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PLASTIC, PROCESSING OF

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1. This standardization handbook was developed by the Department of Defense in accordance with established procedure.

2. This publication was approved on 30 January 1967 for printing and inclusion in the Military Standardization Handbook series.

3. This document provides basic and fundamental information on the processing and fabrication of plastics. It will provide valuable information and guidance to personnel concerned with the preparation of specifications and the procurement of plastic products. This handbook is not intended to be referenced in purchase specifications *except for informational purposes, nor shall it supersede any specification requirements.*

4. Every effort has been made to reflect the latest information on plastic processes and fabrication procedures from a descriptive rather than a mathematical analytical point of view. It is the intent to review this handbook periodically to insure its completeness and currency. Users of this document are encouraged to report any errors discovered and any recommendations for change to Commanding Officer, Pic..anny Arsenal, New Jersey 07801, ATTN: SMUPA-VP5.

ACKNOWLEDGEMENTS

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TABLES

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FIGURES

Figure	*Source*
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2-23	Same as Table 2-1.
2-24 and 3-1	Same as Figure 2-16.
3-2 and 3-3	Same as Table 2-12.
3-4 through 3-8	Same as Figure 2-16.

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FIGURES

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CHAPTER 1

INTRODUCTION

1.1 General. The object of this handbook is to give the military design engineer information about plastic-conversion processes that will help him to achieve an optimum balance of service, economy and reliability. It is noteworthy that design practices which normally give pleasing shapes to the eye—clean, unbroken line, arches, rounded corners, etc—often also give the best structural behavior. Cost factors vary so widely with the performance and production factors of each product that to estimate the cost of production, one must analyze in detail the requirements in each case. Techniques and equations for estimating cost elements in the processing of plastics may be found in the literature, however, it is suggested that up to date information regarding costs be obtained from plastic raw material suppliers, molders, fabricators or other plastic specialists.

1.2 Processing Classification of Plastics. Plastic materials are conveniently grouped into three major classes: thermoplastics, which can be repeatedly softened and hardened by heating and cooling; thermosets, which flow briefly when first heated but then cure into a permanent, infusible mass; and the reinforced plastics, most of which are thermosetting resins containing natural or synthetic fibers.

1.3 Plastic Processing Definition. Plastics (polymer) processing has been defined as an engineering specialty concerned with operations carried out on polymeric materials or systems to increase their utility. The operations produce one or more of the following effects: chemical reaction, flow, or a permanent change in physical properties. Specifically excluded are the chemical reactions involved in the manufacture of resins.

1.4 Process Operational Sequences.

1.4.1 *Thermoplastics.* In thermoplastic processing, the usual sequence is (1) heat the raw material, causing it to soften and be readied for flow; (2) apply forces that cause the material to flow into its desired shape through a die or in a mold; (3) chill the melt, causing it to harden in the desired shape.

1.4.2 *Thermosets.* In typical thermoset processing the partially polymerized raw material is (1) softened and activated by heating, sometimes in the mold and sometimes outside it; (2) forced into the desired shape under pressure; and (3) held at the curing temperature until the final polymerization has progressed to a point where the piece has hardened and stiffened to keep its impressed shape.

1.4.3 *Reinforced Plastics.* Processing of many fiber reinforced thermosets follows the sequence for thermosets enumerated above. However, because of the form of some types of fibers, the resin is worked in the form of a syrup at room temperature, and gravity or other relatively low force suffices to shape the syrup-impregnated fibers.

1.5 Processing Method Classification. Most attempts at classifying the diverse methods of fabrication and processing have met with small success, in large part due to the fact that many final shapes may be obtained by more than one method. The following system of classification of fabrication and processing techniques is possibly the most satisfactory method and is based upon the physical state of the raw product, since this will to a large extent, determine the method of processing:

(a) Solids.

1. Molding.
2. Extrusion.
3. Calendering.
4. Sheet forming.

(b) Liquids and Melts.

1. Coating.
2. Expanding and foaming.
3. Casting.
4. Spinning.

(c) Solids and Liquids.

1. Laminating and impregnating.
2. Filament winding.

Within each of these processing areas many variations have been developed to cope with the characteristics of the three different classes of plastics.

1.6 Process Selection. The following factors are of primary influence in the selection of a process for a given plastic part:

(a) Type of plastic selected to provide the desired physical properties of the finished part.

(b) Physical state of the raw material (solid, melt or liquid or combination thereof).

(c) Compatibility of design elements of part with process to be used.

(d) Part configuration.

(e) Production costs to produce the required number of parts.

Generally, long runs of thermoplastic parts of intricate configuration and medium size are produced by injection molding. Long runs of thermosetting parts of moderate complexity are most economically produced by either compression or transfer molding.

Medium and short run of parts of moderate complexity are often most economically made by machining from stock shapes on conventional metal working equipment. In addition, machined parts are frequently specified when extremely close tolerances (less than ± 0.002 in.) are required.

Parts with large surface areas and comparatively deep draws are frequently thermoformed from thermoplastic sheet stock.

Standard warehouse shapes—sheets, rods and tubes—are produced by casting or extrusion. Extrusion, one of the lowest cost methods of manufacture is also used to produce constant profile parts. Methods used to make plastic films include extrusion, casting, blowing and calendering.

The two most common methods used to produce reinforced plastics are contact molding (hand lay-up) and spray molding. Three other methods—matched die, bag molding, and filament winding—are used for high-strength applications.

Among the more specialized methods of making parts are blow, slush or rotational molding and sintering. Sintering is used with both thermoplastic and thermosetting materials.

In many instances, quantity alone determines which process will be used. Thus every plastic part should be "costed out" by all possible processes to determine the most economical production means.

1.7 Basic Engineering Approach to Successful Plastics Application. Plastics are engineering materials of construction and they follow the same rules as other materials. The following design steps, not necessarily in the order listed, insure the successful application of a plastic part.

(a) Define the End-Use Requirements—Initially the product designer must anticipate the conditions of use and performance requirements of the products. This is the area of considering such things as: environment, load, speed of production, life expectancy, optimum size, weight, maintenance, shape, color, strength and stiffness.

(d) Selecting the Material—Selecting a plastic for a given application involves a compromise between properties, cost and manufacturing process. A firm set of properties and engineering data is required to make a preliminary design. Data may come from handbooks or published literature provided by material manufacturers.

(c) Drafting the Preliminary Design—The designer blends the end-use requirements and the properties of the selected material into a preliminary design. He uses engineering techniques and formulae to achieve economy, functionality and attractiveness in the end item. Production methods will set limitations on design. Material suppliers and processors can be of tremendous assistance at this time. Detailed discussion on design considerations for production will be covered in a later section of this handbook.

(d) Prototyping the Design—The method for producing the prototype may not be the same as that planned for the final production line, but the design should be identical, otherwise subsequent testing will be misleading and yield false results. Here is the first opportunity to see and check the product design. It should be borne in mind that the processing method selected may affect molecular structure, mixing, orientation of molecules, crystallinity, stresses, which in turn will have an effect on end item performance results.

(e) Testing the Design—Every design should be given an actual or simulated service test while in the prototype stage so that all errors or weaknesses can be corrected. The end use requirements will dictate the design testing program.

(f) Design Evaluation—As a result of testing most products can be improved for better production economies, or for important functional changes.

(g) Writing a Meaningful Specification—The purpose of the specification is to eliminate any variations in the product that would not satisfy the functional or economic requirements. The specification for the part should include such things as the materials of construction by generic name, method of fabrication, dimensions, color, surface finish, packaging, printing and every other detail of production to which there could be more than one answer.

(h) Setting Up Production—Before the production line can start, tooling must be designed, built, and integrated with the processing equipment. (In some cases, dies and molds can be started while testing is in progress). Manufacturers and processors are important sources of assistance in designing proper tools to realize production efficiency and economy.

(i) Quality Control—Good inspection practice requires a check list to maintain a consistently good product. The inspection check list, for the most part, should conform to the end use requirements set forth in the specification.

CHAPTER 2

MOLDING

2.1 General. The ease with which plastics can be folded to complex shapes is a major reason for the phenomenal growth of the plastic industry. Most molding procedures employ the following steps: (1) Plastic pellets or powder are heated above the softening temperature; plastics in syrup form do not require this preheating step. (2) Softened or syrupy resins are placed in the mold by force or mere gravity feed. (3) The resins are then cured or "frozen" in the closed mold and the shaped piece is then ejected.

Sometimes the ejected piece can be used "as is," other times trimming, fabrication or other form of finishing is required.

Whereas the outline of the general molding steps are simple, the complexities of producing an economical, functional and reliable part by molding are many. When the complexities are understood by the military designer, designs will be created which will lead to successful applications.

Prior to design, a molding material and a molding process must be selected. Sometimes certain elements in the design, such as thin sections, inserts, or accuracy of dimensions and concentricity dictate the choice of one molding technique over another. No one molding technique and no one type of plastic can meet all requirements. With understanding on the part of the designer and assistance provided by raw material manufacturers and molders the best material and process to meet the major requirements can be found.

2.2 Molding Materials. A wide variety of basic resins are manufactured by the plastics industry and more are being developed each year to improve mechanical, thermal, chemical, optical and environmental properties. Many of these basic resins are not used per se, but are modified with fillers extenders, lubricants, plasticizers, catalysts, inhibitors, promotors, flame retardants, colorants, etc. Therefore within limits a wide and almost infinite variety of properties may be achieved to meet the end use requirements of a plastic part. It is recommended that the designer review Military Standardization Handbook MIL-HDBK-700(MR) PLASTICS dated November 1965, plastics manufacturers literature, plastic textbooks and periodicals prior to selection of the molding material to meet end use requirements. In addition raw material suppliers, molders, fabricators and other personnel with specialized knowledge in plastics can provide valuable consulting advice to achieve a proper choice of material.

2.3 Molding Equipment. There is an extensive variety of processing equipment manufactured to handle the different types of molding material. The more important types (those used on the largest commercial scale) will be schematically illustrated and functionally described in subsequent paragraphs.

2.4 Molding Tools. The success of any molding operation may be limited by the efficiency of the mold design and the quality of the mold construction. The entire molding industry is dependent on the skill and experience of the mold maker. Good molds assure continuous production, excellent finish, easy ejection without part distortion, few rejects, close dimensional tolerances and low cost finishing of molded parts. Through continued use, molds become worn and occasionally break, and once again the mold maker must be prepared to make the necessary repairs and even replace broken mold sections. The mold maker also constructs devices for the loading of predetermined amounts of material into the mold cavities. In addition, the fixture may have to be designed to lock in place the metal inserts which are often used in molded parts. Unloading fixtures are required to remove parts from the mold, some are of the unscrewing type to facilitate the removal of threaded sections from the mold. After removal of the part from the mold, it may be placed on a shrink fixture to hold the shrinkage to fixed accurate limits when cooled to room temperature. Excess materials such as "gates," "flash" or "fins" are removed by means of trimmers, punches and grinders during the finishing operations. "Gates" are feeders which connect the molded piece to the material source in injection and transfer moldings. "Flash" is the excess material squeezed out of a mold as the part is formed. A "fin" is the material which flows into the small gap between moveable mold members. In addition to tools required for cleaning, jigs for drilling unmoldable holes and gages for measuring dimensional accuracy of finished parts are a must. Heavy production schedules justify considerable expenditures in devising special cleaning fixtures for after molding operations. "Pill" dies are special presses which form "pills" or "preforms" to facilitate loading of the mold with a specific amount of molding material. These "preforms" or "pills" are justified in view of the need for stringent quality control. Just how all these tools are designed is left to the mold maker and the molder. However, the design of the mold or even the preform mold may influence the performance of the molded item. For example "weld lines" should not coincide with areas expected to withstand high stresses. Thus, communication between the mold designer and the military design engineer is necessary.

2.5 Molding Design Considerations.

2.5.1 *General Considerations.* To insure proper design close cooperation is required between the engineer, draftsman, the toolbuilder, the molder and the supplier of raw material. The adherence to the basic engineering approach to successful plastic application as outlined in Chapter 1 will eliminate expensive last minute alterations of the production mold, as well as insure there will be no loss of production time.

2.5.2 *Functional Considerations.*

2.5.2.1 *Fillets and Radii.* Both external and internal sharp corners on plastic parts are probably the greatest contributor to plastic parts failure. Therefore, the use of fillets and radii are a "must" when designing the plastics and provide the following benefits:

(a) Reduction of stress concentration points.

(b) Greater structural strength.

(c) Streamlined flow of molten plastics into mold (Fig. 2–1).

(d) Easier and more economical machining of mold (Fig. 2–2).

(e) Easier part ejection.

(f) Longer mold life.

(g) Prevention of chips and breaks during finishing operation.

Sharp corners are required at the parting lines, but even these should not produce feather edges on the mold (Fig. 2–3). All other inside and outside radii where sharp edges are required, should have at least a minimum radius of 0.020 inches (0.508 mm).

Figure 2–4 illustrates the effect of a fillet radius on stress concentration. Assume a force "P" is exerted on the cantilever section shown. As the radius "R" is increased, with all other dimensions remaining constant, R/T increases proportionally, and the stress-concentration factor decreases as shown by the curve. The stress-concentration factor has been reduced by 50 percent (3.0 to 1.5) by increasing the ratio of fillet radius to thickness, six fold (from 0.1 to 0.6). The figure illustrates how readily the stress-concentration can be reduced by using a larger fillet radius. A fillet of optimum design is obtained with an R/T of 0.6. A further increase in R/T reduces the stress concentration only a marginal amount. This is true in general for most shapes; however, other ratios may have to be used on specific parts because of other functional needs. One of the primary points of designing with plastics is that some radius at a junction point is better than none.

2.5.2.2 *Thickness of Sections*. Wall thickness should be as thin as possible, consistent with structural requirements. Thin walls provide material economy and shorter cycles (faster production) due to the more rapid transfer of heat to the cooler mold or die surfaces for thermoplastics and from the warmer mold for thermosets.

Wall thickness should be made as uniform as possible to eliminate part distortion and internal stresses. Figure 2–5 illustrates the incorporation of uniform section thickness in part design. If different wall thicknesses must be used in a part, blend wall intersections gradually as shown in Figure 2–6. Also, under such circumstances, consideration should be given to the use of assembly techniques for assembling two or more molded sections to make the desired part.

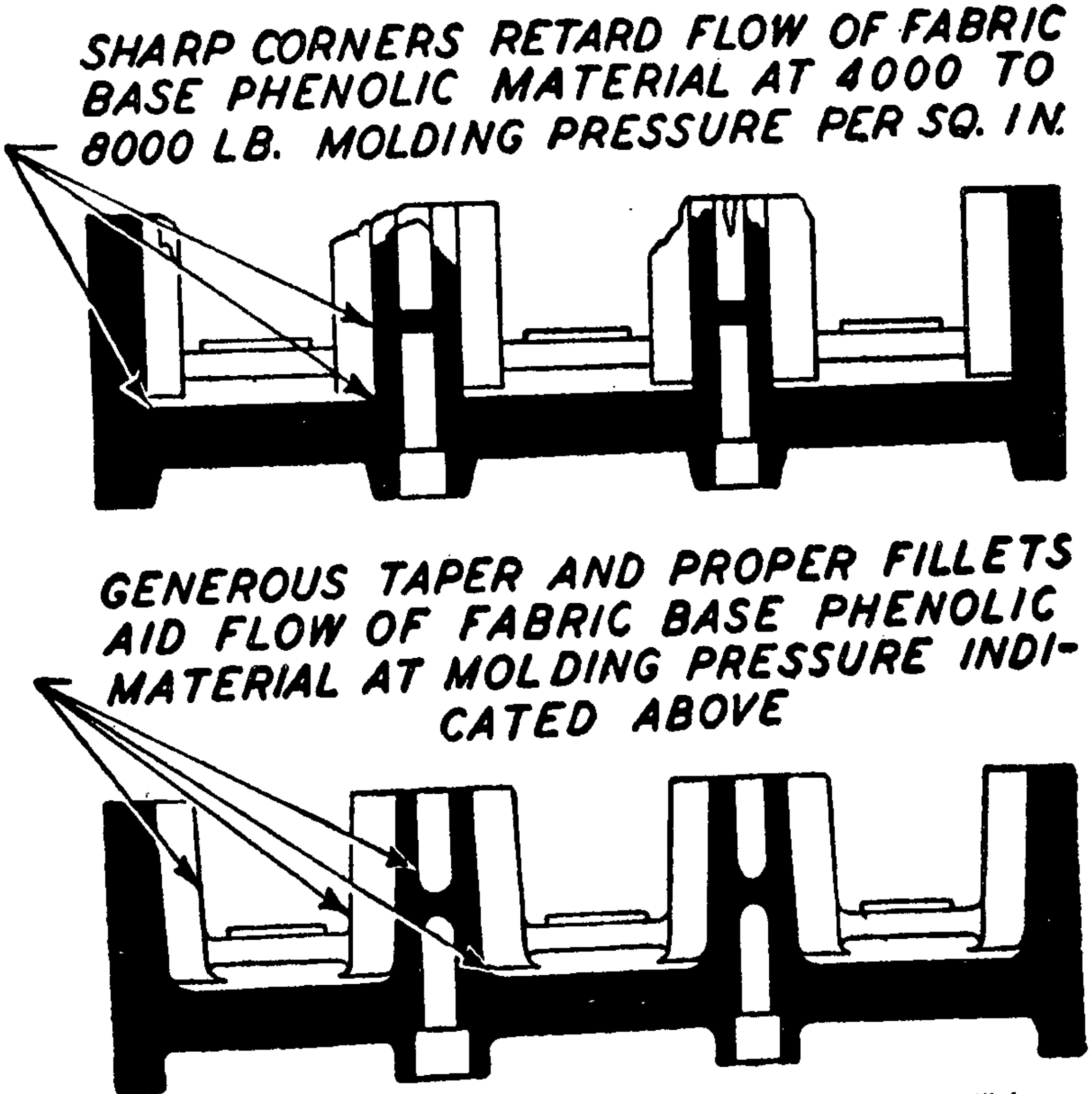


FIGURE 2-1. *Streamlined flow of plastics. Top — Sharp corners responsible for unfilled sections. Bottom — Redesign responsible for even flow and proper fill of all sections.*

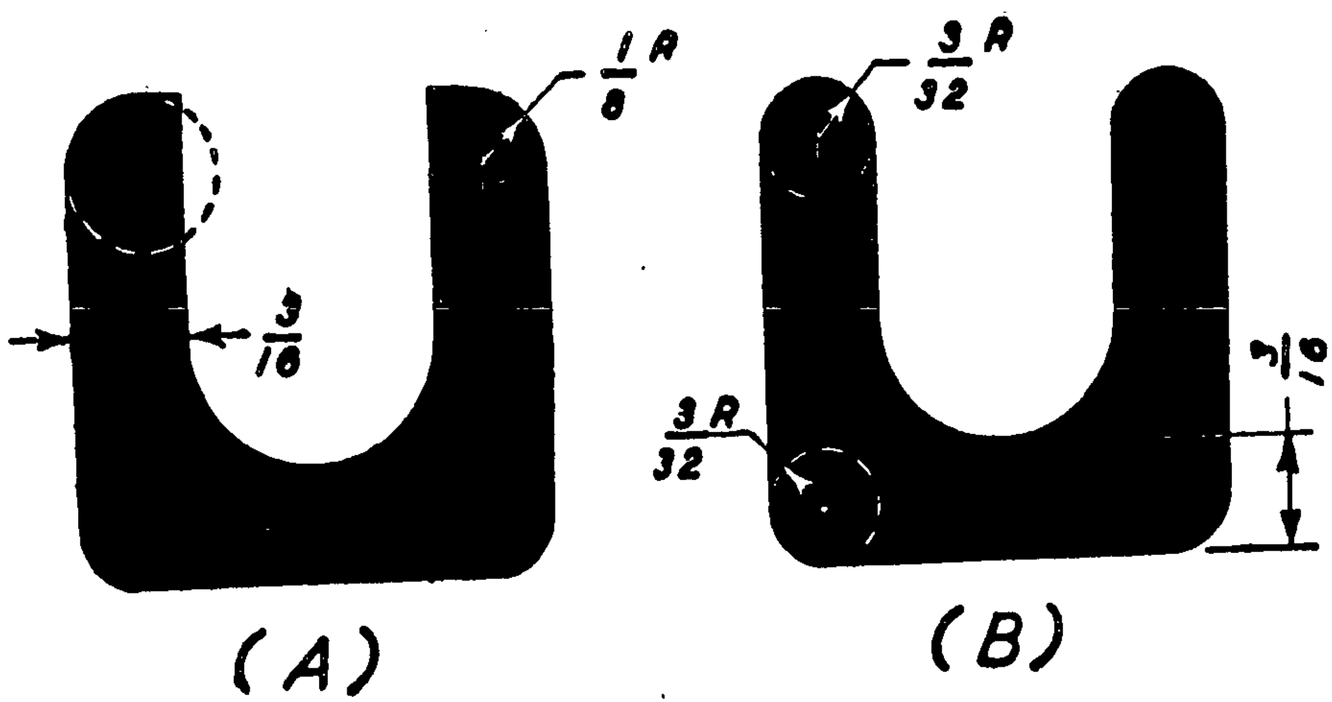


FIGURE 2–2. *Typical redesign to simplify machining operations. Dotted line in (A), shows area cut by 1/4 inch cutter or end mill. Note that this radius extends beyond the desired area and this will necessitate hand chiseling. Revised design, shown at (B) permits radius to be machined easily with a 3/16 of an inch cutter. Radii should be uniform on corners wherever possible.*

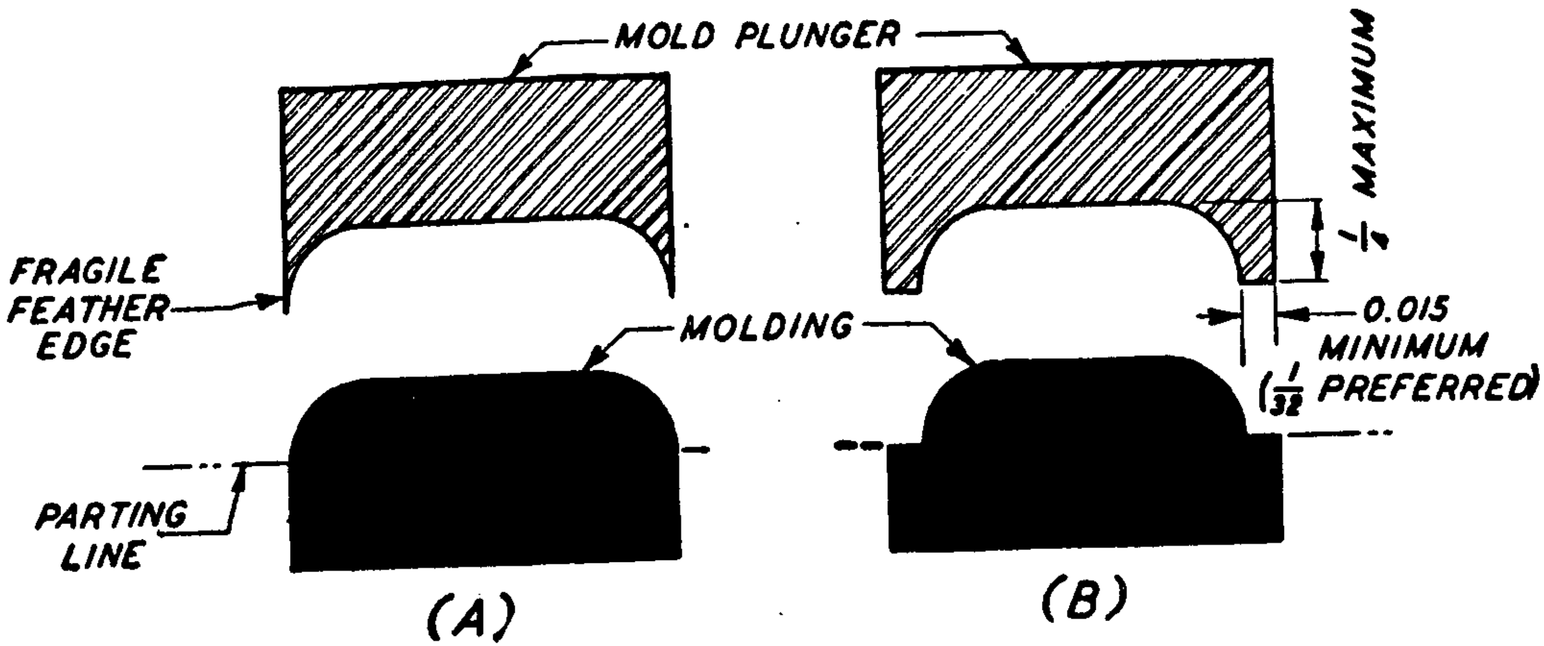


FIGURE 2-3. *Construction shown at (A) has produced a feather-edge that is undesirable from standpoint of maintenance. Stepped corner, at (B), is preferable because its maintenance is negligible.*

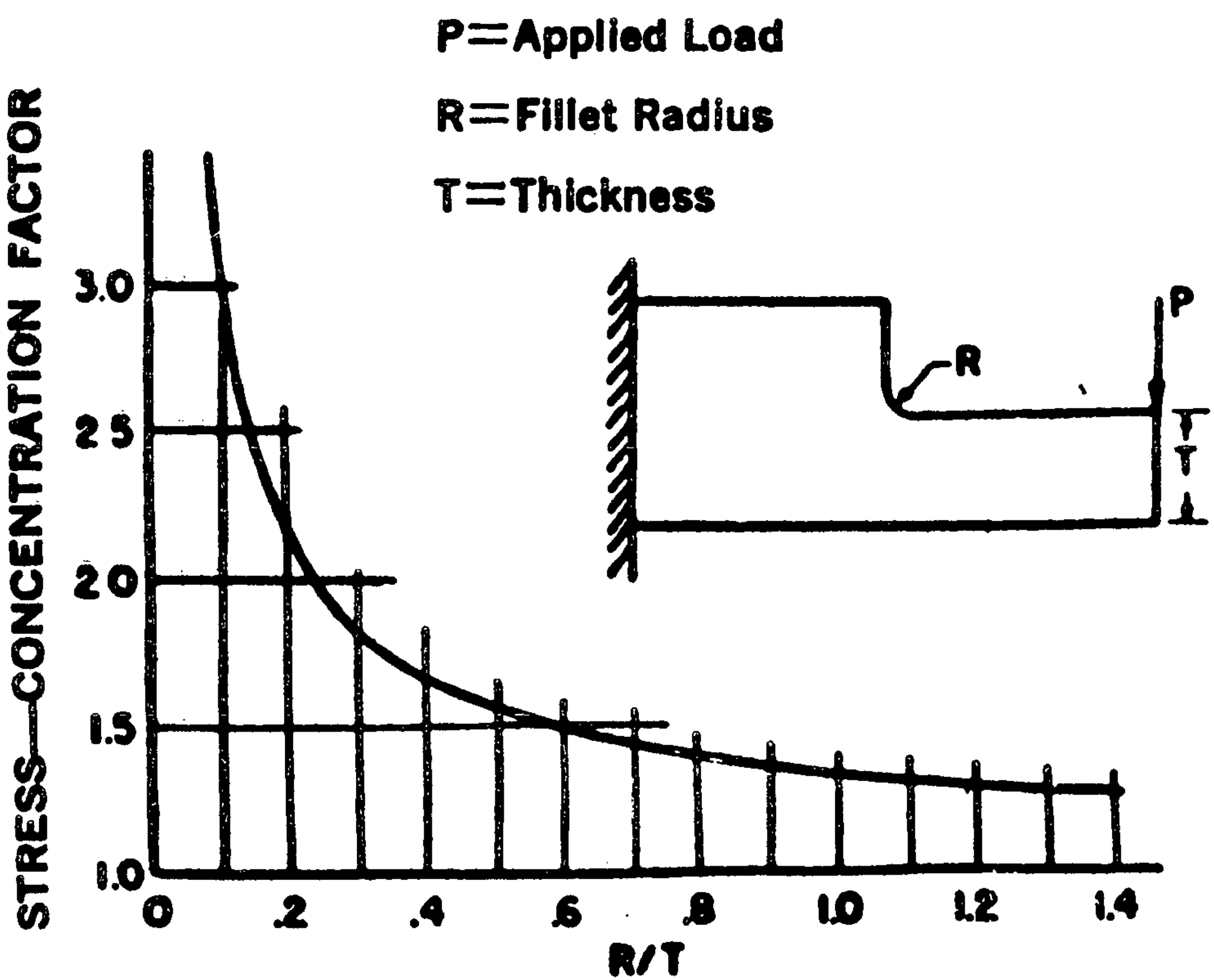


FIGURE 2-4. *Effect of fillet radius on stress concentration factor.*

2.5.2.3 *Ribs and Strengthening Members.* Ribs, flanges and beads can be used to increase part strength without increasing wall thickness. The use of these devices will improve material flow and help prevent distortion during cooling. Ribs which are not properly designed are weak at the wall to which it is joined. Ribs should be tapered in cross section for easy ejection from the mold. Unsupported ribs and beads should be no higher than three times their wall thickness. Ribs or beads on side walls must be perpendicular to insure easy ejection from the mold. See Table 2–1 for the recommended design proportions for ribs.

Sink marks may appear on the surface behind large beads as the part cools. If appearance is important, these effects can be overcome by designing the visible surface to conceal such defects. Matte-finish paints can hide these defects, however, if either a glossy paint or a polished unpainted surface is required the surface itself must be modified. Texture can be applied to the mold to give the appearance of leather, fabric or a sandblasted or hand-hammered surface. Any such nondirectional pattern will provide the disguising needed. An alternative is to use grooves or lines on the visible surface which follow the rib on the underside (Fig. 2–7).

2.5.2.4 *Bosses.* Bosses are small protuding pads used in design to provide reinforcement of holes or for mounting an assembly. The same general precautions to be considered in the use of ribs may also apply to the use and design of bosses. The boss height should not be more than twice the diameter. They should be provided with sufficient draft to insure easy removal of the piece from the mold. When bosses are used for mounting molded parts, it is usually necessary to grind their top surfaces flat. It is recommended that not more than three bosses per mounting surface be used, as they do not require the finishing operations to achieve perfect alignment of four or more bosses.

In the design of pieces required to fit on a flat surface it is often good practice to design an external surface that will project 1/64 inch beyond the normal face, so that it can be easily sanded or finished to a flat, uniform surface.

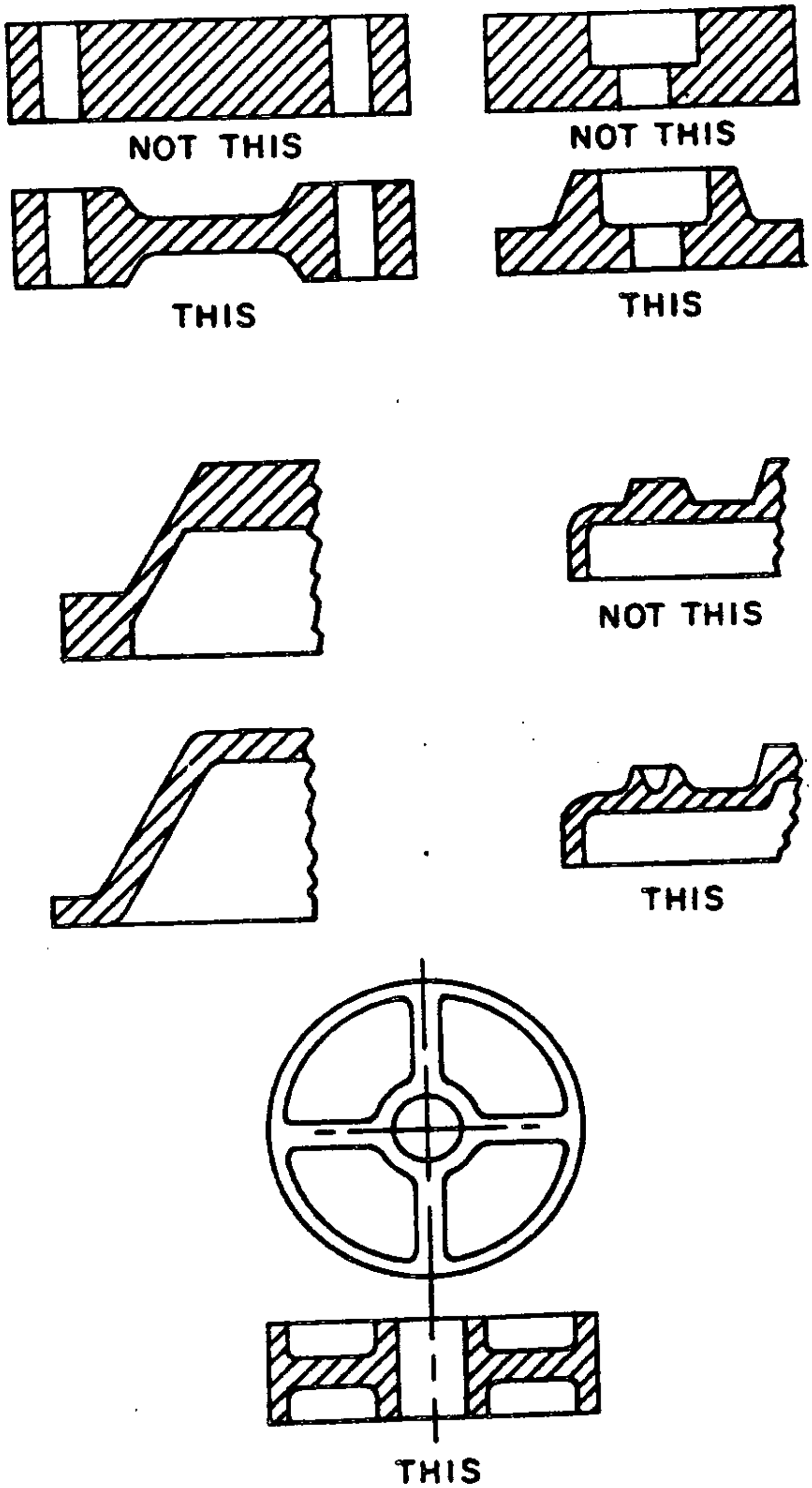


FIGURE 2-5. *Typical methods for obtaining uniform section thickness in part design.*

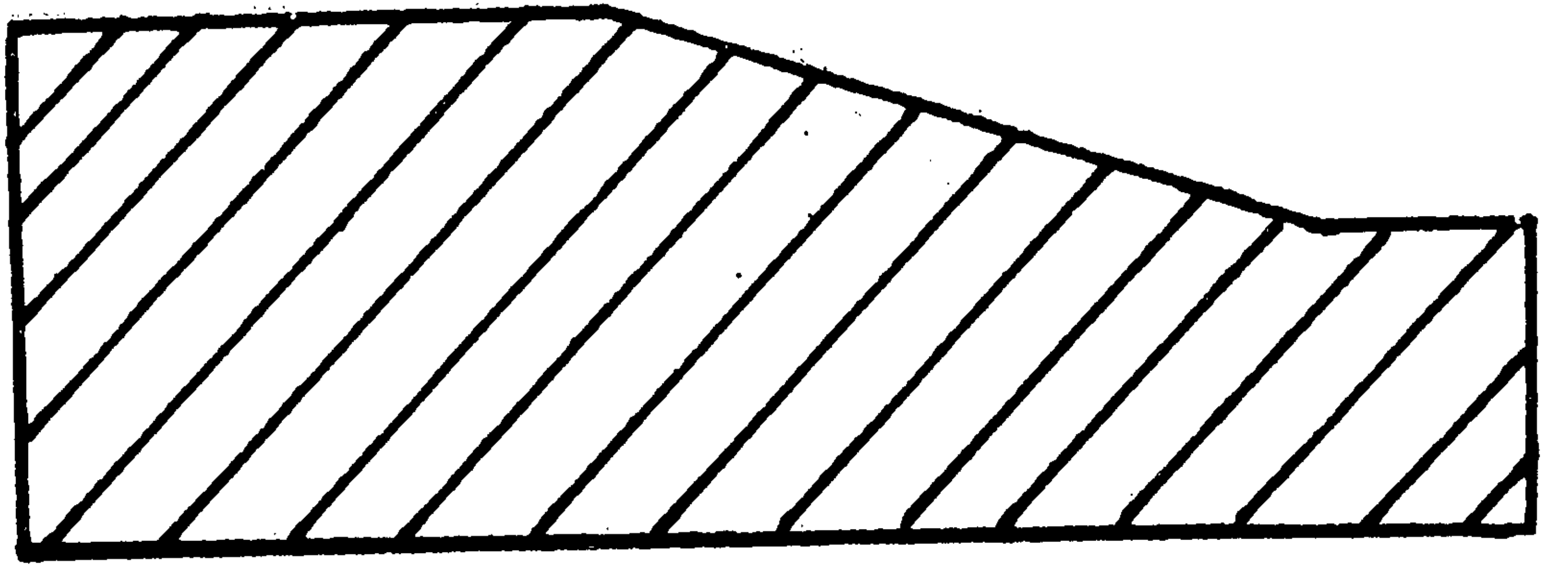
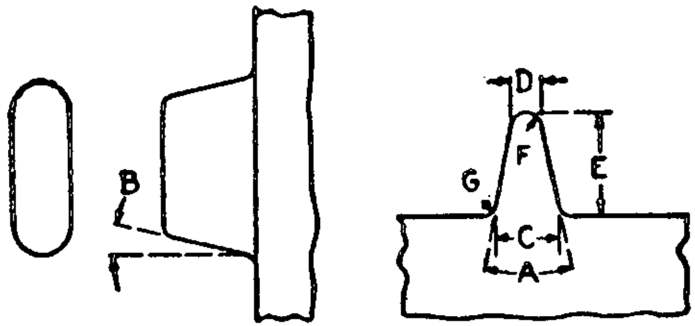


Figure 2–6. Degree Taper or Draft Per Side. All values shown in inches.

