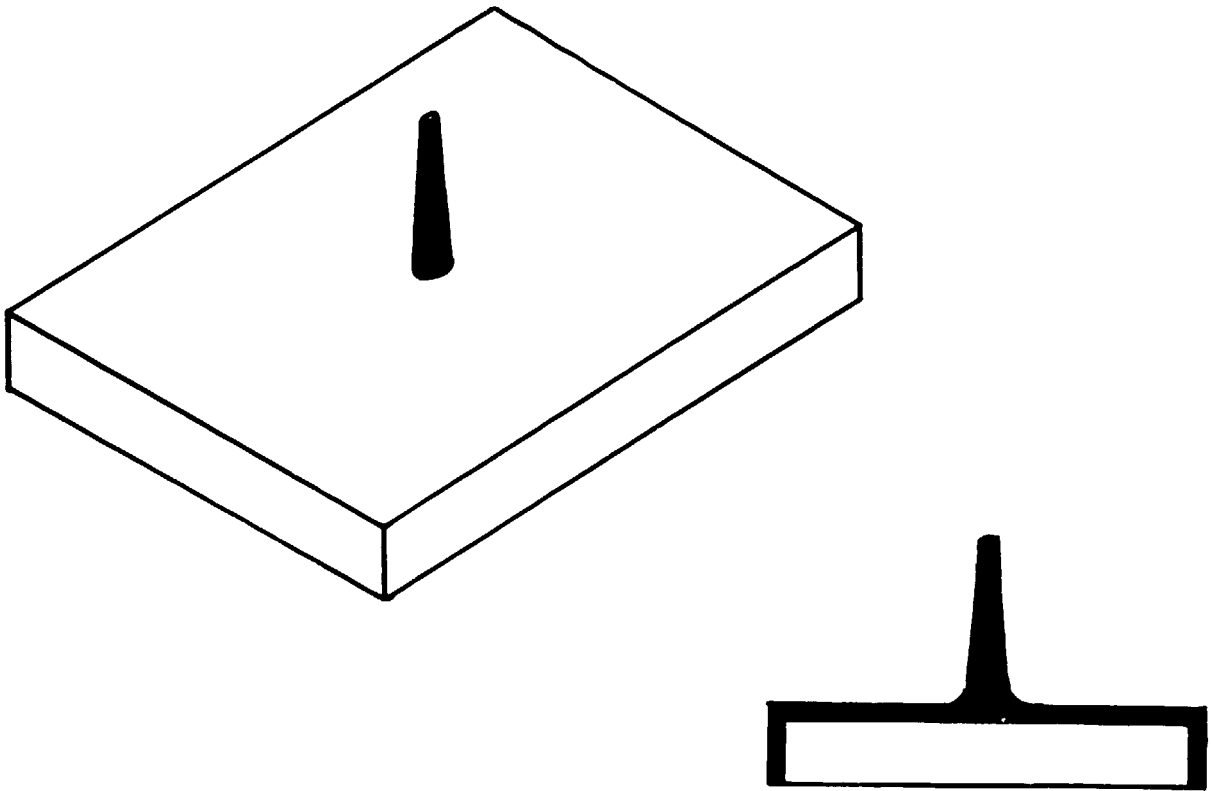


Figure 13. Sprue gate

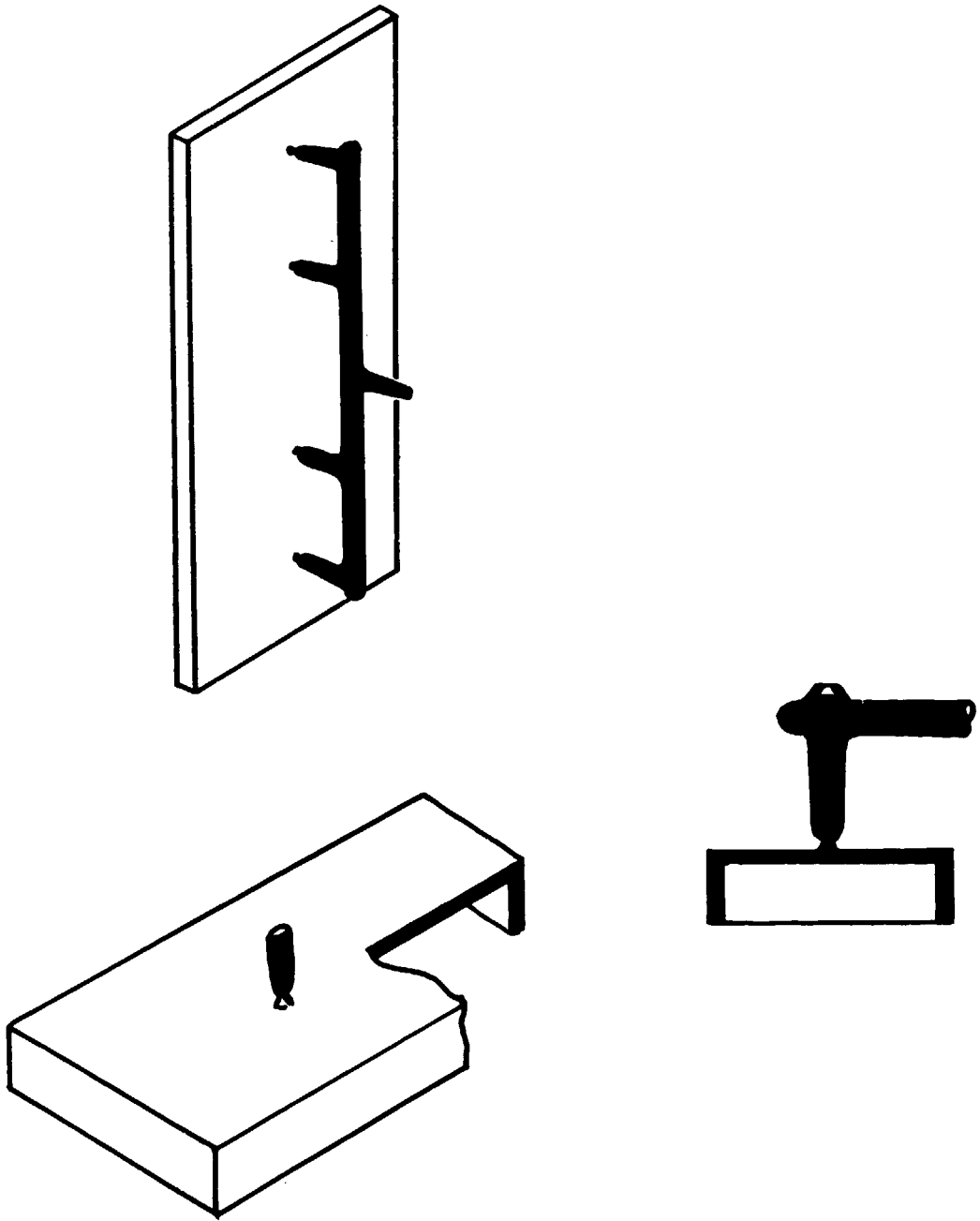


Figure 14. Pin point gate

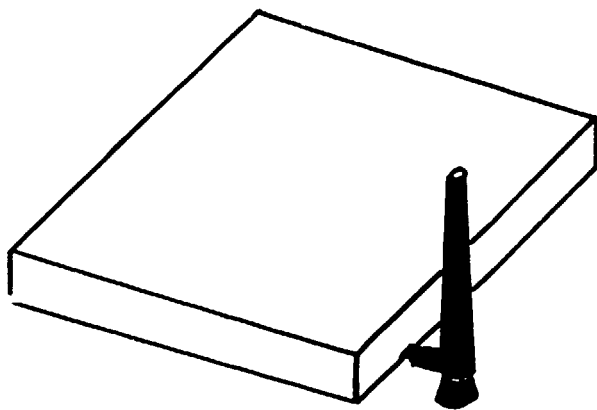


Figure 15. Side or edge gate

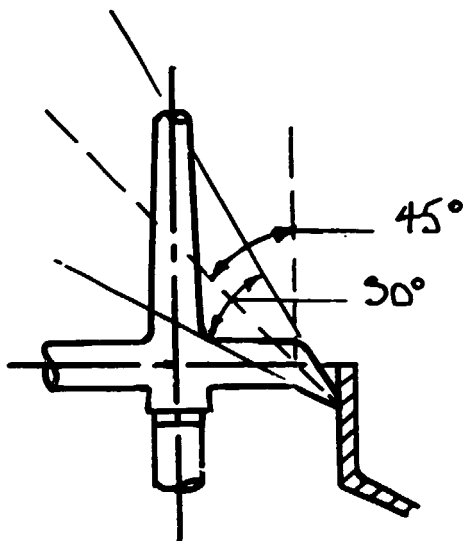


Figure 16. Conventional submarine gate

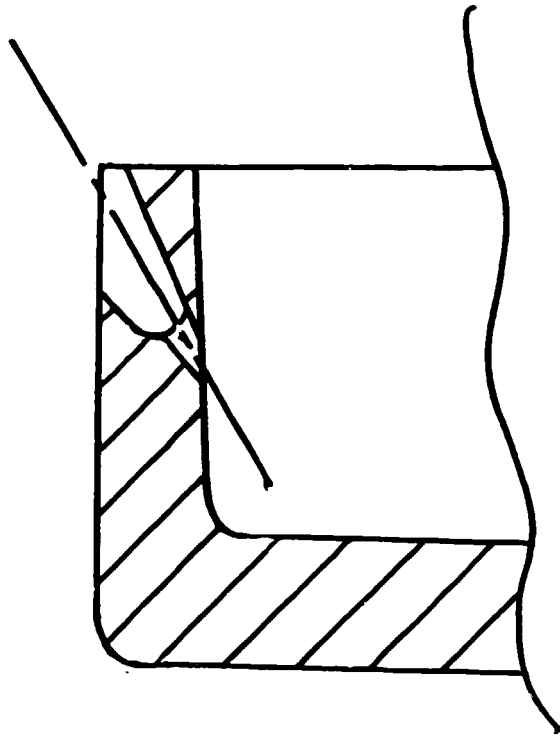


Figure 17. Submarine gate with an additional spherical section

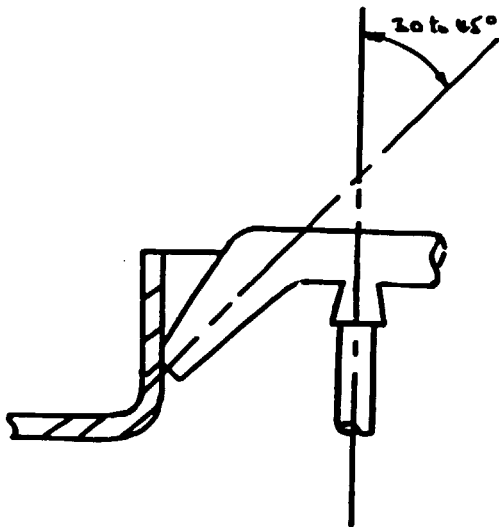
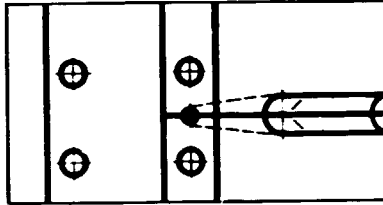


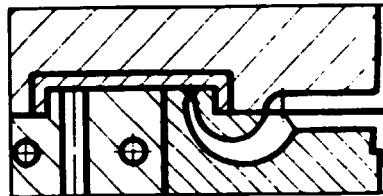
Figure 18. Truncated type submarine gate

Curved tunnel system — for appearance, and for thin parts which require automatic gating this system enables going to the non-visible side or other convenient location on the part. To degate, the curved tunnel requires a good taper, and must be free to bend. For a long curved tunnel, the local reduction of the runner is an assistance. The position and length of the ejection pin fits the sprue on the support during ejection.

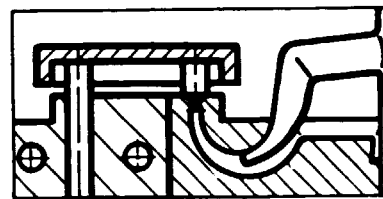
Top view curved tunnel



Mould closed injection ready



Part ejection and first stage



Deflected runner in last stage of ejection

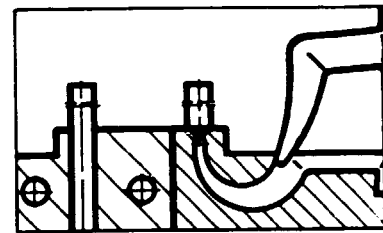
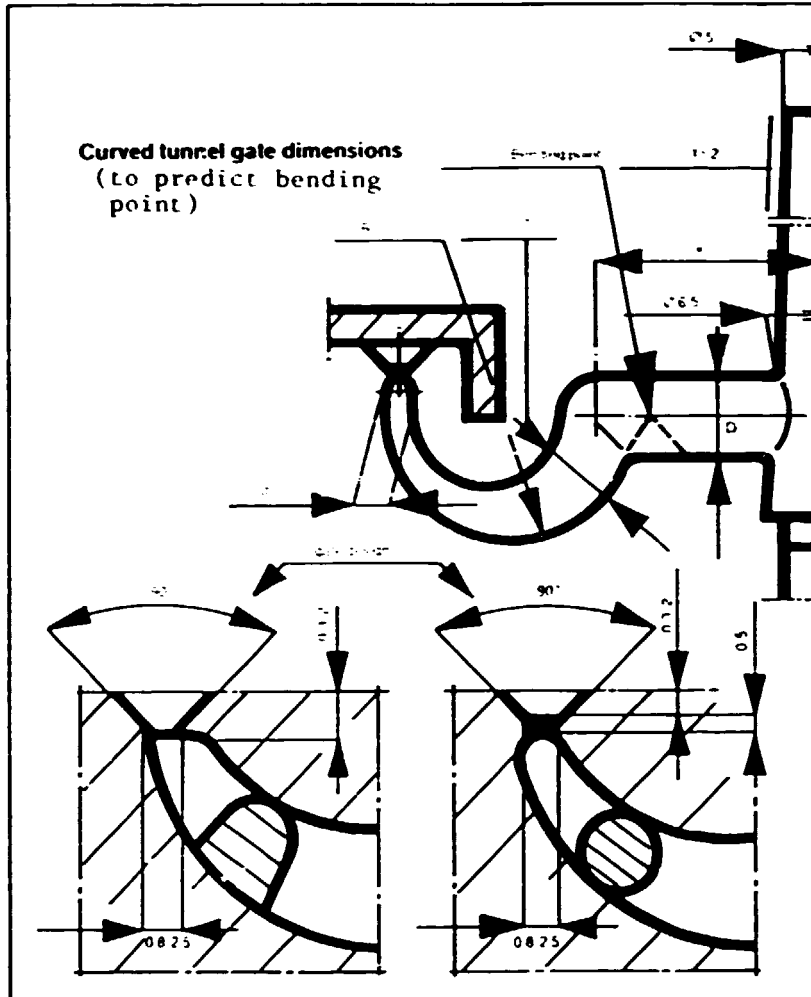


Figure 19(a) Pin point/curved type submarine gate
(Courtesy of G.E. Plastics Ltd.)



$$\frac{X}{D} \geq \frac{2.5}{1} \text{ or min } 15 \text{ mm}$$

D = approx 4 to 6 mm

$d_1 \leq D$ (normally 4 to 6 mm)

$R = 2.5 \text{ to } 3 \times d_1$

d_1 to d_2 equals a taper of 3 to 5° incl

Figure 19(b). Pin point/curved type submarine gate (detail)
(Courtesy of G.E. Plastics Ltd.)

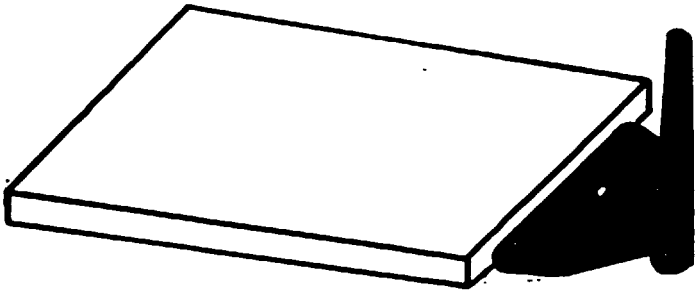


Figure 20. Fan gate

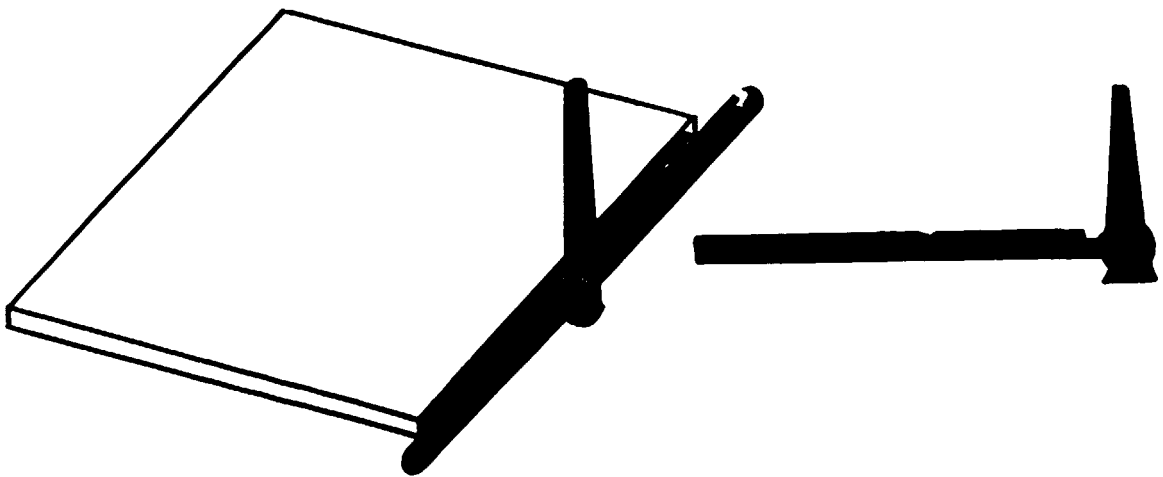


Figure 21(a). Film gate (centre fed)

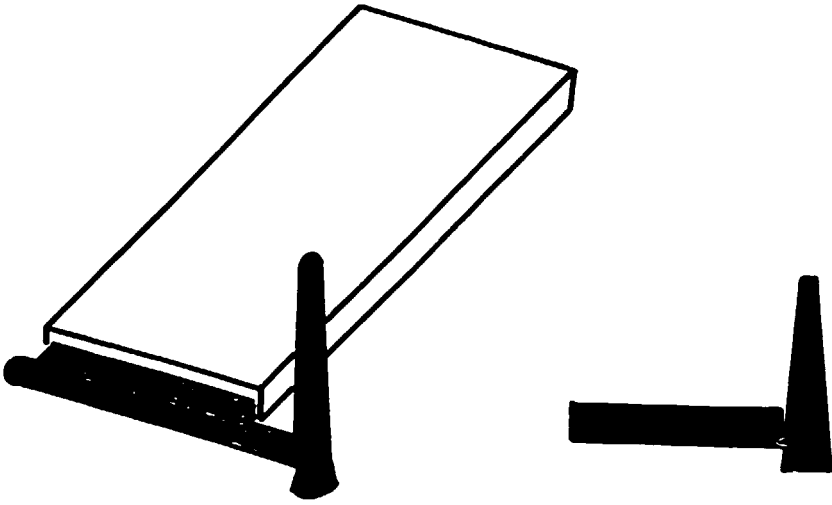


Figure 21(b). Film gate (side fed)

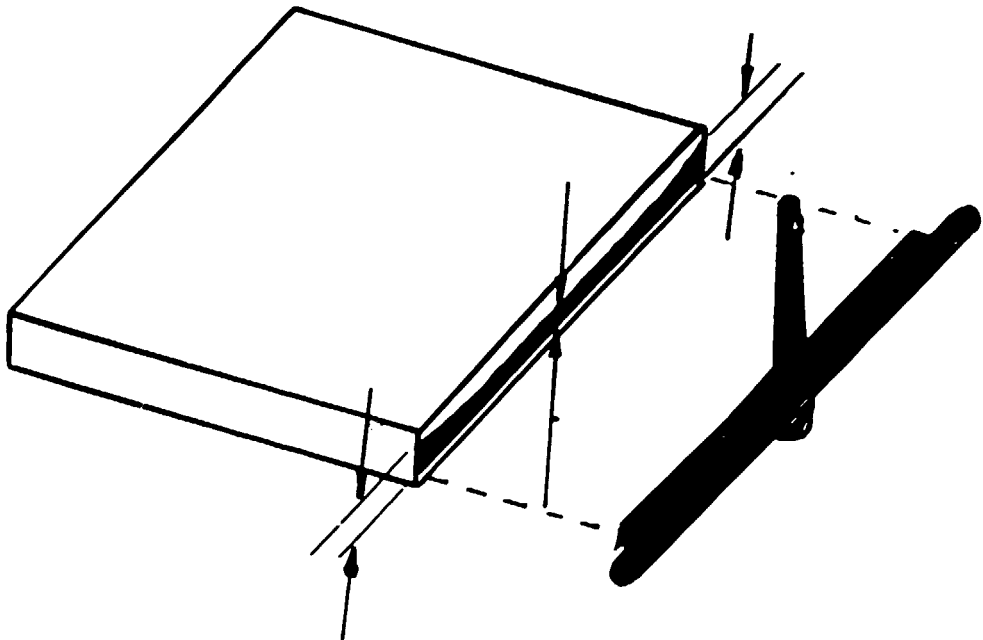


Figure 22. Profile of film gate

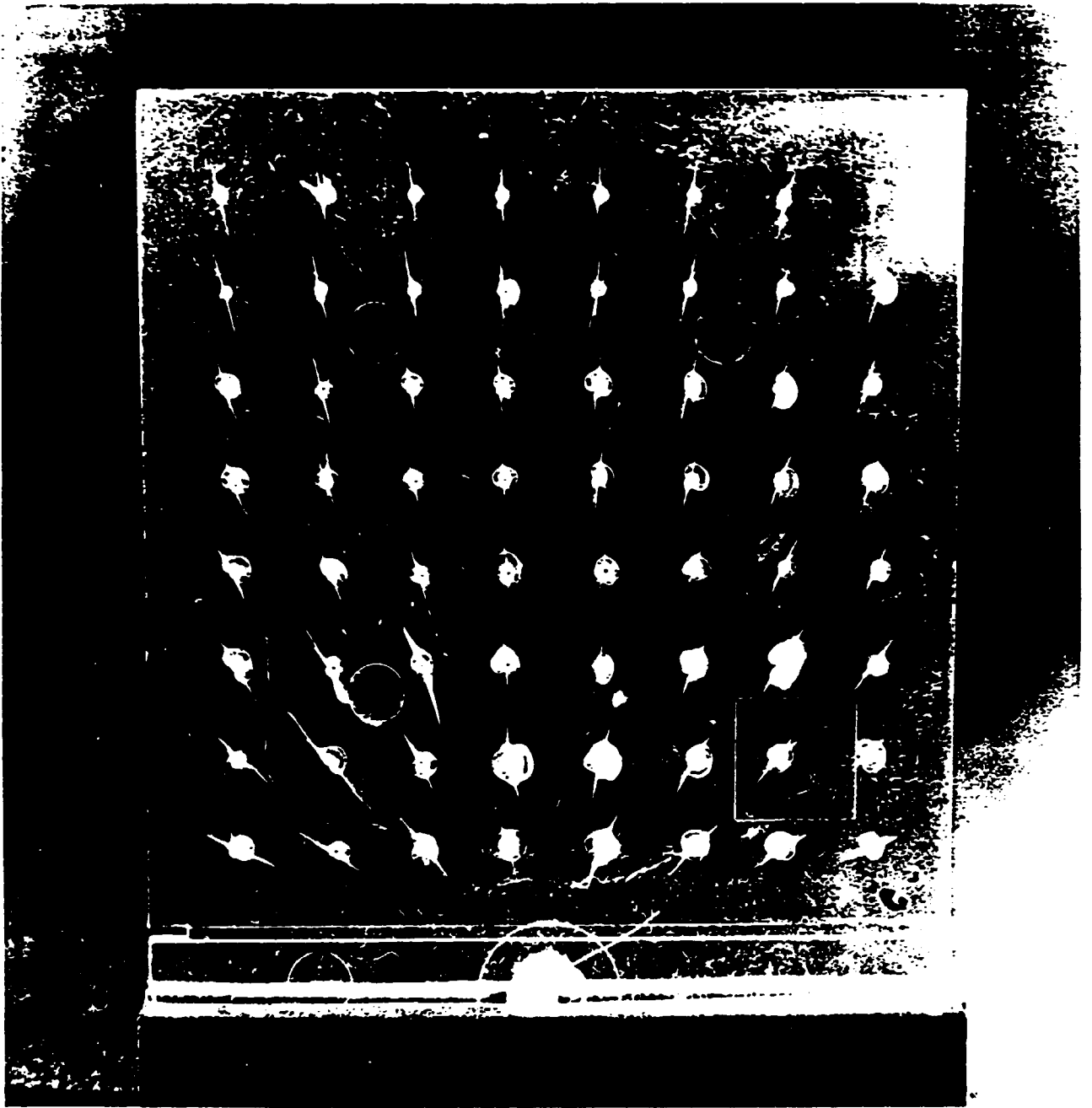


Figure 23. Molecular distribution of a non-profiled centre fed film gate

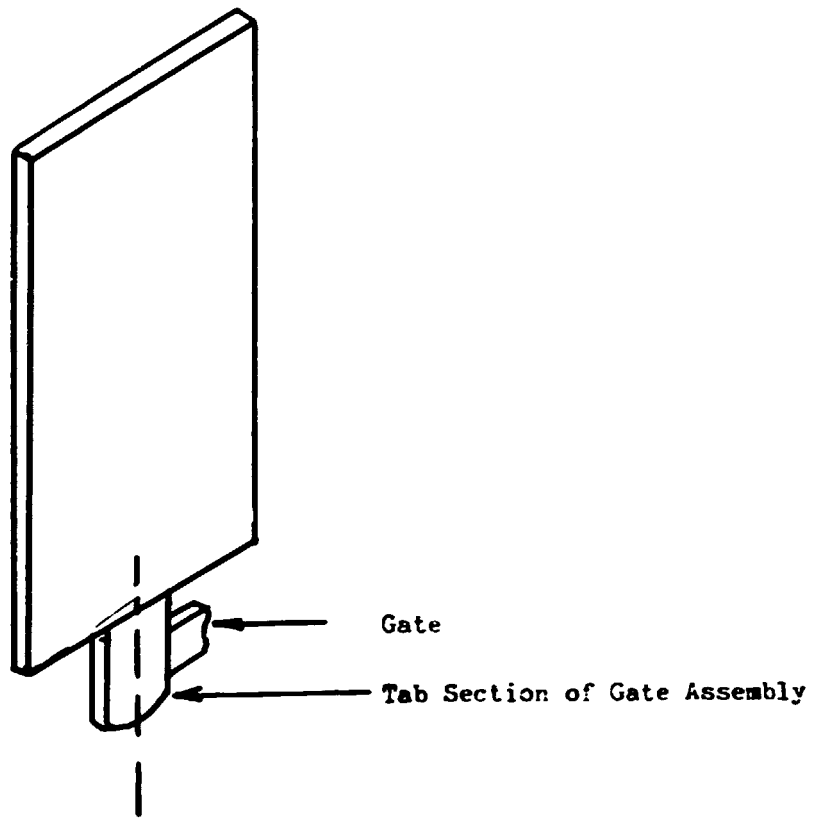


Figure 24. Tab gate

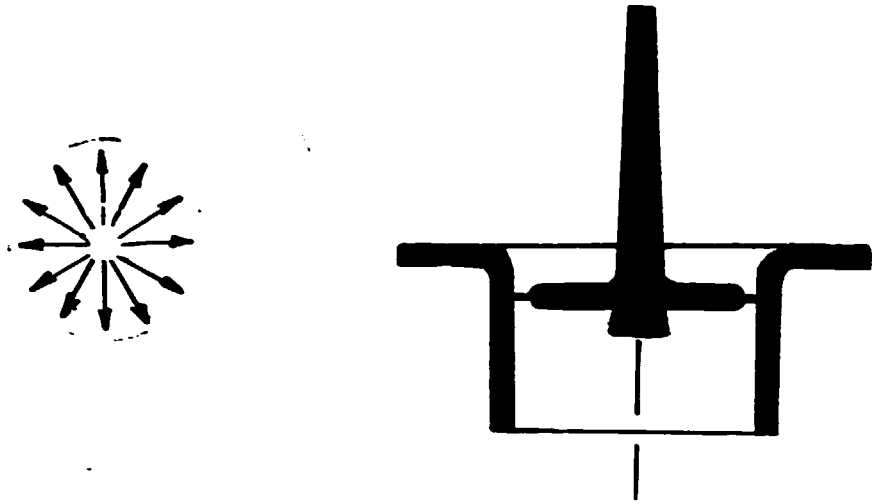


Figure 25. Ring gate

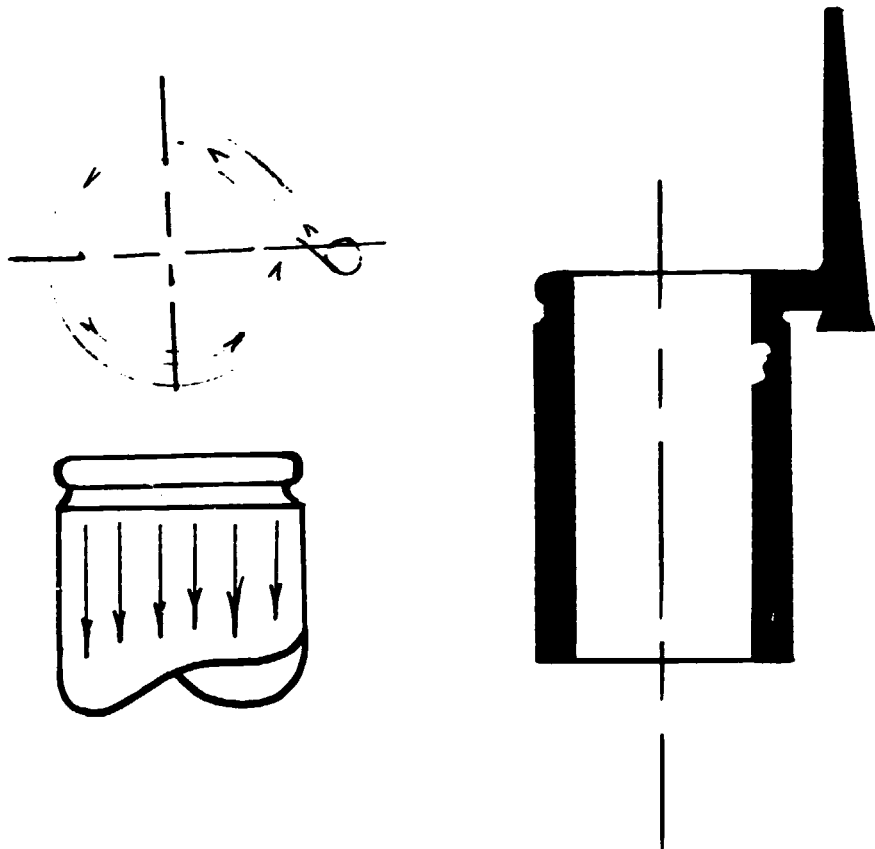


Figure 26. Diaphragm gate

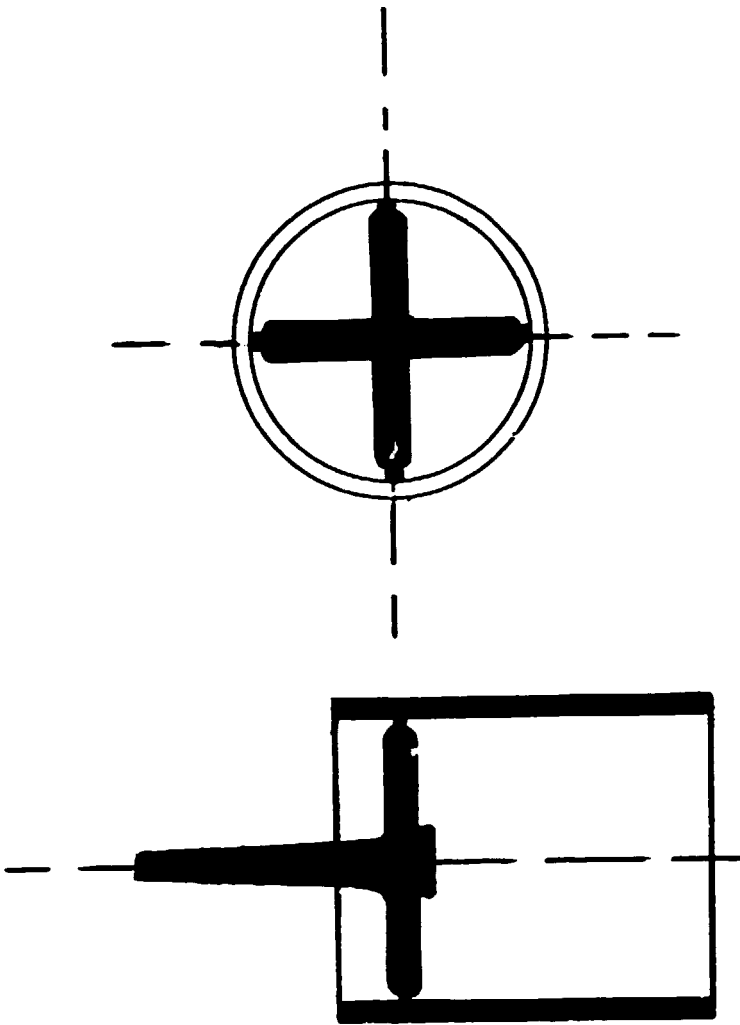


Figure 27. Spider gate

7. TYPES OF MOULDS

The moulds used in injection moulding vary in their size, complexity and cost; in fact the range of moulds employed is as great as the range of injection mouldings themselves. Moulds which are used for prototypes may be relatively cheap, as only a few mouldings may need to be produced from them: such moulds have been produced from a range of materials, e.g. other plastics, dental plaster and low melting point alloys. Production moulds on the other hand may be required to produce tens of millions of parts at very high speed and so their cost and complexity is very much higher. Normally the injection mould consists of two or more pieces of metal which contain an impression of the component which it is desired to produce. If the mould contains only one impression or cavity, then it is referred to as a single impression mould and if it contains more than one impression then it is referred to as a multi-impression, or multi-cavity, mould. Many injection moulds can be considered to be made from two halves with each half being bolted or attached to one of the machine platens. Mould closing, opening and clamping are achieved by the hydraulic system and in order to withstand the large forces involved, the mould is usually manufactured from tool steel. Each mould half is usually compiled of a number of plates or sub-assemblies.

7.1. Conventional moulds: Two plate moulds (see fig 28) are often specified because of their relative simplicity and therefore low, relative cost. For many moulding jobs, moulds other than the two-plate mould are preferred because of considerations such as ease of finishing, feeding and feed system elimination: these are called multi-plate moulds. The multi-plate mould consists of three main parts or plates which when separated form two main openings or daylight (see fig 29). When the mould opens, the feed system drops from one daylight and the moulding or mouldings drop from the other: segregation of the mouldings and the feed system is therefore possible. The use of this type of mould construction means that centre pin point gates can be used in a multi-impression mould. Alternatively, more than one gate may be used to feed the cavity of a single impression mould (see fig. 14), or a three-plate mould may be used when it is required to feed a cavity from a point that is not at the centre of balance of that moulding.

7.2. Undercut type moulds: Mouldings that contain an undercut or recess require a specific design of mould. An undercut type mould (see figs 30(a) and 30(b)) can be defined as any mould which requires moving parts, e.g. splits or side cores located within the mould to move aside and allow ejection of the component in line of draw (mould opening). In this respect they differ from the simple two plate type mould design. Undercut moulds may also, however, be of the three plate or hot runner type design also, but for the purpose of explaining the fundamentals we will discuss mainly two plate undercut moulds. The types of undercut that occur in moulded parts can be classified as:

- (i) External: and
- (ii) Internal.

Within the classification 'internal', moulded internal threads can be included, but these are a special case and the mechanics relating to the

design of the mould are discussed in section 7.3 entitled 'Automated unscrewing moulds'. Pipe fittings which are moulded using the technique of interlocking side cores on the 'split line' of the mould are also a special case often requiring the use of an 'early injection return' mechanism so as to prevent damage occurring to the side cores, and therefore, due to their complexity, will not be covered in this report.

7.2.1. Methods of actuating side cores or splits: There are various methods used to move (actuate) the splits, side checks, or side cores as they are commonly referred to. They are given in order of most common usage:

- (i) Cam pin actuation:
- (ii) Hydraulic core pulling: or
- (iii) Rack actuation technique.