TABLE 2-1. *Recommended Proportions for Ribs.*



	A	B	C	D	E	F	G
Hot-molded	10°	5°	n	n/2	3n	n/4	n/4
Cold-molded	20°	10°	n	n/2	3 n/2	n/4	n/4

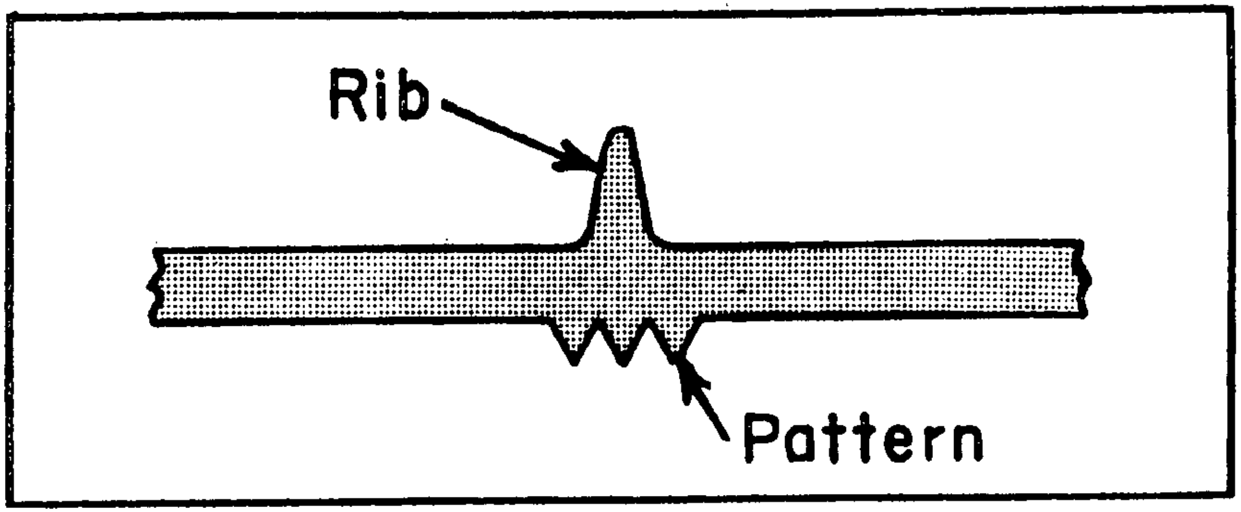


FIGURE 2–7. *Pattern used to disguise a sink mark.*

Avoid the use of high bosses wherever possible as they tend to trap gas, which decreases both the density and the strength of this molded section. Recommended proportions for bosses are shown in Table 2-2.

2.5.3 *Production Considerations.*

2.5.3.1 *Shrinkage.*

2.5.3.1.1 *General.* Shrinkage, an inherent variable characteristic of plastics, is the difference between corresponding linear dimensions of the mold and the molded pieces measured in inch per lineal inch. Generally, shrinkage of plastics vary from 0.001 to 0.015 inch, depending on the type of plastic, shape, constructional material of the mold and molding conditions.

2.5.3.1.2 *Cause of Shrinkage.* The cause of and the amount of shrinkage that will occur in a given molded piece are a variable combination of the following factors:

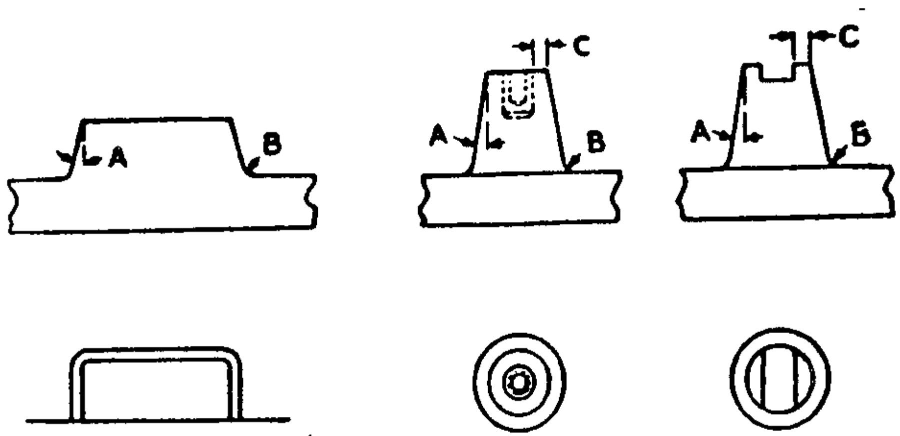
(a) Chemical reactions (especially in thermosets).

(b) Coefficient of thermal expansion of the plastic and cooling temperature range after formation of the molded item.

(c) Degree of the material compression during molding.

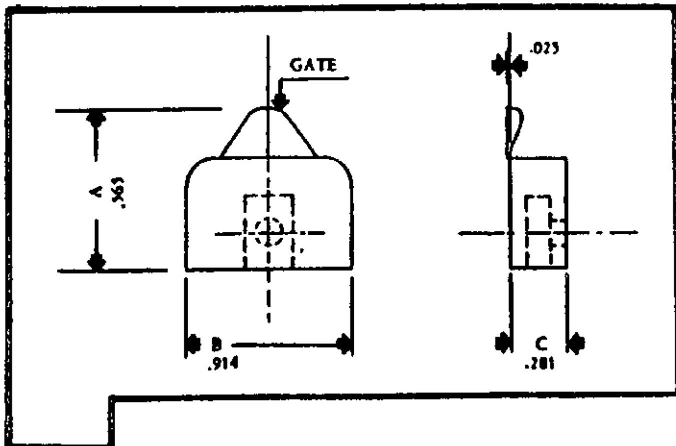
The first factor is an inherent characteristic and is therefore uncontrollable. The second factor is partially controllable in that the thermal coefficient of expansion of the base resin can be modified by the use of fillers, plasticizers, etc. The coefficient of thermal expansion of plastics is greater than that of metals and causes most molded items to be smaller dimensionally than the mold cavity from which they are ejected. Temperature control can be exercised by the molder. Generally, the lower the molding ejection temperature, the less the final shrinkage will be. The third factor is entirely controllable, but its total effect is the most difficult to predict. Generally, the greater the degree of compression, the less the shrinkage will be. Table 2-3 illustrates the effect of molding conditions in the transfer molding of a general purpose phenolic (thermoset) and styrene (thermoplastic) on part shrinkage. Special note should be made of the lesser amount of shrinkage of the styrene (thermoplastic) when compared to the phenolic (thermoset) molded under identical conditions. This illustrates the effect of chemical reaction (crosslinkage) of the thermoset on part shrinkage.

TABLE 2-2. ***Recommended Proportions for Bosses.***



	A	B	C
Hot-molded..........................	5°	1/64 in. min.	3/32 in. min.
Cold-molded..........................	10°	1/32 in. min.	5/32 in. min.

TABLE 2-3.



EFFECT OF MOLDING CONDITIONS ON SHRINKAGE OF PART TRANSFER MOLDED

MATERIAL	MOLDING TEMP.	MOLDING PRESSURE P.S.I.	PRE HEAT	SHRINKAGE — IN./IN. A	B	C	SPECIFIC GRAVITY
General Purpose Phenolic	302° F	3390	None	.0088	.0055	.0049	1.336
	302° F	6780	None	.0062	.0049	.0007	1.330
	302° F	6780	5′ @ 250° F	.0035	.0033	.0014	1.335
	356° F	2260	None	.0088	.0066	.0068	1.335
	356° F	3390	None	.0097	.0055	.0075	1.336
	356° F	6780	None	.0079	.0044	.0025	1.331
	356° F	6780	5′ @ 250° F	.0071	.0022	.0035	1.335
		ALL ABOVE VALUES AVERAGE OF 4					
Styrene	302° F	6780	None	.0018	.0033	.0035	

One may conclude the following after studying the data in Table 2-3 and inset:

(a) Increasing pressure reduces shrinkage.

(b) Preheating reduces shrinkage.

(c) Shrinkage parallel to the direction of flow from the gate (A direction) is greater than across the direction of flow (B direction), or, in general, shrinkage increases with increase of flow of material in mold.

(d) Molding temperature changes do not materially affect shrinkage. This may be explained by the fact that at the higher temperature the material was more fluid and hence was compressed to a greater extent by a given pressure, with the result that the expected effect of higher temperature was neutralized. However, it does appear to be generally true that decreasing the temperature at which the part is released from the mold, to a temperature below that at which the plastic was molded, results in decrease of shrinkage.

(e) Shrinkages in thickness are inconsistent, probably because of slight variations in the closing of the mold, rather than to actual variations in ratio of shrinkage.

Although there may often be counteracting conditions as discussed in (d) above, a summary of individual effects not discussed above is listed.

(a) Design of Piece—When a part has one or two portions considerably heavier in cross-section than the rest, it may be found that if molding conditions are selected for molding the thin section properly, the thicker section will fail to receive an adequate amount of material, or pressure, or cure, and as a result will shrink nonuniformly.

(b) Design of Mold—This is closely associated with molding pressures. The calculated molding pressure is determined from the ram size and hydraulic line pressure and is always somewhat greater than the "effective pressure" or pressure which does the actual compressing of the plastic in the mold. This is so because of mold design types and size and location of gates. Positive molds transmit almost 100 percent of the applied pressure. Flash molds and semi-positive molds transmit an indeterminate amount of pressure. The use of undersize gates may excessively restrict flow and thereby reduce effective pressure. Gate location determines flow direction in the mold, the importance of which was previously discussed.

(c) Plasticity of Material — Generally, the harder flow plastic materials shrink somewhat less than the softer flow materials which have a tendency to flow away under pressure yielding a less dense molding. This is equally true of both thermoplastic and thermosetting materials.

(d) Manner of Loading—The "pills" or "preforms" used in compression molding aid charge distribution in the mold cavity and help thereby to reduce shrinkage.

(e) Pressure Application Rate—Rapid mold closing, particularly on softer less viscous material, produces a "splash" effect in the mold and thereby less dense moldings. The proper rate of mold closing should be experimentally established.

(f) Degree of Cure—Inadequately cured thermosetting materials shrink to a greater extent than the same material properly cured. Thermoplastic parts, especially those with heavy sections, should be cooled in the mold long enough to avoid excessive shrinkage and internal voids.

(g) Multiple Cavity Molds—Variations in shrinkage between pieces from different cavities can be expected due to small differences in pressure, loading and temperature from cavity to cavity.

2.5.3.1.3 *Shrinkage After Molding.* In addition to the preceding causes for shrinkage, thermosetting materials shrink an additional amount due to aging and additional curing. The thermoplastics, particularly those which have been plasticized, shrink in varying degrees due to migration and loss of plasticizer on aging. The amount of shrinkage is dependent on the type and proportion of the plasticizer used.

2.5.3.1.4 *Design Allowances for Shrinkage.* Since there are definite limitations in the control of shrinkage by changes in molding technique, the part designer and mold designer must compensate for it in their designs. Manufacturers of plastic molding material provide mold shrinkage data in terms of inch per inch of molded piece for each material they produce. However, it must be remembered this data is determined from standard test specimens under a given set of molding conditions and is not necessarily representative of the shrinkage produced in a commercially molded part. In view of these circumstances, it is better to assume that the prediction of shrinkage will not be exactly correct, and to have the mold constructed in such a manner that it can be readily modified after sample pieces have been molded and measured. In addition, when molding with metal inserts or two different plastic materials which must fit each other, proper allowances must be made for differences in shrinkage. The avoidance of excessive after-shrinkage under diverse conditions demands exacting care in selection of material molding technique and mold construction design.

2.5.3.2 *Parting Lines.* In compression molding, the closing of the two parts of the molds results in flow of material into the clearance between these parts. This material known as flash occurs at the parting lines of the mold. Flash removal leaves an unavoidable unsightly line which requires buffing. Good design minimizes cleaning costs by providing straight parting lines which clean and buff easily. Molds which have straight parting lines cost less than those which have curved or stepped parting lines. When the parting line does not come at the corner of the part, it should be elevated ("beaded" or "peaked") above surrounding surfaces so that those surfaces will not be marred by the cleaning tools. Flush parting lines, when necessary to use, may be undercut. The advantages of undercutting a parting line are two fold, namely, expensive buffing is eliminated and a stripe of colored paint may be added to the undercut to provide eye appeal. The parting lines of most products normally will come at the edge or corner, where they will tumble clean or can be cleaned easily by filing or spindling. The corner will be radiused when the flash is removed, therefore drawings which show an extremely sharp corner at the parting line should not be approved without a check to make sure that the radius produced by cleaning will not detract from the functionality of the part.

2.5.3.3 *Holes.*

2.5.3.3.1 *General.* The design and location of holes in molded pieces requires the consideration of several factors in order to avoid the introduction of excessive weaknesses and production complications.

Cracking around holes in an assembly is usually caused by inadequate wall thicknesses surrounding the holes. Hole to hole and hole to sidewall distance should be at least the equivalent of the hole diameter. Products containing ribs or bosses are frequently designed with holes too close to the rib depression. This causes cracking on hardening of this thinly molded section between the hole and the depression. To avoid this type of failure, it is recommended that the distance between rib base and hole be 1/3 to 1/2 the diameter of the molded hole.

For threaded holes a linear distance between hole edge and part edge of three times the hole diameter should be provided in order to overcome cracking caused by stress concentrations at the notches of the thread.

Holes are usually produced by core pins which protrude into the mold cavity. These pins do become worn, and sometimes distorted and even broken by the flow and pressure on the compound in the mold. An experienced molder can help with the selection of a process and the mold design to avoid costly production down time caused by pin damage.

2.5.3.3.2 *Through Holes.* Through holes are more useful for assembly purposes than blind holes. In addition, they are easier to produce because the core pin can be supported at both ends. Through holes may be produced either by a single pin supported at each end or by two pins butted together. The first method is generally considered the better practice. When the two-pin method is used, one pin should be slightly larger in diameter than the other to compensate for any misalignment. The butt ends of these pins should be ground flat and when the mold is closed, the clearance between the butt ends should be 0.005 inch to 0.020 inch in order to prevent upsetting the ends of the pins.

2.5.3.3.3 *Blind Holes.* The designer must remember that the pin for blind hole molding can be supported at only one end, and is subject to unbalanced pressures exerted by the flow of plastic during the molding operation which may cause the pin to distort, bend or shear. Therefore, core pins used for blind holes must be short and are limited in length to twice the hole diameter, unless the diameter is less than 1/16 inch, in which case the length shall not exceed the diameter.

Depth of blind holes may be increased by stepping and notching techniques as shown in Figure 2–8.

2.5.3.3.4 *Drilled Holes.* Sometimes it is found to be less expensive to drill holes after molding, rather than attempt to mold them, particularly when they are deep in proportion to their diameter. When holes are to be drilled after molding, they should be generally spotted by the mold. This will facilitate drilling without the use of drill jigs.

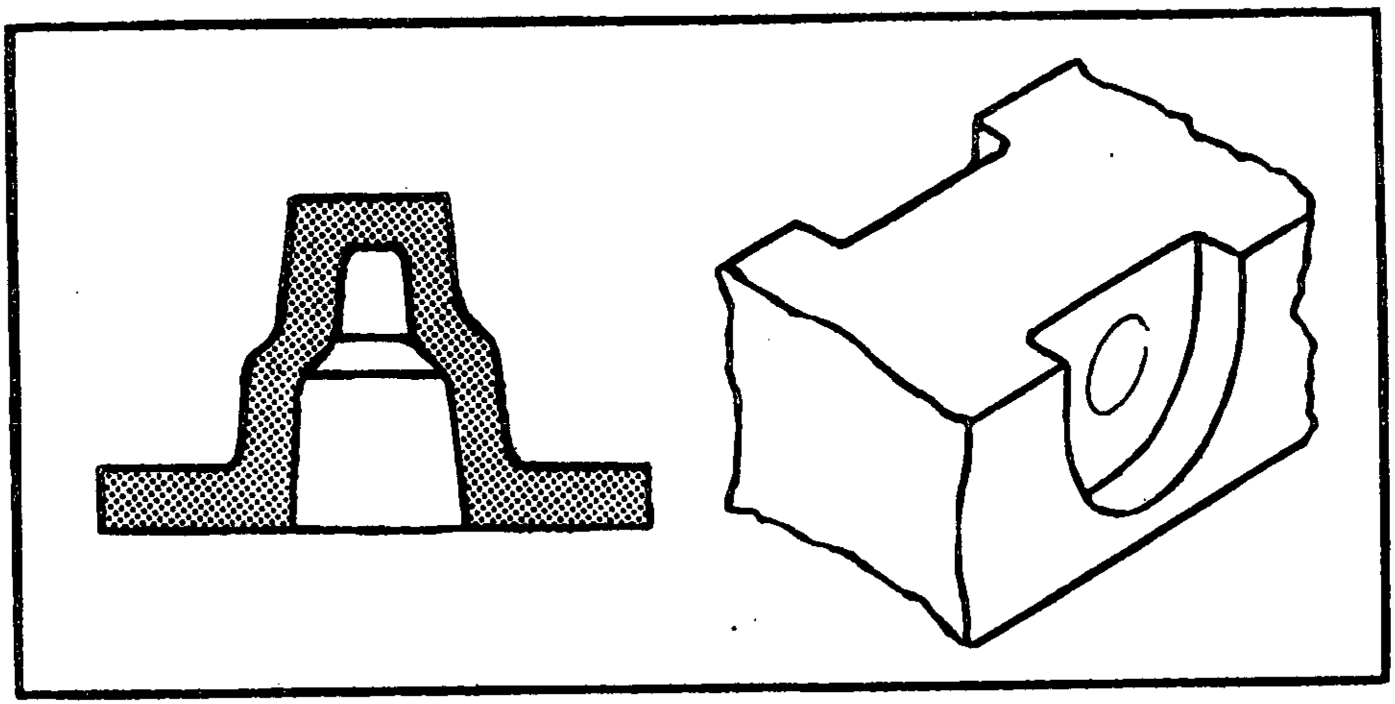


FIGURE 2-8. *Stepping and notching techniques for increasing hole depth in molded parts.*

2.5.3.3.5 *Side Holes.* Side holes are difficult to produce and present problems, which are not easily solved because they create undercuts in molded pieces. Holes which must be molded at right angles to each other necessitate the use of split molds or core pins and therefore are more costly. Besides pin distortion problems, extra time is required to remove pins from the molded piece before it can be removed from the mold cavity. Some automatic removal of side core pins is being utilized in molding but manual operation of such side pins has been found to be more satisfactory. Depth to diameter ratios as previously given for through holes are usually applicable for side holes. However, because of the unpredictable nature of flow patterns and conditions, it may be necessary to determine the maximum side hole depth by trial.

In compression molding, oblique or side holes create a real problem. It is often much less costly to drill such side holes after molding and this practice is followed for all small holes. When long side holes are specified additional support must be given to the mold pin. Pin lengths which do not exceed 2½ times the diameter are satisfactory for compression molding when the pins are supported at both ends. If longer pins are required, it is suggested that transfer or injection molding be used. Designers should not overlook the possibility of designing with "step backs" (Fig. 2-9) on the outside contour of the part, so as to eliminate core pin removal from side holes. In this technique, advantage is taken of the fact that half the hole is produced by the mold cavity, and half by the force plug.

When plastics are forced to flow around a pin in a constricted area, they may not knit well on the far side of the hole (Fig. 2-10). Cracking often develops along these lines because of failure of the material to knit.

Products of the type, which cause this problem must have openings uniformly spaced and as far apart as possible to permit adequate material flow. It may be necessary to leave a heavy flash in large holes to remove the knit line and minimize subsequent after cracking.

Many of the thermoplastics and laminated phenolic materials will withstand punching operations. Designers can take advantage of this by laying out the side holes for punching after molding.

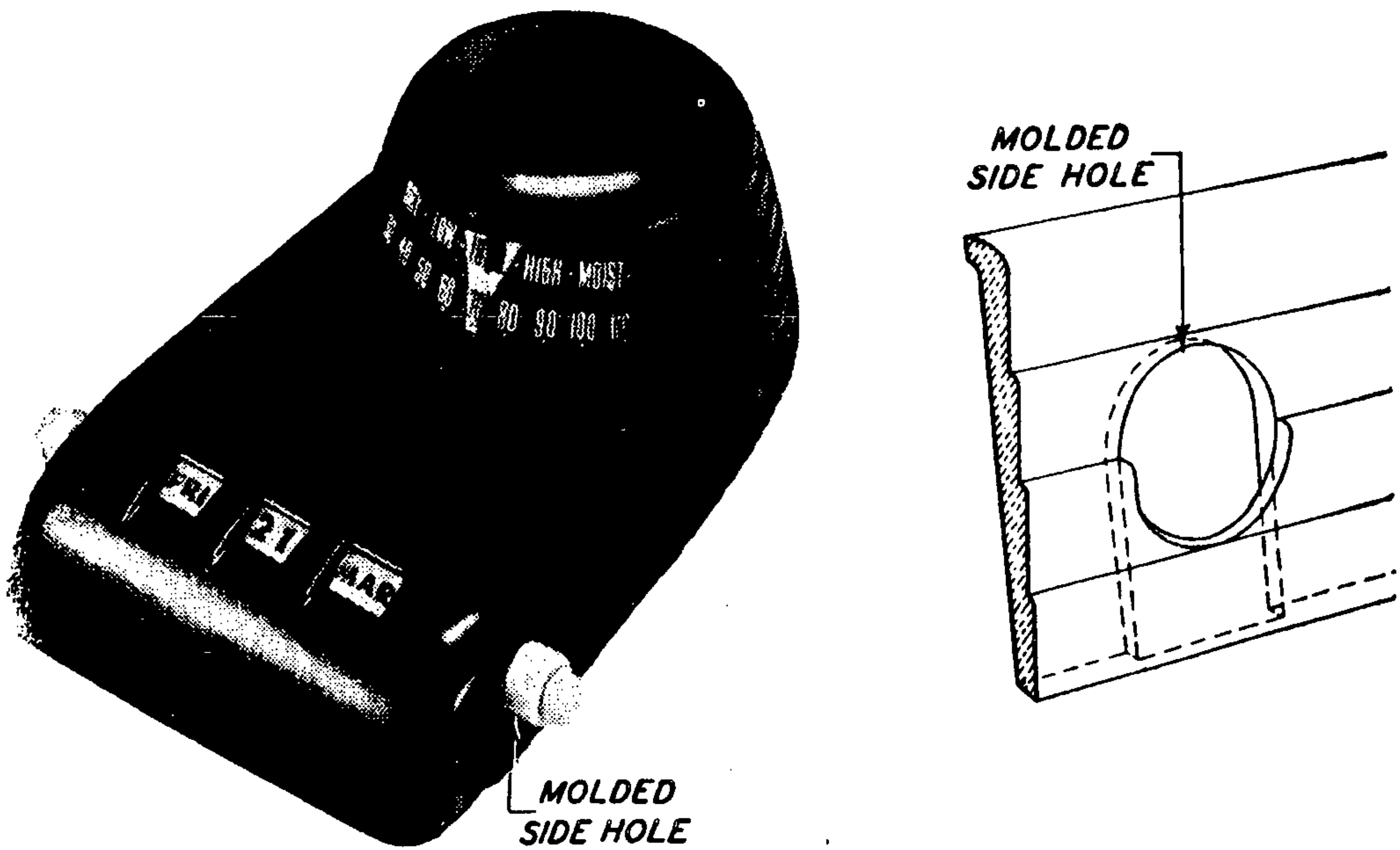


FIGURE 2-9. *"Step back" technique of design.*

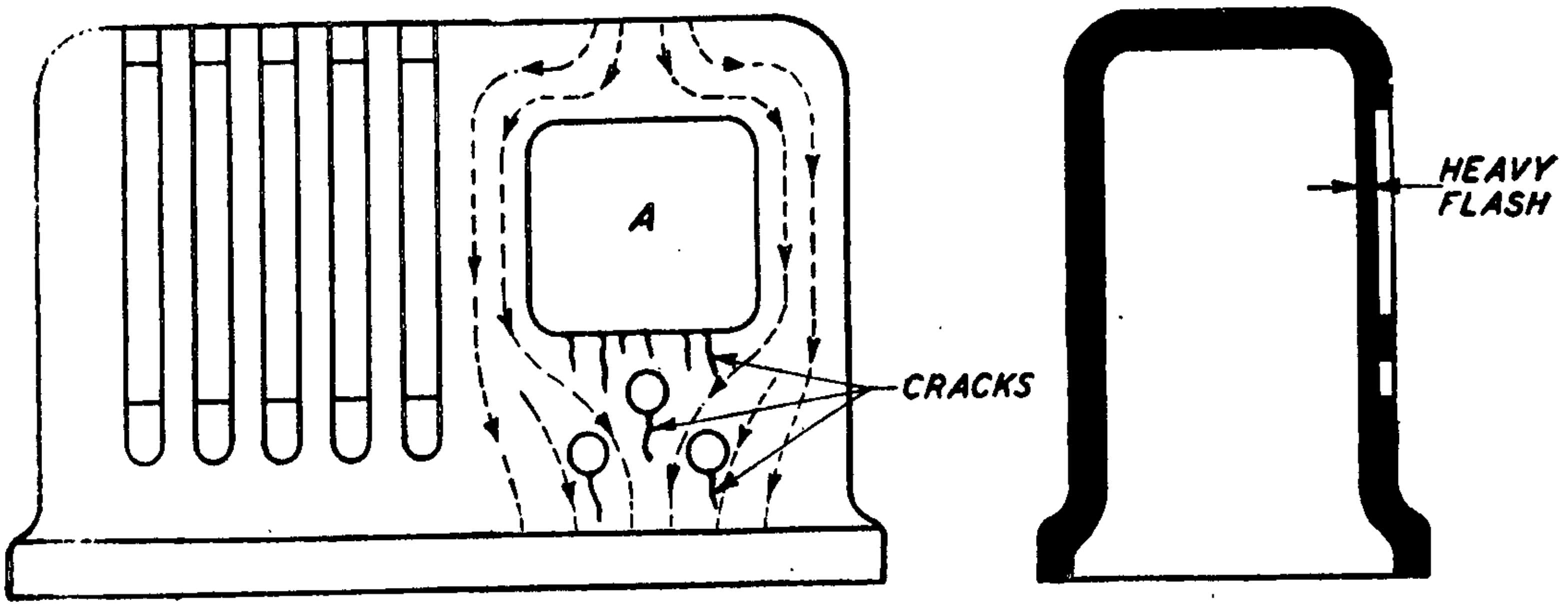


FIGURE 2-10. *Radio cabinet molded with side core to produce opening A and holes below. Cabinet is molded upside down, and the material flow is indicated by the broken lines. A weak section will form below these openings where divided flow meets on far side of pin. This often causes cracking to occur during aging, because compound fails to "knit" compactly. To avoid this, a heavy flash should be used in openings so compound will flow over pin as well as around it.*

2.5.3.3.6 *Threaded Holes.* Threaded holes required in plastic parts for assembly purpose are ordinarily formed by machine tapping or by use of threaded metal inserts. These methods are more economical than to produce the threaded hole in the molding, especially when the hole diameter is smaller than 3/16 inch.

When screws must be removed or replaced, the molded thread is more durable than the machined or tapped thread, but both are inferior to the threaded metal insert. Where large numbers of threaded holes in a part are required, it is better to use metal inserts.

Molded or drilled holes requiring tapping should be slightly larger than those used with metals. The recommended tap drill sizes are given in Table 2-4. Holes should be slightly countersunk before tapping to avoid surface chipping.

Threads molded or tapped into plastics should not be finer than 32 per inch.

Ordinary standard taps dull very quickly, especially with thermosetting plastics. Special plastic drills and taps are available from most manufacturers of the standard kind.

A variation of tapping is the use of self-tapping or drive screws, which eliminates the necessity of a threaded hole. Self-tapping screws cut their own thread when screwed into a straight hole. Drive screws are hammered home and should be used only as a permanent fastening, as they can not be readily removed. See Table 2-5 for hole sizes for self-tapping and drive screws.

2.5.3.4 *Taper or Draft.* Both internal and external drafts or tapers are required to facilitate removal of a part from a mold. The amount of draft or taper varies depending on the molding material, process, wall thickness, part geometry, and depths of draw or length.

Since designers should be on the alert to avoid design details which would obstruct free ejection of the part from the mold, he should provide as liberal a taper as the design will tolerate.

A minimum taper of ½° per side is generally satisfactory, although 1° per side is most desirable for production jobs. If the design cannot tolerate the degree of taper generally acceptable, the following guide may be used.

(a) For parts molded of polypropylene, polyethylene and acrylic resins, a draft of ¼° is usually satisfactory.

TABLE 2-4

TAP DRILL SIZES FOR PLASTICS

For		For		For		For	
Tap	Drill	Tap	Drill	Tap	Drill	Tap	Drill
F 0x80	55	8x30	28	16x16	3	N.C.S.	
1x56	1/16	C 8x32	28	16x18	7/32	1/4x20	5
C 1x64	52	F 8x36	27	16x20	2	5/16x18	G
F 1x72	51	9x24	27	17x16	1	3/8x16	O
2x48	49	9x28	25	17x18	A	7/16x14	3/8
C 2x56	48	9x30	24	17x20	B	1/2x13	7/16
F 2x64	48	9x32	24	18x16	B	9/16x12	31/64
3x40	45	C 10x24	22	18x18	D	5/8x11	17/32
C 3x48	44	10x30	19	18x20	E	3/4x10	21/32
F 3x56	43	F 10x32	19	19x16	E	7/8x9	49/64
4x32	42	11x24	17	19x18	F	1"x8	7/8
4x36	42	11x28	16	19x20	G	N.F.S.	
C 4x40	41	11x30	16	20x16	H	1/4x28	2
F 4x48	40	12x20	16	20x18	I	5/16x24	I
5x30	37	12x22	15	20x20	J	3/8x24	R
5x32	36	C 12x24	13	22x16	L	7/16x20	25/64
5x36	36	F 12x28	12	22x16	M	1/2x20	29/64
C 5x40	34	13x20	12	24x14	5/16	9/16x18	33/64
F 5x44	35	13x22	10	24x16	O	5/8x18	37/64
6x30	32	13x24	9	24x18	P	3/4x16	11/16
C 6x32	31	14x20	6	26x14	Q	7/8x14	13/16
6x36	31	14x22	5	26x16	11/32	1"x14	15/16
F 6x40	1/8	14x24	4	28x14	23/64		
7x28	1/8	15x18	5	28x16	U		
7x30	1/8	15x20	4	30x14	W		
7x32	30	15x22	3	30x16	X		
8x24	29	15x24	7/32				

TABLE 2-5

SELF-TAPPING SCREWS

	O.D.	Thermosetting		Thermoplastic	
Size	Thread	Hole	Drill	Hole	Drill
2	.086	.078	47	.078	47
4	.112	.112	37	.093	42
6	.137	.137	30	.120	31
7	.151	.144	27	.128	30
8	.163	.152	24	.144	27
10	.186	.177	16	.169	18
12	.212	.199	8	.191	11
14	.243	.238	A	.221	2

DRIVE SCREWS

	O.D.	Plastics	
Size	Thread	Hole	Drill
00	.058	.052	55
0	.073	.067	51
2	.098	.086	44
4	.114	.104	37
6	.138	.120	21
7	.152	.136	29
8	.164	.144	27
10	.179	.161	20
12	.209	.191	11
14	.239	.221	2

Note. Molded holes should be formed with a rounded chamfer; drilled holes should be machine-chamfered.

(b) Small simple shapes such as journal bearings (1 in. diameter by 1 in. long) made of acetal or nylon can be molded with no draft.

(c) Where draft is required for a part molded of a nylon resin, 1/8° is usually sufficient.

(d) For most parts made of acetal resins 1/4° is usually sufficient.

Figure 2–11 illustrates what is meant by a tapered wall side, and Table 2–6 shows the relationship of degree of taper per side to the dimensions in inches per inch, and the effect of taper for various depths of piece. For example, a piece 4 inches in depth can carry a 4-degree taper or 0.2796 inches per side (0.0699 inch per inch). However, for a piece 10 inch in depth, the 4-degree taper would amount to 0.6990 inch per side and this would be an excessive allowance.

2.5.3.5 *Threads.* Although almost any thread profile can be economically molded in plastic parts, the three classes of the Unified Thread Standards are the most suitable. This thread form eliminates the feather edge at both the root and tip of the thread.

Coarse threads are easier to mold than fine threads. Threads finer than 32 per inch should be avoided. Threads of class 1 or 2 are adequate for most applications.

Parts with external threads can be removed from a mold either by unscrewing the parts from the mold cavity or by locating the mold parting line along the axial center-line of the screw profile. Internal threads can be produced by a thread core which is unscrewed from the part. If a part has only a few internal rounded threads it may be possible to strip the part over the threaded core, thus eliminating an unscrewing mechanism. Bottle and jar caps are made in this manner.

Threads should not extend to the very end of the part, nor completely up to a shoulder. A clearance of 1/32 inch should be provided at each end of the thread. The wall thickness supporting either an external or internal thread should be at least equal to the depth of the thread.

2.5.3.6 *Inserts.*

2.5.3.6.1 *General.* In plastic parts, inserts can act as fasteners or load supports, or they can be used to simplify handling or facilitate assembly. Inserts may be functional or purely decorative, but they should be used sparingly because they increase cost.

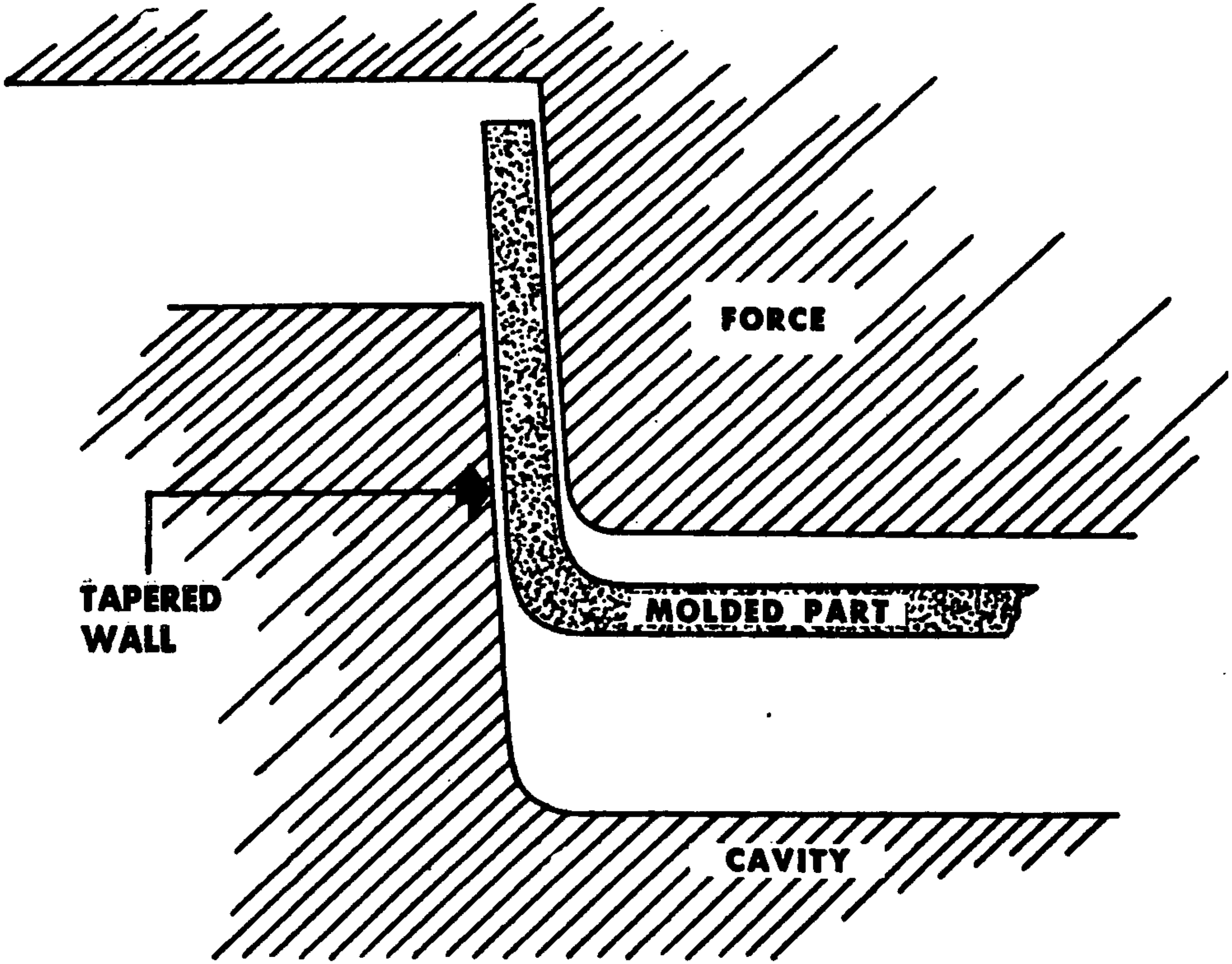


FIGURE 2-11. *Tapered Wall Sides.*

TABLE 2-6. *Example of blending between different wall thickness.*

	1/8°	1/4°	1/2°	1°	2°	3°	4°
1"	0.0022	0.0044	0.0087	0.0175	0.0349	0.0524	0.0699
2"	0.0044	0.0088	0.0174	0.0350	0.0698	0.1048	0.1398
3"	0.0066	0.0132	0.0261	0.0525	0.1047	0.1572	0.2097
4"	0.0088	0.0176	0.0348	0.0700	0.1396	0.2096	0.2796
5"	0.0110	0.0220	0.0435	0.0875	0.1745	0.2620	0.3495
6"	0.0132	0.0264	0.0522	0.1050	0.2094	0.3144	0.4194
7"	0.0154	0.0308	0.0609	0.1225	0.2443	0.3668	0.4893
8"	0.0176	0.0352	0.0696	0.1400	0.2792	0.4192	0.5592
9"	0.0198	0.0396	0.0783	0.1575	0.3141	0.4716	0.6291
10"	0.0220	0.0440	0.0870	0.1750	0.3490	0.5240	0.6990

Well-designed inserts must be easy to load. They must not crush or distort during molding, and they must come free from the mold readily when the part is removed from the mold. Tolerances must be close for tight fit in mold members, and shoulders provided to stop flash from flowing into threads and holes. Inserts must have sharp corners at shoulders or plastic will flow in under the insert and raise it up out of position. Inserts must be surrounded by sufficient plastic to prevent cracking, since the stress on the insert is transmitted to the plastic.

2.5.3.6.2 *Screw-Machine Inserts.* Inserts provided for adding strength to hold down screws, adding screw thread life, providing electrical conduction, etc., usually slow down the mold cycle time and thereby add production cost. The elimination of inserts or the addition of metal parts by automatic means after the molding of the plastic part may provide the answer to faster production at a reduced cost. Often a tapped hole in the plastic, with a drive screw, a self-tapping screw or bolt and nut can be used to reduce cost. Although the ordinary screw-machine-type round insert is common, numerous designs as illustrated in Figure 2-12, are used.

2.5.3.6.3 *Dimensions and Tolerances.* Maintaining a proper accuracy in various dimensions of inserts has been difficult, due to a lack of information on design and standardization of dimensions. However, the National Screw Machine Products Association has compiled the data in Figure 2-13 and Table 2-7 for usual type male and female inserts which are practical for an automatic screw machine operation. Note that the dimensions given for tapper inserts apply only to nonferrous metals where the depth of usuable tapping is not more than 1½ times the tap diameter. On A-2 (minor-diameter) and C (Length of tapped insert) the maximum "Standard" tolerance should be specified whenever possible. However, for closer tolerances, "Precision" can be specified when necessary. To maintain the "Precision" tolerance, reaming and other additional operations will be necessary at additional cost.

If steel inserts are required, Figure 2-13 and Table 2-7 cannot be used in design without several modifications which will result in more expensive inserts when made of brass or, in special cases, of aluminum.

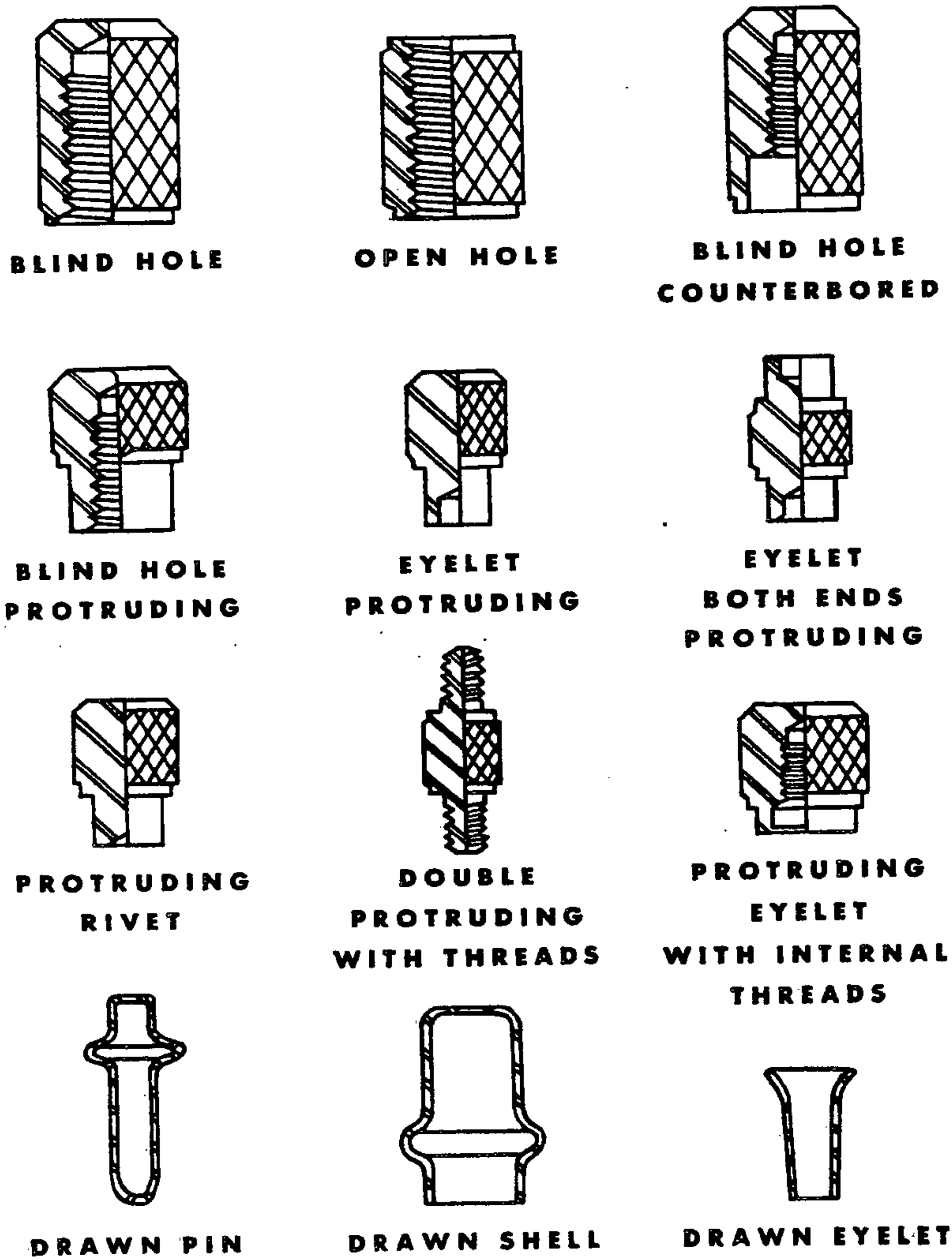
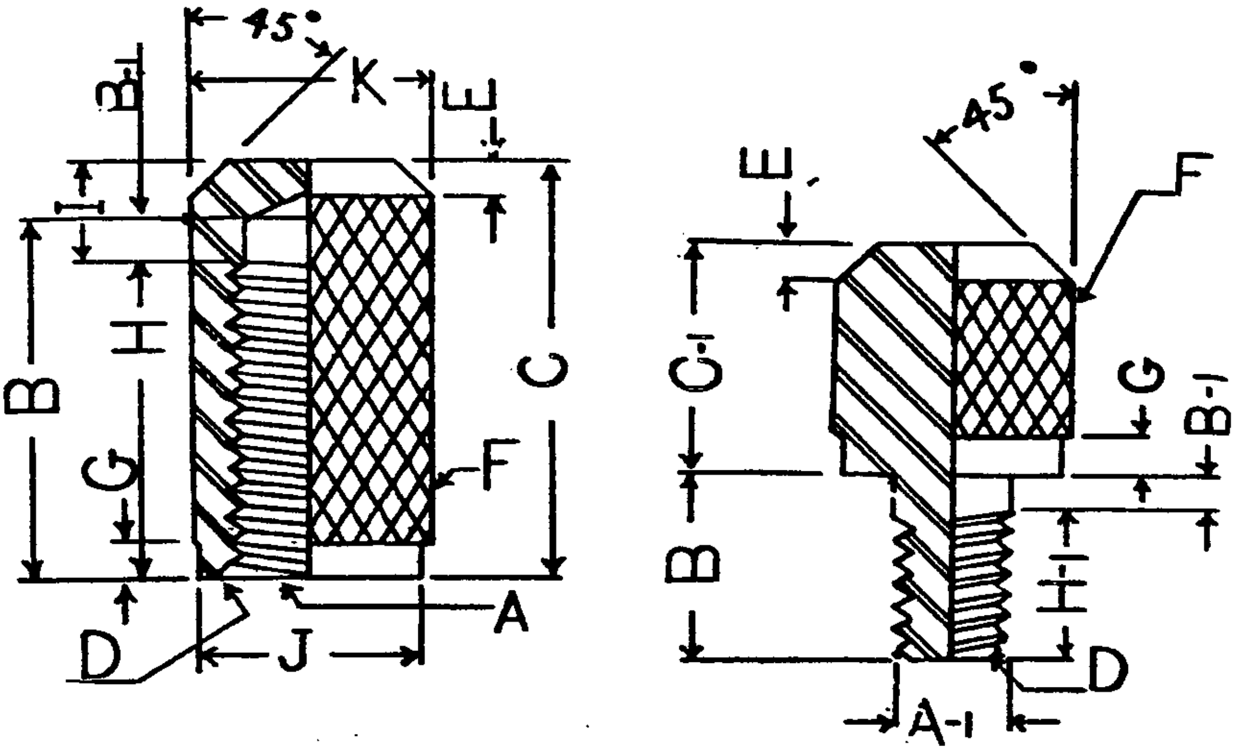

BLIND HOLE
OPEN HOLE
BLIND HOLE COUNTERBORED
BLIND HOLE PROTRUDING
EYELET PROTRUDING
EYELET BOTH ENDS PROTRUDING
PROTRUDING RIVET
DOUBLE PROTRUDING WITH THREADS
PROTRUDING EYELET WITH INTERNAL THREADS
DRAWN PIN
DRAWN SHELL
DRAWN EYELET

FIGURE 2-12.



A	Tap Size "American National" Class 2	
A-1	Major Diameter	
A-2	Minor Diameter "Regular" Tolerance	+ .0025"
	"Precision" Tolerance	— .0005"
B	Depth of Minor Diameter	
B-1	Number of Unusable Thread from Bottom (Cut Thread)	
C	Length "Regular" Tolerance	± .010"
	"Precision" Tolerance	± .001"
C-1	Length of Body Male Insert	± .010"
D	Thread Chamfer	45° ± .005"
E	Body Chamfer	45° ± .010"
F	Knurl	
G	Length of Sealing Diameter Minimum 1/32"	
H	Length of Usable Thread 1½ X Diameter	
H-1	Length of Usable Thread H-1 + B-1 = B	
I	Amount to Add to H to Obtain C. H + I = C	
J	Sealing Diameter	± .002"
K	Minimum Bar Stock Diameter	

Figure 2-13.

TABLE 2-7
DIMENSIONS AND TOLERANCES*

Non-ferrous inserts which have a usable thread length not more than 1½ times the tap diameter.

A		K	J	Tap Drill	A-8	A-1		B-1	I	D and E	Knurl
Coarse	Fine					Maximum	Minimum				
2-56		3/16	9/64	#50	.0700	.0860	.0820	3	3/32	1/64	Fine
	2-64	3/16	9/64	#49	.0730	.0860	.0822	3	3/32	1/64	Fine
3-48		7/32	5/32	#45	.0820	.0990	.0946	3	7/64	1/64	Fine
	3-56	7/32	5/32	#45	.0820	.0990	.0950	3	3/32	1/64	Fine
4-40		7/32	11/64	#43	.0890	.1120	.1072	2½	7/64	1/64	Fine
	4-48	7/32	11/64	#42	.0935	.1120	.1076	2½	7/64	1/64	Fine
5-40		1/4	3/16	#37	.1040	.1250	.1202	2½	7/64	1/32	Med.
	5-44	1/4	3/16	#37	.1040	.1250	.1204	2½	7/64	1/32	Med.
6-32		1/4	13/64	#33	.1130	.1380	.1326	2½	5/32	1/32	Med.
	6-40	1/4	13/64	#32	.1160	.1380	.1332	2½	9/64	1/32	Med.
8-32		9/32	7/32	#29	.1360	.1640	.1586	2½	5/32	1/32	Med.
	8-36	9/32	7/32	#28	.1405	.1640	.1590	2½	9/64	1/32	Med.
10-24		5/16	1/4	#23	.1540	.1900	.1834	2½	3/16	1/32	Med.
	10-32	5/16	1/4	#20	.1610	.1900	.1846	2½	5/32	1/32	Med.
12-24		3/8	5/16	#16	.1770	.2160	.2094	2½	13/64	3/64	Med.
	12-28	3/8	5/16	#13	.1850	.2160	.2098	2½	11/64	3/64	Med.
1/4-20		13/32	11/32	#6	.2040	.2500	.2428	2	13/64	3/64	Coarse
	1/4-28	13/32	11/32	7/32	.2187	.2500	.2438	2	11/64	3/64	Coarse
5/16-18		15/32	13/32	G	.2610	.3125	.3043	2	7/32	3/64	Coarse
	5/16-24	15/32	13/32	I	.2720	.3125	.3059	2	13/64	3/64	Coarse
3/8-16		9/16	15/32	O	.3160	.3750	.3660	2	1/4	3/64	Coarse
	3/8-24	9/16	15/32	Q	.3320	.3750	.3684	2	7/32	3/64	Coarse
7/16-14		5/8	17/32	U	.3680	.4375	.4277	2	9/32	3/64	Coarse
	7/16-20	5/8	17/32	25/64	.3906	.4375	.4303	2	1/4	3/64	Coarse
1/2-13		11/16	19/32	27/64	.4218	.5000	.4896	2	5/16	1/16	Coarse
	1/2-20	11/16	19/32	29/64	.4531	.5000	.4928	2	17/64	1/16	Coarse
9/16-12		3/4	21/32	31/64	.4843	.5625	.5518	2	11/32	1/16	Coarse
	9/16-18	3/4	21/32	33/64	.5156	.5625	.5543	2	9/32	1/16	Coarse
5/8-11		13/16	23/32	35/64	.5469	.6250	.6132	2	3/8	1/16	Coarse
	5/8-18	13/16	23/32	37/64	.5781	.6250	.6168	2	5/16	1/16	Coarse

* See figure 2-14.

2.5.3.6.4 *Anchorage.* During cooling, plastic materials shrink around a metal insert and thus contribute substantially to the holding power of the insert. However, inserts must also be designed to assure a secure anchorage against rotation and pull-out, Figure 2–14.

Avoid the use of sharp corners, except at shoulders, on inserts because they may cause stress concentration and cracking. Diamond knurling provides the most satisfactory anchorage from the standpoint of torque and tension and minimize the possibility of cracking around the insert. The knurling should be deep enough to permit material flow into the depressions, and the insert should have a smooth surface where it protrudes from the molded part. Grooves can be used in conjunction with the diamond knurl. When using grooves, provide one wide groove in the center of the insert, rather than two grooves, one at each end. The center grooves allows the material to shrink or creep toward the center and consequently results in minimum strain within the piece, thus minimizing the possibility of cracking.

2.5.3.6.5 *Wall Thickness of Inserts.* The minimum wall thickness of metal in the inserts is entirely dependent upon the accuracy desired on the inside dimension of the insert. If too thin a wall of metal is used, the combination of stress caused by shrinkage of the plastic material and by molding pressure may collapse the wall of the insert. As a result the diameter may decrease to a point out of the range of specified tolerances. Table 2–7 shows the minimum recommended diameters of bar stocks for various sizes of inserts.

2.5.3.6.6 *Selection of Metal for Inserts.* It is desirable to choose metal for inserts which have a numerical coefficient of expansion closest to the plastic used for the part, in order to minimize differences caused by shrinkage.

2.5.3.6.7 *Minimum Wall Thickness of Material Around Inserts.* If inserts are required, they should be considered first and then the molded part designed around them. The shape and form of the insert governs the wall thickness of material to a great degree, especially when the shapes are irregular or have sharp corners. Other factors to be considered are material type, shrinkage, coefficient of expansion of material and metal insert, modulus of elasticity, flexibility, loss of flexibility on aging, operating temperature range, and moisture sen-

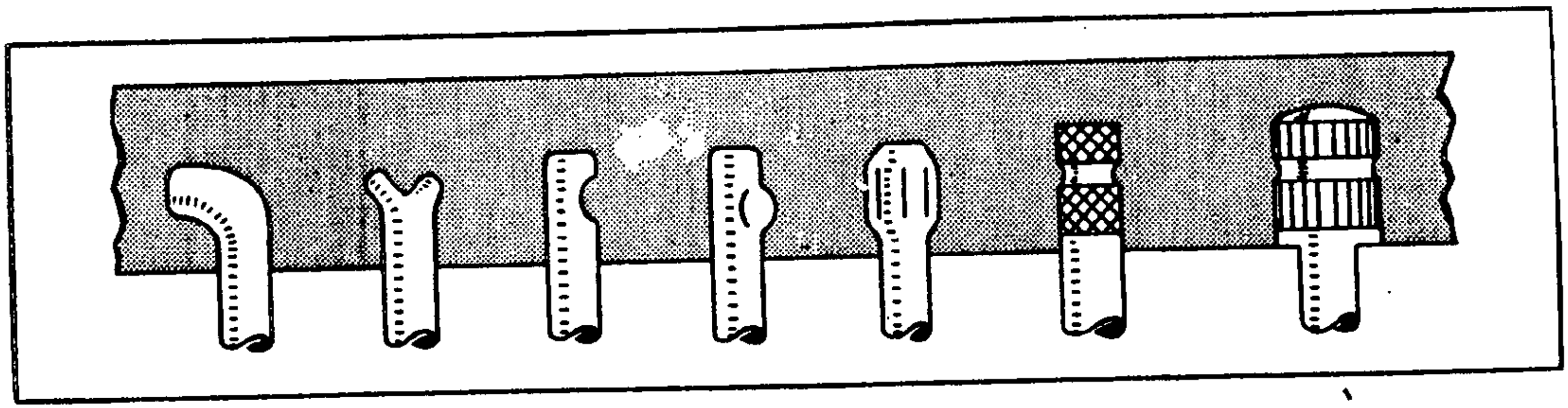


FIGURE 2-14. *Techniques for securing inserts in plastic parts.*

sitivity. Sometimes materials which have a low shrinkage, but are very rigid when cured, will crack. Other materials having higher shrinkage but retaining greater elasticity, will not crack. Each part presents different problems and must be engineered according to design of insert and material used. A simple and safe general rule for gauging the proper thickness of compound around inserts is to use a minimum of one half the diameter of the insert.

2.5.3.6.8 *Insert Design "Tips."*

(a) If possible avoid the use of inserts.

(b) If possible avoid the use of an open-hole insert.

(c) Chamfer corners of inserts wherever possible.

(d) Avoid filling of inserts.

(e) Inserts must be clean and free from an oil or grease film prior to usage.

(f) Avoid too thin a wall or back of insert.

(g) Avoid too thin a wall of plastic around the insert.

(h) Select correct plastic for the application, prior to designing part or insert.

(i) Edges of inserts should not be knurled.

(j) Long inserts must be supported at both ends during molding.

(k) Large inserts should be heated prior to molding in either thermoplastic or thermosetting materials.

(l) Retaining pins must not be too large, nor holes for inserts too tight, otherwise insert will pull out of material.

(m) Standard nuts and screws should not be used.

2.5.3.7 *Undercuts.*

2.5.3.7.1 *General.* The most elementary fact in design for molding is that the piece must be easily removed from the mold after forming. This point is frequently overlooked and many products are designed with undercuts which make it impossible to eject the part directly from the mold cavity.

Parts that require undercuts for functional features, or ease of assembly, require the use of split molds or removable mold sections and lengthen the molding cycle, and thereby increase costs. If possible, avoid the use of undercuts in design.

2.5.3.7.2 *External Undercuts.* External undercuts are located on the outside contours of a piece as illustrated in Figure 2-15. It is obvious that withdrawal of this part from a one-piece mold cavity would be impossible. In the molding of parts with external undercuts, it is possible to design molds around these parts in the following manner:

(a) Cavities are built in two or more loose members which are tightly retained in a "chase" block. After molding, the loose members are removed from the block and the molded piece is easily removed.

(b) Split mold cavities may be built with one-half of the cavity attached to a stationary head and the other half to a horizontal ram which moves in to form the cavity. Then a vertical ram actuates the force plug downward tc provide the molding pressure. Withdrawal of both rams releases the molded piece.

2.5.3.7.3 *Internal Undercuts.* Interal undercuts are those located on the side contours of the molded piece. Such pieces may be removed from the mold but not from the force plug. With the exception of a few special cases, the molding of pieces with internal undercuts is impractical and must, therefore, be avoided.

Such an exception may be found in the design of cases for pressure gauges and other instruments, in which an annular groove or bezel ring is provided to hold the glass in place. The internal undercut is produced by constructing on the force plug of the mold a corresponding raised section of such dimensions and contours that the molded piece, while still hot and flexible, may be stripped off the force plug after being removed from the mold cavity.

The design of pieces requiring a stripped internal undercut should be thoroughly discussed with the molder who is expected to be responsible for the molding. In general, for economic reasons, internal undercuts should be avoided whenever possible.

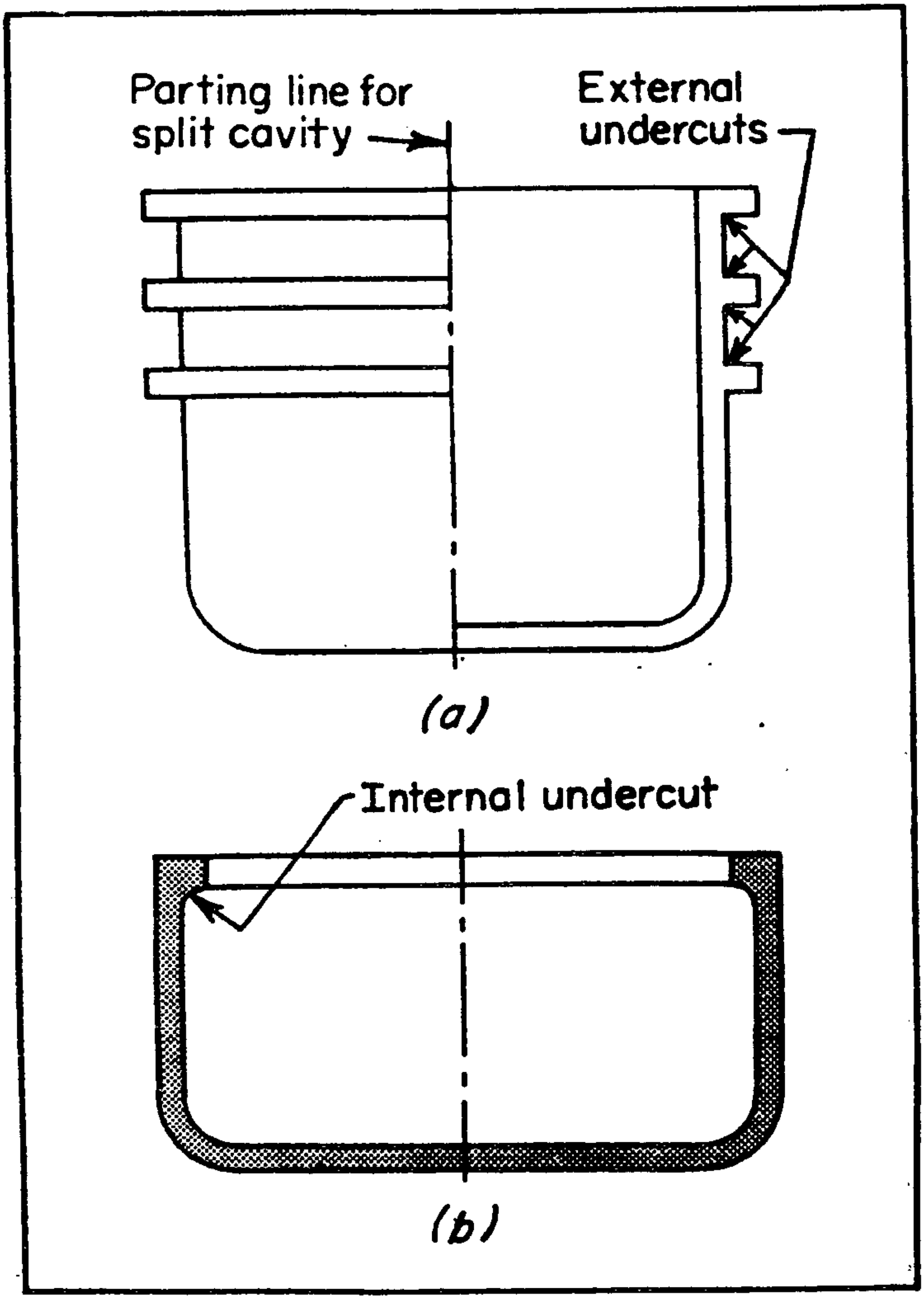


FIGURE 2-15. *Simple moldings with external undercuts, a, and internal undercut, b.*

2.5.3.8 *Tolerances.* The three classifications of molding tolerances are:

(a) Fine Tolerance.
The narrowest possible limit obtained with close supervision and controlled production.

(b) Standard Tolerance.
The usual commercial tolerance that can be held under average conditions.

(c) Coarse Tolerance.
Broad variations where dimensions are not considered an important factor.

In achieving economies, many cost factors depend on liberal dimensional tolerances. Mold costs, labor rates, inspection charges, material costs all go up and production rates go down when extremely close tolerances are required. Regardless of the economics, it is unreasonable to specify close production tolerances on a part that is designed to operate through a wide range of environmental conditions. Dimensional changes due to temperature variations alone can be three to four times greater than the specified tolerances. Also, in many applications, close tolerances with plastics are not as critical as with metals because of the resiliency of plastics.

The following is a general guide for specifying tolerances:

(a) Specifications for plastic parts should indicate the conditions under which the dimensions shown must be held.

(b) Specify over-all tolerances for parts in inch per inch, not in fixed values.

(c) Tight tolerances required only for specific dimensions should be labeled as such. Less important dimensions can be controlled by over-all tolerances.

(d) Generous molding tolerances should be allowed for areas that will be machined after molding.

Production variables such as the number and size of cavities in a mold, also affect tolerances. Use of a multi-cavity mold is usually an economical production method. But as the number of cavities per mold increase, so must the tolerances on critical dimensions. An increase of 1 to 5 percent per cavity is about average. For example, dimensions of a part produced in a single cavity mold may be held to ± 0.002 inch per inch. When the number of cavities is increased to 20, the closest tolerance obtainable may be ± 0.004 inch per inch.

Table 2–8 of dimensional tolerances, called "Standard Molding Tolerances" may be met easily in general commercial practice.

TABLE 2–8
STANDARD MOLDING TOLERANCES

Nominal dimension (in inches)	Tolerances above and below nominal dimensions	
	Hot-molded	Cold-molded
1/4	0.003	0.009
1/2	0.005	0.011
1	0.008	0.014
2	0.010	0.016
3	0.012	0.018
4	0.015	0.020
5	0.015	0.023
6	0.015	0.028
7	0.020	0.032
8	0.020	0.036
9	0.020	0.040
10	0.025	0.048

The above listed tolerances apply only to those dimensions unaffected by opening of the mold or loose wedges. The parting line and loose wedges introduce other variables (Table 2-9) which must be added to the dimensions given in Table 2-8. The cloth-filled materials show greater variation in this respect when compression molded.

TABLE 2-9

STANDARD MOLDING TOLERANCES ON DIMENSIONS AFFECTED BY LOOSE WEDGE AND PARTING LINE VARIABLES

Compression molded	Transfer and injection molded	Cold molded
+0.015"	+0.005"	+0.015"
−0.000"	−0.000"	−0.015"

By using special care and selecting proper material, it is posible, at additional cost, to produce parts which can be held to closer than standard dimensions. These close tolerances are held by the use of shrink fixtures, special care in molding, carefully controlled materials and the development of final mold dimension by trial. Table 2-10 list special tolerances which can be produced when absolutely necessary.

TABLE 2-10

SPECIAL MOLDING TOLERANCES

Nominal dimensions (in inches)	Tolerances above and below nominal dimension
0.500 or less	±0.002
0.500 to 2.000	0.005
2.000 or over	0.0025 per inch

The designer must remember that it is easy to remove metal from the mold, but difficult to add it. For this reason, extra metal should be left on all critical dimensions to be cut away after sampling has indicated the correct mold dimensions.

2.5.3.9 *Knockout Pins.* Most molds use knockout pins or ejector pins to push the part out of the cavity or off the mold force. Use of these pins affords high volume, low cost production. The mold cavity number and molder's identification mark are often placed on knockout pins. When production drawings are made, pins should be located on a hidden surface of the part and can be in the mold force or cavity. If pins are located on exterior surface, make sure that function or appearance of the part is not impared. Concentric ring design can conceal pin marks. In any case, pin marks are always apparent since they are seldom flush with the molding. Knockout pins should not press against thin areas. It is desirable to have these pins push against ribs when possible, especially for thermoplastics, which are easily distorted while warm and soft at ejection time. Large area knockout pins are required for thin sections and soft materials.

2.5.3.10 *Pickups.* Shallow undercuts are often used to make the molded product hold to the mold force or remain in the mold cavity. These undercuts are usually from 0.005 to 0.010 inches high, and the length varies with the amount needed to make the piece hold to the proper mold section. Before adding such pickups, the designer must make certain that these marks will not affect the performance or assembly of the product.

2.5.3.11 *Warpage.* Large flat areas should be avoided since they cannot be held flat and therefore will present a warped appearance. Large surface areas should be "crowned" or slightly convexed a minimum of 0.003 inch per inch, as the warpage variable with the best of materials runs as much as plus or minus 0.0025 inch per inch. When possible, reinforce the edges of large flat areas. Ribs located on the underside are helpful in the reduction of warpage. When an area of substantial size is to be mounted on a flat surface, a depressed center section should be used to avoid all-over flatness. When necessary, the projecting edges around the depressed center section can be ground flat on a sanding belt thereby reducing warpage effects and insuring a good fit. The use of a depressed center section with a "bead" around the perimeter allows for sanding the "bead" flat rather than the entire surface. Overall sanding increases tendency of piece to warp.

2.5.3.12 *Lettering of Molded Products.* When used, lettering must be applied perpendicular to the parting line or placed on side walls which provided sufficient draft for the withdrawal of the lettering from the mold. Lettering may be raised, depressed or face up from depressed paneling.

Raised letters are usually obtained at lowest cost. However, many designers call for depressed letters when paint is to be applied for better visibility.

Small raised letters are generally 0.008 to 0.015 inches in height. Large letters may be 0.016 to 0.031 in height. Considerable draft should be provided on letter sides in addition to generous fillets where letters join the molded piece, otherwise, fragile letters which are liable to breakage in the mold will result. Wide depressed letters should be avoided, as paint will wipe out when excess paint is removed from the surface.

Sometimes highly polished or dull background are used to make mold letters stand out clearly without painting. Clear thermoplastics may be cut in on the underside and contrasting colors for background and lettering will produce an attractive third dimensional effect. Metal inlays, rubber stamps, special inking, decals, etc., are other means of lettering a molded product. It would be well considered for the designer to consult the molder to acquaint himself with the most economical attractive way of lettering a molded product.

2.5.3.13 *Surface Finishes.* It is possible to provide an almost unlimited variety of finishes to molded items. The finishes range from dull to full gloss, untextured to textured, and no decorations to complete geometric pattern decoration. In addition, supplemental finishing such as painting, plating, vacuum metallizing, and hot leaf stamping may be subsequently provided.

2.5.3.14 *Machining Molded Plastics.* Machining of plastics is usually a planned operation to reduce mold or molding costs. With the exception of polystyrene, all thermoplastic may be machined easily by conventional methods. Polystyrene, in some forms, tends to craze when machined. Few cold molded plastics may be machined easily.

Most of the thermosetting materials are machinable. However, it is desirable to subject these parts to an after baking operation of eight to twenty-four hours at 210° to 250° F. to stabilize the properties of the material and to minimize shrinkage after machining.

The thermosetting materials may be punched but it requires considerable experience and know-how, however it is difficult to do a satisfactory reaming job on them. Products using thermosetting materials should not be designed for reaming after molding. If extremely close concentricity or hole diameter is required it must be produced by boring. Reaming cannot be considered for holes having any depth. It is possible to solder to inserts molded in thermosetting materials, but if high-temperature solders must be used, it may be necessary to preheat the parts to 250° F. to minimize cracking.

2.6 Molding Processes.

2.6.1 *General.* A variety of techniques have been developed for molding plastics. In this section we will consider the molding processes which shape an article from a plastic by the application of pressure (and, usually, heat) in a closed chamber. In each molding technique, the fundamental variables that must be considered are always, temperature, pressure, and time. These in turn are governed mainly by the consistency and behavior (flow and reaction to heat, pressure and time) of the molding compound ("mix"), especially the binder.

The materials of the molding compound consist of a resin (binder and compounding ingredients which by their nature and proportions impart a wide range of processability and properties to thousands of finished products.

2.6.2 *Compression Molding.*

2.6.2.1 *Hot Compression Molding.*

2.6.2.1.1 *Process Description.* Hot compression molding is a process which comprises forming an article of desired shape by application of heat and pressure in a suitable mold and then hardening it under pressure and heat in the mold. Figure 2-16 is a schematic cross section of a compression molding press. Generally, the charge or molding mix, in loose or performed tablet shape is placed in a heated mold. The mold is then closed, under a continuously increasing pressure. High pressure is applied to the mold just before it is completely closed to insure that the softened plastic material completely fills the mold cavity. The pressure is maintained until the molded article is cured (thermosetting materials) or cooled (thermoplastic materials), after which the mold is opened and the part removed. Sometimes a mold may be momentarily opened prior to final closing. This action permits gases such as air, ammonia and moisture to escape prior to final molding.

2.6.2.1.2 *Types of Hot Compression Molding Materials.* This process is particularly suitable for the molding of all thermosetting types of material. Occasionally TFE fluorocarbons and vinyls are hot compression molded. However, hot compression molding of thermoplastics is in very limited usage mainly because most such resins can be molded at far higher rates by injection (see later discussion). The major use of compression molding thermoplastics is the preparation of laboratory test specimens.

2.6.2.1.3 *Mold Charge Preforms and Preheating.* Mold charges may be used as supplied (loose granules, beads, chips, scraps of resin impregnated material), or it may be tableted or preformed. Preforming involves the cold molding of accurately weighed compounded resin into simple shapes called "pills." The mold charge "pill" can now be easily preheated and loaded into the mold cavity.