Split type mould assemblies are available as standard from various suppliers of standardised mould parts in the United Kingdom and Europe, e.g. DME, DMS, Hasco. These integrate with the standard jig bored mould plate system to give a wide variation on design and mould manufacture. Such a combination can readily accommodate any configuration dictated by the component design.

7.2.1.1. Cam pin actuation method: This technique is by far the most common method for moving side cores and is usually in the form of a round headed pin (which again is available as a standard mould part). The cam pin is inclined at an angle through the side core and is pulled through the side core upon the opening movement of the mould. Such an action gives a lateral side core movement to relieve the undercut. This movement is determined by the working length of the pin and the angle at which the cam pin is positioned in the mould. (Normally limited for practical purposes to 25°). The movement can be expressed as the working pin length 'L' Sine diameter. A less commonly used cam pin is referred to as the 'dog leg cam pin'. The design of pin allows for a delayed action of the side core to occur as the mould opens so as to hold the moulded parts on the external undercuts whilst withdrawing a relatively long core. This keeps the mould height down and the ejection stroke very much shorter. This method has been successfully used for moulding plastic jugs with the handle at the side, and relatively long cores with small draft angles. It is, however, an expensive method for the mouldmaker to employ necessitating very much more machining than the standard circular cam pin.

7.2.1.2. Hydraulic core pulling: This involves the pulling of side cores within the mould using hydraulic or pneumatic cylinders. It necessitates signals on the forward and reverse strokes of the cylinder so that the pulling of the side cores can be sequenced with the machine opening and closing movement and especially the forward/return ejection movement. The signalling is normally carried out using electrical micro switches or micro proximity devices which make or break an electrical circuit to actuate an instruction (command) within the machine's control unit. If the moulding machine is not equipped for hydraulic core pulling, then an alternative core pulling power pack may be necessary. Hydraulic core pulling can be combined with cam pin actuation in the same tool. Hydraulic core pulling is used normally when the cam pin actuation reaches its limitations in both angle and the length of the core pull (movement). The hydraulic core pulling technique

is used for moving long and large cores, whereby specially designed cylinders are used with built in locking devices to prevent core retraction during the mould filling and packing stages.

7.2.1.3. Rack (core pulling) actuation technique: This is a mechanical method for pulling long cores when the cam pin is not practical or when the machine is not equipped for hydraulic core pulling sequencing. The racks are supplied in 160mm and 250mm lengths with intermeshing teeth inclined at angles of 45° or 30° (see fig 31). The operation of the unit is where one of the racks is pulled across the other and inclined at 90° . The heel block angle must be 2° larger than the tooth angle to avoid 'binding' or seizure ($30^\circ + 2^\circ$) ($45^\circ + 2^\circ$). The side cores are actuated immediately the mould starts to open. The movement of the side cores is equivalent to the ratio of opening to the tangent of the angle of the tooth.

Expressed $\tan^{-1} 45^\circ = 1.0$; and
 $\tan^{-1} 30^\circ = 0.577$.

So for example if a side core has to move 70mm, or core pull of 70mm is required, then using the 45° tooth rack the required mould opening is $70/\tan 45^\circ = 70\text{mm}$. Using the 30° tooth rack the mould opening is $70/\tan 30^\circ = 121\text{mm}$. So, as can be seen, also a large number of designs can be catered for, also this rack method may be used with the cam pin method in the same tool.

7.2.2. Retaining the side cores: After the mould opening movement occurs and the side cores have been pulled into position, it is necessary to retain the side core so that serious damage does not occur when the mould is closed, as a result of the cores being out of or, in the incorrect, position. Various methods of retaining the side cores are as follows, the most common being:

- (i) Springs:
- (ii) Spring loaded ball catches: or
- (ii) Slide retainers.

7.2.2.1. Springs: Used on a stem normally protruding from the back of the side core to keep it pulled back against a pre-set stop.

7.2.2.2. Spring loaded ball catches: The side core is drilled and tapped in a minimum of two places and the plunger inserted with a set screw behind it. When the mould is opened and the side core moved in position the roller balls drop into pre-determined and calculated positions. For lightweight slides.

7.2.2.3. DME slide retainer: This is a positive method of moving the side core back into a spring loaded device which looks like a 'clothes peg'. The side core has a dowel protruding from the sliding surface and as the side core moves and 'clicks' into the slide retainer which is mounted in a pocket in the bolster plate. This technique is normally used for the larger side cores and where a more positive location on the side core is required. This method is often used in conjunction with hydraulic core pulling as any core movement/misalignment on this type of tool could cause extensive damage.

7.2.3. Early ejection return mechanism: An early ejection return mechanism is required when the side core movement passes over the top of the ejector mechanism. This is often the case when producing pipe fittings or complex mouldings, which involve the use of two or more side cores as the distance between the side core and the cavity is determined by the product wall thickness, so they are very close.

7.3. Automated unscrewing moulds: Unscrewing moulds are normally referred to as automatic moulds for the manufacture of thermoplastic components which possess an internal undercut in the form of a thread. These moulds differ from the norm because they have revolving parts to 'de-mould' the thread. The ways in which they can be designed are numerous, but the main drive mediums in common use today are:

- (i) Rack and pinion unscrewing technique:
- (ii) Electric or hydraulic motor unscrewing technique:
- (iii) Collapsible core de-moulding technique: or
- (iv) Helix spindle and nut unscrewing technique.

External threads on moulded components are normally 'de-moulded' using side cores and/or other methods of unscrewing. Internal threads can be 'de-moulded' outside the tool with removable core inserts connected to an air operated hand tool. This type of method is carried out when using a semi-automatic moulding cycle or operation. In some cases, a rounded type thread form which is used for bottle tops may be jumped or bumped off the core using a stripper plate ejection method. Whichever method is chosen, it is important to locate all mould plates accurately so that there is no mismatch between the jig-bored holes used to locate the cores gears and bearings. Most suppliers of standard mould plates today have adopted the principle of many spigot locations in all the plates throughout the mould assembly by means of jig-bored holes which are also used for the guide pins and bushes. This fulfils the requirement for accurate alignment.

7.3.1. The rack and pinion unscrewing technique: This is a common method in use today and normally relies on a hydraulic cylinder operating racks which in turn are directly coupled through the gear teeth to revolving cores. The cores have the thread machined onto the moulding length, therefore unscrewing takes place by 'stroking' the cylinder. This method requires an electrical signal via the machine or ancillary equipment to move the racks in and out at the appropriate times within the moulding cycle. The speed of the downward stroke of the rack determines the speed of the unscrewing. This speed is varied for different threads.

7.3.2. Electric motor/hydraulic motor unscrewing technique: This method is used mainly when the part to be moulded has a large number of threads and is not then within the capabilities of either the 'helix spindle and nut' method, the 'rack and pinion' method or the 'collapsible core' method. Again, a signal is required to successfully operate at the correct time during the moulding cycle.

7.3.3. Collapsible core de-moulding technique: With this method there are no revolving parts involved. The core to form the thread is

segmented and has an inner central pin on which the segments rest against. When the central pin is moved backwards the segments are allowed to collapse to relieve the undercut. This type of unit is expensive, however, it is extremely effective for multi-impression moulds.

7.3.4. Helix spindle and nut method of unscrewing: This method utilises the opening movement of the moulding machine to automatically de-mould the threaded component. The drive mechanism of the assembly consists of a steel 'archimedian' multi-start spindle and a mating nut either of nylon lined steel or manganese-bronze. Unscrewing of the moulded thread is then carried out using the above assembly in combination with ball and roller bearings/bushes, and keys/splines. All of these other parts, are readily available as standard components and therefore reduces the time involved in designing and making the mould. This makes the mould considerably less expensive, but ensures a top quality product having guaranteed accuracy and reliability.

7.4. Family moulds: Family moulds are used to produce a number of different sized plastics components which together form one item, e.g. an assembly kit or lid and base of a container. It is not good practice to have different sized cavities within the same mould as problems are usually experienced in the production and/or in use. The moulding conditions chosen may suit one particular cavity but it is unlikely that they will suit all the cavities and so some of the mouldings may be, for example, over-packed. The end result is that the quality of all the mouldings produced is of a very low standard.

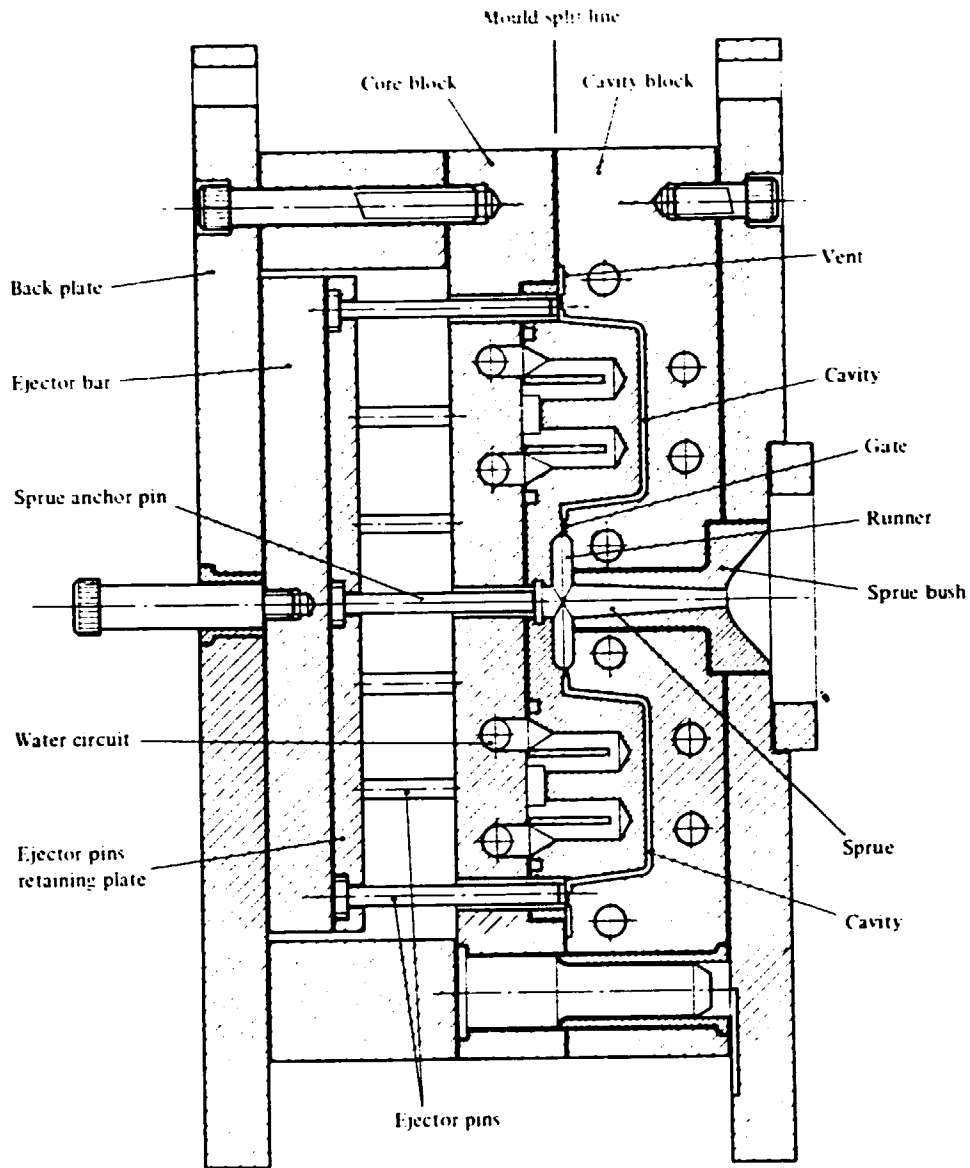


Figure 28. Two plate mould
(Courtesy of Imperial Chemical Plc.)

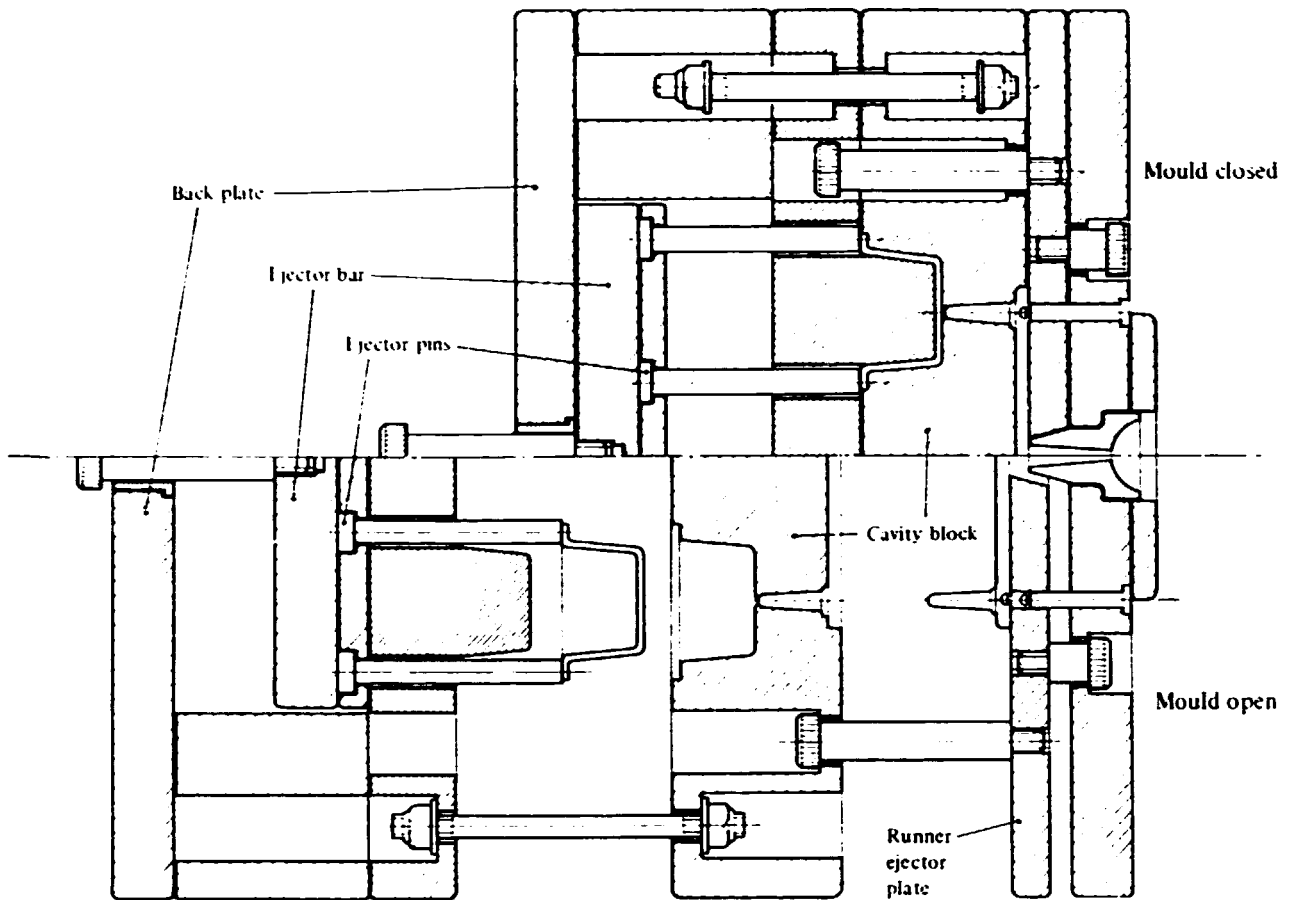
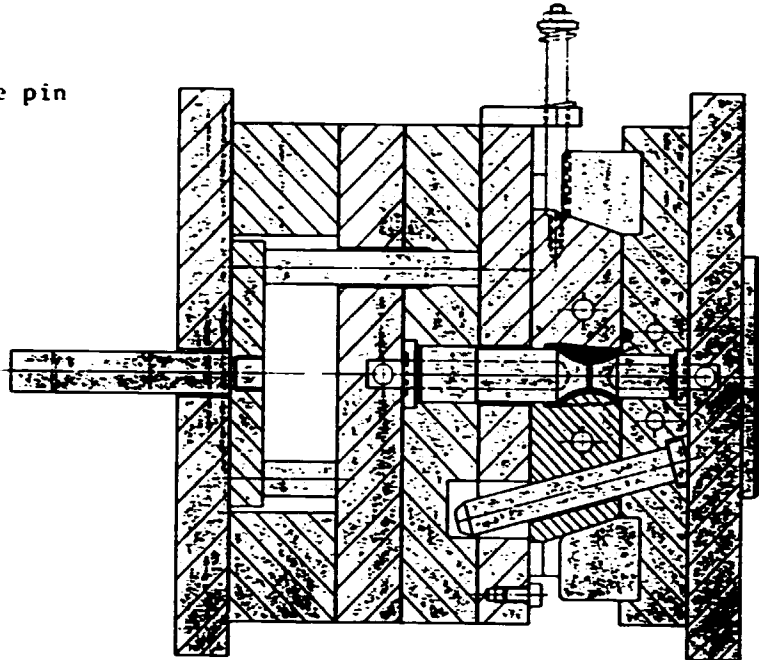


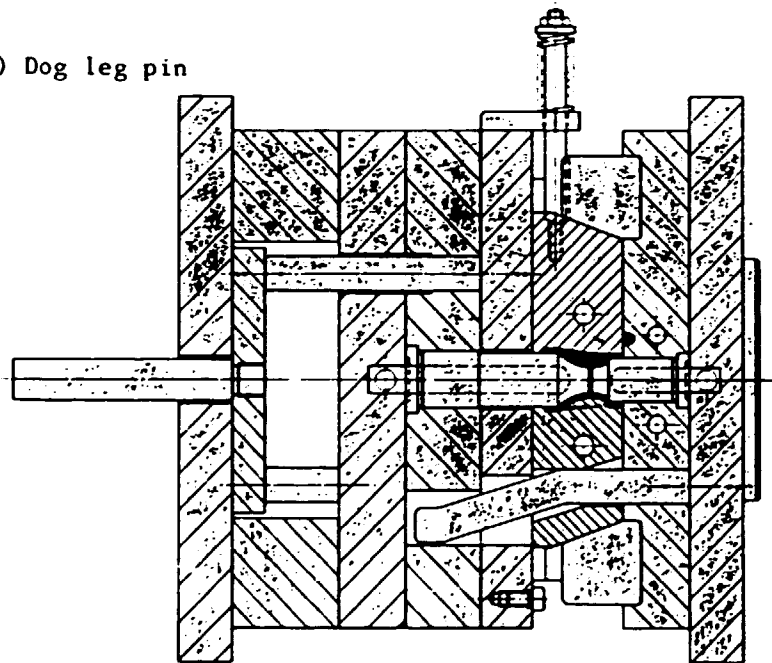
Figure 29. Sectional drawing of a multi-plate mould
(Courtesy of Imperial Chemical Plc.)