Preheating of the mold charge can be accomplished by steam, hot air or electronic high frequency heating. Dry-air preheating is useful when electrical properties of the product are particularly important because it dries the charge more effectively than all other methods.

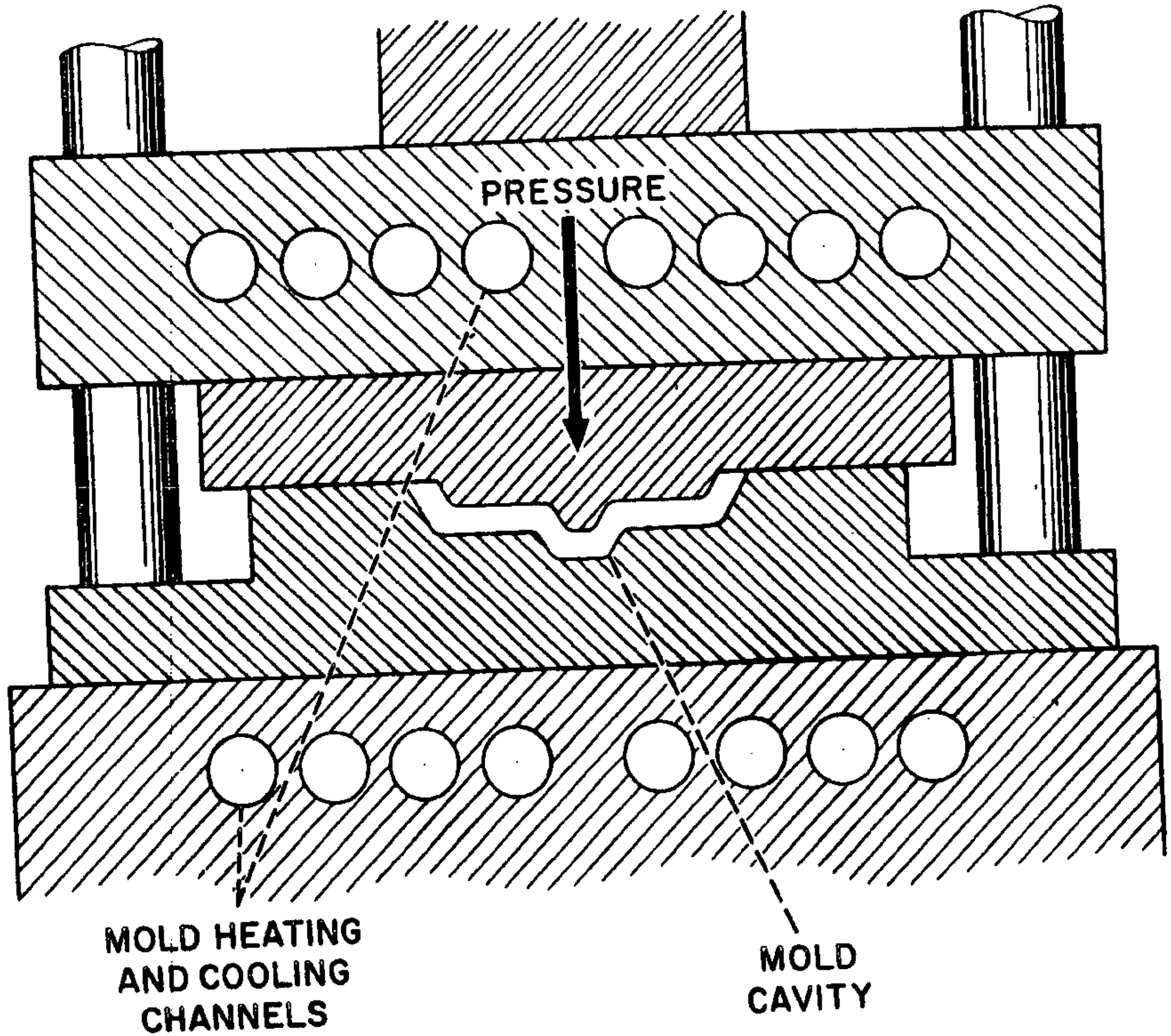


FIGURE 2-16. *Schematic cross section of a compression molding press.*

2.6.2.1.4 *Molding Equipment.* Molding may be performed in hand operated, semi or fully automatic presses, depending upon the rate of production desired and the nature and number of articles to be made. Hand molds are used only for intricate pieces and for very short runs. In semi-automatic molding, the mold is permanently mounted in the press and the molded pieces are ejected automatically. This type of molding is particularly useful for large pieces. In fully automatic molding, the operator supplies material, molding and ejection are automatic and the operator periodically removes finished pieces.

2.6.2.1.5 *Variables of Temperature, Pressure, and Time.* Molding is performed under varying conditions of temperature, pressure and time, depending upon the softening point, fluidity and cure or freeze rate of the material. Preheating of mold charges up to 150° C serve to shorten cycle time, cure thick sections more uniformly, cause earlier flow and uniformity and reduce shear forces set up during molding (hence less trouble with inserts). In addition, preheating removes moisture, thus giving finished part better electrical properties and reduces porosity, blistering, flow marks and internal stress. Overheating of charge is dangerous in that the cure rate may become too fast for handling. Mold temperatures are controlled at a somewhat higher temperature than preheating temperatures and usually varies between 160 to 200° C., except for fluorinated plastics which may require a molding temperature as high as 380° C.

Proper control of mold temperature assists in reducing pressure requirements for mold closing and promotes readier flow and thereby less mold abrasion.

The control of pressure is as important as the control of temperature. The pressure exerted during molding is based upon a knowledge of the cross-section area of the molded pieces and, in molds where "flash" occurs, from the total area of molding material upon which the pressure is exerted. Usually a pressure of 300–500 psi is required for mold closing and a pressure of 1,500–1,800 psi is needed during molding. These pressures are adequate for most materials and, at the same time, prevent fatigue of the steel members of the mold. Higher pressures may cause break down of case-hardened mold metal and cause dimensional inaccuracies in the molded product.

Molding cycle time depends upon the shape and thickness of the molded article and the technique used. Cycle times vary from a few seconds to several minutes.

2.6.2.1.6 *Types of Compression Molds.* Compression molds are of generally four different types of design as illustrated in Figure 2–17.

The *fully positive* mold has a cavity machined to the shape of the molded part with a loading area above, machined to the same shape to accomodate the material required. The plunger is made to the same shape, telescoping into the cavity permitting a vertical flash. This design requires accurate weighing of the loose powder or preform, since the amount determines the thickness of the piece. This type of mold is used when maximum density in a product, such as high impact plastics, is desired, since the total molding pressure is applied only to the projected area of the molded piece. This type of mold is rarely used with thermoplastic materials. It is also not used for multiple-cavity moldings because the dimensions of molded articles will vary with charge weight.

A *Flash-type* mold is one in which confinement of material takes place at the instant of final mold closing. The cavity is constructed to the overall thickness of the part and is used on relatively simple designs with shallow overall thicknesses, with a horizontal flash line. Cutoffs (reliefs) are provided around the cavity on either lower or upper parts of the mold or sometimes both and are in contact when the mold is completely closed. The cutoff prevents the exertion of positive pressure on the contents and therefore maximum density cannot be attained. This type of mold is comparitively inexpensive and pieces formed will be of uniform density.

A *semi-positive* mold is a combination of the positive and flash-type molds and is the type most commonly used. As with the fully positive, the upper and lower parts telescope; like the flash-type however, the material is only partially confined and has some provision for overflow of the slight excess of charge. The mold produces a piece of maximum density, inasmuch as a positive pressure is exerted during the last portion of mold travel, and just before the mold has seated on the cutoff edge. The positive pressure is maintained without the necessity for such accurate weighing as is necessary in the positive type of mold.

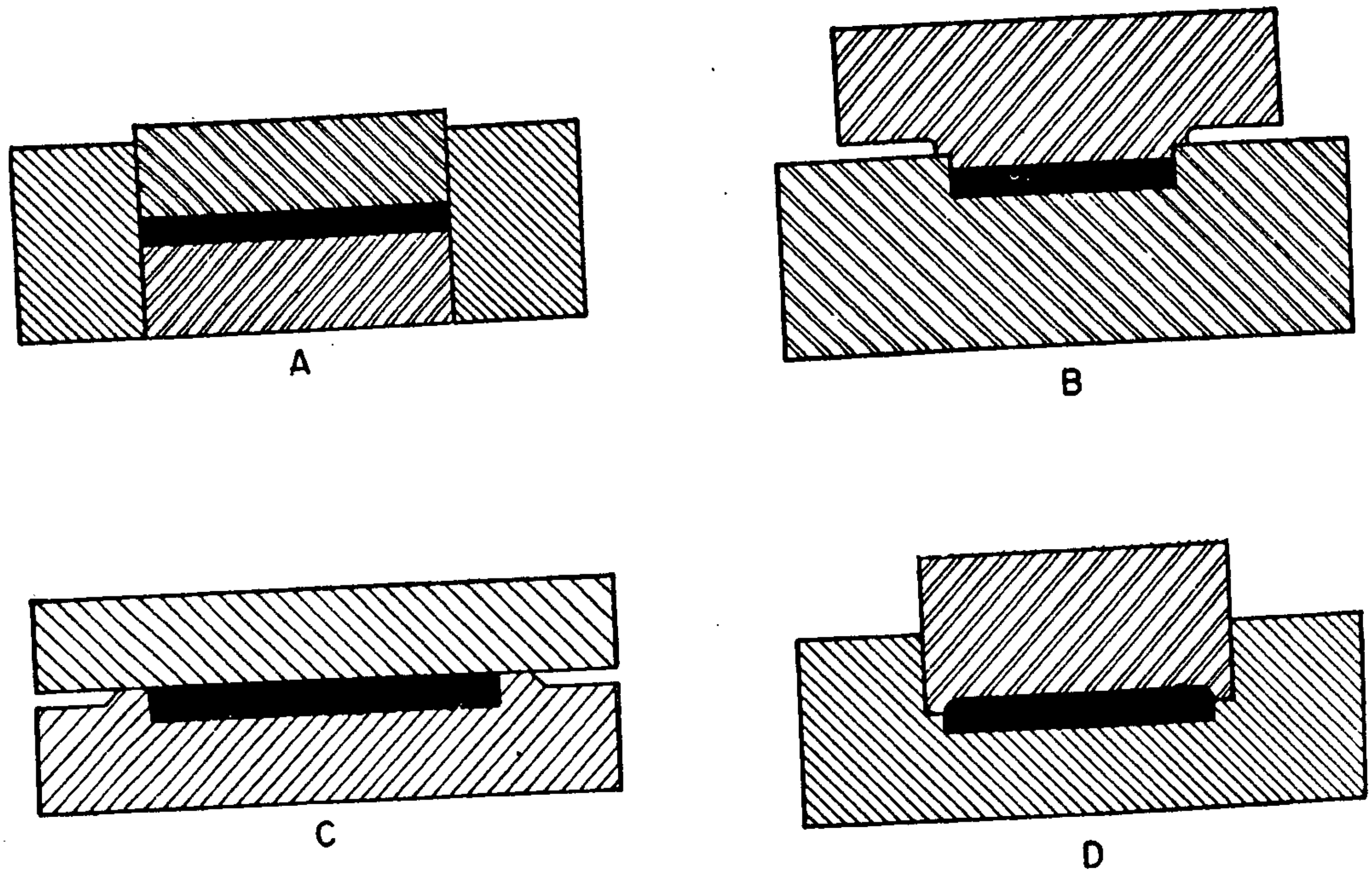


FIGURE 2-17. *Types of compression molds: (a) fully-positive; (b) semi-positive; (c) flash; (d) landed-positive.*

A *landed-positive* mold, which may be either internally or externally landed, is generally used where it is necessary to form a radius, bevel, bead, or some other projection. This type of mold like the semipositive is a combination of the fully positive and flash types, and differs from the semi-positive in that only a small horizontal flash is obtained, full pressure being maintained on this flash and the charge. As with other types of positive molds, there is some telescoping which provides better transmission of pressure to the material than in the flash type. A variation of the landed mold is the *sub-cavity mold,* which is one having more than one subcavity within the main cavity but having only one force.

2.6.2.1.7 *Process Advantages.*

(a) Can be fully automated.

(b) Very little material waste.

(c) High production rate obtainable with multicavity mold.

(d) Finishing costs are low.

(e) Although uneconomical for small thermoplastics parts, it is usually very economical for both thermoplastic and thermosets when articles are too large, in either weight or projected area to be produced on available injection molding machines. Parts can be made which are practically strain free.

2.6.2.1.8 *Process Limitations.*

(a) Not practical for intricate designs (undercuts, side draws, small holes and delicate inserts).

(b) Limited only by the tonnage and size of available press equipment.

(c) Close tolerances (± 0.005 in. or less) are difficult to achieve.

2.6.2.1.9 *Typical Applications.*

(a) Parts of large area and deep draws, such as furniture drawers, radio and television cabinets.

(b) Small parts, such as closure, tube bases, buttons, wiring devices, dials knobs and handles.

2.6.2.2 *Cold Compression Molding.*

2.6.2.2.1 *Process Description.* Cold compression molding is a technique for forming an article of desired shape by the application of 2,000 to 30,000 psi pressure to a molding compound in a suitable mold after which the article is transferred to an oven and is cured at a temperature of 80 to 260° C. depending upon the binder used.

2.6.2.2.2 *Types of Cold Molding Compounds.* There are two types of cold molding compounds which are broadly classified in Table 2-11 below:

TABLE 2-11

Classes	Types	
	Organic non-refractory	Inorganic refractory
1	BITUMINOUS Gilsonite Asphalt Pitches (Blended with Drying oils)	PORTLAND CEMENT
2	RESINOUS Phenolic Epoxies Polyesters	CLAY, LIME, AND SILICA

Most of these materials are usually filled with asbestos fibers, glass fibers, silica and magnesia and must be made at the molding site.

2.6.2.2.3 *Process Advantages.*

(a) Since there is no heating or cooling cycle, the process is very rapid.

(b) Molding materials are comparatively inexpensive.

(c) Since there is no flow or flash, after finishing costs are reduced.

(d) High production rate eliminates the need for expensive cavity molds.

2.6.2.2.4 *Process Limitations.*

(a) Cold molded parts lack surface smoothness and gloss.

(b) Fine mold designs are not reproduced faithfully.

(c) Low mechanical strength.

(d) Cold molding compounds are not available unless mixed on the spot and used almost as soon as they are made.

(e) Excessive mold wear due to high pressures required for molding.

(f) Evaporation of solvents from resinous binders during baking and curing causes shrinkages anywhere from 0.002 to 0.020 inch per inch.

2.6.2.2.5 *Typical Cold Molded Products.*

(a) Connector plugs.

(b) Switch bases.

(c) Outlet covers.

(d) Attachment plugs and caps.

(e) Sockets.

(f) Buttons.

(g) Battery cases.

(h) Checkers.

2.6.3 *Injection Molding.*

2.6.3.1 *Process Description.* When compression molding was used, it was indicated that thermoplastic materials require longer cycle times than the thermosets. Since a longer cycle increases production costs, injection molding was developed to enable the thermoplastic material to compete successfully against the thermosets.

In injection molding, the thermoplastic resin is first heated, melted, mixed and plasticized to a viscous liquid, and then forced into a relatively cool mold whose cavity is shaped like the desired item, where it cools and solidifies. The molded item is then ejected by ejector, or knockout pins, or by air comb plate or other removing devices. Injection molded parts may range in weight from a few ounces to several pounds.

There are two types of injection molding equipment, plunger—(also called ram—or piston—) type and screw-type machines. Much injection molding is still being accomplished on the older, simpler and less expensive plunger machines. However, due to numerous advantages, the screw machine is gaining ground fast.

Injection molding is a cyclical process. The period between forward movement of the plunger or screw and the beginning of the mold opening is known as the clamp time, because during this time the mold segments remain closed and are tightly clamped. This time plus the time period for the mold to open, eject the part, and reclose the mold is called the injection cycle time.

2.6.3.2 *Molding Equipment.*

2.6.3.2.1 *Plunger Injection Molding Machine.* Figure 2–18 shows schematically a lengthwise cross-section of a typical plunger injection molding machine. The resin granules are conveyed into the hopper from which they are gravimetrically or volumetrically dropped into the heating cylinder, while the ram is being retracted. The cycle begins with a rapid forward motion of the plunger which pushes the resin into the cylinder forcing it to compact tightly around the spreader or plasticizing torpedo. The torpedo is centered by fins which also serve to transfer heat from the electric resistance band heated cylinder. Sometimes the spreader has its own self contained heating unit, and is made to rotate to improve plasticization. Heat and pressure join in plasticizing the resin.

As the melt moves forward, temperature equilibrium with the cylinder walls is attained. Mixing occurs around the torpedo and the melt reaches the required fluidity and temperature at the time it reaches the injection nozzle. Then, in one rapid forward motion, the plunger pushes the melt into the mold.

While the resin granules are melted in the hot cylinder, the ram pressure also squeezes the air out of the softened mass, allowing the air to flow back along the clearance between the ram and the barrel and out through the hopper.

2.6.3.2.2 *Screw Injection Molding Machine.* In this type of machine, a rotating screw replaces the plunger. It acts as a plunger, mixer and plasticizer.

Usually, in such machines the rotating screw first moves the melting resin forward and then is itself forced backward by the accumulating melt until the volume of the melt required for an injection shot has accumulated in front of the tip of the screw. Then the screw stops turning, rapidly moves forward, and ram-like, pushes the melt through the nozzle into the mold. Figure 2–19 shows such a reciprocating-screw machine schematically, with the screw in the retracted (A) and the forward (B) position.

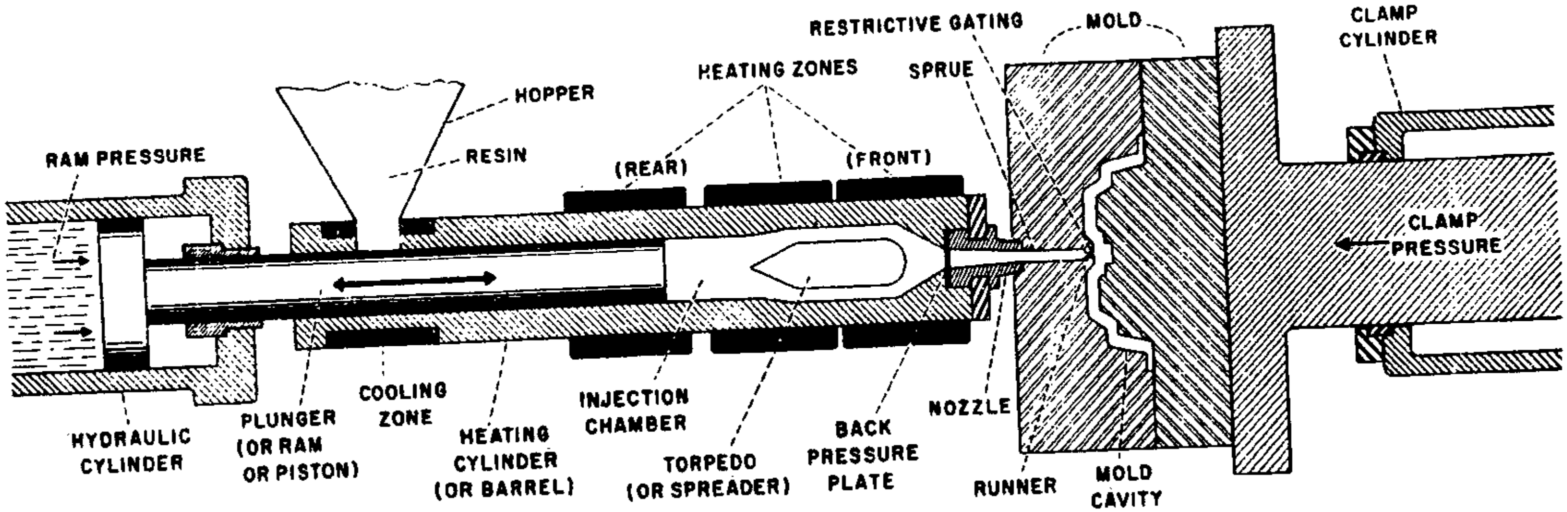


FIGURE 2–18. *Schematic cross section of a typical plunger (or ram or piston) injection molding machine.*

In reciprocating screw machines, the back pressure inside the heating cylinder is adjustable and therewith, the amount of internal heat transmitted to the melt by the shearing action of the revolving screw. An increase in back pressure raises the melt temperature without necessitating external electrical heating of the cylinder. Increased back pressure also improves mixing and plasticizing which are controlled by both melt temperature and pressure.

For efficiency, screw speed should be as high as possible and the cylinder temperature as low as possible. Specific operating conditions are largely dependent on the resin used. However, the screw should be the main contributor of heat, while the cylinder heating bands are required primarily for start-ups and to compensate for heat losses to the outside.

Besides the reciprocating-screw type of injection molding machine, there are other types of screw machines. One has a reciprocating ram moving outside a hollow, stationary screw. Such an arrangement offers advantages because the reciprocating motion of the screw requires complex machinery, the screw rotation has to be stopped before the screw begins to plunge forward, and the screw does not always do as good a plunging job as the much sturdier, plain-shaped ram unit.

2.6.3.2.3 *Preplasticizer-Type Molding Machine.* The molding cycle may be shortened, production facilitated, and shot-to-shot uniformity increased in machines where the resin is first heated in an auxiliary heating cylinder, the preplasticizer, and the melt transferred to the regular injection or "shooting" cylinder from which it is injected into the mold. The injection chamber in the "shooting" cylinder (Fig. 2–21) serves as an accumulator.

Preplasticizers, just like the injection cylinders, may be of either the plunger or the screw type. Two in series combinations of the two cylinders are common in preplasticizer-equipped injection molding machines. Figure 2–20 shows these two combinations schematically.

The ram in the shooting cylinder pushes the melt fast and under high pressure into the mold. In all such possible 2-stage arrangements, both the preplasticizer and the injection ("shooting") cylinder are heated. The resin is fed through the hopper, as shown in Figure 2–20.

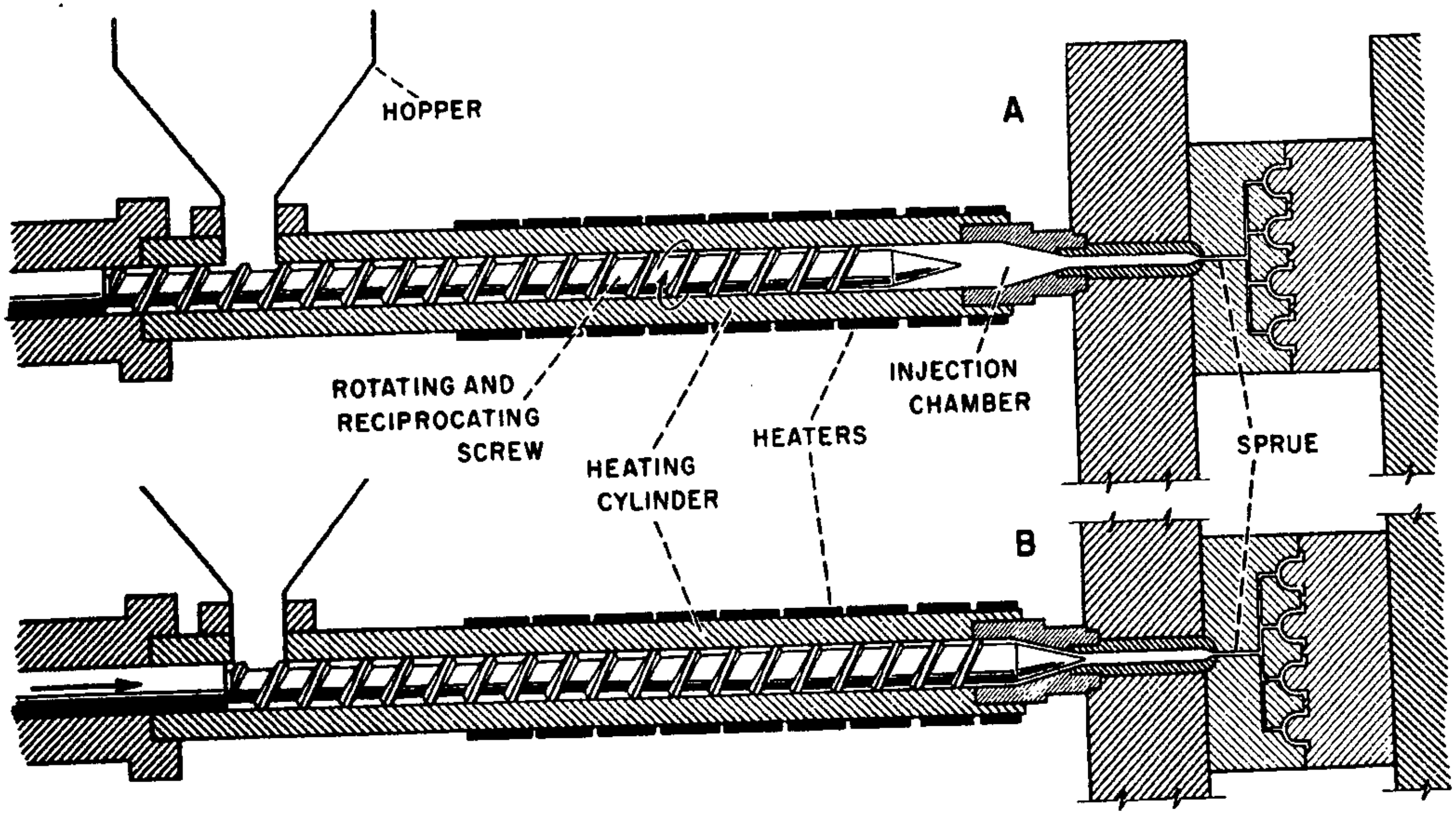


FIGURE 2-19. *Schematic cross section of a typical screw injection molding machine, showing the screw in the retracted (A) and forward (B) positions.*

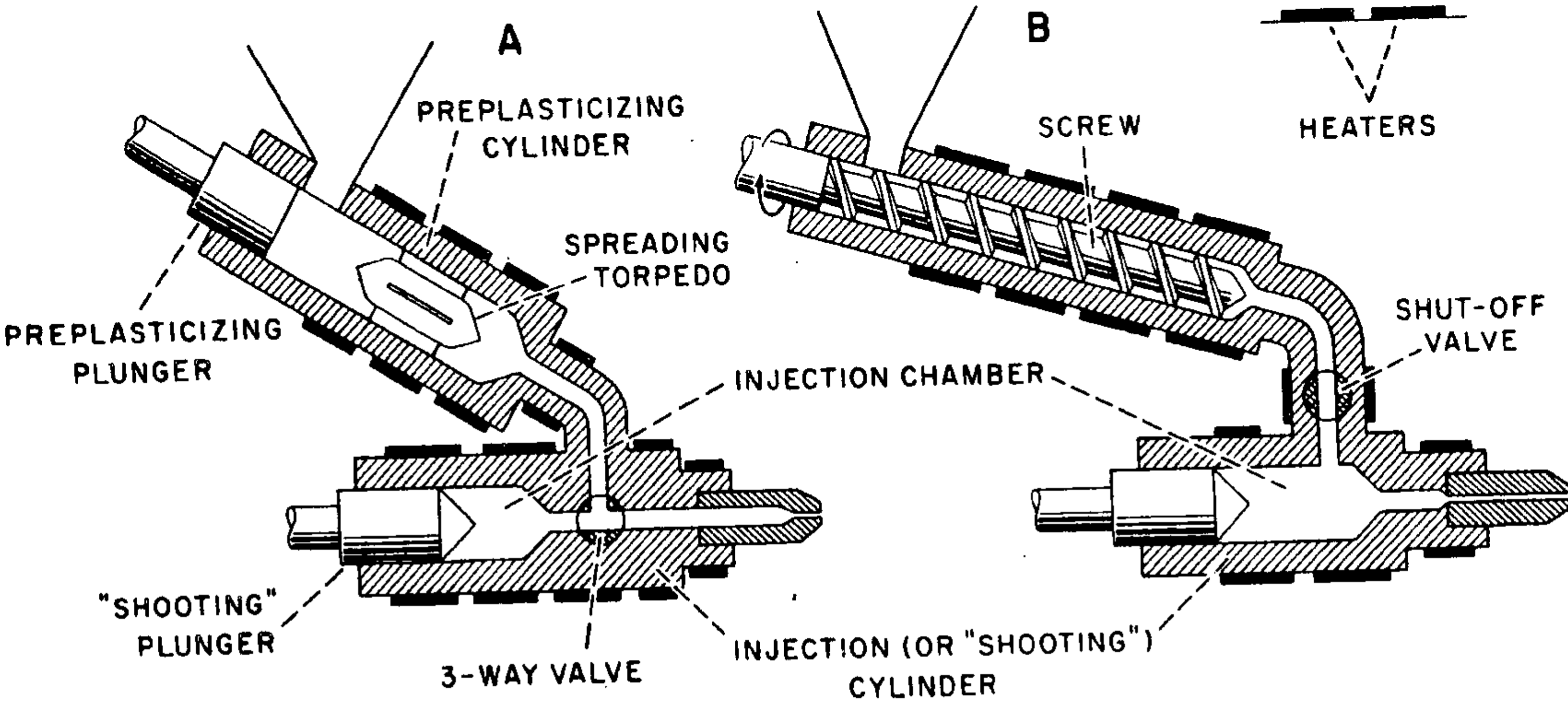


FIGURE 2–20. *Schematic drawings of a plunger-type (A) and a screw type (B) preplasticizer atop plunger-type injection molding machines.*

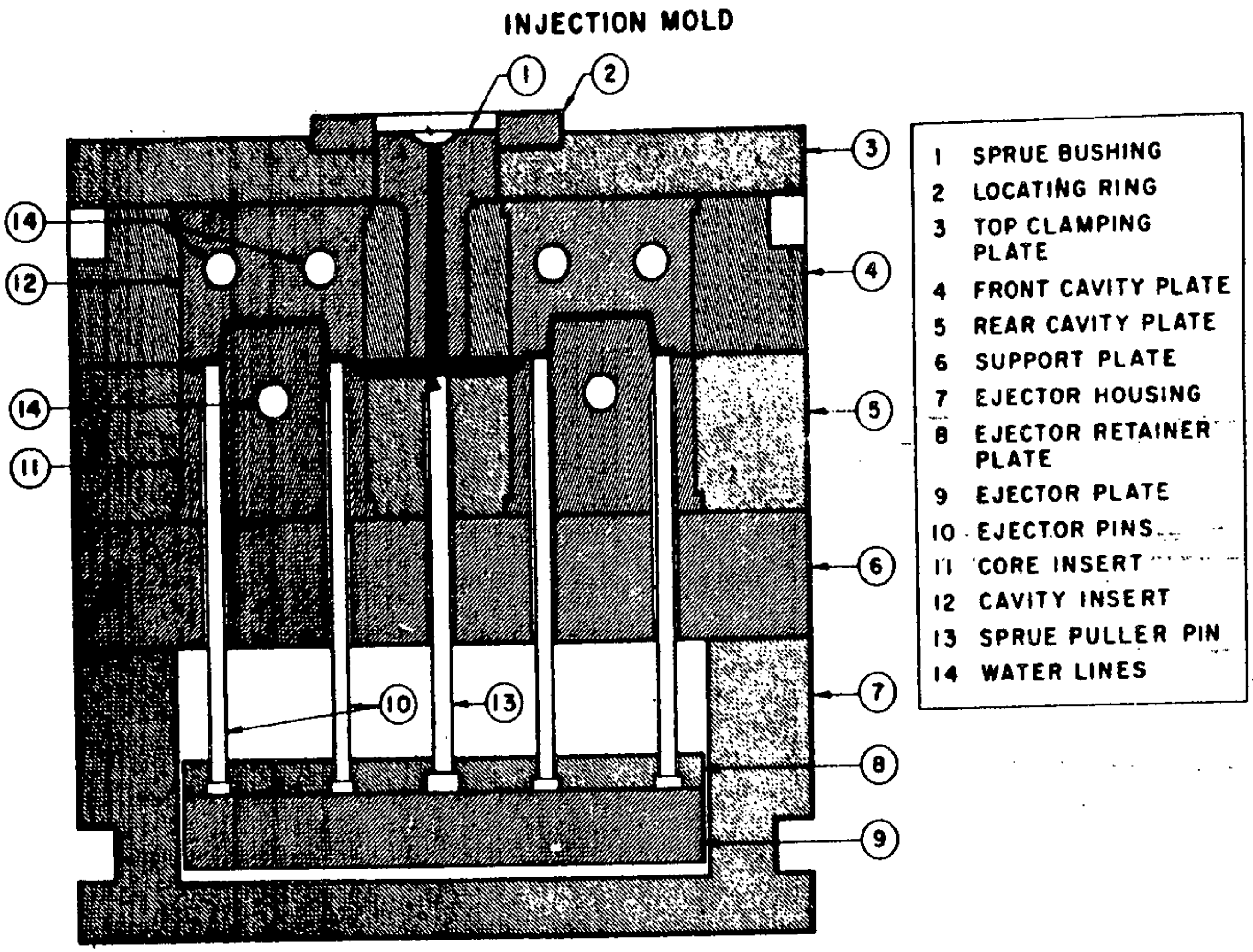


FIGURE 2–21. *Illustrates the various components of an average two-plate injection mold.*

The drawings show the preplasticizing cylinders sitting piggyback, in an inclined position on the "shooting" cylinders. A variety of other arrangements are known. In some 2-stage machines, the screw-type preplasticizer is atop and parallel to the horizontal plunger injection cylinder. In others, a vertical plunger injection cylinder sits on the head (perpendicular) of the horizontal preplasticizing cylinder.

2.6.3.3 *Molding Design and Construction.* There are many types of injection molds. All of them are highly complex structures regarding both design and the metals and alloys used to make their many parts. Each part must be machined and finished to exact dimensions. Its surface hardness must be high to be able to take, without distortions, the tremendous pressures required in injection molding. For these reasons, injection molds are the most expensive molds known in the plastics industry. Therefore, it only pays to injection mold when many thousands of an item are to be produced or if the properties or shape of the piece cannot be obtained by another processing method.

Injection mold designs differ depending on the type of material being molded, necessitating various gating and ejection principles to meet the application with maximum of economy. Production requirements, product life, and allowable product cost factors will dictate the size of the mold, amount of mechanization, and the efficiency that will be required in cycling.

The basic injection mold design from which all others have been developed is the *Two-Plate* design illustrated in Figure 2–21. Here, mold cavities are assembled to one plate and forces to the other plate, with the central sprue bushing assembled into the stationary half of the mold, permitting a direct runner system to multiple-cavity molds or direct center gating to individual cavity molds. The moving half of the mold normally contains the forces and the ejector mechanism, and in most designs, the runner system.

The question of the best mold design should be left to the experts in order to achieve maximum economy and quality.

2.6.3.4 *Variables of Pressure and Temperature.* The injection molder has two basic machine variables which can be adjusted and controlled to obtain mold fill, temperature and pressure. If a particular job is giving incomplete fill ("short shots") of the mold, either an increase of temperature to obtain higher fluidity of the resin or an increase in pressure will correct the situation.

To obtain the best possible molded item in the shortest time and at lowest cost, temperature and pressure within the injection cylinder should be in balance. Figure 2–22 illustrates the relationship of relative pressure (screw or ram vs. injection temperature for four different flow grades of polyethylene to fill a specific mold). Figure 2–22 shows something else: For a specific resin, e.g., Curve 2, a good medium-to-high flow injection molding polyethylene resin, a pressure indicated by point A may be required to fill the mold at an injection temperature of about 450° F. (230° C). If the temperature were dropped to say, 380° F. (190° C), the higher viscosity of the melt at the lower temperature would make it necessary to use a higher pressure such as indicated by point B, to obtain the same fill with the same resin.

Figure 2–22 covers the whole range of injection molding temperatures for low and medium density polyethylene resins (300–700° F.). However, the "normal" molding range as indicated runs from 360–550° F. Temperatures above this range may result in degradation of the resin or in excessively long cycle times or in "flashing" of the mold. Temperatures below this range may reduce gloss and allow unmelted particles to get into the mold. They may also cause underfilling ("short shots") of the mold.

Molding pressures vary considerably and are highly dependent upon machine design and mold design and construction. Commercial machines are available with maximum injection pressures ranging from 8,000 to 40,000 psi. In injection molding, as a rule, the best end products are obtained when the pressure initially is high enough to fill the mold as fast as possible without "flashing."