Figure 3G. Undercut type mould design

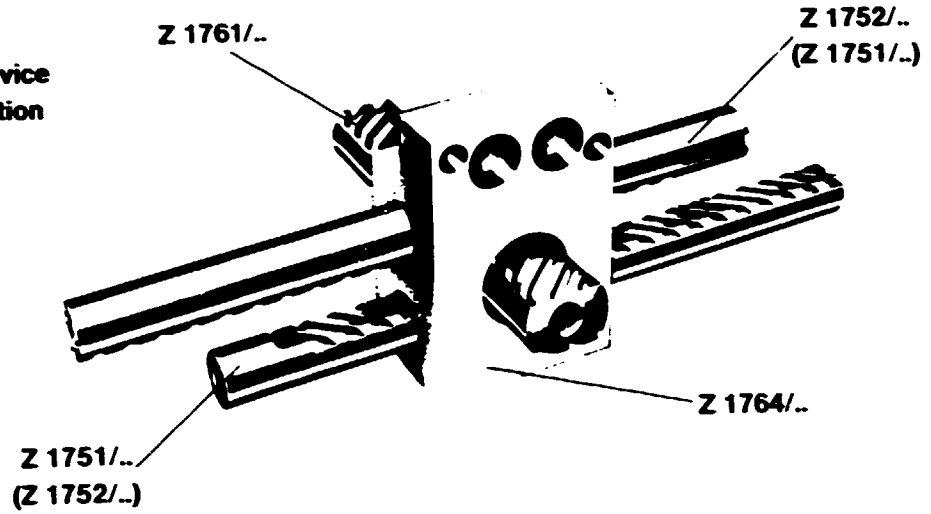
(a) Angle pin



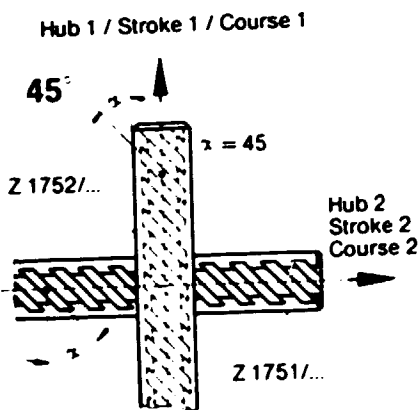
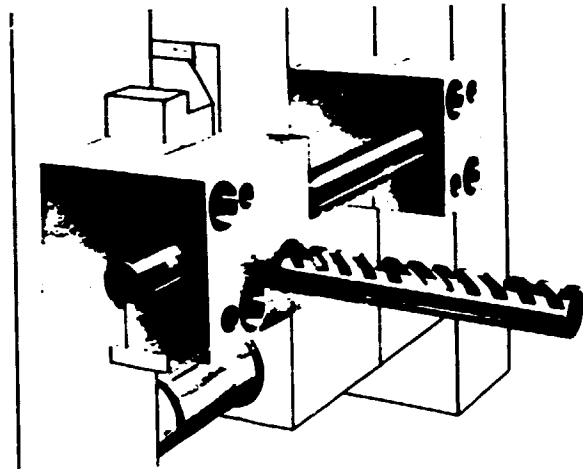
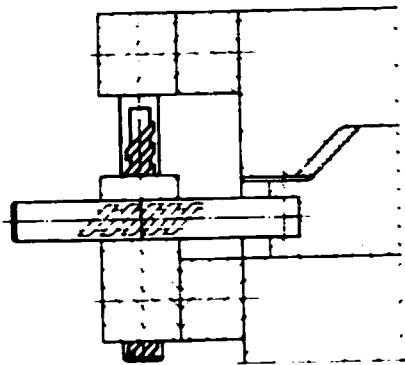
(b) Dog leg pin



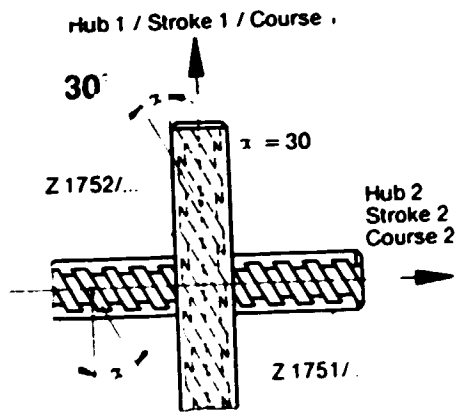
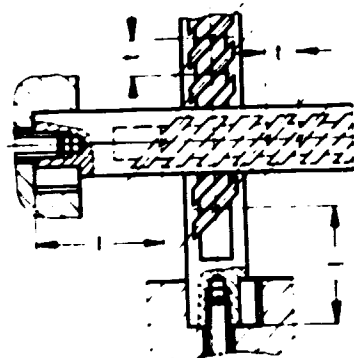
Schiebermechanik
Mechanical Sliding Device
Mécanisme de translation



Anwendungsbeispiel
Example of Application
Exemple d'application



Hub 1 / Stroke 1 / Course 1
 45°
 Z 1752/..
 $r = 45$
 Z 1751/..
 Hub 2
 Stroke 2
 Course 2



Hub 1 / Stroke 1 / Course 1
 30°
 Z 1752/..
 $r = 30$
 Z 1751/..
 Hub 2
 Stroke 2
 Course 2

Hub 1 - Zugstange
 Hub 2 - 0.5774 x Hub 1
 Stroke 1 - tie rod
 Stroke 2 - 0.5774 x Stroke 1
 Course 1 - cremallere menante
 Course 2 - 0.5774 x Course 1

Hub 1 - Zugstange
 Hub 2 - 0.5774 x Hub 1
 Stroke 1 - tie rod
 Stroke 2 - 0.5774 x Stroke 1
 Course 1 - cremallere menante
 Course 2 - 0.5774 x Course 1

Figure 31. Mechanical side core actuation using sliding device
 (Courtesy of Hasco Internorm Limited.)

8. RUNNERLESS TYPE MOULDS

The words 'Hot Runner' generally evoke a strong reaction, either positive or negative, dependent on one's personal experience. To many, hot runners represent a positive step forward in achieving better quality of product or lower unit costs. However, to others, hot runner is an unnecessary evil which create havoc and frustration in their moulding departments. Probably both emotions are quite objective, but are based on limited experience and maybe the truth is that the success or failure of hot runner systems is created at the tool procurement/design stage, rather than the application of a system on the shop floor. In today's environment of high technology, the tool designer is confronted with an awesome array of proprietary 'off the shelf' systems and every material supplier has a list of preferred systems which suit their material. In my experience, there is no such thing as good and bad systems, but different systems, each with their particular merits or limitations and the onus falls on the tool procurement/design engineer to purchase a system suitable to his/her unique needs.

8.1. Definition: A Runnerless System is one which is used to convey and maintain a fully prepared thermoplastic melt to the mould cavity (see fig 32).

8.2. Objectives: For the conventional moulder/mould designer the moulder/mould designer should seek to produce:

A component with:

- (i) the lowest possible residual stress;
- (ii) that has strong weld lines; and
- (iii) that is dimensionally stable.

A thermoplastic material which:

- (i) can be processed easily and has good thermal stability.

A mould with:

- (i) an optimum cycle time;
- (ii) greater reliability regarding mechanical and electrical operation; ease of maintenance; standardisation of mould parts; and the lowest possible pressure and temperature drop between machine nozzle and gate aperture.

A runnerless system with:

- (i) maximum mechanical safety during operation;
- (ii) maximum safety of material being used (e.g. the absence of material degradation within the heated manifold/nozzle assembly);
- (iii) ease of colour/material changes.

8.3. General concepts of runnerless moulds: Overall the runnerless mould should seek to achieve better economics, for example- large components may be moulded having more economic wall sections (thinner) and at lower cycle times, due to the reduced wall sections. Small or thin wall components may be moulded in multi cavity tools more economically, due to the fact that the cycle time is a reflection of part rather than the feed system. In both of the above examples, the product should be of better quality mechanically, due to the more effective hydraulic control of the molten thermoplastic entering the cavities, i.e. a lower pressure drop would be encountered as the molten material is transferred from the injection unit to the mould cavity giving lower moulded-in residual stresses in the product. The use of a runnerless mould should also improve material utilisation, in that the feed system does not have to be reground and reintroduced proportionally with all the risks of thermal abuse and contamination, not to mention capital expenditure on the need for granulation/blending equipment.

8.4. Requirements of a runnerless system: What should a good runnerless system offer?:

- (i) A balanced runner design so that each cavity fills equally;
- (ii) A short heat-up (soak) time so as to allow a rapid troublefree start-up, and also allow for production stoppages of up to five minutes for cleaning the mould and restart without undue problems;
- (iii) An energy consumption which is as low as possible - energy is expensive and too high a temperature can degrade the material;
- (iv) Sufficient insulation - air around manifold to minimise the transfer of heat to the rest of the mould. In addition the manifold plate normally necessitates a cooling circuit so as to ensure that the adjacent mould plates do not expand as accelerated wear can result within the movement of the mould;
- (v) Individual control of the melt temperature for each nozzle, through an accurate thermocouple controlled system;
- (vi) Reliable cartridge/band heaters which are of the low wattage type for heating the manifold;
- (vii) A mould design so that any maintenance/repair work can be readily carried out without removing the mould from the machine (i.e. where blocked gates or faulty tip heaters can be rectified).

8.5. Comparison of runnerless moulds with cold runner moulds: Some of the main advantages over cold runner moulds are:

- (i) No regrind resulting from the feed system - less material waste;
- (ii) Often faster cycle - where previously the cooling time for cold runner system influenced the overall cycle time;
- (iii) Easier to automate the process - due to the absence of the runner;

(iv) Lower energy consumption:-

- a) owing to not having to process the plastics material for the runner system through the machine barrel;
- b) not having to regranulate the runner system;
- c) not having to possibly redry the regrind, depending on the material type.

(v) Reduced labour content - due to not having sprues/runners, enabling an automated process:

(vi) Improved part quality in many cases.

(vii) The mould can be processed using a smaller capacity machine with respect to the clamping force and shot weight.

8.6. Types of runnerless moulds: Runnerless moulds fall into three main categories:-

(i) Hot manifold/nozzle systems with external heaters:

(ii) Cold manifold/nozzles where the heat is applied via a system of heated tubes or probes situated within the flow channels: and

(iii) Insulated runners where the manifold system is run at ambient and the flow channels are suitably large in diameter to ensure a material flow, due to the insulating effect of the outer skins of solid and semi-plasticised materials. In this system the nozzles are generally internally heated. Many combinations of these three basic systems have evolved over the years and are generally available as 'off the shelf' systems by certain manufacturers (see section 8.7 for a list of typical manufacturers).

8.6.1. Hot manifold/nozzle design: As the name implies the manifold containing the flow channels is preheated to a temperature where the prepared melt being transported to the cavities can be maintained at the correct processing temperature (see fig 33). Manifold blocks span the cavities in such a way as to create an even flow to each injection point (i.e. gate), thus ensuring a balanced flow of molten thermoplastics material into each cavity or section of the cavity. Manifold sections are generally rectangular or round and are heated by cartridge and/or band heaters controlled by strategically positioned thermocouples. Temperature controllers must be of the PID (Proportional, Integrative and Derivative) type so as to ensure of the necessary accuracy of temperature control required. Various proprietary systems use either low voltage or direct voltage control, however whichever type is used it is important that a soft start programme is included within the temperature controller. The presence of the soft start programme prolongs the life of the cartridge heaters by a factor of 10. It is recommended that quality steels be utilised i.e. EN30B or P20 pre-toughened, giving a hardness figure in the order of 34 to 48 Rockwell C (Rc).

The transition between the horizontal flow channel and the vertical nozzles should be achieved via a profiled plug securely locked in position. The profile should ensure a smooth change in the flow direction of the polymer melt whilst ensuring that there is no opportunity for the molten material to hang up, stagnate and degrade. When calculating the necessary heater capacity one should consider the type of thermoplastics material to be used: for example PP (polypropylene) being processed at 220/250°C will require less heat mass than a PC (polycarbonate) being processed at 290/310°C. Therefore, it is necessary to calculate the wattage required for the manifold on low melt thermoplastics at 200/250 watts/kg of manifold steel. High melt thermoplastics at 250/350 watts/kg of steel. These figures are calculated utilising approximately 60% of the heater's capability, thus ensuring a longer and more effective heater life.

Insulation of the manifold to cavity/back plates is important. It is recommended that a 6-8mm (0.236 - 0.315in) air gap and ventilation below and above the manifold or insulation board (6mm/0.236in) proves effective in minimising conducted/convected heat loss from the manifold.

Generally, the hot manifold systems utilise externally heated nozzles, which incorporate a thermocouple at each outlet to ensure a good thermal balance. Each nozzle is controlled by a separate controller of the PID soft start type which has the ability to control the temperature to +/- 1°C. The engagement of nozzle to manifold is achieved in one of two ways: either by screwing the nozzle directly into the manifold or by letting a hardened bush into the manifold to achieve a trap fit against sealing ring on the nozzle bush. Titanium rings are often used in this technique to act as a mechanical seal to stop the leakage of material out into the atmosphere. Examples of use of these two nozzle applications would be:- where a nozzle is long, 100mm (3.937in) plus, or where the nozzle centres are close, less than 150mm (5.906in). The screwed in nozzle would be adequate, as there is not too much differential thermal expansion to compensate for. Therefore, one is unlikely to encounter problems with fatigue endurance and the consequential stress cracking of nozzle terminations. However, with nozzle centres in excess of 150mm (5.906in) and short nozzles, then thermal expansion has to be taken into consideration and the slip design would be preferred, where the nozzle/sprue bush are located into the back of the cavity block and the manifold clamped into position, thus allowing the manifold to grow in length without moving the nozzles. Obviously, more care has to be taken to ensure a good seal when using this technique. Usually this is achieved by either bolting the manifold down into the cavity block or alternatively by placing straps over the manifold and once again bolting down into the cavity block. The old way of support pillars on the back plate and sandwiching the manifold has, for the most, been abandoned, due to leakage problems created by distortion of back plates under load resulting in the manifold moving and leaking.

Normally, with today's injection moulding machines comprehensive control system and the availability of accurate temperature control, the need for shut off type nozzles has, for the most part, been removed, as melt decompression can, in externally heated systems, decompress (de-pressurize) the melt sufficiently to remove the problem of the material drooling from the nozzles and gates. However, on internally heated systems, because of the relatively high pressure losses, decompression is not too effective and one

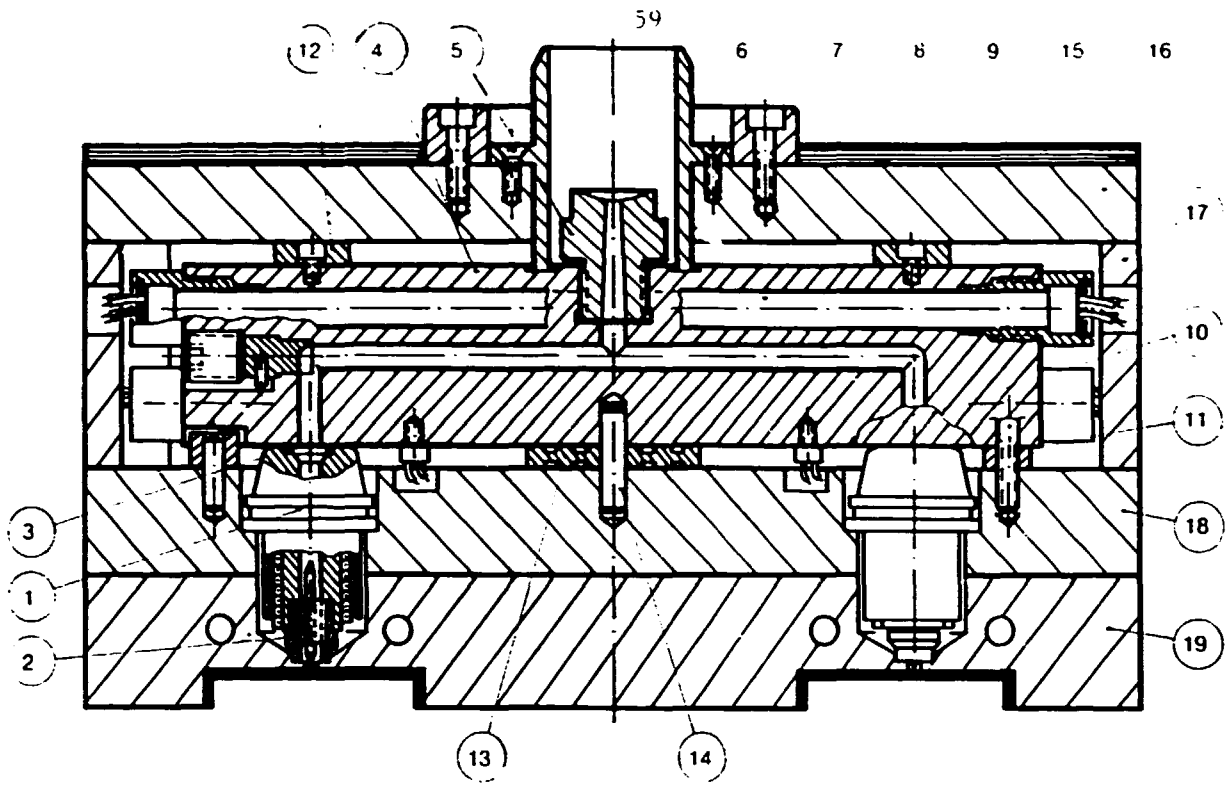
has to substitute screw decompression for a mechanical decompression of the melt via nozzle retraction (sprue break) and a slip bush in the back of the manifold/sprue arrangement.

8.6.2. Internally heated manifold (see fig 34): This system, by far the most popular for commodity thermoplastics materials (such as PS, HIPS, PP, PE-LD, PE-HD and ABS), operates on the principle that relatively large diameter holes are bored through the manifold block, into which heater tubes are inserted. When the system is operational, one achieves laminar flow of plasticised (molten) material along the outside of the heated tube, whilst the outer and solidified material skin acts as an insulating barrier. The principal advantages of this type of system are that one does not have to contend with differential expansion or sealing problems. Also, that it is possible to drop (locate) many nozzles/cavities off one heater tube. Thus, the economics of using such a system become obvious. Power consumption is also very low in this type of system, as the wattage required to keep flow channels open is very low. The changes in flow direction required from main tubes to secondary or probes is achieved by boring the adjoining holes in such a way that they overlap, thus forming a continuous flow channel from machine nozzle to gate aperture. However, the relationship between the flow channels in terms of overlap is important and the manufacturer's recommendations should be strictly adhered to as certain thermoplastics are more difficult to process. Should the recommendations be amended or changed to accommodate high viscosity amorphous materials and semi-crystalline materials with sharp melting point transitions then problems will occur. Without doubt, the internally heated manifold system has achieved its popularity due to its simplicity and avoidance of material leakage, but as with all systems it has its limitations. For example, colour changing is somewhat difficult. The material tends to remain in the dead areas over extended periods and degradation can take place. Therefore, one should be very careful when considering a cold manifold system for engineering thermoplastics where one wishes to retain the optimum property profile from the thermoplastic material.

8.6.3 Insulated runner system with heated probes: The standard insulated system (see runner system fig 35) utilises the principle that thermoplastics materials are poor thermal conductors and given that one can cut a flow channel large enough, it is possible to keep thermoplastic suitably molten in the feed system between cycles. Many insulated runner systems do utilise start up heaters in the manifold and without exception all use probe heaters (see fig 36) to ensure that the gates stay open i.e. do not freeze off preventing material flow into the cavity. In principle, the system uses trapezoidal or full round runners of 20 to 30mm (0.787 to 1.181in) in diameter through which, opposite the gates, vertical heated probes are situated of various configurations. In order to facilitate start up and colour change, the manifold splits horizontally along the centre of the feed channel. Snatches are often used to ensure the solidified feed breaks away on the desired half of the tool. The two halves of the manifold are usually clamped using quick release tapered clamps along the outer edges of the manifold. The principle advantages of this system being a more cost effective system to produce components from a wide range of thermoplastic materials: proved to be capable of using materials like polyamides (nylons) and polyacetals (POM). The disadvantage of the system is the high pressure loss encountered during mould filling and in the event of a lengthy interruption to the process cycle, it is necessary to remove the solidified feed before recommencing.

8.7. Some typical suppliers of runnerless systems: The following list is by no means an exhaustive one, however these systems are well proven and considerable success has been obtained from each type.

<u>Manufacturer</u>	<u>Type of System</u>	<u>Remarks</u>
DME 'COOLONE'	Internally heated	Low power consumption
DME 'HOT ONE'	Externally heated	Manifold low voltage
MOULDMASTER	Externally heated	Cast beryllium copper
DMS PLAGATE	Externally heated	Nozzle pressure displacement
SEIKI SPEAR	Combination system	Low voltage tungsten probe pulse heated
INCOE	Internally heated	Shut off valves available nozzles
EUROTOOL	Combination system	Internally heated nozzles
FURSE	Nozzle internally heated	-
HASCO	Externally heated	Nozzle shut off system also available
YARSLEY	Combination system	-
EWIKON	Combination system	Manifold low voltage induction heaters



Components

Pos.

- 1 Nozzle Body
- 2 Nozzle Tip
- 3 Seal Ring
- 4 Hot Manifold
- 5 Nozzle Seat
- 6 Center Ring
- 7 Locating Ring
- 8 Heater
- 9 Heater Puller
- 10 Thermocouple
- 11 Spacer Ring
- 12 Ricer Pads
- 13 Center Support Block
- 14 Center Pin
- 15 High Temperature Insulator Sheet
- 16 Top Plate
- 17 Risers
- 18 Support Plate
- 19 Cavity Plate

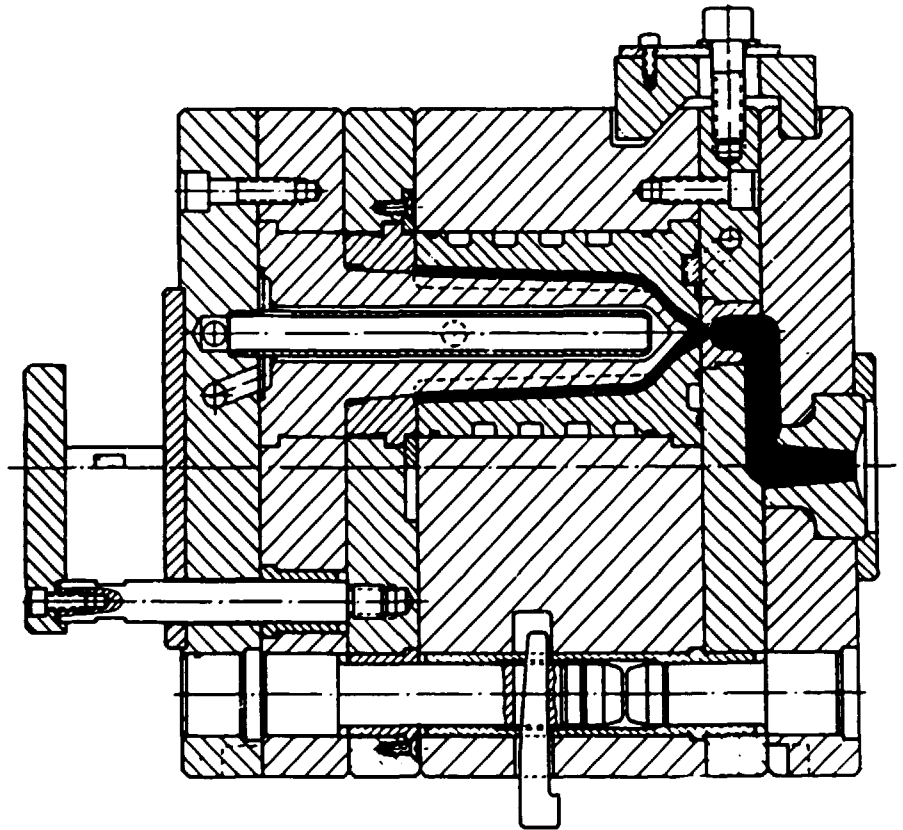


Figure 32. Typical runnerless moulds
(Courtesy DME (Europe) UK.)

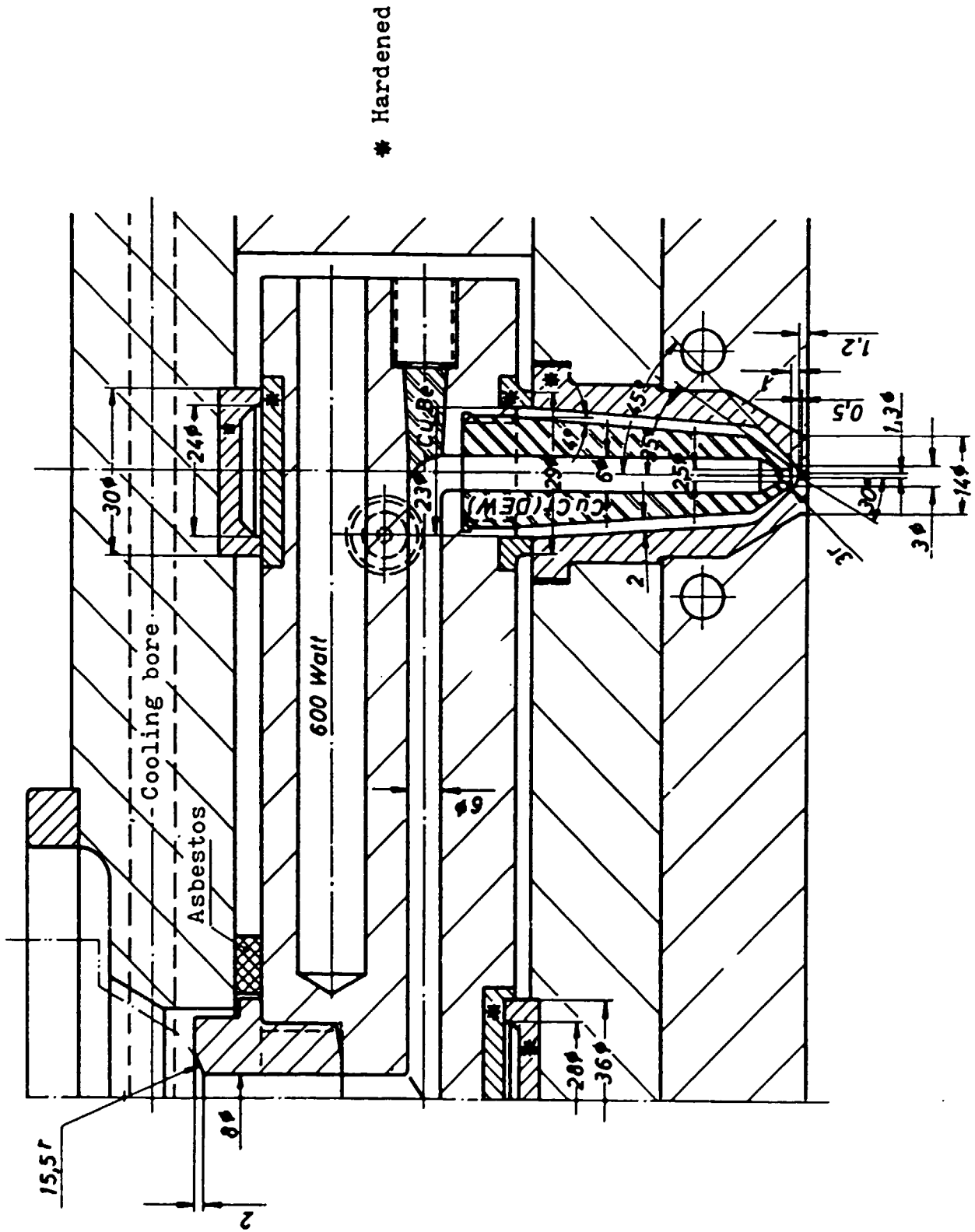
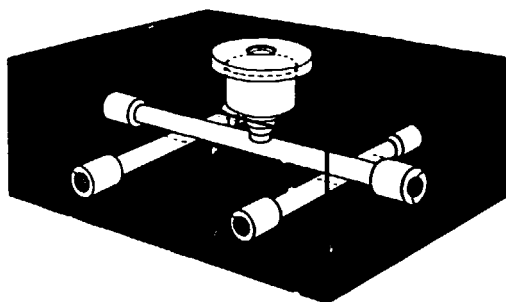


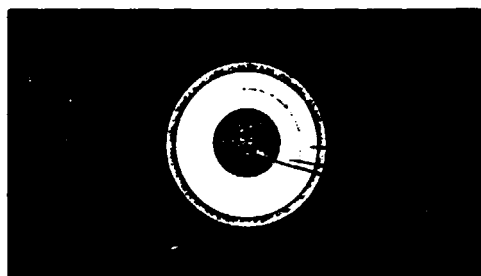
Figure 33. Hot manifold/nozzle design

Figure 34. Internally heated manifold/tube design
(Courtesy DME (Europe) UK.)



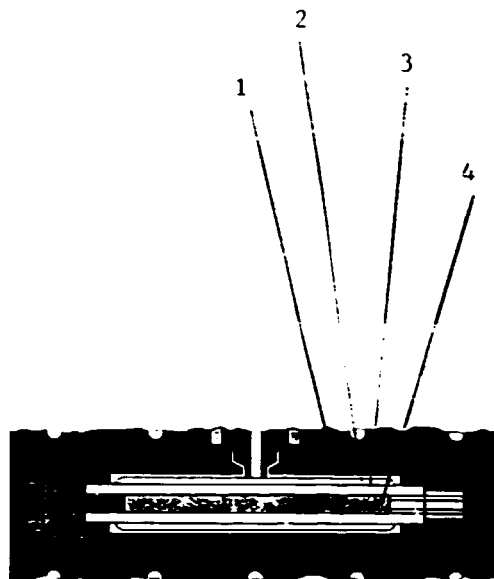
H-Sample with Heated Adaptor Set into the Distributor Plate

Positioning and fixing with end caps.



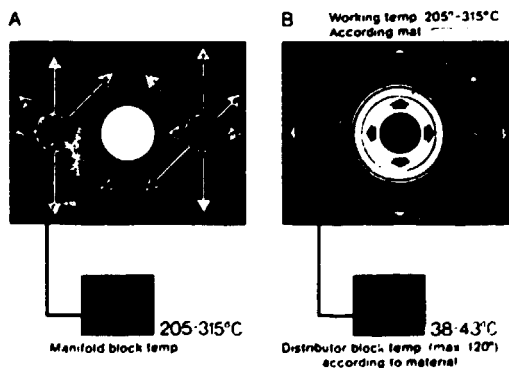
Cross-Section of the Distributor Plate

- 1 = plasticised plastic
- 2 = insulation layer
- 3 = distributor tube
- 4 = cartridge heater with thermo-couples



Longitudinal Section of the Distributor Plate

- 1 = plasticised plastic
- 2 = insulation layer
- 3 = distributor tube
- 4 = cartridge heater with thermo-couples



Thermal Conditions in the DME Distributor System

- A. Conventional hot runner manifold.
- B. DME distributor tube system. No temperature fluctuations or over-heating. The "Cool One" DME hot-runner system saves up to 70% energy.

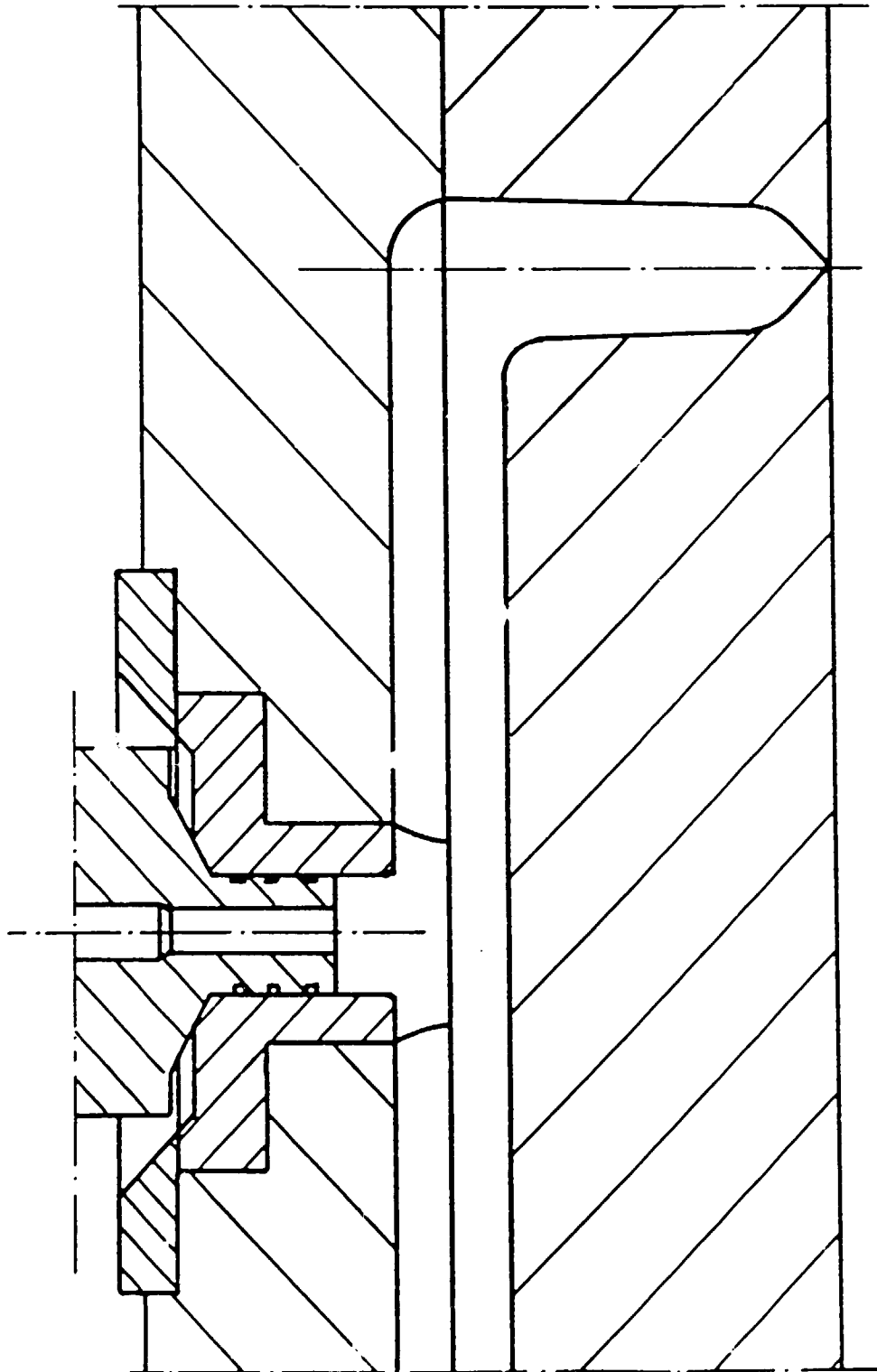


Figure 35. Insulated runnerless design

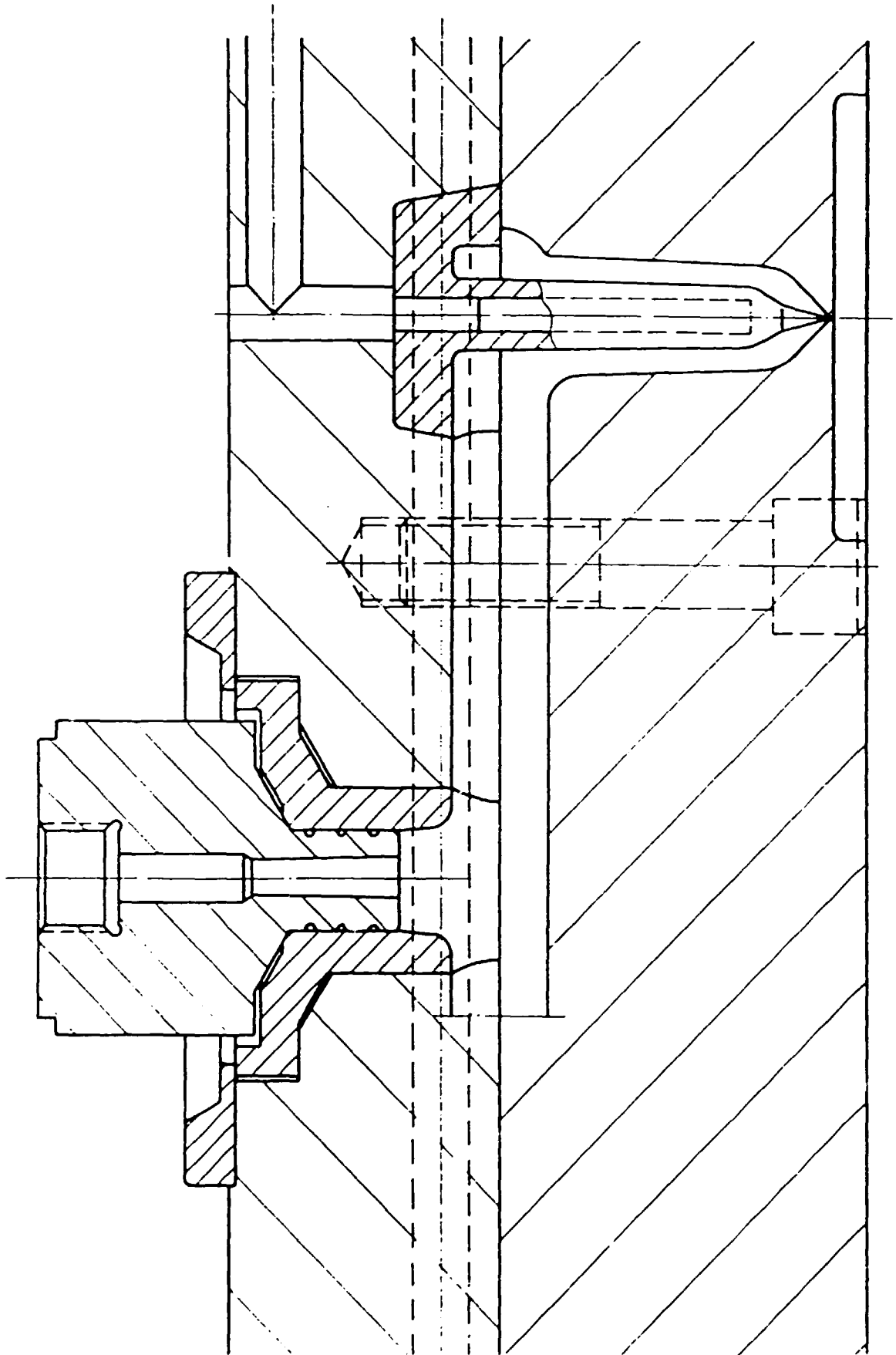


Figure 36. Insulated hot tip runnerless design

9. CAD/CAM IN MOULD DESIGN AND MANUFACTURE

Nowadays the availability of a CAD/CAM system using a common three-dimensional database for design, analysis, draughting, documentation and manufacturing without the operator needing to learn a computer programming language is becoming increasingly evident within the mould design and manufacturing industry. CAD/CAM allows the mould designer and manufacturer to maintain a high level of technical competence and shorter delivery times with respect to mould manufacture. It also creates a facility where the customer can be regularly updated of the progress of the project. This creates confidence between both parties thus forms the basis of a lengthy business relationship.