The curved bands in Figure 2-22 also show how a molder can do the same job with the same pressure at a lower temperature by switching to a higher flow resin. The horizontal line from point A (curve 2) to point C (curve 1) shows that if a job can be done with one grade of polyethylene resin at 450° F. the higher flow grade of polyethylene resin could do the same job at 380° F. at the same pressure provided that the other properties of the higher flow grade do not adversely affect the particular job.

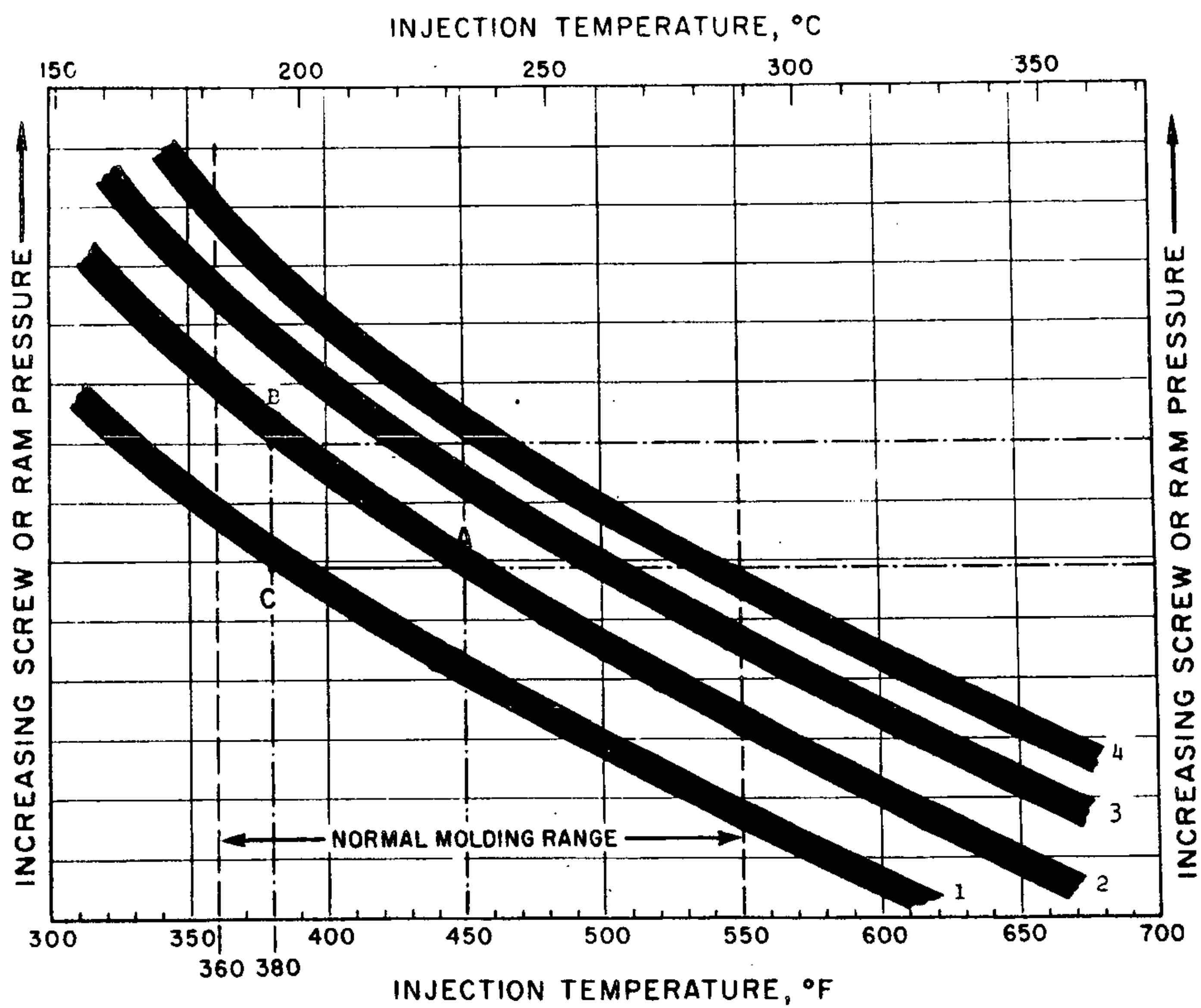


FIGURE 2–22. *Temperature-pressure relationships for Polyethylene resins of several melt indexes.*

As a rule, a reduction in pressure without switching to a higher flow grade of resin must be accompanied by an increase in cylinder temperature to obtain mold fill. Conversely, an increase in pressure without a change in resin must be accompanied by a reduction in temperature to prevent "flashing" of the mold. Pressure and temperature are the two main variables which are juggled by the injection molded to obtain certain desired properties of the molded item.

2.6.3.5 *Process Advantages.*

(a) Rapid production rate with resultant low cost per part.

(b) Intricate configurations are possible.

(c) Metallic inserts can be molded in at slight additional cost.

(d) Rejects, sprues, runners and gates may be reground and reused in the process.

(e) Surface finish can be controlled to produce patterns of a high luster.

(f) Little finishing required.

(g) Good dimensional accuracy is obtainable.

2.6.3.6 *Process Limitations.*

(a) Not practical for short runs because of high tool and die costs and time delays necessitated by their manufacture.

(b) Part size limited by machinery dimensions, strength of mold clamps and plasticizing capacity of cylinder. A ten-ton machine is required to make a molded article weighing a pound and a half.

(c) Plastic chills too fast when filling thin sections, causing incomplete parts. In addition, the rapid chilling causes "locked in" internal stresses in the part which may give rise to stress cracking.

(d) Limitations on design (difficulty with undercuts and some types of holes) imposed by need to open mold to remove part.

2.5.3.7 *Typical Applications.*

(a) Housings, casings for appliances, landmines.

(b) Handles, knobs, gears, impellers, light covers, and medallions.

(c) Ammunition containers, fittings, fan blades, grills.

(d) Steering wheels, bearings, valve and pump parts, coils and fasteners.

2.6.4 *Transfer Molding.*

2.6.4.1 *Process Description.* In hot compression molding, it was noted that solid molding powder is fed into the mold and passed through successive stages of fusion, flow and cure. During the initial stages of flow, when material plasticity was low, tremendous shearing forces were set up which tended to distort or displace inserts and even snap off locating pins. Thick sections had a tendency to remain uncured in the interior and eventually led to distortion and shrinkage of the piece after removal from the mold. Transfer molding was developed to overcome these difficulties and is in a sense an injection molding technique applied to thermosetting materials.

In transfer molding a thermosetting mix is subjected to sufficient heat and pressure in a "plasticizing pot" or "loading well" to convert the mix to a quasi liquid, after which it is forced by a plunger into a closed mold kept at a temperature high enough to cause rapid heat hardening to take place. The transfer molding process differs from thermoplastic injection molding in that heat hardening takes place in the heated mold rather than the "freezing" of the thermoplastic in a rather cool mold.

Figure 2–23a shows the overhead loading well and the mold in position between the platens of a press. The mold is closed and still empty except for inserts, ready to receive the shot of heat-plasticized mix from the transfer pot through the properly designed orifices. Figure 2–23b shows the mold still closed after receiving the shot. The mold is not opened until the shot has heat-hardened (polymerized or cured) in the heated mold.

2.6.4.2 *Types of Material Used in Transfer Molding*. Since the materials being heated in the loading well (transfer pot) are of the thermosetting type, it is obvious that temperature and time of heating must be so controlled that the mix does not set up in the pot and jam the machine. Since heat hardening is a chemical reaction, it is dependent upon temperature. The plasticizing pot is held at a temperature where the plastic binder in the mix will fuse without hardening rapidly. For example, the setting time of a

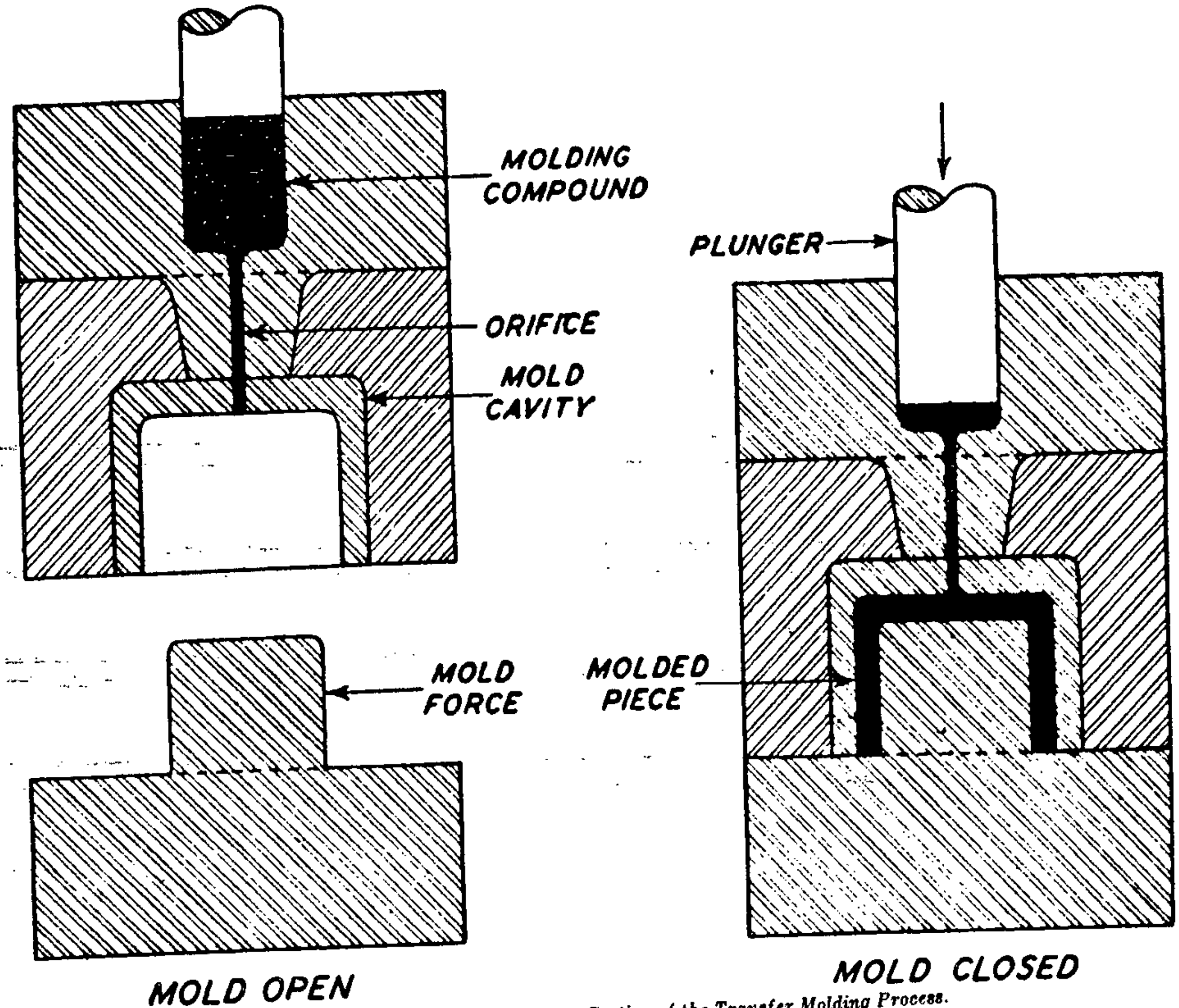


FIGURE 2-23. *Schematic Cross Section of the Transfer Molding Process.*

wood-flour-filled phenol—aldehyde molding mix may vary as follows:

Temperature, °F.	Heat-hardening time, secs.
356	34
302	68
267	170

In preparing superior transfer-molding binders, it is wise to keep the original amount of cross-linkage at a low level and incorporate less active catalysts and even put in a cross-linking inhibitor in the molding mix.

Although transfer molding has been successfully applied to all commercial types of thermosetting materials, some are better adapted to the purpose than others. The urea aldehydes are somewhat critical, in that their setting time is strongly dependent on a very narrow range of temperature and molded pieces often lack dimensional stability. The melamine-aldehydes, on the other hand, set more slowly. Because of their longer flow period they are every bit as adaptable to the method as the phenol-formaldehydes. It has been found possible to prepare phenol-furfural resins that may be held for 45 minutes at a temperature high enough to cause fusion and yet not heat-harden. Blends of phenol-formaldehyde and phenol-furfural resins have been found particularly suited for making transfer molded articles of highly desirable properties. Mineral-filled, cellulose-filled and fabric-filled melamine formaldehyde materials have been employed in transfer molding with good results. The melamine molding materials which are best suited to transfer molding have a comparatively long period of plastic flow. Some modifications of the basic resin may be necessary to enhance this property. These compounds as a class show pronounced after-shrinkage tendencies than do the phenolics. This tendency can be reduced considerably by proper control of the resin, suitable compounding of it, and proper drying before molding.

2.6.4.3 *Process Advantages.*

(a) Thin sections and delicate inserts may be used.

(b) Flow of material is easily controllable.

(c) Dimensional accuracy is good.

(d) Production rates are rapid.

(e) No deep loading well is required.

(f) Less wear on moving parts and much less tendency toward breakage of pins.

(g) Core-pins having a length to diameter ratio of 10–1 can be used.

(h) Shorter and more uniform cure times for finished pieces.

(i) "Flashes" are quite thin or absent altogether, thus reducing finishing costs.

(j) Air and other occluded gases are expelled in the plasticizing chamber so that blistering is practically eliminated.

2.6.4.4 *Process Limitations.*

(a) Molds are elaborate and are usually more expensive than compressive molds.

(b) Waste is high since material left in the pot, sprues and runners must be discarded, therefore small piece molding in high volume can be done more economically in multiple-cavity compression molds.

(c) Part sizes are limited usually to 16 ounces and under.

(d) Coarse fillers can be strained out, therefore part may not be as impact resistant as a part molded of the same material using the compression molding technique.

2.6.4.5 *Typical Applications.*

(a) Automobile distributor heads.

(b) Camera and projector parts.

(c) Switch parts.

(d) Electrical parts.

(e) Buttons, closures and coil forms.

2.6.5 *Blow Molding.*

2.6.5.1 *Process Description.* This process is one in which thin-walled, hollow, thermoplastics are produced very rapidly by basically two techniques. One technique makes use of continuous extrusion of hollow molten tubes or parisons which are then blown to final shape within the inside contours of a mold. The other technique produces a preform or parison in a mold by injection. The parison is then transferred to a blowing mold for completion of the shaping of the part.

Although a large variety of blow molding equipment is commercially available, the process resolves itself to three phases which occur simultaneously as illustrated in Figure 2–24.

(a) Melting and mixing of plastic in barrel.

(b) Formation of parison through a circular die.

(c) Inflation of parison in the flowing mold, cooling and ejection of the finished piece.

Although the actual blowing of the part takes only about a second, 2/3 of the mold cycle time is taken up by the cooling of the piece. Therefore, the speed of melting and parison formation must be geared to the amount of cooling time required, in order to attain continuous production.

The blow molding methods developed are not only based on the two techniques for parison formation (extrusion and injection molding), but on the number of dies and blowing molds (single, twin, multiple), on mold motion (mold stationary, reciprocating, rotary), means of injection of compressed air, steam or other compressed gas into the blowing mold (vertically downward blowing mandrel, upward blowing pin, hollow needle sideways), and so forth.

Regardless of the type of blow molding equipment being used, three trends of development are paramount:

(a) Increasing speed of production.

(b) Machines suitable for a wide variety of products.

(c) Minimal finishing operations on the end product.

2.6.5.2 *Essential Factors in Blow Molding.* The object in blow molding is to produce hollow ware plastic products at the lowest possible price consistent with the quality requirement.

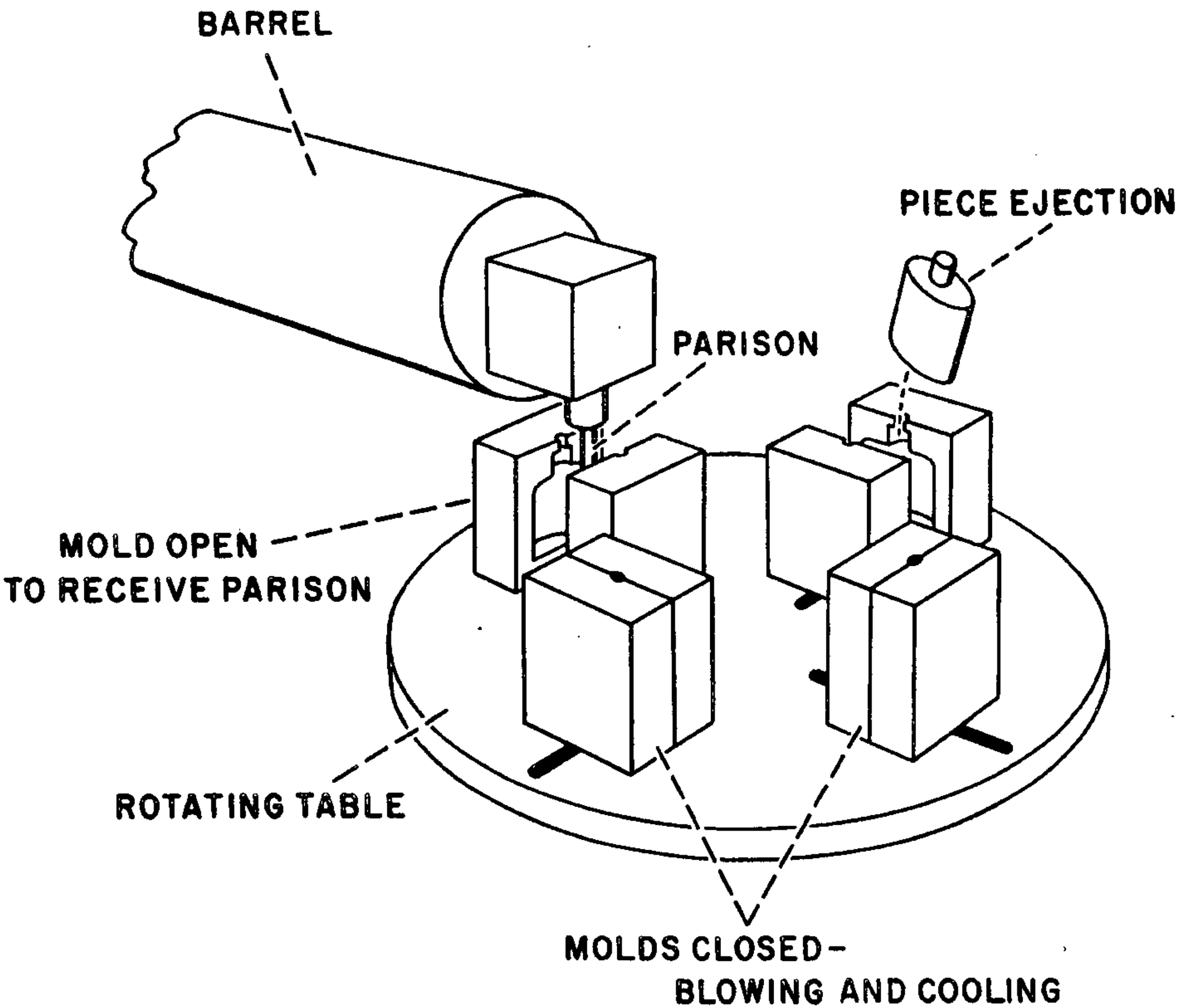


FIGURE 2–4. *Multiple station turntable for blow molding.*

Desirable end products properties may be quite different, depending on the particular case. Often, such properties as resistance to environmental stress cracking, shrinkage, impermeability, and taste, are not important, e.g., in most toys. On the other hand, for containers used for packaging household detergents, they are important, and so are stiffness, deterioration due to temperature fluctuations, or ultraviolet radiation, discoloration, odor, piece weight, as well as wall thickness uniformity, and parting line thickness.

Since each end product calls for particular properties, the selection of the most suitable resin for each application is very important. Resin selection is not an easy job. The problems must be clearly defined beforehand. Careful investigation of the end-use properties must be made. Moreover, resin requirements vary with the blow molding procedure and the available equipment. The inherent physical properties of a resin may be modified by altering processing and operating conditions during the fabrication process, starting in the extrusion or injection machine and ending in the blowing mold. The main influences are those exerted by heat (or cooling) and pressure, and the time and duration of these influnces are essential.

2.6.5.3 *Materials Used in Blow Molding.* The process is used mainly for polyethylene and polypropylene. Frequently nylon, acetal, cellulose acetate, and butyrates are blow molded. Occasionally ABS, styrenes and rigid and flexible vinyls are blow molded. Blow molding data for some of these plastics is given in Table 2–13.

TABLE 2–12
BLOW MOLDING DATA FOR VARIOUS PLASTICS

Material	Cellulosics	Acetal	Poly-carbonate	Poly-propylene	Poly-ethylene	Polyvinyl chloride
Extrusion temp range, °F.	330–370	350–370	450–500	390–425	350–400	300–325
Extrusion press range, psi.	1000–2000	....	3000	2000	2000–4000	1000–2000
Screw compression ratio.	1.6:1+	3.1+	2.1:1–2.5:1	3.5:1–4:1	3:1–3.5:1	2:1
Screw L/D ratio.	13:1–30:1	over 20:1	over 20:1	20:1 and over.	20:1 and over.	20:1 and over.
Blowing pressure psi.	25–50	over 100	over 100	75–100	50–150*	75–100*
Mold Temp., °F.	100	230–270	250–280	60–80	40–160*	80–150*
Shrinkage, mil/in.	2–7	15–30	5–7	20–50	30–50*	2–30*

* Depends on formulations and other mold conditions.

2.6.5.4 *Process Advantages.*

(a) Excellent for large thin wall part production.

(b) Extremely complex parts are possible.

(c) Parts are nearly free of strains, eliminating warping and stress cracking.

(d) Molds are relatively simple and inexpensive, permitting economical short runs.

(e) Production rates are very rapid, especially for small and medium sized items.

2.6.5.5 *Process Limitations.*

(a) Generally restricted to hollow or tubular parts.

(b) Overall dimensional tolerances are high (± 5% is considered good commercial practice).

(c) Excessive thinning of part wall occurs if configuration of mold varies too greatly in cross section from one area to another.

2.6.5.6 *Typical Applications.*

(a) Bottles.

(b) Carboys.

(c) Containers.

(d) Heater ducts.

(e) Housings.

(f) Packaging Units.

2.6.6 *Reinforced Plastics Molding.*

2.6.6.1 *General.* All plastics can and have been reinforced by a variety of fibrous material in filament, veneer, mat, batting, and woven form. The plastics include both the thermosetting and thermoplastic type, with the former predominating at present. The reinforcements may be glass, asbestos, sisal, nylon, metal, wire, wood, paper, cotton or other natural or synthetic materials.

A distinction should be made here between reinforcements and fillers as used in plastics components. Reinforcements as the word implies, serves to reinforce and strengthen the resin, whereas fillers are used largely as economical extenders which contribute little or nothing to ultimate strength properties.

Physical properties of reinforced plastics molded parts depend primarily upon the amount of reinforcement used. That is, the greater the ratio of reinforcement to resin (usually expressed in terms of percent by weight) the better will be the final physical properties. Of equal importance for many applications, is the direction of reinforcement or "grain" in the molded part. To achieve maximum physicals in a reinforced plastic molding, the resin must penetrate the entire mass of the reinforcement and "wet" every fiber, yet there must not be resin-rich or resin-starved areas to create property variations. This optimum condition can be reached only when resin viscosity and cure time are balanced against ease of penetration of the mass of the reinforcement, either with or without pressure as dictated by the particular molding method.

The methods described herein for the production of reinforced plastic parts are usually termed "low-pressure" molding methods since pressures required, if any are much lower than those required for the conventional procedures of compression, injection and transfer molding.

2.6.6.2 *Reinforced Plastics Molding Methods.* There are many basic procedures for producing reinforced plastic parts, and each with variations. However, basically all procedures consist of three steps: laying up the reinforcement, saturating it with the resin and curing the resin.

2.6.6.2.1 *Contact Molding*. This process is also termed "hand-lay up" since reinforcements are laid uniformly by hand on either female or male molds, or in varying thicknesses to obtain additional strength at predetermined points. The reinforcements are then saturated with catalyzed resin by either brushing or spraying techniques. To assist in obtaining complete saturation and wetting of the reinforcement, rolling techniques and preimpregnation of the reinforcement web by passing it through a resin bath before lay-up are frequently practiced.

During hand lay-up, the reinforcements may be cut and fitted to the mold contours; this makes the procedure ideal for prototypes and sample runs, since changes can be made as work progresses.

The surface of the molding that is in contact with the mold is smooth, the exposed surface may be improved by covering it with cellophane during or after rolling.

Hand lay-ups are normally cured at room temperatures and without pressure (contact molding), although oven heat may be used to accelerate curing. They can also be cured by vacuum, pressure and matched die techniques which will be subsequently described.

The polyesters and epoxies find major usages in hand lay-up, which is the simplest available method for producing reinforced plastics parts with a minimum of equipment. Molds are inexpensive and need only be strong enough to withstand the weight of the lay-up. In special cases even the mold may be eliminated; swimming pools, for example, have been made by placing the lay-up against the smoothed sides of the excavation and boat hulls have been produced by using a lightly covered framework as a mold.

2.6.6.2.2 *Spray Molding*. This process is a mechanized extension of hand lay-up. Glass roving is fed through a chopper which cuts it to predetermined lengths and projects these chopped pieces into a resin stream in such a way that the resin and glass are simultaneously deposited on the surface of the mold. This mixing process assures the coating of each strand of reinforcement with resin. The deposited mix may then be rolled and cured as in hand lay-up.

The equipment used is portable, making the process adaptable to on-site fabrication, maintenance and repair work. It is possible to automate the process and complex shapes can be easily covered. Skilled and experienced operators are required for obtaining uniform moldings.

2.6.6.2.3 *Contour Weaving and Molding*. In this process the reinforcement is woven on specially adapted carpet looms to the shape of the final object. It is then pulled over the mold and impregnated with resin by brushing or spraying. Resin and curing methods are the same as for hand lay-up.

This process is particularly valuable in producing parts of irregular contour where glass mat or cloth will not drape well or may require extensive and complicated hand tailoring. Glass content is easily controlled, time consuming hand-tailoring is eliminated, part reproducibility is improved and design freedom to specify "beefed-up" areas is enhanced.

2.6.6.2.4 *Preforming and molding*. While contour woven reinforcements may be considered to be preforms, the term is usually applied to the more fragile masses of reinforcements built up as mats or felts on screens shaped close to the contours of the final mold. The mass is held together by a small quantity of binder resin. Build-up of the preform is accomplished either by blowing or sucking chopped or continuous roving against the preform screen, or by suspending pre-impregnated chopped strands in a water slurry and passing the slurry through a preform screen. In one dry method, a spray of binder resin is directed at the preform screen simultaneously with the roving; in the other, the roving is fed into a plenum chamber and drawn to the screen by suction. In both, the binder resin is cured before removal of the preform. In the wet slurry method, the preform screen is removed from the slurry tank and the preform dried by hot air until it is strong enough to handle.

Preform molding is accomplished in matched metal molds. After the binder has cured, the preform is placed in one-half of the mold in the press and an accurately measured amount of molding resin is carefully poured over it and the mold is closed. The resin flows under heat and pressure to thoroughly impregnate the entire mass of the preform.

Preform molding is very economical for turning out complex shapes on a production line basis, is easy to automate and uses the lowest cost reinforcements.

2.6.6.2.5 *Vacuum Bag Molding.* In this process, all types of lay-ups are covered with a sheet of cellophane, polvinyl alcohol or acetate and the joints sealed. A vacuum is then drawn under the sheet; atmospheric pressure on the sheet forces entrapped air and excess resin out of the lay-up. This improves resin distribution, uniformity and the smoothness of the unfinished side of the molded piece, in addition to enhancing densification and part strength.

2.6.6.2.6 *Pressure Bag Molding.* Both pressure and heat can be applied to the lay-up during cure by use of the pressure bag molding method. A tailored bag, usually of rubber sheeting, is placed against the lay-up and covered with a sealed pressure plate. Air or steam is then introduced at pressures up to 50 psi and maintained until the resin is cured.

Lay-ups that can be molded by the pressure bag method are the same as those molded by vacuum bag molding. Advantages of uniform resin distribution and surface finish are, of course, even further improved with the pressure bag method compared with vacuum bag.

2.6.6.2.7 *Autoclave Molding.* In this method, the entire lay-up is placed in a steam jacketed autoclave and the air pressure raised to as high as 100 psi. This extension of the pressure bag method has all of the latter's advantages plus ability to handle parts with higher glass loadings and still maintain uniformity of resin impregnation.

2.6.6.2.8 *Match-Die Molding.* This process is similar to metal stamping. Male and female molds have close fitting, and telescoping circumferential areas to seal in resin and trim reinforcement. The ultimate in physical properties on a fast automated production line can be achieved by this process. Here, the resin and reinforcement are molded under heat and pressure to produce parts that have excellent uniformity throughout.

Molding pressures may range from 100 to 200 psi or more, depending on the material used; temperatures can range from 225 to 300°F. Cure cycles may be as short as 1 minute or as long as 5 minutes or more, depending on the material used, as well as on the thickness and shape of the part.

Mats can be molded to simple shapes by much the same procedures as in preform molding. The flat mat is inserted over one-half of the metal mold in the press, resin is poured over it, and the mold is closed. Fabrics and prepregs are handled in the same manner.

2.6.6.2.9 *Pultrusion.* In this process continuous strands of reinforcement are impregnated with a resin and then pulled through a steel die which sets the shape of the stock and controls the resin content. Final cure is effected by pulling the die-formed stock through a suitable heating oven. This process produces flat and profiled shapes. Tapered shapes are produced by techniques of centerless grinding. Pultrusion is a continuous process that can be run at a speed of 5 to 6 ft./minute.

2.6.6.2.10 *Centrifugal Casting.* Low labor and tooling costs, adaptibility to automation and production of parts of uniform wall thicknesses and with good inner and outer surfaces are some of the advantages attainable with the centrifugal casting process for turning out pipe and similar reinforced plastic forms. The part is formed against the inner surface of a hollow mandrel. Chopped reinforcement and resin are placed inside the mandrel and are uniformly distributed as the latter is rotated inside an oven. Tanks and pipes of all sizes are produced by this process. The casting mandrel may be made of either metal or reinforced plastic.

2.6.6.2.11 *Continuous Laminating.* In this process the reinforced fabric or mat is impregnated with a resin by passing it through a dip tank. It is then run through the laminating rollers between cellophane covering sheets. The distance between the rollers control the thickness and resin content of the laminate. The resin is cured by passing the lay-up through a heating zone.

This process is inherently an automated one, which is capable of producing 4-ft. wide sheets at a rate in excess of 10 ft./minute. Corrugated and flat sheet for construction panels, glazing, roofing, electrical insulation, etc., may be produced by this process.

2.6.6.2.12 *Filament Winding.* In this method of lay-up, fibrous glass strands, rovings or tapes are wound on a suitable mandrel or mold. The mandrel may be stationary or may revolve around one or more axes. The filament is usually guided by cam-actuated mechanisms. Because the tension on the glass can be accurately controlled during winding, a pre-stressed condition is achieved which assures that each strand will take its equal share of stress under later working loads and that the tensile strength of the part will be as high as possible. Also, since the reinforcement can be laid down in precisely controlled patterns, strength can be placed where needed and abrasion between strands of glass can be held to a minimum.

The strands or roving can be fed to the winding control mechanism through a resin bath, or preimpregnated roving or tape may be used. Curing may be at room temperature, in an oven by infra-red or by vacuum or bag molding.

Filament winding uses the lowest cost reinforcement to produce moldings with the highest strength/weight ratio possible. Specific strengths higher than heat treated steels can be obtained.

The shape of filament wound parts is obviously restricted to surfaces of revolution, round, oval, taper and even square. However, ingenious design can often overcome the limitations of shape. Tank ends or closures, for example, can be produced two at a time on an elliptical mandrel of suitable size. The closure can then be positioned on the tank mandrel and the filament winding of the tank shell overcapped onto the prepositioned ends.

2.6.6.3 *Molds for Reinforced Plastics.* Molds are simple and inexpensive and can be made of many materials. The choice is governed largely by the pressure and or heat to be used, if any; the expected number of pieces to be made; and the surface finish required on the molded reinforced plastic parts.

Regardless of the material selected, molds must present surfaces that are smooth as the surfaces desired on the molded reinforced plastic pieces. The mold surface must also be non-porous, otherwise it must be sealed before molding.

Some of the most popular material for reinforced plastics molding include the following:

(a) Wood—easy to fabricate and easily reworked to accommodate design revisions during mold making and after test runs have been made. Surfaces must be sealed and polished prior to use. Wood molds are not suitable for heat and pressure usage.

(b) Plaster—plaster molds are suitable for short runs where neither heat nor pressure are used. Surfaces are porous and must be sealed; more durable molds can be made by impregnating a material with a liquid resin. Plaster is often used for single use molds to produce parts with extensive undercuts or complex configurations. After cure, the mold is simply broken apart and removed in pieces.

(c) Reinforced polyester—molds made of reinforced polyesters are fairly durable and can be used even in press molding. Where long production runs are in prospect, a master may be made in plaster or wood and the required number of reinforced-polyester molds produced from it.

(d) Cast plastics—cast phenolics and epoxies make satisfactory molds and are also strong enough for short runs of press molding.

(e) Sheet metal—low pressure molds for contact, bag, and autoclave molding are easily fabricated from sheet metal, but they will not stand the pressures of press molding.

(f) Cast and machined metals—molds made of these materials are required for long runs of press molding with matched metal dies. Cast aluminum is satisfactory for some purposes but does not take a very good surface finish. Alloys such as Kirksite make good molds for short to medium runs, but for longer run a fine-grain cast iron such as Mechanite is considered to be much more satisfactory.

Cast iron molds are considered best for complex shapes because the original shape can be very close to the finished shape and a minimum of machining is needed. Where shapes are simpler, it may be found less expensive to have molds fabricated from tool steel.

2.6.6.4 *Pre-Impregnation of Molding Reinforcements.* The mating of resins and reinforcement calls for considerable skill on the part of the operator to produce uniformly good pieces. In addition, large demands are placed on good housekeeping practices to prevent rapid accumulation of resin spills, reinforcement clippings, batches of prematurely cured resins, and other debris.

Two ways have been developed to overcome many of the difficulties of handling liquid resins and bulk reinforcements: premix and prepreg materials. Both forms offer convenient ways of insuring uniformity of finished product with a minimum of in-shop supervision.

2.6.6.4.1 *Premix.* Prior to molding, the reinforcement (usually chopped glass roving) is thoroughly mixed with the resin, pigment, catalyst, etc. The product which is formed is the molding compound which can be precisely divided into uniform mold charges and formed into the final shape under heat and pressure in metal molds. The process is akin to compression molding which was previously discussed.

The molding compounds, either made in the molding plant or supplied by custom formulators, can be formulated to meet many specific end-use requirements at the lowest possible cost per pound. The mixed compound may be weighed into bulk charges or extruded into a rope like form for easy handling and measuring.

2.6.6.4.2 *Prepreg.* Resins combined with reinforcements in easy-to-handle sheet or other form are known as prepregs. They are produced by impregnating continuous webs of fabric or fibers with molding resin under conditions which permit close control of resin viscosity, resin-reinforcement ratio, etc. The resins are then advanced to B-stage or partially polymerized. In this state, the materials can be stored for reasonable lengths of time under normal storage conditions.

When prepregs are subjected to heat and pressure, cure of the resin is completed and molded parts are produced with remarkable uniformity from piece to piece. While prepregs cannot be cured at room temperature and therefore cannot be used for contact molding, they can be formulated for use in all other molding processes.

Prepregs aid in inventory reduction, eliminate in-shop problems of material formulation, eliminate waste and are adaptable to automated mass production techniques.

Prepregs come in literally thousands of combinations of resins and reinforcements. Standard line products include prepregs made with epoxies, phenolics, polyesters, melamine, silicone and a variety of elastomers. Most common reinforcements (in the form of woven fabric, mat or roving) are glass, asbestos, paper, nylon, high-silica glass and graphite.

2.6.6.5 *Surface Finishing of Reinforced Moldings.*

2.6.6.5.1 *Gel Coats and Color.* Patterns of reinforcements that appear on the "as-molded surfaces" are not always desirable nor do integral colors always afford the desired gloss or brilliance to the end item. Therefore, gel coats which are molded into the surface of the parts are used to solve these problems. In addition gel coats serve as protective finishes which effectively prevent the moisture wicking action of glass fibers that may protrude from the surface of the molded part.

These coatings are based on pigmented polyester resins, usually modified to cure to a flexible form that will achieve maximum impact strength. The gel coat is applied, without added reinforcement, directly to the surface of the mold by spraying, after the mold itself has been thoroughly cleaned, polished and coated with a parting agent.

Where still higher brilliance and gloss is required, reinforced plastic surfaces may be sanded, primed with a primer coating and sprayed with a standard baking or enamel or lacquer. Where exceptionally high gloss or color retention is required, a final coat of clear melamine, alkyd or other lacquer may be used. A smooth well molded surface is essential to a good enamel or lacquer finish.

2.6.6.5.2 *Surfacing Veils and Mats.* Another method of producing a smoother surface on molded reinforced plastics pieces is to use a fibrous glass mat or veil laid up against the mold face. Both mat and veil are very light non-woven fibrous glass materials made up of continuous filaments. They contribute little to the strength of the lay-up but act to draw a slight excess of the resin to the mold surface. The resulting resin richness compensates for any slight resin shrinkage that might occur, and forms a smooth surface which virtually eliminates the pattern of the heavier reinforcement underneath. Main difference between mat and veil is that mat is stiffer and is used on flat or only slightly curved surfaces; veil is much softer and will drape easily to follow compound curves without cutting or tailoring. It is especially recommended for improving the surface of parts made from preforms. Veils are sometimes referred to as overlay mats.

2.6.6.5.3 *Film Surfacing.* Latest approach to improving the surface and weatherability of polyester-glass reinforced plastic is to laminate a polyvinyl fluoride film to the exposed surface. The film, with an additive to prevent passage of damaging ultraviolet light and highly oriented to minimize wrinkling, is heat bonded to the reinforced plastic surface.

2.6.6.6 *Advantages of Reinforced Plastics Molding.*

(a) Articles of large area with very high strength to weight ratios can be readily fabricated.

(b) Mold costs per unit area are much lower than with conventional high pressure molding methods.

(c) Strength can be hand tailored into preselected areas of the part by adding additional reinforcement to the locations.

(d) Lends itself to the molding of all types of composites, such as high strength skins to low density cores.

(e) Lends itself to on site fabrication techniques.

(f) Complete integral assemblies are produced in one operation from numerous small parts.

2.6.6.7 *Limitations of Reinforced Plastics Molding.*

(a) Production is slow and costly because of time required to handle and lay-up resin treated layers.

(b) Uniform molding pressure (hence uniform densification) is difficult to obtain where one mold member is a flexible membrane and abrupt changes in part thicknesses occur.

(c) Dimensional accuracy of finished part is not as positive as with conventional high pressure molding. However, this is dependent on the type of resin and how thoroughly the fibers are impregnated.

2.6.6.8 *Typical Applications for Reinforced Plastics Molding.*

(a) Boat Hulls.

(b) Ducting.

(c) Fusilages.

(d) Helicopter rotor blades.

(e) Missile bodies and components.

(f) Nose cones.

(g) Radomes.

(h) Rifle stocks and gun barrels.

(i) Rocket motor cases.

(j) Sonar domes.

(k) Sandwich panels.

(l) Thermal and acoustical insulation.

(m) Printed circuit boards.

(n) Tanks and pressure vessels.

(o) Automotive bodies and components.

(p) Backing for Ceramic armor plate.

2.6.7 *Plastisol Molding.* Plastisols are dispersions of polyvinyl chloride resin in suitable liquid plasticizers. They vary in consistency from water thin liquids to heavy pastes at normal room temperatures. At about 350° F, fusion takes place, resulting in a tough solid mass. Because of this liquid-to-solid conversion without the need for pressure, plastisols are adaptable to simple, economical molding of a wide range of products.

Only lightweight inexpensive molds are needed for molding. Plastisols are 100% solids and no significant loss in weight occurs during fusion. Low-viscosity plastisol liquids can be pumped, poured or sucked into a mold, or the mold may be dipped into the liquid.

A new approach, expecially for rotationally molded products, are the so-called rigid plastisols. Usually, these are prepared by compounding acrylic ester type monomers into the vinyl dispersions. During molding, these monomers polymerize to hard, high molecular weight polymers. In other instances, types of plasticizers are used that are formulated to cross-link during fusion to produce the rigid product.

2.6.7.1 *Dip Molding*. Dip molding consists of dipping an internal mold into the liquid plastisol, fusing or fluxing and then stripping the finished article off the mold. The molds which are used with this technique are usually solid and are made of cast or machined aluminum, machined brass, steel or ceramic materials.

Although molds may be dipped at room temperature, they are usually preheated to control the thickness of plastisol retained on the mold. For wall thickness of 1/16 to 3/32 inch the mold is heated to approximately 300° F. prior to dipping. Heavier wall thickness may be obtained by increasing the mold preheat temperature. Molds are rapidly immersed in plastisol and withdrawn at a rate of 4 to 6 inches per minute. Inversion of the mold after withdrawal from the plastisol will allow for redistribution of excess liquid. Fusion takes place when the dipped mold is heated to 350°–400° F. in an oven for times from 5–15 minutes. The mold is then cooled and the article is then stripped from the mold.

The process lends itself to dipping of combinations of plastisol sponge and skins which are useful for insulated items. High rates of production are attainable through the use of many molds which can be both simultaneously dipped, cured and stripped in an automated production line.

2.6.7.2 *Slush Molding*. In this process, a preheated hollow mold is filled with plastisol. The material on the mold walls is allowed to gel and the excess is returned to reservoir of plastisol. The thickness of the deposited film is controlled by mold temperature and duration of plastisol dwell in the mold.

This process usually uses electroformed copper or fine aluminum sand-cast molds. Heat is applied to convert the plastisol to an elastromeric solid; the mold is then cooled for convenient handling while stripping the molded piece.

Most of the production lines using slush molding follow one of two basic systems: single pour or double pour. Both are readily adapted to conveyorized lines.

A single pour involves a filling station where preheated molds are filled by vacuum, gravity or pressure. If gravity or pressure filling is used, the filled molds are either spun or vibrated to eliminate bubbles at the extremities. After filling, the molds are sometimes reheated to the temperature needed to produce the required wall thickness, after which the excess liquid plastisol is drained out. The plastisol lining left in the mold is then fused in an oven at temperatures of 350 to 375° F. Fusing time depends on the molded piece and its wall thickness. Following the fusing cycle, the mold is cooled and the molded articles is stripped.

In the two-pour method, the cold mold is filled, usually by gravity or by pumping and vibrated to remove bubbles. It is then dumped, leaving a thin film of plastisol on the surface. By filling a cold mold in this manner there is less chance of entrapping air or of any possible gelation taking place over fine details at the extremities. After dumping and draining, the mold is passed through an infra-red or hot air oven to fuse or semi-fuse the first skin. The mold is filled a second time, dumped and allowed to drain and passed through a second oven for final fusing of the plastisol part and is cooled and stripped. The length of time the mold is in the first oven determines the wall thickness of the final part because the heat of the mold retained from the setting or fusing of the first skin will determine the ultimate thickness of plastisol deposited on the walls of the mold.

Sponge plastisol may be similarly handled when items such as boot socks and toys are manufactured completely of sponge. When a plastisol skin-sponge combination is desired, a two-pour system is used, with sponge vinyl plastisol poured in the second step.

2.6.7.3 *Rotational Molding.* This process produces a completely enclosed hollow molding in two piece molds. A predetermined amount of plastisol is introduced into one-half of the mold, the two mold parts are then clamped together and the mold is simultaneously heated and rotated in two planes.

There are several advantages to this process, namely: part weight may be accurately controlled; less possibility of contamination of plastisol; the reject rate is lower; there is less scrap; and the operation is much cleaner.

Molds can be either electroformed copper; cast or machined aluminum. The molds can be polished or left unfinished depending on whether a smooth glossy finish or rough dull finish is desired.

The simplest type of rotational equipment is the batch type. Basically it consists of a platform which rotates the previously loaded and clamped molds in two dimensions within a heated oven. Fusion may take place in the rotator or for greater speed may be simply gelled in the rotator oven and fused permanently in another oven.

In the continuous process the molds are automatically filled volumetrically, automatically closed, rotated and heated, cooled by water spray or cool air, automatically opened, and the finished part is removed. The equipment is conveyorized and highly mechanized and therefore necessarily complicated. High production with a minimum of labor is achieved in this process.

In order to achieve differences in wall thickness, the mold may be constructed with variations in wall thickness. Since heat is transmitted more slowly through a relatively thick mold wall, the molded section in this area would be thinner in relation to other areas of the article.

2.6.7.4 *Low-Pressure Injection Molding.* Low-pressure pumps of the grease-gun variety are used in this process to inject the liquid plastisol into a two piece mold or cavity. The molds must be designed with bleeders at the cavity extremes to allow for complete filling. This filled mold is placed in an oven for fusion at 350° to 375° F. At this temperature; it generally requires 7 minutes to fuse or cure 1/8 inch of cross section. After fusion, the mold is removed from the oven, cooled, opened and the finished solid part is removed.

For the most part, solid plastisols are made by batch rather than continuous process because of the longer periods of time required for fusion. However, the process is excellent when a limited number of parts are required since mold costs can be kept low.

2.6.7.5 *In-Place Molding.* The outstanding moldability and versatility of plastisols have led to some very significant large-volume applications which can be designated "in-place molding." Most successful use of this type of operation has been in the field of gasketing.

For example, two leading manufacturers of the new dry, pleated paper, automotive air cleaner have used plastisols to great advantage in molding end seal gaskets. The air cleaners are made by placing the filter and support elements in a ring like mold filled with liquid plastisols and then fusing the plastisol. The operation is repeated for the other end. The process is really a casting process for plastisols.

2.6.7.6 *Combined Processes.* There are occasions, particularly with plastisol skin-sponge vinyl combinations, when the use of two of the above mentioned methods is advantageous to produce a single product. Such items as automotive arm rests, gaskets, toys, squeeze balls may be produced with a tough outer skin of vinyl plastisol and a solid interior of expanded vinyl. The skin may be formed by spraying, slush molding or rotational molding; the interior by casting, low-pressure injection, or rotational molding.

For products requiring an exterior surface completely covered with plastisol skin, a combination of rotational molding and low pressure injection molding may be used. The skin is molded in the normal rotational manner and cured, after which the vinyl sponge or foam is injected into the still closed mold. For vinyl sponge the quantity used is predetermined, for foam the mold is simply filled. Then the mold is either placed back in the rotational unit or into a conventional oven.

For products having a plastisol skin on only a portion of the exterior surface, several methods may be used. The plastisol may be sprayed on the surface of the mold either with or without masks and then set or fused. The skin plastisol may also be slushed into the mold and cured, and then the sponge or foam cast and fused.

2.6.7.7 *Advantages of Plastisol Molding.*

(a) Molds are low in cost.

(b) Large parts may be molded.

(c) Relatively high degree of complexity is possible.

(d) There is comparatively little shrinkage.

(e) Thickness may be controlled by temperature and duration of slurry exposure to heated face of mold.

2.6.7.8 *Limitations of Plastisol Molding.*

(a) Tolerance may vary widely.

(b) Thickness may vary substantially if initial temperature of mold varies, since part thickness is a function of heat.

(c) Plasticizers used in conjunction with the plastics to form the plastisol have a tendency to migrate with time, causing cracking and embrittlement.

(d) Selection of materials is extremely limited.

(e) Production rates are relatively slow.

2.6.7.9 *Typical Applications.*

(a) Large containers.

(b) Cushioning of all types such as seats and arm rests.

(c) Flotation objects.

CHAPTER 3

EXTRUSION

3.1 General. Extrusion is the process of applying heat and pressure to melt resins and forcing them through accurately dimensioned dies to produce continuously shapes in the form of—

(a) unsupported film and sheeting, pipe and other profiles.

(b) film for coating paper and paper board, metal foil, cellophane, plastic films, cloth, and other substrates.

(c) coating around wire and cable.

The extruder (Fig. 3-1) is fairly simple as far as its basic operations is concerned.

The material in the form of pellets is fed into the funnel shaped hopper. It drops through the feed throat into the channel of a screw rotating within the hardened liner of the extruder barrel, or cylinder, and is forced forward by the rotating screw flights. As it moves, it is heated, melted, thoroughly mixed and compressed by a series of complicated flow patterns inside the screw channels. On its way through the barrel, the solid pellets must be transformed into a homogeneous melt. A poorly mixed, non-homogeneous melt may yield an end product with non-uniform cross sectional dimensions, with wavy rough surfaces, and with high residual strains. When films are extruded, they may, for the aforementioned reasons, be of non-uniform gauge, lack strength, gloss and clarity. Finally the melt passes through the screen pack and supporting breaker plate and the adapter to the die. The screen serves as a filter for any foreign material and increases back pressure in the extruder, especially when no extruder valve is used.

Heat which softens the resin is supplied in two ways—by external heating and by internal frictional forces brought about by the compounding and compressing action of the screw. The amount of such frictional heat supplied to the polymer is appreciable; in many extrusion operations it represents most of the total heat supplied to the resin. Electricity, steam or hot oil can be used to heat the barrel externally. Electric resistance heating is generally preferable because it is most convenient, responds rapidly, is easiest to adjust, requires a minimum of maintenance and is generally the least expensive in terms of initial investment.

Accurate control of the barrel temperature is essential, because the viscosity of thermoplastic resins changes considerably with temperature. The barrel is divided into several heating zones, as indicated in Figure 3-1. The hopper throat and part of the feed section of the screw must be water-cooled to prevent the resin from melting prematurely and sticking to the hopper throat before reaching the screw.

If electric resistance heaters are used, there are usually 2 to 8 independently heated zones, the temperature of each zone being regulated by a proportioning or a stepless heat controller. The temperature of each zone is usually taken by a thermocouple seated in a well in the barrel wall and inserted deep into the barrel wall.

If the thermocouples sense the temperatures of the barrel wall, the temperatures measured are not identical with those of the melt itself which controls the behavior of the resin in and outside the die. Therefore another well-insulated thermocouple should be inserted through the die adapter into the well itself to determine the actual melt temperature as close to the die opening as possible. Quality of the extruded product is closely dependent on the viscosity and, hence, the temperature of the melt.

The length to diameter (L/D) ratio of an extruder is an important characteristic of the barrel design, since it determines the relative amount of inner barrel surface available for shear or mixing and heat transfer. The ratio is defined as the length of the barrel from the rear of the feed hopper to the braker plate, divided by the nominal inside diameter of the barrel. Although extruders are available in a wide range of L/D ratios from 16:1 to 30:1, most common ratios are 20:1 and 24:1. Present trends indicate future predominance of 24:1 and 28:1 L/D extruders.

Of the many extruder screw designs in common use today, the most widely used is shown in Figure 3-2. In this constant pitch, gradual transition metering screw, channel depth is greatest in the feed section and is constant until it smoothly decreases through the transition section to the constant depth of the metering section at the forward end of the screw.

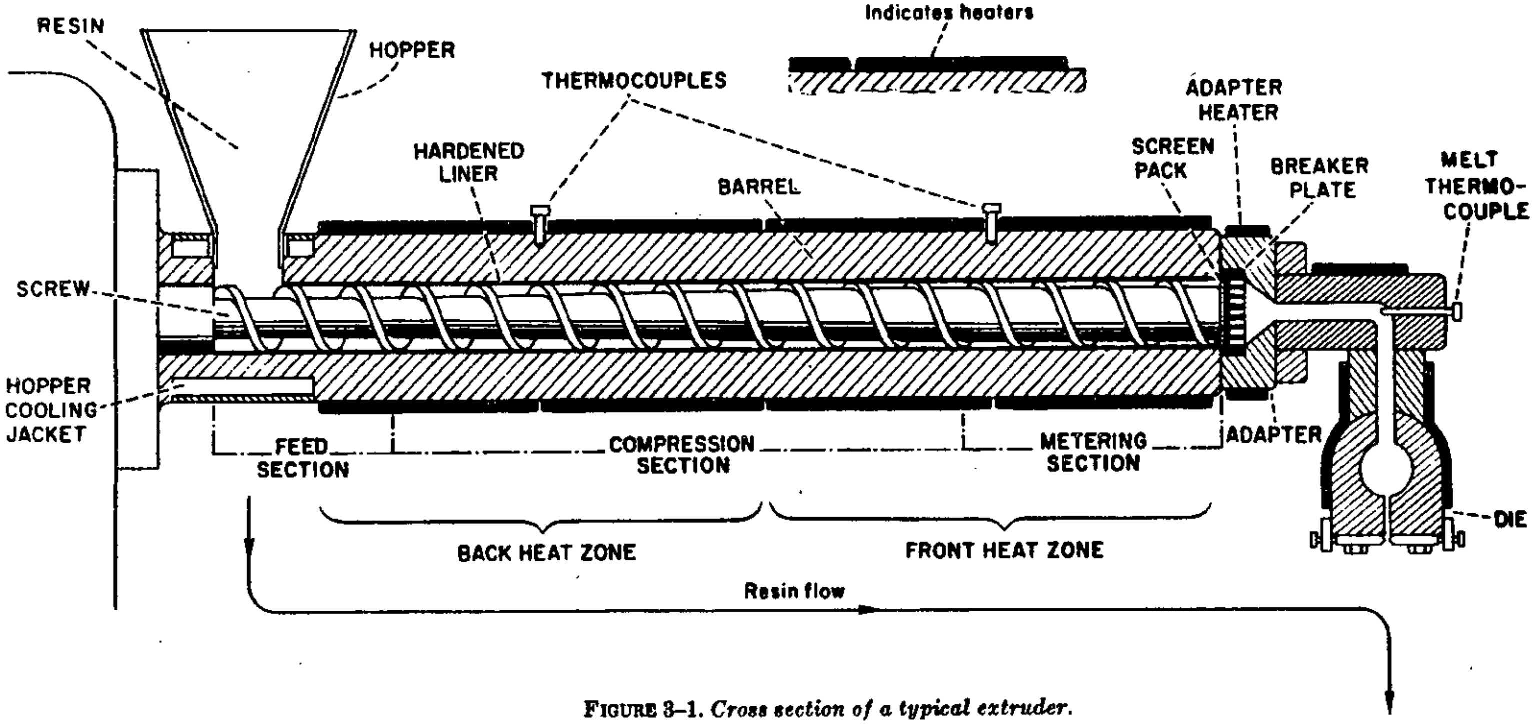


FIGURE 3–1. *Cross section of a typical extruder.*

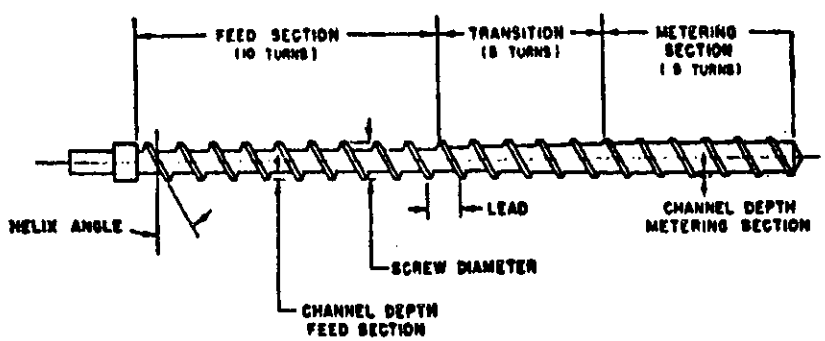


FIGURE 3–2. *Typical screw design.*

The screw design is considered optimum when the granules entering the screw in the feed section are fully plasticated into a homogeneous melt prior to the entry of the mass into the metering zones. The melt is pumped through the latter section to the die at a uniform rate. In the feed section, the screw channel is designed to have a conveying capacity in excess of that of the transition and metering sections. This is done to avoid starving the forward sections.

Studies of the feeding of solid granules through extruders have resulted in the following conclusions:

(a) the maximum granule conveying rate will be achieved when the friction between the inner wall of the barrel and the granules is at a maximum and the friction between the granules and the screw is at a minimum.

(b) the optimum helix angle of the screw depends on the friction between the plastic and the screw and barrel. In most cases this angle is approximately 15 to 20 degrees.

Most screws are hollow bored for liquid heating and cooling and are constructed of 4140 alloy steel. Flights must be hardened by some procedure, either flame hardening or coating with Steelite #6 because of the wear which takes place between the snug fitting screw and barrel. Chrome plating the screw is standard procedure because the plating makes for better corrosion resistance and easier cleaning of plastic from the screw.

The screen pack is placed in the extruder barrel between the end of the screw and the entrance to the adapter and is supported by the breaker plate. The latter, which also serves as a seal between the extruder and adapter consists of a perforated heavy metal plate. The screen pack may influence extruder operations in various ways: Back pressure in the screw metering zone may be increased by using a screen pack consisting of many dense, or fine mesh screens. This back pressure effect of the screen pack occurs at lower temperature and pressures such as are used in blown film extrusion. Higher back pressures at a given screw speed improves mixing and homogenizing and therewith, extrusion quality, though it may reduce output slightly. (Output can be regained by increasing the screw speed slightly.) The temperature of the melt may be raised somewhat by using a much heavier screen pack meaning more or finer screens or both—which, by increasing the pressure generates additional frictional heat. The amount of compounding which can be achieved by denser screen packs is limited, because the melt temperature begins to increase with higher pressure. When high output rates are required, only a few coarse screens may be used. A few high output extrusion operations may use no screens at all. However, this procedure is generally not recommended, since it impedes the compounding and melt temperature stabilizing action of the extruder and removes the safety bonus of protecting the die from tramp metal or other contamination.

The use of pressure valves to increase or decrease pressure and thus control pressure at the extruder head has gained widespread acceptance. Pressure valves provide good pressure control and take this function away from die design and screen pack arrangement. Internal and external types of pressure valves are available.

The internal pressure valve is a movable screw which can be adjusted forward or backward to increase or decrease pressure. Moving the screw varies the size of the opening between the end of the screw and the breaker plate and adapter.

External pressure valves make use of some type of pin arrangement which varies the size of the opening at the extruder adapter, thereby varying pressure.

The die must be designed in such a way that it maintains the melt at a constant temperature and meters it through the die lands at a constant rate and in a shape close to the cross section ultimately desired in the extruded item. If necessary, adequate allowance must be made in the design of the die opening to produce the exact desired cross section dimensions after extrudate has been drawn down and shrunk through cooling.

3.2 Pre-Extrusion Operations. The extrusion operator today has a large choice in both the type of shipping container and quantities of resin he may receive at his plant. Naturally, bulk shipments are becoming quite popular because of quantity price discounts.

Although there are many extrusion operations in which material as it arrives at the plant can be used "as is," there are cases in which the material must be preconditioned by (1) drying and/or (2) compounding or blending. For example, hygroscopic materials such as cellulose acetate and acrylic resins may pick up moisture when exposed to the atmosphere. If these materials are not dried prior to extrusion they will produce poor quality extrusions containing bubbles or surface imperfections. Some resins, such as polycarbonates and nylons, are packaged in sealed tins. These resins need not be dried if they are used immediately after opening. In the case of polyvinyl chloride, it is often more desirable and more economical to receive raw resin and compound it at the extrusion plant to "tailor" it to the specific application which is being extruded.

A good rule-of-thumb for drying is to use as high a temperature as possible without causing discoloration (oxidation) or caking (melting).

The process of blending materials before extrusion may be divided into two general categories: (1) the simple addition of a single or limited number of modifying ingredients, such as the addition of color, regrind, or a slip agent in polyethylene, and (2) a preparation of a more complex formulation, such as vinyl compound from resins, plasticizers, fillers and other ingredients, or the blending of two resins to develop a mixture having more desirable properties than either resin alone.

The first type of blending operation is relatively simple and may be accomplished by simply dry blending with the base resin and then extruding the mixture. The second type of blending may be accomplished by placing powdered resin in an agitated blender which is jacketed for heating. Liquid plasticizers, stabilizers, fillers and other ingredients are then added to the agitated resin mass, usually by means of spray nozzles to prevent lumping of the material and to improve dispersion. Heating of the agitated powder is continued until all liquid components are absorbed and the completed powder blend is dry to touch and free flowing. After the dry blend is completed, the batch is cooled.

Although such blending techniques are frequently used for vinyls, the same techniques are applicable to other thermoplastics, provided they are cheaper and available in powdered form and that appropriate changes in blending process variables are made as regards temperature and cycles to suit the material being run on the extruder.

There are many highly efficient mixers on today's market, but however mixed, the powdered blend should be screened to insure that agglomerates are not fed to the extruder. In certain instances, dry blends may be extruded and pellitized to facilitate feeding the production extruder. However, in most cases the dry blend may be fed directly to the production extruder without difficulty. Whether pelletization will be necessary will depend on the particle size of the resin and the formulation used.

Feeding pelletized material to the extruder has the advantages of cleaner handling and less dusting at the hopper, less tendency to bridge or clog in the throat of the hopper, and less occluded air fed with the material which can cause bubbles in the extrudate. Also, it is easier to use hopper dryer systems with pellets than with powders if the material needs drying prior to extrusion. When finely divided particles or powder is fed to the extruder, a vacuum hopper can be advantageously used in place of the ordinary hopper. Powders generally contain a large amount of occluded air and unless the extruder is a vented type, this air can be carried through and appear in the finished product as surface imperfections or bubbles. In addition to vacuum hoppers, other feeding devices have been designed to prevent clogging at the feed throat and to provide a constant feed to the extruder screw. Often these consist of nothing more than a vibratory device attached to the hopper to agitate the material and thus keep it moving freely. One type of feeding device has a deep flighted screw to move the dry material smoothly into the throat of the production or plasticating extruder. A vibratory motion insures a smooth flow.

Some consideration has been given to feeding liquid polyvinyl chloride plastisols directly to an extruder. As the plastisol passes through the extruder and is heated to fusion temperature, it gels, and the extrudate is essentially the same quality as that obtained when compounded polyvinyl chloride material is extruded. When extruding plastisols the throat of the hopper is sealed and the liquid is pumped to it under pressure.

When pelletized material is being fed to the machine and no special feeding devices are used the material is simply allowed to flow by gravity into the revolving flights of the screw. The port through which the material is fed is designed to feed the screw flight either tangentially (not undercut) to the outer screw diameter or directly overhead.

3.3 Flat Film Extrusion.

3.3.1 *Process Description.* Typical dies for unsupported flat film extrusion or for extrusion coating are shown in Figure 3-3, in cross section perpendicular to the length of the dies. Such dies are usually fed from one end and mounted in line with the extruder barrel. Film take off systems operate along a line at right angles to the centerline of the extruder screw axis.

In the first die shown, the melt enters through a tear drop shaped manifold which increases in cross sectional area going away from the entrance of the manifold. This is done to decrease the resistance to flow of the melt at progressively larger distances from the manifold entrance. This more evenly distributes or equalizes the flow of melt into the die lips at all points along the length of the die. Additional control of the flow rate and of the film or melt thickness as it exits from the die is achieved by adjusting the opening between the die lips and by using several heater zones along the length of the die to control melt temperature distribution. All inside surfaces of the die which will come into contact with melt should be chrome plated and finished to a high polish because the slightest surface irregularities will result in gauge variations, striations (parallel grooves), and weakened film.

Such dies may also be fed from the center, in which case the die would be mounted at right angles to the extruder and the flow of material through the take off system would parallel the direction of extrusion. In this case, the cross section of the feed manifold would be minimum at the center and would increase toward each end of the die. Both types are used for unsupported film extrusion and for coating work.

Temperature variations along the die length can cause changes in dimensions and characteristics of the extrudate. Therefore accurate control of heat distribution to attain temperature uniformity along the die length is mandatory. Heaters on the die should have an input capacity of about 200 watts per inch of die length and should be zoned to provide uniform heating of the die. In addition to better quality of extrudate, warpage of metal die components is prevented by uniform heat distribution.

Die temperatures should generally be set to the same temperature as the melt issuing from the extruder and entering the die, to prevent setting up of temperature gradients in the melt. Adjustments of die temperature require about 15 to 20 minutes to come to equilibrium with the melt within the die, therefore such time must be allowed in order to accurately check the extrudate profile at a given temperature setting.

Low die temperature settings generally produce rough film surfaces and lower film thickness at the film edges. It is common practice to operate wide manifold dies with the set temperatures at the end 5 to 10 degrees hotter than at the center. The higher temperature at the ends lowers the viscosity of the melt and thereby counteracts the lesser material feed caused by the lateral pressure drop in the manifold.

As the resin film leaves the die it is "drawn down" by pulling it away from the die at a speed higher than the issuance speed. This results in the width and thickness of the extrudate "necking down" to a smaller width and gauge than that which issued from the die. The film width and thickness reductions are directly proportional to the speed differential between the die and take off web velocities.

Cooling off the extruded film may be achieved by one of the following methods depending on the end properties desired in the film. The methods include: (1) casting the hot film onto temperature controlled metal rolls. (2) cooling with chilled air. (3) passing the film through a controlled temperature water bath and (4) any combination of the above. The method selected and the rate at which cooling takes place affects film surface quality, clarity, flatness, gage, physical and mechanical properties and over all production rate.

Films may in effect be calendered as they leave the die and are cast on the cooling roll by placing another roll on top of the cooling roll. This roll may have a plain surface or be engraved so that the film is embossed at the same time. This method is often used to control gage, but the initial gage of the film entering the system must be fairly uniform to insure full contact of the calendering roll. Also the calendering roll should be in good alignment with the cooling roll, or it will introduce gage or film thickness non uniformity.

Air is not used to any great extent as a cooling system, since air blasts can introduce film distortions. In addition the air cooled films are cooled more slowly and are therefore not as clear as those cast on polished chill rolls.

Films leaving the die never have a clean square cut edge and therefore require that edges be trimmed. Trim scrap is usually collected by a pneumatic conveyor which feeds the material to a grinder and thence immediately hack into the extruder for rework, or it may be collected and stored for rework at some later time. After trimming the film is wound on rolls preparatory to storage or shipment. The finished rolls may be further processed into narrow widths by either slitting the rolls with a knife or saw without rewinding, or using more conventional slitters to slit the film into reel width as it is rewound. Flat film can currently be produced in any width up to about 72 inches and in thicknesses up to 10 mils (by definition of film). The most widely used gages run from 0.5 to 5 mils.

3.4 Extrusion Coating.

3.4.1 *Process Description.* This process is similar to flat film extrusion, except that some means is provided at take off for feeding the substrate to the coating station below the die. A pressure roll is provided to press the emerging film from the die against the substrate to insure intimate contact and promote good adhesion. Figure 3–14 shows a schematic cross section of a typical extrusion coating setup.

Adhesive strength of coatings to substrate is directly proportional to substrate porosity and inversely proportional to the resin melt viscosity. Greater adhesions are therefore obtainable by using more porous substrate and lower melt viscosity resins and by increasing temperatures to reduce resin viscosities.

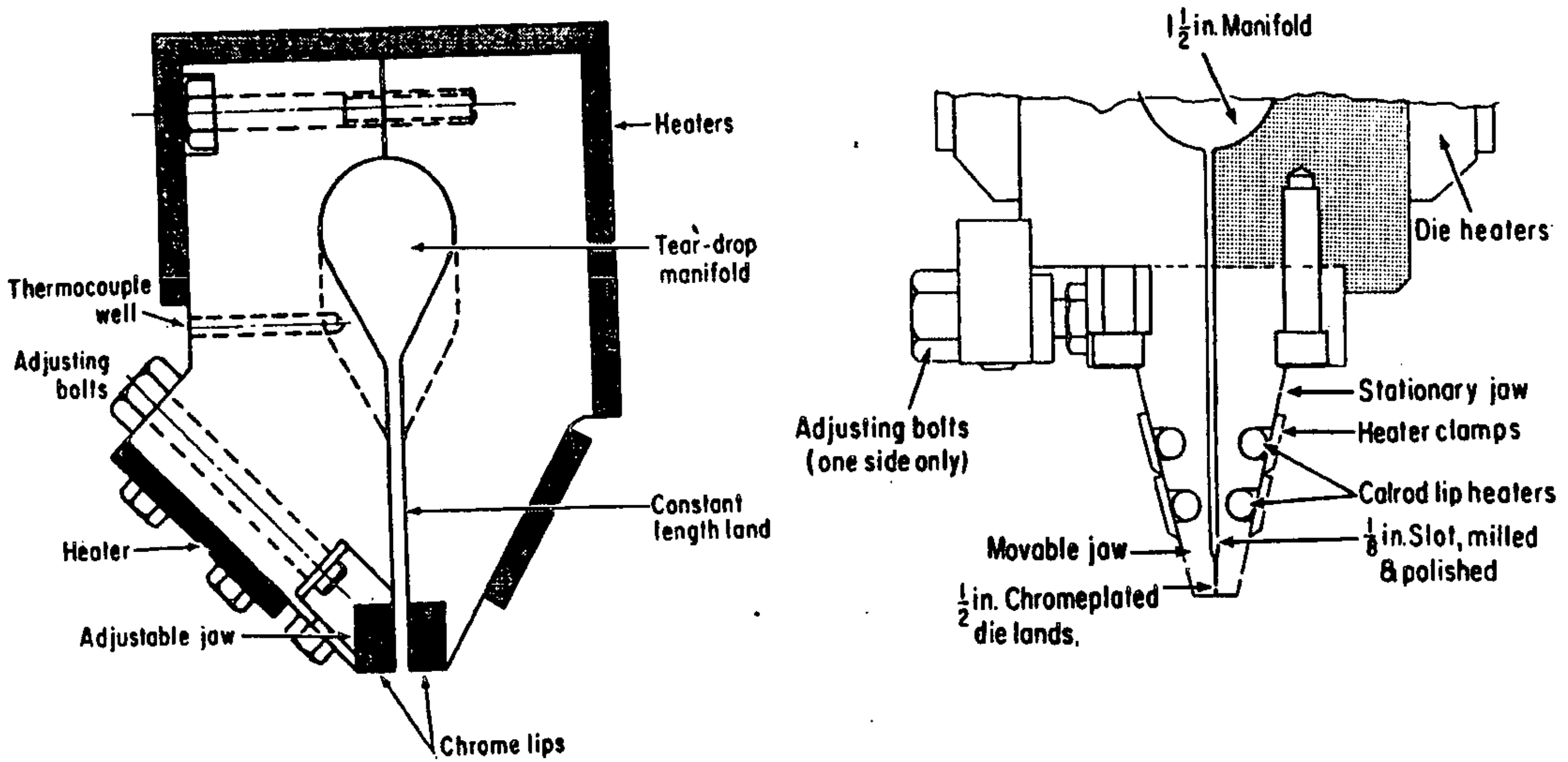


FIGURE 3–3. *Two different designs of flat film extrusion dies. Note lip heaters in die above for precise temperature control.*

Chemical nature of the resin (polar groupings), surface tension of resin relative to surface tension of substrate and cleanliness of the substrate also have an effect on adherence of coating to substrate.

Production rates are limited mainly by the adhesion of the resin and the drawdown performance of the extruded film. Currently webs up to 13 feet wide are coated commercially with polyethylene at speeds from 125 to 500 ft/min and coating thicknesses from less than 0.25 to 2.5 mils.

The extrusion coating system eliminates the use of solvents, drying, solvent recovery systems fire hazards and toxicity of solvent vapors. Also, extrusion coatings have an advantage over hot melt and calendered coatings as thin as 0.25 or less may be applied, whereas the hot melt and calendered coating lower limits are 1 and 2 mils, respectively.

3.5 Blown Film Extrusion.

3.5.1 *Process Description.* In this process, the molten resin enters a ring shaped die either through the bottom or the side. It is forced around a mandrel inside the die, shaped into a sleeve, and extruded through the die opening in form of a comparatively thick walled tube. The tube, while still molten, is expanded to a "bubble," a hollow cylinder of desired diameter and correspondingly lower film thickness. The expansion is accomplished by the pressure of internal air entering through the center of the mandrel. Once the bubble has been expanded to the desired diameter for the required lay flat width, no additional air needs to be let in through the mandrel to keep the "bubble" blow up dimensionally stable.

The bubble after a few yards of free suspension, is flattened between two nip rolls. Usually the bubble is extruded and pulled upward as depicted in Figure 3–5 which is a schematic drawing of the process. Downward extrusion is occasionally used for very thin gauge film production because the upward draft of warm air will help to cool the bubble at the nip roll take off point. However, the bubble is usually cooled by air from a ring around its lower end as shown in Figure 3–5.