9.1. Computer aided design (CAD): The description of the object being designed can be generated by interactively constructing various geometric entities. The description forms a complete three-dimensional model of the part which is stored in the computer memory. Computer software programs are available to produce two dimensional (2D) and three dimensional (3D) modules enabling varying levels of component complexity to be readily catered for. Some components only need to be specified by two-dimensional drawings whereas complicated components such as car bumpers and facias require full three-dimensional consideration. The description/shape of the model is derived from a particular CAD package/system. Within the software package functions are provided for examining, analysing and evaluating the model as it develops, and for modifying the design to the user's satisfaction.

9.1.1. Compatibility of various CAD systems: In order to ensure compatibility is available for various computer software the data must therefore be converted into a neutral format to allow it to be read into the mould-maker's or end users' CAD/CAM system. The most widely used format for this data exchange is IGES (The Initial Graphics Exchange Specification.) Although IGES is the most commonly used format, other formats are being developed and released to widen the available scope of neutral formats. The IGES specification itself is constantly being enhanced. Using these neutral formats and custom interfaces, mould-makers can set up a dialogue with their customers by transmitting data to and from their respective CAD systems. This data will usually come in the form of a three-dimensional wireframe model. The mould-maker can interrogate this model, add his required modifications, such as draft angles, parting line recommendations, gating position, and then pass this data back to the customer. The customer can then examine the revised three-dimensional model and check to see if these changes are acceptable. Such a dialogue can take place at any time and as many times as necessary to ensure the correct mould design is obtained. Once complete, the stored model - which must be a complete and accurate description of the object - can be put to a variety of uses. Fully dimensioned engineering drawings can be produced; numerical control (NC) instructions can be generated for the manufacture of the part by converting machinery or by stereolithography; or the model can be used to generate input for various analytical processes which includes a finite element analysis. Commercially available hardware and operating systems, which are compatible with other computer systems in use, enable it to form the core of a computer integrated manufacturing (CIM) system.

9.1.2. The involvement of the mould designer in component design: While mould designers do very little, if any, original piece part design, the interesting feature that has arisen as a result of using CAD in the plastics industry is an area that has evoked change. Because of the closer links forged from the ability to exchange three-dimensional data, moulders have found that they now get involved much earlier in the design cycle with their customers and thus have an increased influence on piece part design. On many occasions this has proved to be invaluable in terms of component manufacturing lead times.

9.1.3. Flow analysis/modelling programs for mould design: There are a number of computer aided mould design software programs used for the evaluation/analysis when injection moulding a particular component with a particular plastics material. These techniques allow a more scientific method to take the place of the costly and wasteful trial and error methods of the past. The injection moulding process is very complicated - hence the reason why computer solutions are beneficial. Not all the problems can be solved with one program and therefore a series of programs are often needed. Firstly, the fundamental problem of melt flow prediction must be dealt with so as to provide a sound basis for further analytical exercises to be carried out (e.g. cooling analysis shrinkage and stress determination). Therefore, in general computer aided mould design programs are written and presented in a modular structure. The fundamental module is the polymer flow analysis. This software and methodology consists of four components:

- (i) a material database;
- (ii) a modelling program which will reproduce geometries and information regarding the materials behaviour;
- (iii) various analytical programs which predict flow patterns and characteristics; and
- (iv) results programs which display the findings in an informative way.

These four components work together to give a complete flow analysis capability. It is also possible to integrate this type of program with most CAD/CAM systems by means of a dedicated interface. By examining the results from the 2D analyses the designer can define and specify a range of injection (processing) parameters within which to operate the completed mould. If, from the initial set of results obtained, an appropriate set, or range of conditions cannot be found, the analysis can easily be run again with a change of material, melt temperature, gating position, mould temperature or a combination of any of these parameters. This would be the simplest form of mould analysis; but there are many types with differing levels of complexity of analyses. A more complex level of analysis would be a full three-dimensional finite element analysis. From the three-dimensional wireframe model (that would have been already created on the CAD/CAM system) a finite element mesh is generated. A full analysis of the model can then take place by the user specifying the necessary processing parameters. The results of the analysis enable the mould designer to identify a number of important features. It also ensures that the processor (moulder) is given the correct processing conditions (which includes the moulding machine's shot and plasticising capacity and required locking force) needed to produce the component. These results can either be tabulated or, more usefully, graphically displayed on the three-dimensional model in the form of contours or coloured bands.

9.1.4. Advantages of using the analyses programs: The most obvious advantage of using the collection of mould analysis programs in conjunction with CAD/CAM comes from the ability to simulate and verify the various options available to the designer and moulder before finalizing the design and cutting metal. It can also provide the mould designer and manufacturer with a powerful tool in the dialogue with the customer. Instead of arguing that 'I believe that the design is unusable under certain conditions', it can be demonstrated analytically that the mould is unsatisfactory. The designer then can demonstrate to the customer that with certain modifications, maybe the addition or movement of a gate, the mould can become efficient in its use. This level of technology and service can only improve the customer's confidence and relationship with the moulder and mould-maker.

9.1.4.1. Other types of software programs: In conjunction with the flow analysis program, additional software is available to analyse:

- (i) the cooling circuitry of the mould thus providing:
 - a) recommendations to cooling circuitry layouts;
 - b) an improvement in component quality;
 - c) an improvement in productivity (cycle time reduction).

(ii) the shrinkage/warpage characteristics of the moulded component thus relating physical characteristics of the final product to the inherent nature of the thermoplastics material. For example, the molecular orientation, the rate and degree of crystallinity, the volumetric shrinkage and the amount of stress relaxation can now be more effectively considered than previously. This type of approach and software package enables a more scientific and effective understanding when determining the specific shrinkage value so as to achieve correctly sized components. The above software also identifies the degree of warpage that the component may experience, whilst in service, as a consequence of the type and grade of polymer used, the moulding conditions and mould cooling circuitry selected, and the component geometry. This information is essential to the product designer/design engineer when evaluating the overall effectiveness of the component design. Additional programs are being currently derived for estimating cycle times, and assessing the end performance and life expectancy of the component, whilst in service. Each of these additional programs have been designed to be included in a modular scheme so that from the initial information/data collection a complete analysis of the product can now be ascertained with respect to the design and manufacture through to its end usage and life expectancy.

9.1.5. Designing of the mould by CAD: Once the piece part design has been defined in the CAD/CAM system, the actual mould can then be designed around it. Mould design is an area where CAD/CAM can be applied at a very productive level. From the three dimensional model, two dimensional views can easily be derived. Mould plate design, using standard plate components, is a perfect application for parametric programming. This provides the user with the ability to automate the functions available in the CAD/CAM system and may allow the user to interact with the program as it is running, enabling an infinite number of variations to be created. This programming facility saves

an enormous amount of design and draughting time. Standard elements (components) for mould-making have long since been an important feature in the design and manufacture of injection moulds. During the changeover period from conventional drafting techniques to CAD work stations, it became common to use the proven scale 1:1 master drawings and design proposals that included standard elements. Such information was obtained from data carriers. The objectives which were set - in addition to supplying high-quality products - were directed at using computers to aid in the field of CAD-orientated design. To accompany these an extensive range of standard mould elements comprising of up to 30.000 individual components was made available. The use of such programs is becoming more popular than previously imagined.

9.1.5.1. Incorporation of the CAD standards program into the existing software systems: The basis of the standards component program is a catalogue-like database, often called the 'standards data bank'. The interface between the standards data bank and the relevant CAD software is created by a system-specific, graphically interactive programming language. This program is integrated into the existing software in such a way that the user (in this case the mould designer) has free access to any standard element in the catalogue when using the design program. The designer/user is guided through the CAD catalogue program by structured menus giving explicit instructions at each stage. The designer is, therefore, able to use the standards program without excessive training, thus enabling a quicker return on the initial capital investment. All standard elements are addressed by a catalogue or code number. Each program being written according to each individual standard component manufacturer such as Hasco, DME and Uddeholme. The individual elements of the catalogue are preset and called up in chronological order and the inputs are automatically checked for correctness and, in the event of incorrect inputs or operator errors, the menu request and instructions are repeated. If those standard element dimensions are selected which are not available in the catalogue, the program can be designed to offer possible alternatives. The result of a catalogue call-up is an accurate component drawing of the standard element. All functional dimensions are accurate up to 2 decimal places, and even details such as undercuts, radii and chamfers are accurately taken into consideration. The element selected is positioned directly within the design drawing at the point specified. Geometric manipulations such as translations, rotations or erasure of an element are possible, as is the use of levels/layers. Such levels permit the design to be broken down so that it can be easily read and understood. This is particularly useful when designing the cooling channel layouts in relation to the positioning of the ejection mechanism. Various views and sections permit the designer to work with all necessary drawing elements, such as plan views, and sectional elevations. In addition, all the standard elements selected are automatically entered onto a separate parts list.

9.1.5.2. The advantages of using a CAD standards elements program: The application of the CAD standards mould elements program offers a number of advantages, such as:

(i) the standard elements can be called up using the catalogue numbers and can be positioned true-to-scale directly in the design:

(ii) the designer is relieved of repetitive, conventional routine drafting and has more time for creative design:

(iii) all the standard element data which is stored within the data bank has an accuracy of two decimal places. Therefore graphical representation/display of the standard elements is true-to-scale:

(iv) important functional dimensions of the mould, such as the overall dimensions, the lengths engagement/working lengths of guide pins, ejectors or the dimensions of the runner/gating systems, can be determined at an early stage in the design phase, due to the conciseness when displaying the standard elements:

(v) workshop drawings for further machining of the standard components are taken directly from the design. Single element drawings, such as for machining mould plates, shortening ejector pins, machining core pins or adapting sprue bushes or hot-runner blocks, can be drawn directly from the CAD representations of the catalogue standard elements:

(vi) the user of the CAD standard program is in a position to quickly find alternative solutions for a particular mould design. He/she can draw up and compare various concepts - such as designs for multi-cavity moulds, ejector and gating systems:

(vii) all inputs are automatically checked for correctness inputs of incorrect catalogue numbers or operator errors are recognised and the input can be repeated:

(viii) components called up from the CAD standards data bank are automatically compiled into a parts list to enable the raw material to be readily ordered; and

(ix) the standard programs are very user friendly thus reducing the amount of training needed to become proficient. As a result of the program dramatic reductions in the time to design the mould are readily achieved.

9.1.5.3. The disadvantages of the standard components program: The disadvantages are few, however for the mould designer to become experienced in the use of each of the available software programs he/she must be familiar with the format and numbering procedure of each program. Quite often a mould designer will select different standard components from various standard elements suppliers when using conventional drafting techniques. Similar selection of standard elements from different suppliers, when using the computerized technique, can be more difficult and clumsy to use, thus giving rise for mistakes to occur. Due to this problem only one or two standard element programs (usually one) may be selected to be used when designing the mould. This approach can restrict the overall effectiveness of the performance of the mould as it is designed around the limited range of components which are only available to the particular selected standards program. This approach may not always produce the best design of mould.

9.2. Computer Aided Manufacture (CAM): Numerical control (NC) programming has always been acknowledged as being the area where it has been straightforward to see the benefits from the installation of a machine tool related to a CAD/CAM system. The NC programmer starts where the tool designer leaves off. The programmer generates the NC data by graphically driving a tool over the two-dimensional or three-dimensional model the designer has already created. A machining programming capability gives the user the ability to perform, point to point operation, profiling, pocketing and zig-zag machining in a two or two and a half axis motion. The user is asked to input

such features as clearance planes, cutter offsets and engage/retract vectors. All of these operations can be performed on two-dimensional geometry with the programmer adding three-dimensional data (such as clearance planes) as and when needed. Multi axis machining provides the user with a full three-dimensional machining capability. This allows tool paths to be generated on any surface. The tool axis can be defined as being square to the bed of the machine tool (three axis), as an arbitrary fixed vector (four axis) or normal to the part surface (five axis). A post-processor is required for each different machine tool/controller combination on the shop floor. Most CAD/CAM vendors have a library of 'off the shelf' post-processors, but experience has shown that, typically, a new post processor would almost certainly have to be created for one or two machine tools. The problem with this approach has been the time element. Typically, it would take three months to create a new post-processor. Therefore, there has been a trend for vendors to develop Generic Post-Processors. The user can quickly create a post-processor, depending on the complexity of the machine tool/controller combination.

9.3. Numerical control (NC) and computerized numerical control (CNC): The difference between NC and CNC machine tool control systems is to regard the NC machine as a down market version of the more powerful CNC. The main difference may be found in the intelligence of the two systems. The one is working within a framework of co-ordinates that must be specified in order to keep the cutter in the correct position. This information is entered into the machine control unit by the programming screen on the machine. The more powerful CNC is able to use sophisticated software which can either make use of tape input or guide the operator through an manual data input (MDI) program using a logical sequence of conversational prompts. Programming can be carried out in imperial or metric units, whereby features such as scaling, mirror imaging and many other functions can be readily carried out. CNC is more flexible than NC as once NC tapes are cut they are awkward to modify. With CNC the tape is simply the output of an easily editable program: dimensions and instructions are keyed into the computer and fed by providing a link for post-processed data to be transmitted from the CAD/CAM system into the correct machine tool controller. Hundreds of combinations of cutting parameters can be preprogrammed, and stored in the computer memory. This information may be called up at any time. Hundreds more can be programmed by the operator for automatic switching at different stages in the cutting program. This operation completes the process of design to manufacture.

9.4. Effects of computerization: The advanced performance of the CNC type of machine does not mean there is less scope for the basic NC machine. For example, there is still much wisdom in letting NC machines carry out simple tasks as distinct from the highly complex ones. By programming a machine to drill an array of holes or to mill out the pockets in a bolster releases a skilled man to carry out other more important tasks. Many illustrations of mould-making, particularly milling operations, show conveniently how easy it is to propel a fairly substantial cutter along a path over a complex surface. Very seldom does one see the small diameter cutter painfully removing small amounts of metal at the bottom of a pocket or along the edge of a rib. The type of machining usually required in mould-making demands the use of a wide variety of cutters and, therefore, to get the best result the CNC machine not only has to be the master of the geometrical

interpretation of the surface but it should also be able to change tools quickly and easily to make the most efficient use of its machining time. Slowly steps are being taken to realise that probably the best route to mould-making is via a combination of machine processes in which the benefits of CNC are used to machine quickly the contours required on a soft graphite electrode material. The actual machining within the mould is then carried out without tool-changing by an electro-discharge machine. Even in this area the advent of CNC is moving to control a range of electrodes that can be used in turn.

9.5. Realisation of CNC: CNC controlled machines are becoming a conventional production tool for all mould manufacturing companies. Because of the fact that the functions, availability, and performance of these machines and controls will greatly depend on the qualifications of the personnel involved, therefore the training of personnel to fully utilize the advantages of CNC becomes an ever increasing factor of importance. This trend was, among other things, one of the reasons why the universal milling and boring machine has been added to the machine manufacturer's stocklist. Some machines are particularly suited for practical CNC training, by virtue of their minimum floor space requirements and favourable price to performance ratio. In order to provide additional support, certain machine manufacturers have developed a new instruction/ training system in the form of a simulation package, which can be used for programming and program testing prior to, or without, using the actual machine. Moreover, advanced training material such as 'Diagnostics' is offered for testing the control electronics. This type of material includes with it a reader-printer-punch combination, and a magnetic tape cassette unit, as peripheral equipment. The training courses are divided into several areas:

- (i) the practical training course for the machinist or mould-maker:
- (ii) the theoretical/practical course of how to program the machine tool and troubleshoot using the 'Diagnostics' package.

10. TYPES OF STEELS USED FOR INJECTION MOULDS

The cost of manufacturing a plastics component is considerably influenced by the outlay on the injection mould. Therefore the economical manufacture and long service life of the mould are of the utmost importance. In order to manufacture moulds to a high quality the mould-maker expects the steel to be of a suitable quality which gives good machinability, stability in heat treatment, polishability of the steel surface, corrosion resistance, good etching response and high wear resistance.

10.1. The cost of the steel: The manufacture of an injection mould involves high costs due to the high degree of skill needed to produce the mould. In general the steel cost will only represent approximately 12-14% of the total cost so the difference in the price per kilo between various steel manufacturers is in the long term unimportant. However, what must be borne in mind is that a mould is only as good as the steel it is made from in terms of rigidity and dimensional stability.

10.2. The selection of the steel: To select the grade of steel that is to be used for an injection mould is not always a simple task. An important prerequisite of steel selection is knowing the working conditions and type of stresses to which the mould is to be subjected, such as its working temperature, the changes in working temperature that may occur during its production life, and whether it will be subjected to additional stresses such as tension, pressure, torsion, bending, abrasion or corrosion. The increasing use of reinforced thermoplastics materials means a higher demand on the abrasion resistance of the steel. In general there is no one steel that will suit all the requirements of a particular application, so the selection will nearly always be a compromise.

10.3. Types of steels used for injection moulds: The steel used for an injection mould is called a 'tool' steel. The name 'tool' distinguishes the type of steel used to that of a steel used for structural applications, because of its method of manufacture and the quality control procedures incorporated within the manufacturing process so as to produce a steel of high quality. The types of 'tool' steels used for injection moulds fall into various categories, each of these types will be discussed below.

10.3.1. Case hardening steels: A case hardening steel, also called a low carbon or mild steel, has a carbon content of less than 0.2% which means that when the steel is heated and quenched it does not harden appreciably due to the small amount of carbon. To increase the surface hardness of this steel a surface treatment called carburising is required. This treatment introduces additional carbon into the surface of the steel so as to produce a very hard and rigid outer skin. In its heat treated condition a case hardening steel offers a combination of a hard wear resistant surface with a soft tough core. After carburising and hardening, depending upon the grade of steel used, a surface or case hardness of between 52-62 Rockwell C (Rc) can be achieved. The carburising depth, or thickness of hardened skin, will normally be 0.6 to 1mm. As a result of the high surface hardness and modern de-oxidation methods used during heat treatment, a polished surface can be obtained on the finished product. The disadvantage of using a case hardening steel is the dimensional changes that occur during the surface treatment process. The most correct and careful heat treatment procedure cannot always guarantee the extent of dimensional change that may occur to the heat treated part. If additional machining is required to rectify the dimensional changes, then care should be taken so as not to completely remove the hardened skin. Another disadvantage with this type of steel is that after the machined part has been heat treated

any additional modifications required to the part may not always be possible without further heat treatment taking place: this may lead to further dimensional changes taking place.

10.3.1.1. Types of case hardening steels: The most common type of case hardening steel used for injection moulds is AISI P2. This steel as well as the AISI P21 has a core strength after heat treatment of approximately 1200 Nmm^{-2} . This steel is particularly good for cavities that are subjected to high mechanical stresses in local areas. A surface hardness of up to 54 Rockwell C (Rc) can be achieved and if nitrogen gas is used during carburising, and the hardening process is carried out in a vacuum an excellent surface finish is obtained on the heat treated part.

10.3.1.2. Uses of case hardening steels: Case hardening steels are often used for the manufacture of cavities for a multi-impression mould. The most popular manufacturing technique used to produce various sized cavities is called 'hobbing'. The hobbing process consists of a master male hob, which is identical to the required cavity shape, being forced under high pressures into a soft (annealed) blank of case hardening steel. The resultant effect is that the soft steel deforms (i.e. undergoes cold flow) and produces an identical female version (cavity) to that of the male hob. Once the cavity shape has been produced and all the necessary machining operations completed, a case hardened surface is applied to the cavity to give it protection. Hobbing is an extremely economical manufacturing process for multicavity injection moulds, particularly where identical cavities are required. The use of an AISI P4 type case hardening steel has proven to be very successful for this purpose as it can be supplied with an as-annealed strength as low as 380 Nmm^{-2} (120 HB). Due to the low carbon content of this steel (0.04%), an after heat-treatment core strength of $800/900 \text{ Nmm}^{-2}$ maximum is only possible. This must be borne in mind when considering the use of such a steel for injection/compression moulds, otherwise collapsing or bruising of the mould surfaces will take place.

10.3.2. Quenched and tempered steels: The use of quenched and tempered tool steels, i.e. pre-toughened or pretreated, is increasing for the manufacture of injection moulds. Pretoughened steels are primarily used for large moulds or moulds with intricate shapes where the risk of failure is likely due to dimensional changes, distortion or tension cracks occurring during the heat treatment operation. The main advantage with this type of steel is that no additional heat treatment is necessary, after mould manufacture, prior to production. Because of this the mould manufacturing costs can be considerably reduced. If necessary the surface hardness of the steel can be increased by nitriding or flame hardening. Typical steels that fall into this category are AISI P20 and AISI P20 + S which have a working strength and surface hardness of 27-32 Rockwell C (Rc) respectively. AISI P20 + S is the sulphurized modification of the P20 steel and has the ability to be more easily machined enabling higher metal removal rates due to the increase in sulphur content (0.05% compared to 0.02% for P20). Good polishability is still obtained because the intentional sulphide inclusions in the steel have a lower hardness than the surrounding matrix. It should be pointed out that when considering using the electro discharge machining technique (EDM) on AISI P20 + S steel, sulphides are non-metallic and a streak effect can become

noticeable in the machined surface, and also AISI P20 + S should not be used where the cavity is to be textured or surface etched. If AISI P20 + S is to be used, always ensure that any EDM or texturing of the cavity takes place on the grain end and then the surface defect is not so readily noticeable.

10.3.3. Through hardening steels: Through hardening steels are used for injection moulds because of their high hardenability, compressive strength and more importantly their ability to be hardened throughout. Due to their high compressive strength they are best suited for moulds being subjected to high compressive forces. A significant advantage of the through hardening steels, when compared to case hardening ones is the absence of any additional machining operations after heat treatment, due to its good dimensional stability. Compared to that of the case hardening steels, there is no risk of removing the carburized surface zone, thus necessitating a further heat treatment process. The two most common types of through hardening steels used, for both mould plates and cavity/core inserts, are EN 30B and AISI H13. When heat treated through hardening steels can attain hardnesses of up to 65 Rockwell C (Rc), however hardnesses of between 48 to 56 Rockwell C (Rc) are more commonly used. The Ni-Cr-Mo (Nickel, Chromium, Molybdenum) alloyed steel (EN 30B) is very tough and can be readily heat treated. The Cr-Mo-V (Chromium, Molybdenum, Vanadium) alloyed hot work steel (H13) was primarily used for the metal diecasting industry, however nowadays it is extensively used for injection moulds. To improve the wear resistance properties of a through hardening steel its surface is nitrided. When a nitrided surface is required, then the H13 type steel, with its high retention to tempering, is ideally suitable. Both of these steels are supplied and machined in the soft (annealed) condition and can then be heat treated by the vacuum hardening process. Through hardening heat treated steels (i.e. 48 to 56 Rockwell C (Rc)) are often used to resist deformation of the mould cavity walls due to the high cavity and/or clamping pressures used during the moulding operation. Other grades such as AISI D2, D3 and AISI O1 can also be used for mould inserts. All of these steels have very high wear resistance and are predominantly used for various applications such as pressure pads of injection-compression moulds and for moulds to accommodate glass reinforced thermoplastic materials.

10.3.4. Corrosion resistant steels: When processing chemically corrosive thermoplastic materials such as PVC or flame retardant compounds, the surface of the mould has to be protected. This is usually carried out by means of a thin layer of hard chrome or nickel being deposited electrochemically on the surface of the steel (i.e. chrome or nickel plating). There are, however, distinct disadvantages with both these processes as the thickness of deposition often varies across the mould surfaces. One of the main problems occurring with surface coated moulds is the tendency of the galvanic layer to chip, particularly with sharp edged mould inserts. If the breakdown of the coating occurs then the entire coated mould surface has to be stripped and then repolished. Only then can the surface be replated with a new protective layer. The use of corrosion resistant steels has considerably increased, because of the problems associated with chrome and nickel plating and the cost savings involved. The two corrosion resistant steels which are commonly used are both classified under the same category of AISI 420. One

grade of AISI 420 contains 13% chromium . however where the corrosion attack is of a more intensive nature, as is the case of processing PVC, then the grade which contains 16% chromium in addition to 1.2% molybdenum is recommended. The 16% chromium alloy is usually supplied in the pre-toughened condition with a core strength of between 900-1100 Nmm^{-2} . Because of its better corrosion resistance, the 16% chromium grade is often preferred even though the pre-toughened hardness is lower than that attainable when heat treating the 13% chromium grade. To increase the surface hardness of these steels it is possible to nitride them, but the corrosion resistance of the steel is reduced when it is nitrated. Both these steels have good dimensional stability during heat treatment and can be heat treated to a hardness of up to 54RC.

10.3.4.1. Reasons for use: The main reasons for using corrosion resistant tool steels are:

i) the increase in the production life of an injection mould when using corrosive thermoplastics materials:

ii) the cost savings achieved in terms of lower manufacturing and in-production maintenance costs (compared to a through hardening steel that requires additional surface coatings):

iii) the resistance to corrosion due to the formation of condensation on the mould surface when using chilled water as a cooling medium:

iv) the prevention of corrosion taking place on the inner surface of the water cooling channel. (With other types of steels failure of the cavity or core plate often occurs due to the formation of tension cracks in the plate surface. These cracks are a direct result of corrosion occurring in the water cooling channels. However mould plate failure is more prevalent when the thickness of metal between the front edge of the plate and the inner surface of the water channel is less than 8mm/0.314in).

v) the use of this steel for runnerless type moulds. An important point to note is that corrosion resistant steels have a lower thermal conductivity value than other steels. This means that additional cooling circuits are necessary when using corrosion resistant steels so as to ensure the amount of heat needed to be removed from the mould is comparable to that removed when using other types of steels. However its lower thermal conductivity characteristic is ideal when using this steel for hot runner manifolds on runnerless type moulds, as the heat losses are much lower than found with other steels, therefore obtaining a more uniform surface temperature of the manifold.

10.3.5. Hard material alloys: When processed some reinforced thermoplastics materials cause extensive wear to the mould surfaces, particularly when using the through hardening type steel. The wear resistance of a through hardening steel can be improved by an additional surface heat treatment such as ion implantation or titanium nitriding. To overcome the

wear problem and/or avoid the extra costs involved to carry out the additional surface treatment the use of a hard material alloy is now being considered. The technology used to produce a hard material alloy is somewhat different to that used for a conventional steel. The excellent wear resistance of the alloy is not achieved by simply increasing its surface hardness but by increasing the carbide content within the matrix of the steel. However when the carbide content is increased other changes occur to the steel's properties such as toughness, tensile strength, ductility and machinability. For these reasons the applications and use of hard material alloys tend to be selective.

10.3.5.1. Composition of hard material alloys: Hard material alloys contain a specific amount of titanium carbide to give a carbide content of between 45 to 50% by volume: the remaining percentage comprises of the steel binder. Since it is not possible to achieve a carbide content of 45% by volume in a steel using the traditional smelting methods, the production of hard material alloys is carried out using the powder metallurgy technique. The percentage of titanium carbide considerably influences the wear resistance property of the alloy. However the wear resistance is not only dependent upon the extent of the carbide content but also on the carbide type and the composition of the binder (i.e. the steel). It is the steel binder that ensures the alloy retains suitable toughness, machinability and hardenability properties.

10.3.5.2. Reasons for use: Compared to a through hardening type steel, the carbide content of hard material alloy is in the region of double. In spite of this high carbide content, these materials can be easily machined, in the annealed condition, and will achieve surface hardnesses of up to 70HRC following heat treatment. The isotropic (uniform) microstructure of the hard material alloy, created by the process of powder metallurgy, together with the low coefficient of thermal expansion of titanium carbide, results in zero dimensional change and distortion during heat treatment. The use of the alloy, in association with traditional steels, is ideally suited for injection moulds, however the cost of the hard material alloy is very expensive and therefore is only used in areas of the mould where high wear or corrosion resistance is needed. The rest of the mould is made of a through hardening steel that is tougher and more economical to use and machine. The wear resistance of the hard material alloys enables the working life of certain mould parts to be increased by ten fold, when compared to identical parts made from conventional through hardening or surface hardening steels.

11. MECHANICAL PERFORMANCE OF AN INJECTION MOULD

The manufacturer of plastic mouldings (i.e. moulder) when purchasing an injection mould will expect from the mould-maker a mould that:

- (i) has been completed and delivered according to stated time schedules;
- (ii) has the ability to produce components of a specified quality at the required production rate;
- (iii) will have a long production life with low maintenance costs.

In order for the above requirements to be met some fundamental design principles need to be considered.

11.1. Considerations for the mechanical design of an injection mould: When designing an injection mould two important areas need to be considered as follows:

- (i) the design of the mould to accommodate the characteristics of the molten thermoplastics material and the shape of the product to be moulded;
- (ii) the design to suit the properties of the mould-making material (in particular steel).

The latter requirement is very often overlooked and, therefore, many mould failures occur as a result of poor performance, etc.

11.2. Engineering design principles of an injection mould: The design of most moulds produced from steel is carried out empirically, for two reasons:

- (i) the concise mechanical property data, that is, tensile strength, and elongation and impact strength are not always available on most grades of steel because, at the working hardness levels the material becomes too brittle for meaningful and consistent information to be obtained; and
- (ii) the stresses developed in moulds, when in service, cannot be accurately predicted because of many external influences (such as heat treatment, machining techniques etc.). As a consequence of the above the selection of steel, the thickness of plates used, the hardness of mould plates and the overall design of the mould is usually based upon experience.

Therefore depending upon the amount of training and/or experience gained the success of the mould is largely dependent upon the designer. Hence the need for communication is imperative when designing moulds to enable a number of skilled people to interact and create a design which is a successful workable entity from the design, manufacturing and processing points.

11.2.1. Design principles: The failures that are often attributable to mould failure as a consequence of poor engineering design are as follows.

11.2.1.1. Sharp corners on mould components: Moulds which incorporate sharp internal corners, as in square holes, are prone to failure (cracking) during the heat treatment process. Sharp corners are necessary in many types of moulds. When they are not, always replace with the largest fillet radius possible. Even with the best handling during the heat treatment process moulds which are manufactured from oil and water hardening steels are likely to show some evidence of cracking in sharp corners. A technique to overcome the crack problem, with oil hardening type steels, is to initially machine the corner with a generous radius and after hardening re-machine the required radius. This process is not recommended for water quench steels because of the shallow chill (i.e. hardened surface) which would be removed by the additional machining. Wherever possible use oil hardening steels if sharp corners are required.

11.2.1.2. Changes in section thickness on moulds: Wherever possible uniform wall sections should be used when designing the components or accessories of the mould. Quite often the heat treatment process is blamed for the resultant failure, when the real fault is the poor mould design. If a thick section (or volume) is designed adjacent to a thin section, then during the quenching cycle of the heat treatment process the thin section cools rapidly and hardens before the thick section. This causes excessive stresses which often results in distortion, and/or cracks appearing on the heat treated component. Wherever possible use two part assemblies if drastic changes in wall section are essential. If one part components are necessary then use oil hardening steels or stepped quenching temperatures during the hardening stage of the heat treatment process.

11.2.1.3. Correctly position the holes/cutouts on mould plates: One of the major reasons for failure occurring on mould plates is the amount of material which is left either side of a cut out or hole. To effectively utilise the space within the mould, cutouts are usually designed to be as close as possible. More often than not the amount of wall section left between each cut out, or the internal edge of the hole and the edge of the plate, is too small. Upon heat treatment, the internal stresses created within the plate are particularly excessive in the thin section causing cracks to occur from the edge of each cut out. The wall section between cutouts should not be less than 18-20mm (0.7 - 0.8in).

11.2.1.4. Thickness of mould plates: The overall height or thickness of a mould should be related to the size or depth of component to be produced. Moulds that are correctly designed should use plate thicknesses of a required thickness in relation to its area. In general the thickness of a plate should be not less than 20mm (0.8in) unless particularly specified as in the case of the ejector plate assembly.

12. MOULD COOLING REQUIREMENTS

Polymers require a conductive and frictional heat input in order to produce a flowable melt of uniform viscosity. Once the melt is shaped to the desired form, heat must be removed so as to enable ejection of the product from the mould. The amount of heat to be removed varies with each polymer, but to ensure that components are in a distortion-free condition, it is essential that sufficient heat has been removed prior to ejection. The amount of heat which is carried into the mould is removed by:

- (i) conduction into the machine;
- (ii) radiation; and
- (iii) a fluid circulated through the mould.

In the majority of cases (iii) is the most important and is usually achieved by water circulation although water/glycol mixtures and oil are also used. The rate of heat removal is dependent upon the design of the cooling circuitry, the size of cooling channels and the flow rate of the cooling medium. The majority of moulds are designed with insufficient cooling channels and therefore require a longer period of time to dissipate the heat than is normally required. This in turn, directly effects the overall cycle time. As the cooling time usually represents approximately 65 to 70% of the cycle time it is an area where considerable savings can be made with respect to cycle time reduction. In many instances the introduction of CAD has enabled the cycle times of existing production moulds to be reduced, i.e. up to 25%, by either inserting additional cooling circuits or modifying the original cooling circuitry of the mould based upon the findings from the analyses.

12.1. Heat removal from the mould: Each thermoplastics material has a specific set up (solidification) time in accordance with the thickness of the component being moulded and the melt and mould temperatures used. This set up time can be calculated, using the Ball and Shussman equation, to an acceptable accuracy. Such information then enables the amount of heat energy needed to be removed so as to achieve the calculated set up time and the coolant flow rate, for a particular cooling channel diameter. These important calculations provide the basis for correctly designing the mould cooling circuitry.

12.2. Size and position of cooling channels: In general the diameter of the cooling channels is too small and the length that the cooling medium has to flow along is too long. This usually results in a temperature variation across the mould surface which can be as much as 10-15°C. Hence the cooling time for a particular component is often determined by the hottest point of the mould (i.e. the time taken to dissipate the heat from that particular area of the mould). When moulding components such as PS, HIPS, PC, ABS, PMMA etc. (which are amorphous materials) the temperature differential may be accommodated for by simply extending the cooling time. However if a temperature difference of 10°C (18°F), occurred when moulding components of a crystalline material (e.g. PA66, LDPE, HDPE, PP etc.) then the resultant product could warp or twist, upon extraction from the mould, due to differing shrinkages occurring. Such a defect would not be overcome by extending the cooling time. It is a known fact that the distance of channels from the cavity face affects the overall control of the mould surface temperature and the rate of heat removal.