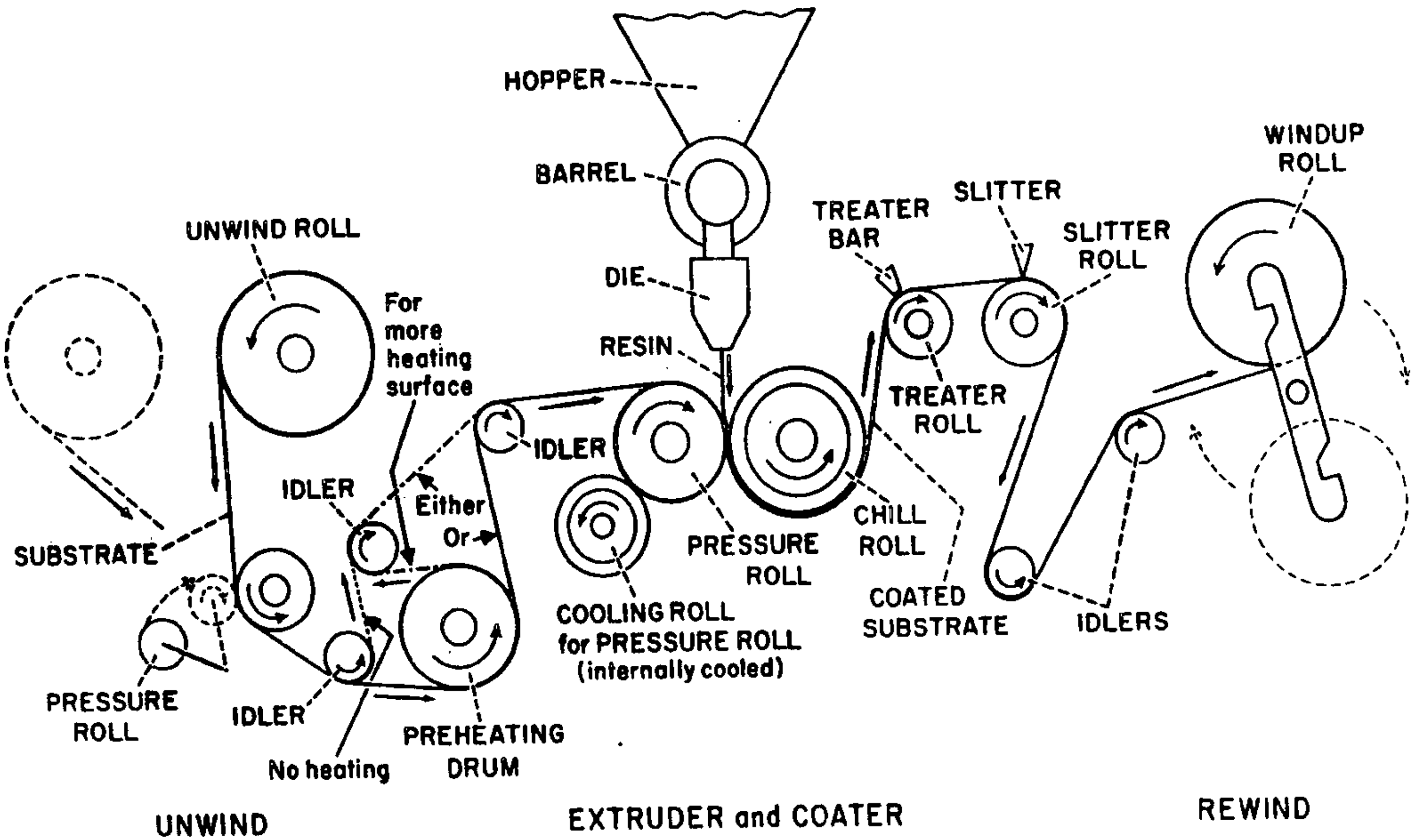


FIGURE 3–4. *Schematic cross section through the entire extrusion coating set up, with unwind and rewind equipment.*

Take off speeds range from 35 to 300 feet per minute, on small die diameters in the production of blown film down to gauges as thin as 0.35 mil. Fast take off speeds are profitable and there is no particular risk for thin gauge film; thicker gauges require a large volume of cooling air at fast take off speeds.

Air pressure and all other factors affecting film gauge, such as extruder output, take off speed, temperatures along the barrel, must be strictly controlled to obtain uniform film gauge. Control of the quantity and direction of air is just as essential in this respect. Most important, the width of air is just as essential in this respect. Most important, the width of the die opening, that is, the position of the mandrel within the die, must be well adjusted to obtain uniform film gauge. Variation of ± 10% in gauge thickness will usually require adjustment of one of the aforementioned gauge controlling factors, even though the extruded film is otherwise acceptable.

In blown film extrusion, barrel temperatures are comparatively low. Lower resin temperatures permit faster production rates without the "frost" line (Fig. 3-5) too far above the die. The frost line is the ring shaped zone where the bubble frequently begins to appear frosty because the film temperature falls below the softening range of the resin. When adequate cooling of the hot film is provided, melt temperatures may be increased. In practice, the frost line is not always visible and therefore it may be defined as that line around the expanded tube ("bubble") where the final diameter is reached. When visible, the frost line is a level ring shaped zone around the bubble. The height of the frost line increases with tube diameter and may vary between 4 and 24 inches above the die face for tubing up to 3 feet in diameter. The recommended height range is 8 to 18 inches above the die. The higher the frost line, the more critical gauge control becomes. The frost line is essential controlling molecular orientation in the machine and transverse and thereby, some physical properties of the film like tear, tensile and impact strengths.

The frost line can be lowered by means of extruder output or take off speed. However the preferable way of adjusting the height of the frost line is by means of the volume of cooling air blown against the bubble as resin output goes up, the frost line height goes up. The height may be lowered by letting more cooling air blow against the bubble.

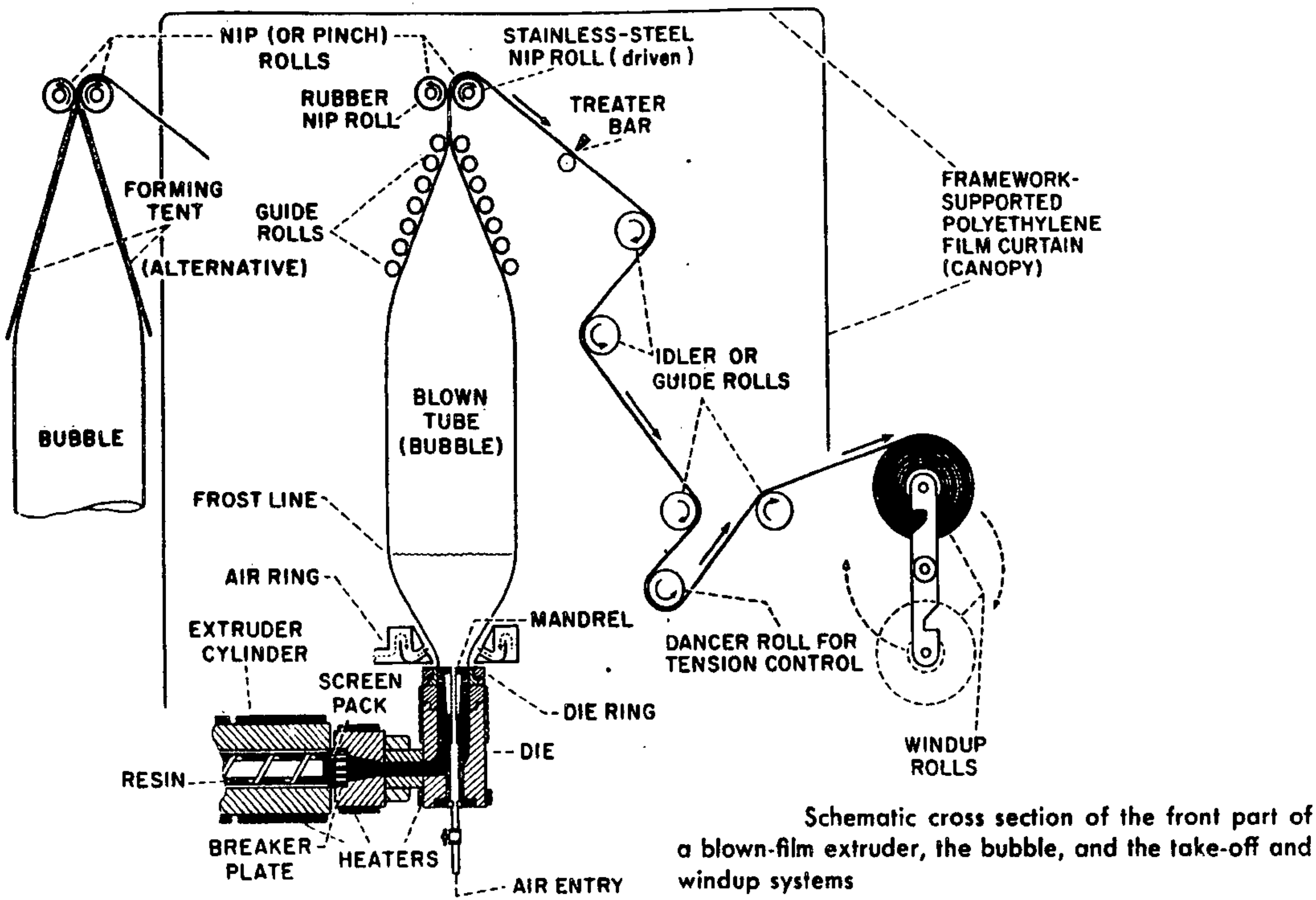


FIGURE 3–5. *Schematic drawing of the blown film process.*

Raising the frost line gives the film more time to solidify. This results in a smoother surface and thus, higher clarity and gloss. When it goes too high film blocking or sticking may occur. To overcome sticking cool water may be circulated through the stainless steel nip rolls.

The frost line must always be as level as possible. The primary cause for a rising or dropping frost line in spots may be improper adjustment of the die opening. This may cause variations in film thickness and thereby, non uniform film cooling and a non frost line. A non level frost line may be caused by uneven cooling around the air ring.

The die has one or more ring shaped heating zones, and its temperature should be the same as the melt temperature. Both should be as high as the extrusion equipment permits to obtain the best appearance. At too high a melt temperature, however, the resin viscosity may become too low, causing the bubbles to become unstable and possibly break. It is customary to start the blowing at lower temperatures, and gradually raise the temperature to determine the optimum temperature for the particular resin being used.

The ring shaped gap (die opening) between the mandrel and the die ring ranges from 15 to 35 mil. There are some dies in which openings can be varied. Larger openings increase output slightly but make gauge and frost line more difficult to control. It also tends to promote film snap off, particularly when the film is drawn down to a gauge of 0.5 mil or less. There is a relationship between die opening and film gauge which is known as normal drawdown. The value for normal drawdown varies between 15 and 16 and is the die opening divided by the film gauge. For example, if one wishes to produce a film gauge of 1.5 mil he would set the die opening at between 15 and 16 times as much or between 22.5 and 24.0 mils.

The most important adjustment of the blown film die is its centering to obtain a uniform gauge. Once the die ring is fairly well centered by adjusting bolts, small corrections in film gauge thickness can be made by moving the cooling air ring slightly.

Any space between the bottom of the air ring and the die face should be enclosed to prevent air from being sucked onto the film. If air is allowed to reach the film in this area, it may cause uneven film cooling and consequently, uneven gauge.

Operating with the right blow up ratio in blown film extrusion is necessary to obtain the best film optical and strength properties. Blow up ratios between 2 to 1 and 3 to 1 will result in optimum film properties. The blow up ratio is the bubble diameter divided by the die diameter. This ratio must not be confused with the lay flat width which is the film width after the film passes through the nip rolls. Lay flat width is 1.57 times the bubble diameter. Therefore, blow up ratio equals $\frac{1}{1.57}$ or 0.637 times the lay flat width divided by the die diameter. From these relationships one can compute either the blow up ratio if the lay flat width and the die diameter are known, or the lay flat width if the blow up ratio and the die diameter are known.

The reason that a number of optical and physical properties are highly dependent on blow up ratio is easy to understand if one examines the nature of the polymeric resin which is composed of long, chain like molecules. As the film tube is pulled up and thus stretched by the nip roll take off, the molecules tend to line up in the machine direction. They stay oriented in this direction if the bubble is not expanded. The film will be easier to tear in this direction than in the transverse direction. Most commercial films have this type of uneven orientation. However, in blown film extrusion, the blown film is caused to stretch in both the machine and transverse direction and causes a more balanced molecular orientation in all directions. This better balance in molecular orientation, in turn affects the film optical properties and some of its strength properties in a favorable manner. Generally the best balance of optical and mechanical properties in both directions is attainable at a blow up ratio of 2.5, but this depends also very much on film gauge, die opening, and take off speed, and the amount of draw down in the machine direction (stretching). Ratios higher than 3 may result in too much orientation in the transverse direction, while ratios lower than 1.5 may result in too much orientation in the machine direction. Low blow up ratios will cause hazing and mechanical weakness in the transverse direction. High blow up ratios may increase the tendency of the film to wrinkle on the wind up roll, increase weakness in the machine direction, and decrease output slightly.

The blown film method is used for polyethylene, polyvinylidene chloride and nylon, and could be used for any thermoplastic having adequate melt viscosity, oxidation resistance, etc.

The blown film process achievements are (1) balancing the physical properties of the film in two directions and (2) ability to increase or decrease a given physical property. Application advantages include the fabrication of bags with but one heat seal instead of the two seals required for conventional flat film.

However, extrusion of flat films has certain advantages over blown films. These are, faster production rates, easier and better width and thickness control, faster printing speeds and can be printed on both sides at one time whereas the blown film can be printed only on one side at a time.

3.6 Chill Roll or Cast-Film Extrusion.

3.6.1 *Process Description.* In this process, the hot melt is extruded through a die slot and is cooled by the surface of two or more water cooled chill or casting rolls (see schematic, Fig. 3–6).

The extruder may be a conventional flat film extruder with a length to diameter (L/D) ratio of 20:1 or greater, used in conjunction with a "T" or "coathanger" die. The chilling and take off machine is more elaborate and different from that used for flat film extrusion.

The hot resinous melt is dropped onto the first chill roll which it contacts tangentially. The alignment of this roll is critical in relation to the falling film. Wherever wrinkling of thin film occurs on the chill rolls, the first roll must be carefully repositioned in relation to the die lands.

The optimum temperature for a given resin should be established and it is advisable to control the temperature gradient across each roll to within 3° C. maximum variation.

A highly polished chromed surface on the first roll improves the gloss and smoothness of the film.

The use of the multiple number of chill rolls aids in the cooling and setting of the film. It is also desirable to maintain the shortest possible distance between the chill rolls and between the last chill roll and the wind up equipment. Short distances minimizes whipping of the film, which is one cause for the wrinkling of the film on the roll.

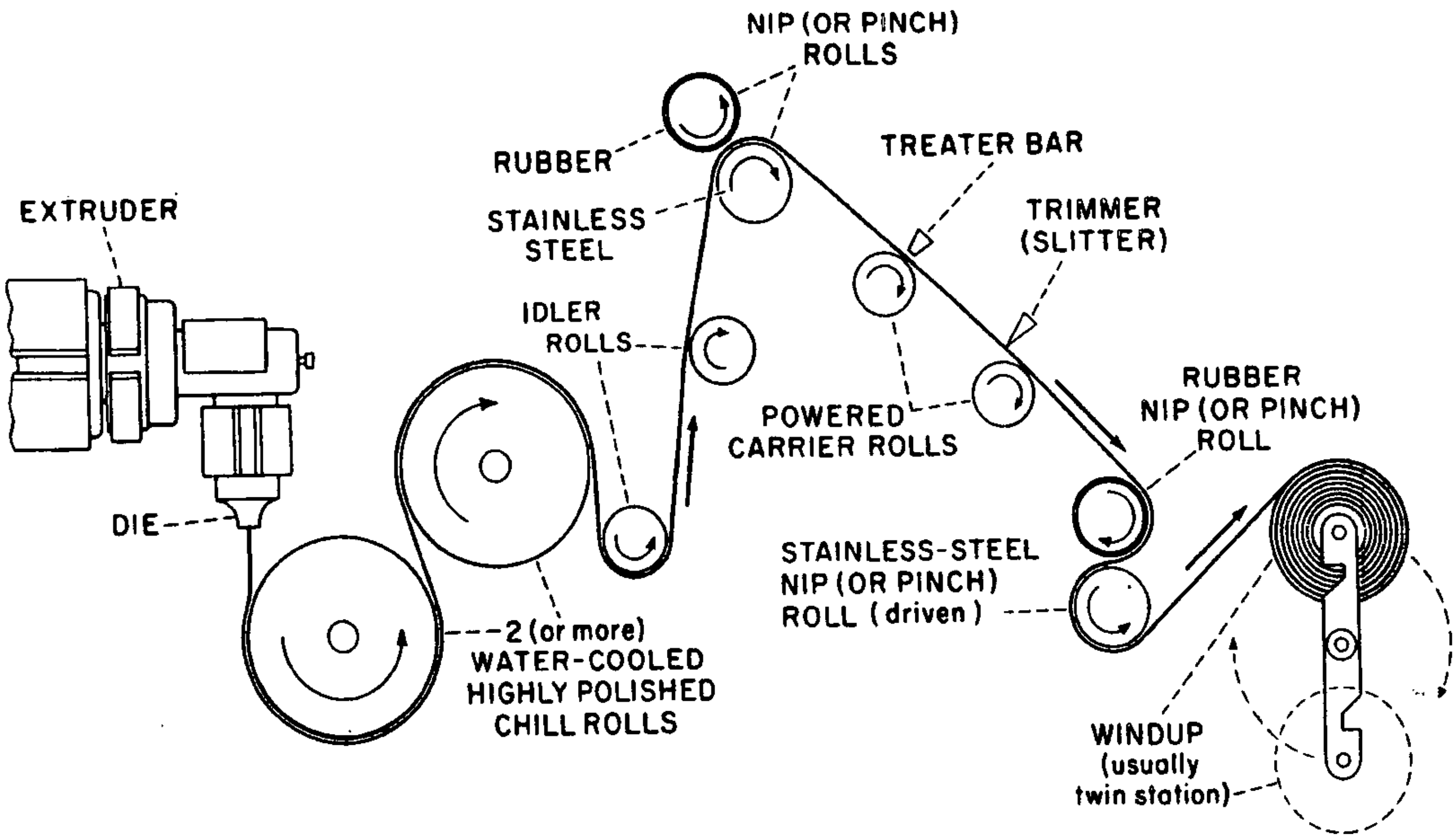


FIGURE 3–6. *Schematic drawing of chill-roll film extrusion equipment.*

The frost line of the film on the first roll should be straight because a crooked or jagged line would indicate non uniform cooling or gauge and this could result in warped and puckered film.

The die lands should be comparatively long—minimum 5/8 inch to smooth out the film. Striations across the film may present a problem in thin gauge cast films produced at high take off rates. Apparently, several factors contribute to striations. Among these are local temperature differences in the hot web produced by non uniform metal masses in the die jaw plates, possible film shrinkage in the transverse direction on the casting roll, fundamental resin properties, uneven die settings, poor flow conditions during film formation, and unrelieved strains in the film.

In cast film extrusion, the take off pull is supplied by driven rolls, over which the film moves on its way to the wind up station. Nip rolls may be included in cast film equipment close to the slitter or the wind up rolls to be available in case trouble develops in these sections.

Film casting permits increased outputs over other methods. Gauge thickness can be controlled with a greater degree of uniformity and optical properties such as gloss and freedom from haze are superior to those films produced by other means. However, cast films lack uniform molecular orientation and therefore do not possess the same toughness as blown or water quenched films which will be discussed next.

Process variables such as extrusion temperature, chill roll temperature, take off speed and resin variable such as melt temperature and density have pronounced effects on the ultimate cast film properties. For example, increasing extrusion temperatures can improve the gloss by as much as 50% and lower the haze by as much as 70%. However, rising temperatures will decrease film strength. While this decrease is not nearly as significant as the improvement occurring at the same time in optical properties, it must be taken into account whenever film strength is critical.

A decrease in casting roll temperature reduces haze slightly, slightly decreases yield strength, decreases Elmdorf tear strength, and increases dart drop impact strength. There is also a pronounced tendency to increase puckering.

Film take off speeds between 50 and 200 ft/min have only negligible effect on the neck-in of film made from low viscosity resins. When resin of high viscosity are used, neck-in is increased with increasing take off speeds.

It was found that increasing the density of polyethylene from 0.917 to 0.933 g/cu. cm. improved gloss and decreased haze. Also, yield strength was very favorably affected and so were friction factor and Elmdorf tear strength in the transverse direction. Neck-in increases linearly with density.

An increase in melt index (decrease of viscosity) improves gloss and reduces haze, tensile strength, and impact strength. Neck-in increases with the logarithm of the melt index.

In view of the great variability in film properties which are obtainable, a combination of resin properties and extrusion conditions must be established for each specific application.

3.7 Quench-Tank Film Extrusion.

3.7.1 *Process Description.* As the process name implies, the hot melt resin is extruded through a die and the film is cooled in a quench water bath. From under a polished guide shoe or roller in the bath, the cooled film is pulled out by a pair of nip (or pinch) rolls. The "bead" is trimmed and the film is wound up on a wind up roll.

The air gap, that is the distance from the die to the surface of the quench bath is generally between 1 and 5 inches. A greater air gap may result in too much neck-in and beading of the film web at edges. Cleaning and changing of dies is made easier if the height of the quench tank is adjustable.

The quench water temperature, just as the melt temperature, has a pronounced effect on the film properties. With extrusion temperature remaining constant, lower quench temperature improve slip and resistance to blocking, while higher quench temperatures result in film easier to wind without wrinkles.

Good water temperature control in the quench tank is obtained by water circulation. Dirt must be kept out of the quench water, and turbulence which will cause wrinkling must be prevented.

3.8 Sheeting Extrusion.

3.8.1 *Process Description.* Heavy gauge flat film material more than 10 mil thick is called sheeting. The upper limit for extruded sheet is generally 1/4 in. Sheet thicker than that is usually cast or compression molded from pelleted polymer or from a sandwich of thinner sheets, although extrusion of 1 inch sheet is being done.

Extruders used for sheeting are of conventional design, however the dies and take off equipment are somewhat different (Fig. 3–7).

The polymer is fed to the extruder through a hopper. Frequently, a pneumatic or mechanical hopper loader is used. A higher extrusion rate can be obtained by preheating the polymer, be means of a hopper loader dryer. Pre heating also eliminates any water which may have condensed on the polymer during storage or following transportation into a warm, humid atmosphere.

In general, a screen pack consisting of 20-80-120-mesh screens is ample. However, the actual screen pack depends on the extruder type, increasing in mesh as more mechanical working on the polymer is required.

Sheeting is extruded from a die similar to a flat film die. There are, however, two basic differences—the use of an adjustable choke or restrictor bar and longer die lands (Die lands are the parallel surfaces of the die jaws through which the material extrudes). In addition, sheeting dies are usually more heavily constructed to reduce warping of the die lands.

The choke bar is an adjustable bar located between the manifold and the die lands to distribute the molten polymer uniformly. Used to smooth out gross variations in gauge, the bar is usually set at the beginning of an extrusion run and is not changed during the run.

Length of the die lands may vary with sheet thickness. However, since die pressure increases with die land length, the lands should not be longer than necessary to insure high sheet quality. For high quality sheeting the surface of the lands must have a high polish. One of the die jaws is adjustable to permit making minor changes in die openings to maintain close control on sheet gauge uniformity. The die opening should be set about 10% wider than the desired thickness of the finished sheet.

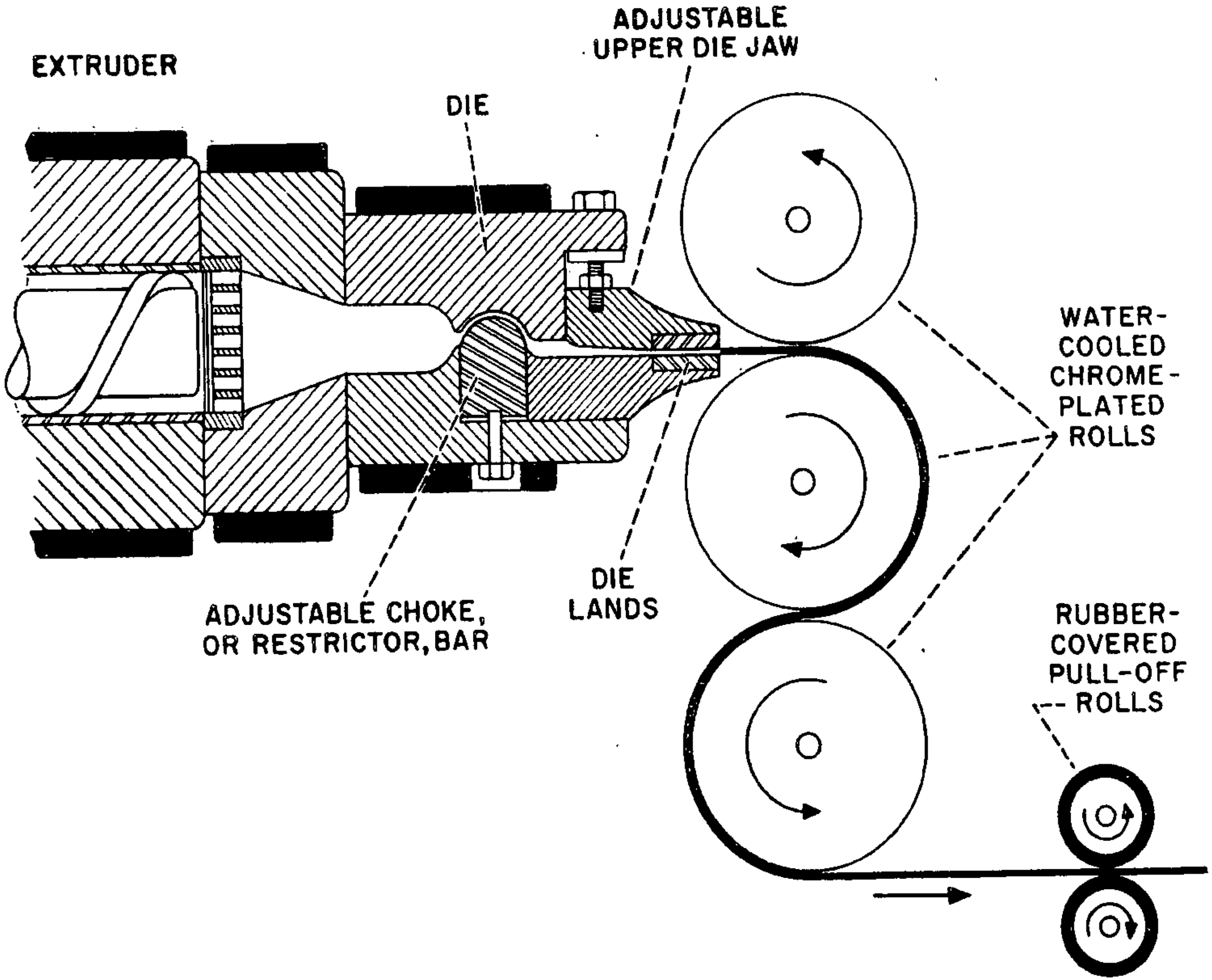


FIGURE 3-7. *Cross section of a sheeting die and take-off unit for sheeting.*

The take off unit for sheeting usually consists of a vertical stock of three driven, highly polished, chrome plated rolls and a pair of driven, rubber covered pull off rolls. The chrome plated rolls serve three purposes —cooling, gauge control, and imparting a desired finish to the sheet, such as a high polish or some embossed pattern. The cooling rolls are generally of twin shell construction to permit close temperature control of the surface. The coolant is usually water of closely controlled temperature. The diameter of the rolls is generally in the range of 8 to 12 inches, depending on the linear speed of the sheet and the amount of cooling required. The rubber rolls serve for tension control and as a pull off device.

The spacing between the top and middle rolls should be set 5 percent more than this thickness. The spacing between the rubber rolls should be usually about 5 percent less than the sheet thickness, to maintain a uniform pull on the sheet.

The variable speed drive for the take off unit must have very uniform speed. It must be easy to adjust to permit making smaller changes in speed.

The framework for the take off unit must be relatively free of vibration, since, even slight vibration may cause a wavy appearance of the sheet and pulsating variations in the gauge.

Sheet up to about 0.030 inches in thickness can be rolled up like film. Sheet thicker than that should be cut to the desired length and stacked as flat sheet.

The screw is generally run neutral, that is with no internal cooling. The melt temperature should be high enough to yield a high quality sheet and low enough to facilitate processing. Die temperatures should be set to maintain the melt temperature.

Roll temperatures have a decisive influence on the quality of the finished sheet. If the rolls are too hot, the sheet will not be cooled sufficiently for easy handling and will tend to curl in the transverse direction. If the rolls are too cold, the sheet will curl in the machine direction, resulting in a pitted surface.

3.9 Profile Extrusion.

3.9.1 *Process Description.* A "profile" may be a continuously extruded product of any cross section. However, by common usage in the plastics industry, a profile has a more irregular or more complex cross section than any of the products already discussed, and generally, the relative over all size is small.

The equipment for the extrusion of profiles resembles that for heavy gauge film extrusion, but much faster take off rates can be used. The die, take off and wind up or shear off equipment are different.

Profile dies offer some unique design problems. It is the function of the profile die to deliver the preplasticized resin stream from the extruder screw in the desired cross sectional shape at constant velocity to the cooling and postforming process. The die must shape the plastic stream, and equalize its velocity throughout its cross section. Contrary to expectations, a rectangular die will not produce a flat cross section in the extruded material. This is because more friction occurs at the edges of the die, so that the cross section will taper at the edges. In order to compensate for this effect, the die is made concave toward the center if a rectangular section is desired. It is also true that a die used for the production of tubing is not necessarily circular. For tubing a die forms the outside of the tube, while a core or mandrel, supported by a "spider," forms the inside. Air pressure of about 1 to 3 psi is sometimes fed through the "spider" to the inside of extruded tubing in order to prevent collapse of the tubing before it is hardened after leaving the die. "Spiders" supporting a mandrel against the inner walls of the die should be located well "upstream" to prevent die, or weld, lines from forming in the extruded pipe. Tube imperfections may also result from dies which are not smooth and from poor or complete lack of streamlining in a die. Any "dead spot" in a die can cause resin hold up and intermittent "sloughing off" of degraded resin into the tube or pipe wall.

For profile extrusion the melt is forced out at a comparatively low temperature, and in a rather viscous state. After the melt is extruded through the die various procedures may be used for chilling and sizing the profile.

As previously mentioned, the cross section of the die land is neither equal to nor directly proportional to the size of the desired extrusion profile. During the cooling and drawing steps, the melt is reduced in size. The amount of reduction is not uniform in all directions and will vary with material cross section, method of cooling or post forming, rate of extrusion, process conditions, and degree of orientation required. For these reasons profile extrusion is an art rather than a science.

Sizing and cooling may be accomplished by mandrels (water or air cooled), internal air pressure, air cooled internal and external sizing rings and water cooled forming boxes.

After having been cooled sufficiently, the profile is frequently drawn through some device to check the width and gauge of the cross section prior to shearing the plastic shape to the desired length or in the case of tubing or pipe, for wind up on a friction type clutch assembly.

The draw or pull roll (or pipe take off equipment) is located immediately after the cooling station. The relative speeds of the take off equipment and the extruder are important in controlling size. The pull off traction unit must firmly grip the extruded form without slipping and must have a variable speed control in order to change speeds for different materials.

Whenever design permits, it is good practice to use uniform wall thicknesses and reduced corners when intending to use the profile extrusion method.

3.10 Wire and Cable Coating.

3.10.1 *Process Description.* Wire and cable coating is a specialized form of extrusion and is usually done only by companies engaged primarily in the production of wire and cable with all types of insulating materials, as opposed to custom extruders. Plastics most commonly used for wire coating are polyethylene and elastomeric vinyls, with nylon and fluorocarbon used mainly for special applications where insulations are needed that must be able to stand up under high temperatures.

Cross head dies, similar to the one shown schematically in Figure 3–8, are used for wire coating and may also be used for cable jacketing operations.

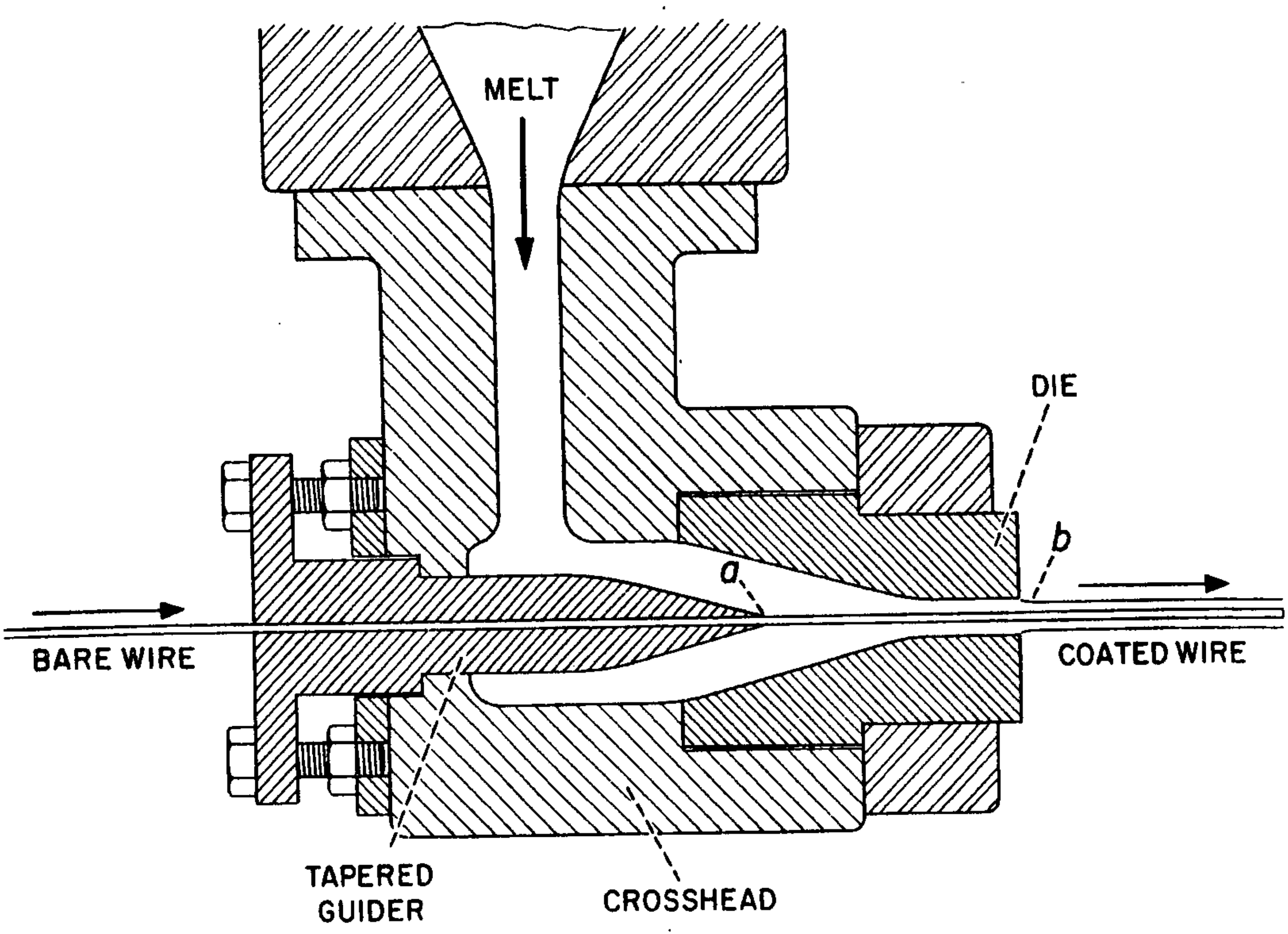


FIGURE 3-8. *A crosshead holds the wire-coating die and the tapered guider.*

In wire coating, the bare wire is introduced into the rear of the cross head and passes through the mandrel and guider tip. Channel space in the head is kept to a minimum to avoid hand up areas and to insure uniform melt pressure distribution around the wire being coated. The die design shown in Figure 3-8 is used in the so called "pressure technique" in which the melt is applied inside the die or extrusion head while still under extruder pressure.

Another wire coating technique is the "tube on" method. In this case, the die design is similar to that in Figure 3-8 but the guider tip protrudes beyond the face of the die. When this type of die is used, the tubing of insulation is formed first and then drawn down onto the wire after the wire leaves the cross head extrusion die.