The need for control circuits of greater volume, as the quantity of the plastics material increases, is apparent. The rate of flow in a channel of given diameter can sometimes be increased by raising the pumping pressure. This in itself increases the efficiency of heat removal. The actual cooling circuit layout is greatly dependent on the shape of the part and of the cavity. Multi-cavity moulds can cause problems in circuit design whereby each cavity should have an identical heat removal pattern. If the cooling channel lengths are too long, then changes of the coolant flow rate and pressure drop within the cooling channel will result. There may also be an unacceptable temperature rise between the first cavity and the last if a looped series system is used. To avoid these problems in multi-cavity moulds, each cavity should have its own circuit. To avoid too many cooling circuits an alternative approach is to form a small group of cavities which have a separate circuit. However, the latter design is a compromise and will not be as effective as the former design. The position of a cavity within the mould is also an important factor. If it is at a corner in a multi-cavity layout, it may be necessary to use higher temperatures to compensate for the extra loss of heat by radiation. Conversely, cavities in the centre of a mould block would need to be controlled at a lower temperature level. Hence the reason for the use of individual cooling circuits to each impression. In some cases, the need for the temperature to vary in different parts of a mould system can also be met by using the heat passed into the channel from the first cavity for adjustment further down the circuit. This technique is adopted when using one cooling circuit for a group of cavities.

12.2.1. Typical cooling channel diameters: The following table gives typical channel diameters for given component wall sections. Included within the table are guidelines for the position of the cooling channels in relation to the mould cavity/core surface.

Component wall thickness	Cooling channel diameter
mm	mm
2	9 to 10
4	10 to 12
5	13 to 15
6 and above	15 to 17

The distance between each cooling channel should not be more than three times that of the selected cooling channel diameter. The distance between the cavity surface and the edge of the cooling channel should not be greater than one and a half to twice the selected diameter. The closer the distance the channel is to the cavity surface the higher the rate of heat removal, however the strength of the wall section is important so as to prevent failure (cracking) occurring to the mould plate/insert.

12.3. Heat transfer of mould material: The thermal conductivity of the mould material is another factor in thermal transfer. Heat from the melt must pass to the control circuits through the cavity wall. Conductivity is important to the rate of heat dissipation. The thickness of the mould is clearly also important, and the distance the heat has to travel has a very important effect on the dissipation rate. The heat transfer rate of the construction material must obviously be taken into account when designing the mould. The low conductivity of stainless steel is noteworthy and can, in some circumstances where surface finish is critical, be of benefit. However, this material has lower abrasion resistance than some other types of steel and therefore care should be exercised in using stainless steel with an abrasive material such as glass-reinforced nylon.

12.4. Series and parallel cooling circuits: As with electrical circuits, channels may basically be linked either in series or in parallel, for similar reasons. Series cooling is often used where the amount of the heat to be removed is not large, as with small cavities, slow cycles or where the melt does not carry a great amount of heat. Parallel cooling circuits enable each cavity to receive the same flow rate of cooling medium and temperature thus providing the basis of uniform cooling across the mould surface. Quite often both types of circuit designs are combined for a particular mould. This system may be used in cavity or core blocks in a large multi-cavity tool, where some blocks of series-cooled cavities would be joined in parallel. This would ensure an equal temperature balance, allowing for the variation in heat dissipation rate caused by changes in the volume of metal and differences between cavities. Demands for improved product performance and more rapid cycles have made major improvements in heat control essential.

12.5. Cooling channel efficiency: It is imperative to be able to maintain high efficiency in the channels without the need for excessive maintenance. It is incorrect to assume that the rate of heat removal from water flowing through a channel depends only on its temperature. The passage of water through a channel may be either by laminar flow or turbulent flow.

12.5.1. Laminar and turbulent flow: Laminar flow occurs when the water velocity is too low. The critical velocity depends on the viscosity of the fluid, its temperature and the relationship of these factors with the diameter, cross-section and interior finish of the channel. Laminar flow is analogous to the behaviour of a river, with more rapid flow in mid-stream than at the bank, where the volume of water passing is hence less. Indeed, the water at the edges tends to form a barrier between the main central flow and the banks. The situation with laminar flow in a cooling channel is similar thus preventing effective heat removal. Turbulent flow is analogous to a fast flowing stream passing over rocks and other obstructions during its passage. By incorporating this technique for injection moulds the presence of turbulent flow allows the water to more effectively transmit the heat from the entire surface of the inner bore of the cooling channel. Turbulent flow can be achieved by several means such as increasing the volumetric flow rate, the introduction of air into the cooling medium and incorporating flow control within the cooling channel. Several techniques of control circuit manufacture include roughening the inside of the channel bore slightly which has an effect of increasing the surface area, thus increasing the rate of heat transfer. Another variation on surface roughening is to cut a screw-thread pattern or to insert a coiled wire spring in the channel. Also, in some cases, it may suffice just to change the flow pattern from laminar to turbulent to achieve the desired cycle time.

12.5.2. The problem of scale/deposits within the cooling channel: The build-up of deposits within the cooling circuit is a continual threat to cooling efficiency. In known hard-water areas, steps should be taken to soften it and a descaling unit regularly used - certainly each time the mould is removed from the machine, or otherwise at least monthly. Rust deposits are an obvious hazard with all steel moulds, the effects of which can be reduced by nickel-plating the interior channels. This is effected by chemical (e.g. 'Kanigen') plating, rather than by electrodeposition. Rust can only form when oxygen is present, so that steps to de-aerate the water may well be of benefit. However with the presence of descalers and water softeners the presence of air is not so important from the build-up point of view.

13. MACHINING TECHNIQUES USED FOR MOULD MANUFACTURE

This report is written to cater for readers who will be associated with the manufacture of moulds. It would be time wasting to dwell, in detail, on the typical machining processes that are generally available, for example milling, turning, grinding, drilling, boring, etc. These processes are extensively covered in most Engineering Workshop Manuals/books. However, it is important to expand on those areas in which development is continually taking place in an effort to maintain accuracy whilst, at the same time, increasing productivity and profitability.

13.1. Copy-milling: Conventionally copy-milling is carried out from a full-size model of the component. Stylus and cutter size are matched so that the transfer of geometrical information is absolute. In general the largest cutter possible is used to machine away the bulk of the waste material. In certain instances pre-machining is carried out on a separate machine, or the original cavity-block is cast-to-size as near as possible to minimise the machining and the amount of material transformed into swarf. Depending on the size of model and the number of cavities required, it is possible to copy-mill more than one component simultaneously. In this way it is also possible to copy-mill right and left hand cavities simultaneously. The following of the model is no longer hand operated and the majority of modern machines use either hydraulic or electronic copying systems. Electronic copying systems tend to have overtaken the earlier hydraulic systems mainly because of the trend to more powerful D.C. drives on the machine tool spindles. This also tends to fit with further development of CNC milling machines and the ability to carry out the whole machining operation directly from tape or from a dedicated computer system. However, it is still not an easy task to prepare a CNC tape directly from the dimensions given on a drawing. As a result of the use of more powerful computing techniques and the use of graphics, it is becoming increasingly more frequent to find companies actually designing components using CAD techniques. Consequently, it is less difficult to produce the necessary tape which can be made compatible with a fairly wide range of multi-axis CNC milling machines. One of the more prominent contenders for the rapid transfer of design data into workable programs is the Swiss Company FIDES S.A. who offer a computer package called EUKLID. This CAD/CAM development when used in conjunction with FLURI multi-axis milling machines provides a fairly potent combination no matter whether one contemplates the machining of the model, the graphite electrodes for EDM (Electro-Discharge Machining) operation or, indeed the cavity itself. As graphite is easier to machine than most other materials used in mouldmaking there is a growing tendency to use CAM packages to produce electrodes. As a result it would appear that the growth in the use of E.D.M. techniques in mouldmaking will continue to play an increasingly important role, unless, as yet unknown reprographic systems emerge.

13.2. Grinding: With so much emphasis placed on the utilisation of machine tools it has been shown that the process of grinding has far more potential for development than many of the other traditional machining processes, other than the electrical methods of machining.

13.2.1. Grinding techniques: From what has already been said there is plenty of scope for machines to produce highly accurate flat and cylindrical components. Whilst these can be rough machined prior to heat treatment, using most kinds of machinery, grinding machines are needed to bring the components to the finished state.

13.2.1.1. Conventional grinding machines: Surface grinders are used largely to prepare the blocks of steel which make up the inserts of the mould. Mould parts are ground accurately on all sides so as to fit together precisely enabling the mould to close, or bed out, properly and to prevent the leakage of plastic material giving rise to what is commonly called 'flash'. Cylindrical grinders can take on several roles, the most common being the grinding of internal and external forms. These machines are capable of producing core pins and guide bushes just as easily as other parts of the mould such as cavities which have circular internal and external forms. Many of these machines are now being controlled by computers so that it is possible to program a series of operations which will automatically produce the mould part to its final form. Such machines have not yet found their way into the toolroom as measuring sensors and automatic wheel-dressing techniques are not yet sufficiently advanced.

13.2.1.2. Form and profile grinding: These are specialist grinding machines which are often found in close proximity to the toolroom but are not used all that often in the process of mould manufacture. For cylindrical parts that need complex variations in shape it is possible to dress or crush the surface of a wheel to produce the desired form. The basic accuracy of this operation is to be found in the means of shaping the wheel. More sophisticated CNC machines are to be found producing the profiles that may be required. It is possible to apply the control either to the diamond dressing unit or to control the wheel along a profile until the desired shape is reached. Such machines are used mainly in the production of segmented inserts when other methods are not possible or desirable. The segmental approach to mouldmaking has largely been replaced as a result of the advances that have taken place in the EDM field.

13.2.1.3. Jig grinding: The use of the various jig grinding techniques is a very significant advancement on jig boring operations. As a result of the many advances in machine design, wheel design, and the use of CNC it is now possible to produce highly accurate shapes possessing an excellent surface finish by controlled grinding. The use of small diameter grinding wheels rotating at very high speeds has made it possible to attain surface finishes and accuracies that are unobtainable by other machining methods. The use of cubic boron nitride (CBN) wheels has been shown to reduce machining times by as much as 20% to 30%. Mould components that need to be manufactured using this technique are very special and usually very expensive. Typical examples of the kind of application that would be treated in this way are precision gear wheel inserts, some types of plastic closures for perfume bottles, electrical switch components and components for the automotive industry.

13.3. Electro-discharge machining (EDM): Over the last ten years more confidence has been placed in electro-discharge machining techniques and more and more mould-makers are using this technique to remove metal to produce the mould cavity and core. However, there is still a tendency for mould-makers to make use of traditional cutting methods to machine away the bulk of 'easy-to-get-at' material, leaving the more intricate operations to the EDM process. Nevertheless the additional benefits offered by EDM in making it possible to machine the mould steel in the hardened state has led some mould-makers to machine totally by EDM with the material in the heat-treated state. This avoids the risk of cracking or distortion which sometimes occurs during heat-treatment after the bulk of the expensive work has been done.

The decision to heat-treat the mould steel before or after manufacturing the basic cavity is something of a compromise because, not only is the material easier to cut but also, polishing is easier to carry out when the mould is in the annealed state. However, significant advances have been made in the use of EDM techniques, and it is now possible to produce very fine surface finishes that need a minimum of hand polishing after the EDM process has been completed.

13.3.1. Principle of EDM: EDM is an electro-thermal process whereby heat is generated by the passage of an electric current, during a spark discharge, which cannot be transferred fast enough into the bulk of the material due to the low thermal conductivity of the workpiece (steel) material. Hence the temperature of a small local area of steel increases rapidly to the extent that the material melts and vapourises leaving small craters on the surface. The volume of material removed is dependent on a number of different factors however the more intense the discharge the more material will be removed. In practice the discharge takes place in a fluid, usually a hydrocarbon fluid such as kerosene which is called a dielectric. The main reason for the fluid is to increase the breakdown resistance of the path between the electrode and the workpiece and hence help to concentrate the energy of the discharge. It also provides a reasonable way of cooling the workpiece and in flushing away the products of the discharge. The waste material usually comprises a black oily sludge which is the result of degradation of the dielectric and small spherical particles which are formed as the vapourised workpiece material condenses within the cooler regions of the dielectric. A great deal of research has been carried out on the performance of dielectric fluids not only to achieve good metal removal properties but also to make sure that there are no health hazards when a number of electro discharge machines operate within the same environment. The significant characteristic of an EDM operation is that the workpiece material may be removed quite independent of how hard or how flimsy the state of the material. There is no contact between workpiece and electrode and there are no cutting forces. Hence the reason why EDM is so well adapted to the intricate type of machinery that is needed for the deep boss, the thin reinforcing ribs or applications such as the blades of fans and the small, accurate pockets formed in electrically insulated components such as those used in electrical contactors or switches.

14. STACK MOULDS

A stack type mould could be described as a more complex runnerless type mould. It is extremely important that processors are fully conversant in the running of runnerless type moulds before attempting to use a stack type mould for production needs.

14.1. Definition of a stack mould: A stack mould is where one set of mould cavities/cores are immediately positioned behind another set. This means that the number of cavities are doubled from a given platen area. Thus a 300 tonne machine with a machine hour rate of say \$35 per hour can yield almost equal the output of a 600 tonne machine costing say \$55 per hour.

14.2. Description of a stack mould: These moulds consist essentially of a central plate which houses the runner system and cavities; and two sets of cores and core retaining plates plus ejection mechanisms. The centre plate is normally quite heavy and is best supported on hardened slides on the machine bed and/or if not too heavy by means of phosphor bronze elements which slide on the tie bars or the bed of the moulding machine. There are various methods of linking the centre plate with the two ejection mechanisms - these are:

(i) by a lever system, where a central lever is mounted on the centre plate and is connected by two arms fixed to the ejection plates. This mechanical system allows both levels to open at the same time: or

(ii) by the common technique of utilising a rack and pinion with the pinion mounted on the centre plate and two racks, mounted on the ejection plates. The central hot runner manifold system is fed by a sprue bar or tube, which is heated by means of band heaters, through which the molten plastic passes from the machine nozzle to the manifold and is then distributed through heated nozzles to the cavities. The ejection mechanisms used for this type of mould are very similar to the type used for a conventional runnerless mould. The essential difference is that one of the ejection mechanisms fitted to the nozzle side plate (i.e. fixed platen side and therefore needs to be operated by hydraulic cylinders mounted in the mould or on the machine nozzle side platen from the machine hydraulic system. With the new generation of polyolefin container moulds, ejection is carried out solely by air.

14.3. Types of gating systems used: There are three main types of hot runner gating systems, all of which are used in stack moulds.

(i) the standard gate - is a general purpose design used when the component can be gated on the face and gate protrusion is not too critical:

(ii) the edge gate - is used for parts that cannot be gated on the face. With this type of gate one, two, or more parts can be fed from each nozzle. As the mould opens, the gate pip is sheared off, leaving a mark similar to the cold runner tunnel gate appearance:

(iii) the valve gate - this is a variation of the standard gate in which a central pin is operated pneumatically or hydraulically which shuts off the flow of material through the gate after the mould has been filled with molten material. It is used when minimal or zero gate vestage is required or when a large gate is required for fast filling with low shear rates. Engineering materials are more readily processed using this type of gate.

14.4. Machine requirements for stack moulds: Stack moulds not only require a high degree of skill to optimize the processing conditions so as to ensure that maximum efficiency is obtained, they also rely the performance of the moulding machine. In order to achieve such results the specification of the moulding machine needs to be considered, prior to purchase, so that it is able to fulfil the necessary demands expected of it. The more important requirements are given below:

(i) the machine has good reliability and control of the material metering/dosing:

(ii) has adequate distance between the machine platens to accommodate the additional mould height and opening stroke to allow for component ejection and removal:

(iii) the injection unit is capable of plasticising the additional amount of material in the required screw recovery time:

(iv) should have hardened slides on the bed of the machine:

(v) it has sufficient injection capacity to fill the mould at the expected mould fill time - usually an accumulator is included on the machine to assist in achieving this requirement:

(vi) stable platens to counteract any deflection that may be incurred during the filling of the cavities, particularly when moulding thin walled components:

(vii) sufficient hydraulic pumping capacity to carry out all the functions on the machine including ejection and the closing of the gates.

14.5. Types of thermoplastics materials used for stack moulds: The more popular materials which are used for stack moulds are the easy flowing grades of PP, PS, and the PEs. This enables thinner sections and long flow paths to be used to produce components for the packaging industries. At present developments regarding the engineering type materials are being actively carried out to extend the use of stack mould technology for technical mouldings.

14.6. Types of components produced using stack moulds: Stack moulds are used for high volume production -usually in the 20 to 50 million annum requirement. The initial outlay of the mould i.e. up to \$220,000, therefore the production quantities need to be of this number in order to recoup the cost of the mould. The types of components that are included in this high volume sector are lids and bases for petri dishes, kidney dialysis plates, 35mm slide holders, film containers, aerosol caps, dairy food containers, flower pots, base cups for fizzy drinks bottles, cutlery for airlines and drinking beakers.

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Runners and Gates: B. Smith (Mouldmaking '83 Symposium, Solihull, Paper 4).

CAD/CAM in Plastics: D. Treacher McAuto UK Ltd (BP&R 1985).

Effects of Plastics Materials on Mould Design: Tony Whelan and John Goff (Mouldmaking '86 Symposium, Solihull, Paper 1).

Injection Moulding of Engineering Thermoplastics: Tony Whelan and John Goff (1987).

SELECTED LIST OF PUBLICATIONS ON MOULD DESIGN AND MANUFACTURE

The following books are recommended for additional reading so as to broaden the knowledge and understanding of mould design and manufacture.

<u>Title of book</u>	<u>Author/s</u>	<u>Publisher/s</u>
Flow Properties of Polymer Melts	J.A.Brydson	Newnes Butterworth.
Plastics Mold Engineering Handbook)	J.H.Dubios and	Van Nostrand
)	W.I.Dribble	Rheinhold.
Injection Moulds	H.Gastrow	Carl Hanser Verlag.
Injection Mould Design	R.G.W.Pye	Longman Group.
Injection Moulding Machines	A.Whelan	Elsevier Applied Science.
Developments in Injection Moulding-2	A.Whelan and	Elsevier Applied
	J.L.Craft	Science.
Developments in Injection Moulding-3	A.Whelan and	Elsevier Applied
	J.P.Goff	Science.
Mould-Making Handbook	Klaus Stoeckhert	Carl Hanser Verlag.
Injection Moulding of Engineering Thermoplastics	Tony Whelan and John Goff	Van Nostrand Rheinhold.
Injection Moulding of Thermoplastics Materials-1	Tony Whelan and John Goff	Van Nostrand Rheinhold.
Injection Moulding of Thermoplastics Materials-2	Tony Whelan and John Goff	Van Nostrand Rheinhold.
Mould Making and Design	G.Menges	Carl Hanser Verlag.