Die design can significantly affect the surface quality of the coated wire, especially when working with the thin coatings or at high coating speeds. Ultra streamlining will alleviate these difficulties. Also, land length should be provided in accordance with the type of wire produced; short lands should be used with small diameter extrusions while lengths up to several inches are more successful with large diameter heavy coatings. As in all extrusion work, close control over the die temperature is mandatory.

Coating thickness may vary from 5 mil to more than ½ inch. High wall thickness may be obtained by more than one pass. The coating operation of the die is often measured by its draw down. Draw down is the ratio of the cross sectional area through which the melt is extruded (at a, Fig. 3-8) to that of the finish coating (at b).

The thickness of the coating wall, the resin type used, and the type and condition of the extruder and its components determine the temperatures required for wire coating. For thin coatings which present less of a cooling problem, temperatures can be higher than for thick coatings. High extrusion temperatures generally result in coatings of better physical properties and in higher production rates.

Polyethylene coated 22 to 26 gage wire is extruded at speeds up to 2000 ft. per minute using a cross head die and temperature between 480 and 580° F. Because of the high rate of speed, water adjacent to the surface of the submerged coated wire tends to be carried along with it. Unless this is prevented, the water acts as a thermal insulator as it heats up from the hot wire while being carried along. To improve cooling, the wire is pulled through a series of wipers or sponges while submerged in order both to wipe off the hot water film and to allow cool water to contact the coated wire.

When thick wire coatings are involved, slow cooling of the plastic is a must if good adhesion of the insulation is to be maintained and voids in the insulation itself are to be prevented. If quenched quickly, the coating tends to shrink away from the wire. Water at about 175° F. in the first section, and getting progressively cooler as the wire travels through the bath is recommended. With thin coatings, the water in the first section is controlled at about 165° F. Cooling troughs are about 20 ft. long.

Preheating of the wire removes moisture, oil and other foreign matter, it also pre-expands the wire so that on cooling there is less of a differential in shrinkage between metal and plastic.

It is desirable to use rapid quenching when extruding thin coatings of crystalline plastics such as polyethylene or polypropylene because it induces the formation of a more amorphous type of structure in these plastics and thereby results in a more flexible type of coating.

In addition to the usual take off equipment for cooling and winding the wire, the extrusion line usually incorporates a section of equipment which tests the wire for pin holes and other faults in the insulating coating as it moves along at high speeds. The equipment usually consists of a device which applies a high voltage charge between the outside of the coating and the metal conductor; and faults cause visible electric arc discharges. In addition to insulation checking, there are diameter gauges and eccentricity gauges which are employed for controlling these variables.

In cable coating, an aluminum or steel sheathed cable is fed into the cable coating die. If the cable contains many plastic coated wires it is necessary to hold the extrusion temperature low enough to prevent the melting and subsequent fusion of the coated wires which make up the cable. This temperature limitation places greater demand on some cable coating resins, because they must flow well at temperatures lower than those generally used in wire coating.

The next step after coating the cable is cooling. Cable is usually water cooled, the cooling trough sitting flush with the end of the die. Faster cooling prevents the possible fusion of coated wires. The coated cable then enters a diameter gauge which checks the gauge uniformity of the coating. From there the cable goes to the windup unit. Usually, a tension unit will be set between the diameter gauge and the windup unit to maintain constant, uniform tension on the cable.

In addition to requiring better flow properties, cable coating resins must have greater resistance to environmental attack and greater strength than wire coating resins. Cables may be underwater, underground, in ducts, or in the atmosphere. It must be capable of withstanding extreme conditions in any of these places for long periods of time. Cable which is placed under water often is subjected to internal air pressure to prevent the entry of water should the cable rupture. This requires greater strength in the coating than normally required for wire. Furthermore, many conduits contain lubricants which act as stress cracking agents on certain polymeric coatings such as polyethylene.

The windup capstan provides the main pulling force as the wire or cable is drawn through the coating thickness, provided constant extrusion speed is maintained. With thinner coatings, continuous windups are generally employed because of the high speeds involved. If the speed of the output capstan is not constant, the speed of the wire or cable through the die cannot be constant either, and this will result in outer diameter variations of the coated wire or cable.

There are a few principles which can be used as guides for obtaining the best long-lived wire and cable coverings at the lowest possible cost:

Variations in the outer diameter of coated wire or cable must be reduced to a minimum. The minimum outside diameter is usually determined by customer specification. Variations in the outside diameter above this minimum use extra quantities of resin. Highly uniform electrical grade resins with uniform flow characteristics will reduce excessive variations and provide easier control at high production speeds.

CHAPTER 4

THERMOFORMING

4.1 **General.** Thermoforming is one of the fastest growing segments of the plastics industry and is expected to continue growing at a rapid rate. The process consists basically of heat softening a thermoplastic sheet and then applying a force (usually differential air pressure to the sheet so that it conforms to the shape of a solid mold. There are many variations to the basic process which will be subsequently described. The technique has gained wide acceptance for large, relatively flat contour shapes, such as door panels, contoured packages, contour maps, protective helmets and all sorts of containers.

4.2 Thermoforming Equipment.

4.2.1 *Basic Equipment.* Most thermoforming machines are fully automated, only requiring the operator to insert the flat plastic sheet for heating and to remove the formed object from the machine. Machinery in use today is equally divided between sheet fed "batch forming" and roll fed "continuous forming." In some cases, the continuous former can be fed right out of an extruder. Batch forming is generally used where the sheet is too thick to be rolled up; its major use is in the forming of inner door liners of refrigerators. Three stage rotary machines are used for this type of product. Such machines consist of a loading/unloading station, a heating station and a forming station. The heaters and molds are fixed in their stations, while three frames set 120° apart cycle the sheets. Some manufacturers use two heating stations thereby making a 4 station machine. In a typical cycle, a rotary machine can form a high impact polystyrene sheet 36 x 60 in., in size and 110 mil thick in 2½ minutes.

Single station machines are also still used. Loading, heating, forming and cooling is done at the same station; the loading and unloading is done by hand, but the forming sequence is automatically controlled. Production rate is generally slower since operations must be carried out sequentially.

A few machines try to achieve a compromise between the rotary and the single stage by having two mold stations. In these units, one sheet is molded and cooled while a second is heated. This type of machine is especially useful for making simple products from thick polyethylene sheet, where cooling limits the rate of production and molds are inexpensive.

Continuous machinery is popular for making thin walled containers and disposal cups and lids. It generally consists of fixed heating, molding and trimming devices, through which the sheet moves intermittently. In some set ups, the trimmer is a separate unit but it is usually still located in line with the other machinery.

Continuous machinery is used to make several small items simultaneously. This means that the end user must make a choice between large or small molding areas in line with the following criteria:

(a) Large area molds produce more product per cycles, and therefore offer increased output rates.

(b) Large area molds cost more, and require larger, more expensive forming machinery and trim fixtures.

(c) Large area molds are heavier; this reduces the maximum speed with which they can be moved—thus increasing cycle time. This criteria applies, of course only for products with rather thin walls, where machine motion is the limiting factor in determining speed, rather than the heating or cooling cycles.

(d) Large area molds have less edge per unit area, and thus have a lower trim percentage.

In practice, both large and small area molds have their utility. Smaller, fast machinery (1 to 3 sq. ft. of molding area) is used where complex molds, pressure forming, or short runs are involved. Large machines (5 to 8 sq. ft. of molding area) are more commonly used for the simpler lids and round containers that may be required in large volume.

Ten cycles per minute is not an uncommon production rate on the large machines, some are built to run as high as 15 cycles per minute, providing products are thin enough to be heated and cooled in this short period of time. Fifteen cycles per minute is a typical speed for modern small area machines, with some models operating as fast as 40 cycles per minute where the cooling time required permits it.

The need to choose between small and large areas also exists in the batch type, single stage forming machines. However, it is not as vital a factor with such machines since the bulk of this market is in large parts for appliances and vehicles that are made at rates of one or two parts per cycle.

Of course, other factors such as mold cost, machine out put per dollar invested, trim die costs, trim percentage, material costs, market needs, and product design, all enter into the decision. Each job must be evaluated on an individual basis.

Theoretically, the ideal thermoformer is a machine which consists of two platens, each provided with compressed air and vacuum supply that can be applied at any time and in any sequence and in which the motion and air vacuum operation of each platen is independent of the other.

4.2.2 *Auxiliary Equipment.* Along with the basic thermoforming machine, several other auxiliary units are often needed.

4.2.2.1 *Mold Temperature Controllers.* Water recirculators or temperature controllers keep the forming molds at constant temperature, and are used on many machines (with the possible exceptions of simple or experimental forming units where precision is not important.)

4.2.2.2 *Trimming Equipment.* There are commercial presses, special machines and integral trimmers which all do the job of trimming. The integral trimmer (combined with the mold) eliminates the job of subsequent trimming, but requires precision construction and alignment to insure a neat, sharp cut and also provisions must be made for quick removal of the parts from the forming area.

One method of trimming is based on the use of a horizontal saw. This allows for fast removal of parts from the forming area no matter how irregular the parts are. The cut is relatively rough and because the cut is parallel to the plane of the sheet, it is quite difficult to retain the flange or rim often needed to strengthen the part or to be used in subsequent sealing operations.

Forming systems can be fitted with automatic stackers either at the former or at another place to which the parts have been transported. In some cases, automatic packing and counting devices may be incorporated into the unit.

4.2.2.3 *Lip Rollers.* Lip rollers work by heating and mechanically deforming the softened edges. They are set up either in line with the thermoformer or as a subsequent operation. Three types of lip rollers are commercially available. One machine trims and rolls right on the molds; another feeds the untrimmed molded web continuously into a three stage rotary press which first trims and then rolls the lips of containers.

4.2.2.4 *Heaters.* Heating of thermoplastic is accomplished by radiation or conduction. The radiant heater operates as 375 to 650° C. and imparts the necessary softening required for forming. Heating speeds may be increased by placing heaters above and below the sheet to be formed. Care must be taken to avoid getting the sheet too hot, for it may sag too much and (a) touch the mold, marring the sheet; (b) touch a bottom heater and burn holes in itself; (c) lose sufficient hot strength so that tearing occurs during molding; (d) make unsightly folds when formed; (e) discolor or scorch with or without blistering and bubbling. If the sheet is too cold when formed, webs may also appear and tearing may occur. In addition cold sheet will not fill out details completely; in extreme cases it will not even be drawn completely into or over the mold.

The ideal solution is to make sag help, not hinder the operation, by having the sheet sag into the cavity of a female mold. The male mold can then be mounted as a plug and brought down over the sheet into the hollow created by the sag; the sheet is then forced back up to the mold by pressure or vacuum. If the mold design does not permit this type of solution, then one of the following techniques may be used:

(a) Enclose the volume under the sheet and keep a positive air pressure in this space.

(b) Enclose the space above the sheet and pull a vacuum to prevent sag.

(c) Support the sheet with high temperature elastic bands or film, to be drawn into the mold with the sheet if the mold is below the sheet. Bands or cords must be placed so that their marks on the sheet are not objectionable. If several items are being made, they can be placed so as to fall in between the bands or film.

(d) Deliberately introduce low level orientation into the sheet during extrusion. The internal strains are relieved during heating, and tends to cause shrinkage opposing the sag.

The selective control of heat input to different areas of the sheet is useful and sometimes necessary—first, because there is always heat loss at the frame edges; and second, because using different heat inputs to different sheet areas help to provide uniform wall distribution in irregular molds. Some heaters provide greater intensity at sheet edges while others are wired in independent circuits which can be varied as needed. In the "screening" technique ordinary window screening is hung under the top heater. The screening absorbs part of the heat and causes a differential heating of the plastic sheeting below in a pattern determined by the shape of the screens.

Contact heating has some limited usage, especially in pressure formers. The sheet is mechanically pressed and clamped onto the heater plate around the edges. It is further held firm by (a) vacuum drawn through holes in the heating plate, or (b) by positive air pressure on the unheated surface, or both. Contact heating is not essential for all pressure forming operations, but is almost a must for certain materials, such as thin oriented polystyrene. With oriented polystyrene, contact and clamping holds the material in place against the shrinkage forces released in the sheet by the heat. Also, the heating of thin sheet by conduction is relatively fast; since oriented polystyrene is transparent there is no problem involving the limited absorption of radiant energy. With well designed plates, edge trim can be kept very low. However, contact heating introduces difficulties in plug assist forming (since its use is possible only with complex heater plates). Also, the heater plates and molds are expensive and must be well made to avoid marring and uneven heating.

An operation which is used on a limited scale in thermoforming is preheating prior to feeding sheets to the thermoformer. This procedure is advantageous to use when sheets are thick, or quick heating might scorch or create uneven hot spots on the sheet. It will insure constant feed temperature regardless of ambient temperatures and thereby reduce rejects on fixed production cycles.

4.2.2.5 *Vacuum Systems.* Most thermoforming equipment have built in vacuum systems, while others can be fed from a central system. Vacuum tanks must be appreciably larger than the largest anticipated volume to be enclosed between the sheet and the mold; also, that volume must be capable of being quickly evacuated. In larger machines a 3 to 5 horsepower motor vacuum pump will suffice.

Vacuum adds versatility in sheet manipulation, plus an extra atmosphere of differential force. Many pressure formers rely solely on air pressure to do the forming.

4.2.2.6 *Compressed Air.* In thermoforming, compressed air has many functions, some of which are listed below:

(a) Aids in pre-blowing or pre-stretching sheet.

(b) Warm air passed between sheet and mold or plug aids in avoiding sheet marring and premature cooling.

(c) At 75 or 85 psi will provide the actual forming force.

(d) Cooling the formed parts.

(e) Actuating frame, mold, clamps, trimmers as well as other machine motions.

(f) Conveying formed parts by blowing them from forming area into a receptacle.

4.2.2.7 *Thermoforming Molds and Plugs.* Mold and product design are probably the most important factors in a successful and economical thermoforming operation. Attention to these elements is often neglected, to the point that the thermoformer may be asked to produce a product more suitable to injection or blow molding, or other fabrication techniques.

4.2.2.7.1 *Material and Construction.* Cast aluminum is usually the construction material selected for both mold and plug because of good thermal conductivity, relatively light weight and excellent machinability. Brass, steel or magnesium may also be used. Vacuum molds must withstand approximately 14 psi; while pressure forming molds must be capable of withstanding 100 psi or greater.

Mold wall thickness should be within 3/8 to 5/8 inch where possible, but never below 3/8 inch in order to prevent the possibility of leaks. Mold porosity problems may be overcome by treating the mold cooling chambers with a good grade of boiler sealing compounds.

Molds can be cast in one of three ways:

(a) Coring cooling and vacuum passages into the cast mold.

(b) Casting with cooling tubes and vacuum chambers in sites.

(c) Hollow casting of the mold with tubing soldered to openings in back of mold surface.

Seamless stainless tubing is recommended. The diameter should be 1/2 inch or greater and should be spaced approximately 2 1/2 inches apart to insure proper conductance.

Cored molds are superior in controlling temperature and providing structural strength to withstand forming pressure.

Machined aluminum molds cost more than the cast aluminum mold but are superior with regard to thermal conductivity and dimensional accuracy. Cast aluminum, using machined inserts where necessary, is most common for high production molds.

Epoxy molds and wood molds are inexpensive and ideal for limited production, such as in the proving and testing of formed parts. For production runs, their poor heat conduction would be detrimental to the economics of the system.

Steel molds are heavy, expensive to machine and their conductance is lower than aluminum.

4.2.2.7.2 *Vacuum Holes.* Vacuum bleed is used to withdraw the air trapped in the mold at a controlled rate for two reasons:

(a) So that the entrapped air may be used to stretch uniformly the section or web of plastic sheet over the plug as it is being inserted into the mold.

(b) So that the material being drawn into the mold does not contact the corner mold surface, which would cause chill marks.

Number and size of vacuum holes to be drilled into the mold cavity and their location will vary, depending on mold size, contours, thickness of sheet material and the desired draw rate.

An ample number of holes should be provided in order to form the plastic as rapidly as possible. The area of the vacuum channeling should be four times greater than the area of the vacuum holes in order to provide a sufficient vacuum force.

For high impact polystyrene and ABS resins 30 mil diameter holes are required for sheet thicknesses of 60 mils or greater. For sheets below 60 mil, it may be necessary to use hole diameters under 20 mil regardless of sheeting thickness because of the tendency of this material to show more pronounced hole markings.

Molds may be split or inserts used leaving a 10–15 mil slot that may extend around the entire part. Slots are desirable because they allow greater air passage and show no more of a vent mark than vacuum holes of equivalent diameter.

Holes and slots should be situated in areas into which the sheet will be drawn last. Holes should be spaced 1/2 inch apart to obtain fine detail reproduction of the mold. Two to three inch spacing of holes is customary for flat areas.

Each hole should be back drilled to within 1/8 inch of the mold surface with a drill of larger diameter than the hole in order to minimize flow restriction through the passage.

To develop sheen on the contact surface of the mold, sand blasting may be used. This technique provides a certain amount of coarseness to the finish through which air can pass when the forming vacuum is applied.

4.2.2.7.3 *Mold Cooling.* Large deep draw parts are cooled by conducting heat from the sheet through the mold and by blowing air against the exposed surface. Water spray must be used in a fog form, otherwise there is a danger of spotting the part.

When forming large, deep draw parts of ABS and high impact polystyrene, mold temperatures of 140–170°F. are recommended for a high quality run. While lower temperatures permit faster cooling, they may also produce undesirable thermal stresses that will adversely affect dimensional stability and reproduction qualities of the formed parts.

In air pressure forming, mold temperatures can be much cooler because the pressure forcing the sheet against the mold cavity wall will allow for faster conduction of the heat from the sheet. Result is faster cycling than obtainable by straight vacuum forming.

4.2.2.7.4 *Undercuts and Part Removal.* To remove parts with slight undercuts, mechanical strippers with air ejection are used. Air ejection overcomes the vacuum and breaks the seal in the mold cavity while the mechanical strippers push the web of parts from the mold surface.

Split molds or split section molds or cavities can be designed that will separate after forming so that the part or parts can be removed without being damaged. The split mold is necessary to release parts having unusual design configurations or sharp undercuts.

When parts are formed over protrusions in the side wall of the molds, the protrusions must be retracted before the part can be removed from the mold. Following retraction of the protrusion, the vacuum seal must be broken by air ejection and the frictional force between part and mold must be overcome. For small parts mechanical strippers work well but for large parts the vacuum seal is broken by slowly retracting the mold. After this, the platen can be fully retracted much faster.

4.2.2.7.5 *Plugs.* Cast aluminum is used not only as mold material but plug material as well, by most high speed production thermoformers. Less expensive wood plugs covered with cloth or felt may be used for experimental work.

All metal plug heaters should be thermostatically controlled with minimum temperature fluctuation. Plug temperatures will vary, depending on the type of material being formed, but usually runs from 260–290°F. for high impact polystyrene and ABS.

If the plug is too hot, material may stick to it or else stretch too thin where it contacts the plug. If plug is too cold, however, material may chill and set on contacting the plug, resulting in thick spots and chill marks.

Plug should conform to the general shape of the cavity, but should have no built-in details and should range from 70–90% of cavity volume, regardless of cavity size.

Plug speed is coordinated with vacuum bleed and must be adjusted for smooth, positive operation. Too fast a speed causes sheet material to stretch too thin while too slow a speed causes drag lines to form. Plug speed is influenced by sheet temperature and timing and amount of vacuum bleed. Experienced thermoformers can easily determine the proper speed by the quality and uniformity of the formed parts being produced.

4.3 Thermoforming Techniques.

4.3.1 *Straight Forming.* The least complex technique is known as straight, or cavity, forming. The heated sheet is clamped over a cavity or mold box and either vacuum or air forces the sheet against the mold.

There are several characteristic features of parts made by this technique:

(a) The sharpest detail is on the side next to the mold.

(b) The thinnest sections are in the corners at the bottom of the mold.

(c) Parts with vertical walls or even slight undercuts will release after forming since the sheet shrinks away from the mold upon cooling.

(d) Cavities may be placed close together in multiple molds without danger of webbing taking place between parts.

4.3.2 *Free Forming*. In this technique, the heated sheet is clamped over a mold box which is evacuated only slightly. This causes a blister or dome to be formed without bringing the sheet in contact with the mold box except at the edges where it is clamped. If air pressure is used to blow a bubble, this process is called free blowing. These techniques produce parts with exceptional surface finish, freedom from blemishes, clarity and excellent optical properties.

4.3.3 *Drape Forming*. Parts too deep to be drawn in straight forming are often inverted and drape formed over either a positive or combination mold. In this process, the heated sheet is mechanically pre-stretched over the mold before the sheet is formed by air pressure. At the completion of mechanical stretching, the sheet is drawn over the edges of the mold platform to obtain the necessary seal so the space between the sheet and the mold may be evacuated.

Parts that are drape formed over positive molds have several characteristic features.

(a) Sharpest details is on the side next to the mold.

(b) Thickest section is on top of the mold, and the thinnest area is at the corner joining the mold side wall and base.

(c) Drag or chill lines often appear on the side of the part, indicating a rapid change in material thickness. This occurs because the sheet that first contacts the top mold surface is chilled and does not tend to stretch as much as the surrounding uncooled sheet. The chilled sheet is usually drawn slightly during the remainder of the draping operaton so the drag line appears on the side a short distance from the top.

(d) Positive molds used in drape forming must have a sufficient degree of wall taper to prevent the sheet from locking on the mold as the sheet shrinks during cooling. Rigid materials generally require greater wall taper than flexible materials, since the flexible materials may be partially stripped from the mold if this becomes necessary.

(e) Parts with relatively straight side walls or those spaced close together will often have a web or excess fold of material at the corners or as a bridge between two parts.

4.3.4 *Plug or Ring Forming*. This method is a forerunner to drape forming, and is usually accomplished by a draping action between die sections without additional air pressure forming. The tooling consists of a positive mold and ring or clamping frame which matches the contour of the mold base. The heated sheet is held in the ring and the mold is forced through the ring drawing the sheet to the contour of the mold. Mold shapes are usually simple so no further forming by air pressure is necessary. Molds are generally non-conductive to lessen chilling of the sheet during forming.

4.3.5 *Slip Forming*. This is a variation of plug and ring forming using a slip ring which holds the sheet loosely. An oversized piece of heated sheet is placed on the spring loaded slip ring, and as the ring is drawn over the mold, the material is allowed to slide through the ring giving a drawing action. The ring approximates the contour of the mold base so that after the drawing operation no further forming by differential air pressure is required. The process is limited to simple shapes made with material of above normal hot strength.

4.3.6 *Snapback Forming.* In snapback forming, the heated sheet is drawn slowly into a vacuum chamber to a predetermined depth by slight differential pressure. Once the bubble has been drawn, the mold is brought down into the bubble until the edges of the mold seal on the box. The slight vacuum in the box is then released and the sheet is then allowed to snap onto the mold. The mold is vented for air escape, and the space between the mold and the sheet is sometimes evacuated to obtain better details in the formed parts. The top of the mold must also be vented to prevent the entrapment of air.

4.3.7 *Reverse-Draw Forming.* This technique use nearly the same equipment as snapback, but the material distribution in the formed part may be very different. The major difference in the process is the reverse position of the bubble. In this case heated air is introduced into the chamber and the sheet is billowed upwards. The mold is then lowered into the bubble until it seals on the chamber. The pressure build up in the billow chamber forces the sheet to conform to the mold shape. Again, the mold must be vented and it may be evacuated if greater differential pressure is desired.

4.3.8 *Air Slip Forming.* This technique is similar in many ways to snap back forming, but the method of prebillow is different. The sheet is clamped to the top of a vertical walled chamber and the prebillow is achieved by a pressure buildup between the sheet and the mold table as the mold rises in the chamber. The mold table is gasketed at the edges to form a sliding seal against the chamber wall. Upon completion of the stroke the space between the mold and the sheet is evacuated and the sheet is formed against the mold by differential air pressure.

4.3.9 *Plug-Assist Forming.* This technique combines many of the good features of both straight and drape forming to give parts of uniform material distribution which are easily removed from the mold. The heated sheet is clamped over the mold and a plug carries the sheet down into the cavity. As the plug enters the sheet, the air beneath the sheet is compressed, causing the sheet to billow up around the plug. This action prevents the sheet from contacting the cavity lip as the sheet is stretched into the activity. The plug stops near the bottom of the mold, the mold is evacuated, and the sheet is transferred from the plug to the mold by differential pressure. Once the part is formed the plug may be removed from the mold.

It is best to restrict the area of sheet which is sealed against the mold. This allows more definite control of the forming operation and eliminates any differences in sheet area used for the center or edge cavities in multiple molds. Usually an area greater than the exact projected area of the part is used, since material between cavities can be carried into the mold and used for sidewalls.

For large area, deep drawn parts, the distance from the clamping frame to the sidewall of the cavity may be as much as 25% of the cavity depth. With small multiple molds it is usually not practical to space the cavities far enough apart to allow this much extension on the projected area. For containers with depth-to-diameter ratios exceeding 1:1, the spacing between the cavities is often less than 1 inch. Shallow containers may have even closer spacing. As the clamped area more closely approaches the projected area, the drawing action will be more severe and there must be closer alignment between clamping frame, plug, and cavity.

Also the thickness of the original sheet must be increased to maintain the same wall thickness in the formed part. Spacing cavities closer together results in more efficient use of sheet, thereby lowering the percent of trim.

Often with combination molds, such as refrigerator inner door panels, it is not possible to effectively restrict the area for plug assist forming a compartment within the mold. In such cases it is almost impossible to obtain the proper billowing as the plug enters the compartment and there is a tendency for severe drag lines from the upper edges of the compartment. In some instances, the billowing can be obtained by introducing air under the sheet to build up pressure.

The optimum sheet temperature is usually a compromise and is often near the middle of the forming range. Excess heat may cause material degradation, yet the higher sheet temperatures tend to minimize any undirectional orientation which might occur during the drawing process.

There are practical limits on the upper temperature which can be used, since excessive temperatures will cause thinner sections in the bottom of cavities, and the tendency for drag lines from the plug or lip of the mold will be accentuated. Also, most sheet materials sag excessively at elevated temperatures making it difficult to handle the sheets in conventional forming machines.

Perhaps the most important aspects of plug-assist forming are the variables relating to the plug. The plug is about 70 to 90% of the cavity volume regardless of the size of the cavity involved. This means the clearance between plug and cavity increases with an increase in part size. The plug conforms to the general contour of the cavity, although it is usually left smooth and undetailed.

4.3.10 *Plug-Assist-Reverse-Draw Forming.* In the forming of large area, deep drawn parts it is often desirable to precede plug penetration with a pressure buildup beneath the sheet causing it to billow upward. This prebillow tends to eliminate any heavy section which might occur in the center of the bottom. It also makes the load buildup on the plug more gradual which tends to lessen any sudden change in plug speed as it enters the sheet.

4.3.11 *Air-Cushion Forming.* This is another variation of plug-assist forming in which air is introduced through the plug as it enters the sheet. This technique tends to reduce any sticking or dragging which might occur between the sheet and the plug as it enters the cavity. The process is also intended to improve material distribution, especially by eliminating a heavier section across the bottom of plugs used for large area parts.

4.3.12 *Plug-Assist-Air-Slip Forming.* It is often desirable to combine forming techniques to achieve improved material distribution in complex parts. The plug-assist-air-slip combination would appear ideal for forming high ridge, positive shapes with deep cavity sections such as most refrigerator inner door liners. With this technique the sheet billows upward as the mold rises. Just before the upper ridge of the mold strikes the bubble, the plug is introduced from the top, reshaping the bubble to accommodate the mold ridges and at the same time carrying the material into the cavity sections. If properly controlled the material may be uniformly distributed before it contacts the mold.

4.3.13 *Matched-Die Forming.* As the terms implies, a pair of matched molds form the softened sheet and no additional air pressure is needed. The dies are designed to allow for the thickness of material remaining after forming. The dies or molds are normally mounted on press platens, the softened sheet is placed in the open mold, and the mold is closed to form the part. If the dies are made of a hard material such as metal or thermosetting plastic, close alignment during forming is required to keep the dies properly matched. Often one die is of a softer material, such as foam rubber, which is not cut to the exact contour but simply forces the sheet to conform to the opposite die face. This modification requires less critical alignment during die movement.

4.3.14 *Special Forming Techniques.* Several of the more prominent new forming techniques are discussed in the following paragraphs.

4.3.14.1 Form-fill-seal machines convert a roll of sheet into containers, fill them, seal their tops with a preprinted plastic film or plastic-coated foil, and finally trim them out of the web.

4.3.14.2 *Skin and Blister Packaging.* In skin packaging, the item to be packaged acts as the mold and is placed on a printed card. A thin, clear sheet is heated and drawn right over the item, adhering to the card, which is either adhesive coated or else porous enough so that the atmospheric pressure forces the plastic to effect a mechanical seal by locking into the paper. Tough films such as plasticized PVC, cellulosics, ionomers, etc., 4 to 10 mils thick, are used, and can often cover sharp corners and points without tearing.

In blister packaging, the blisters are bubbles preformed over simple molds, and designed to fit the contours of the object to be packaged. A separate operation is needed to adhere the blister to the card, but this can be done in line with the forming. Inside the blisters, the items are not rigidly held, but are completely enclosed and visible.

Both methods are used for packaging of many common hardware items. Skin packaging is slightly less costly since it needs no molds, is a single operation, and often uses thinner sheets; blisters are frequently used, however, because they make neater-looking packages, do not cause curling or warping of the card, and allow easier removal of the packaged items. In addition blisters can be stapled or folded into a card, as well as fastened with adhesive. Any thermoforming machine can do both types of packaging, but special machines which have shallower draw limits, provisions for feeding the cards and packaged items, and provision for trimming the finished item are normally used. Recently, skin packaging techniques have been introduced that completely eliminate the film or sheet stage, instead, hot molten film is extruded over the cards and items, as they move past the extrusion dies.

4.3.14.3 *Embossed Sheet.* ABS luggage and high density polyethylene automobile panels are examples of embossed thermoforms. The sheet is embossed during extrusion under conditions that result in minimum flattening and grain loss during heating in the thermoformer. Heating from the unembossed side is also helpful in retaining grain, and twin heaters are therefore commonly employed. Prestretching helps avoid localized thinning, weakening, and grain loss. Male molds are preferred in order to keep the grain on the outer visible side.

Where the product requires either (a) very detailed and deep grain; (b) very complex patterns; (c) a pattern differing from point to point on the piece in a planned way; and (d) absolute freedom from distortion, it may be advisable to consider a textured female mold. Such molds also find use where runs may be too short to justify fabrication of a special embossing roll.

4.3.14.4 *Laminates and Other Surfacing.* Polystyrene sheet is often decorated by laminating a preprinted film of oriented polystyrene film to an extruded sheet of high-impact polystyrene. This technique is also used for polyolefins and other thermoplastics. Sometimes an adhesive is necessary, as with combinations of polyvinyl chloride film on high impact polystyrene. These composites can all be thermoformed, although inks and adhesives must be able to withstand forming conditions.

Thick laminates can also be made with a thin layer (5 to 20 mils) of "special" sheet over a base of lower cost uncolored or off colored plastic. Economics result from the concentration of high cost additives such as pigments, ultra violet light absorbers and antistatic additives in the surface layer where they are needed.

Sheets are also available surfaced with flock or textiles, vacuum metallized, painted, etc. These are thermoformable to a limited degree, depending on the nature of the surfacing. In some cases, especially for deep draws, it is preferable to apply surfacing to the formed part instead of the sheet. In others, the ease of treating a flat sheet and the consequent economies may be more important.

4.3.14.5 *Gloss.* Much effort has been expended toward getting the best possible gloss on formed sheet. The original method was to laminate a 1 to 2 mil film of oriented polystyrene to high impact polystyrene sheet during extrusion. This was satisfactory, but added about 5% to material cost and weakened the product because the annealed oriented film embrittled the surface.

Heat glazers were then developed. These units quickly melt the sheet surface just after extrusion. This produces less surface embrittlement, but introduces the danger of discoloration. It also does not improve gloss as much as laminates do.

It is important to remember that the gloss of a flat sheet may not be permanent, but may disappear in forming. New lots of glossy sheets should therefore always be pretested.

4.3.14.6 *Porous Sheet.* Sheet with perforations, porous thermoplastic textiles, and even extruded non-woven netting can all be thermoformed with the aid of thin solid films on the side of the sheet away from the mold. These helper films can remain as part of the product, or else can be made of an incompatible plastic and peeled off.

4.3.14.7 *Blown Bottles From Sheet.* Several machines for doing this type of work have been developed. The best known works from a roll of sheet, usually PVC. The unit folds the sheet lengthwise in half as it heats it, clamps it and blows it into a mold, and then trims out the containers. Automatic filling can be incorporated into the unit. As compared with blow molding, this technique offers ease of printing and coating, intermittent operations (can economically be run on 1 or 2 shifts per day), and ease of forming square and other irregular containers. It is more costly, since it requires sheet as feed material.

Another firm offers a compromise system whereby two sheets are simultaneously extruded parallel to each other, and fall still hot into a blow mold in such a way that the air blowing nozzle comes between them. This double sheeting technique is being used to form automobile ducting.

4.3.14.8 *Ribs and Inserts.* Ordinarily, products are designed with ribs and flanges to get maximum stiffness (hence minimum material needs). But since forming starts with a sheet essentially constant in thickness, large variations such as are found in injection molded ribs are hard to achieve. in some cases, therefore, preformed wires and rods are inserted into or onto the mold, and remain with the product upon release, thereby strengthening it. The forming usually locks the inserts in place.

4.4 **Advantages of Thermoforming.** Thermoforming, wherever applicable, offers certain advantages over injection molding. In the first place, investment is low. Forming machines cost less than injection molding machines and the same is true for the molds. Because thermoforming molds are much simpler than injection molds, making and delivering them takes much less time. Since they can be produced from such materials as wood, plaster, scrap metal, cast aluminum or cast iron, it is often possible to get into production in a matter of a few days. This compares with a number of months it required for the construction of a complex injection mold.

For these reasons, thermoforming is generally preferable to injection molding whenever the number of finished parts is small. However, where machine and mold costs can be discounted because of the high production volume, injection molding is often preferable, since in that case, injection molding the item is usually cheaper than thermoforming it. The thermoforming process can produce rather larger parts and, using the same mold, items of any desired thickness between 10 and 150 mils can be produced by varying sheet thickness and the heating and cooling sections of the forming cycles. Average thin walled parts may be produced at 3 cycles per minute in a multi-cavity thermoforming mold.

Flat sheets can be preprinted in multiple colors by silk screening, lithographing, or other printing or hand decorating methods. The distorted preprinted decoration is brought into true dimension when the sheet is thermoformed. This is much cheaper than the corresponding post fabrication decorating required for injection molded items.

In thermoformed items usually fewer strains occur than in injection molded pieces. This makes the forming procedure preferable wherever maximum strength per unit thickness of the piece is required. Furthermore, in thermoformed pieces no weld lines occur which occasionally are the reason for weakness and consequent failures in injection molded pieces.

Another advantage of thermoforming flexible materials, such as polyethylene, is that even if the mold has undercuts the object can still be easily snapped loose from the mold after being formed. Relatively thin lids and closures have been thermoformed.

4.5 Disadvantages of Thermoforming. Thermoformed pieces generally require trimming. Although machines are available with automatic trimming mechanisms which eliminate removal of the pieces for a separate cut off operation, the versatility of the thermoforming process is reduced.

Detail and gloss is not as sharp or high as injection molded pieces.

The conversion of resin into sheeting prior to thermoforming increases the cost of the thermoformed piece. However, this cost may be somewhat reduced in larger fabricating shops which have the facilities to produce sheeting and utilize the scrap generated in the process.

4.6 Typical Applications. Typical parts which are made by the thermoforming process are: automobile dash boards, door panels, and tail lights, aircraft canopies and windshields, signs, displays and light fixtures, housewares, toys, television tube masks, furniture drawers, trays, refrigerator parts, luggage and instrument panels.

CHAPTER 5

MISCELLANEOUS PROCESSES

5.1 Calendering. Calendering is an alternative to extrusion when film with certain special properties is to be produced. In calendering, the melt is passed through 3 nips in a series of heated steel rolls where it is compounded into film of desired thickness. In the nip between the first pair of rolls, the resin "bank" is formed into a sheet whose thickness is further reduced in passing through the second and third nips. The final thickness of the sheet is determined by the gap between the last pair of rolls, the gauging rolls. Finally the hot sheet is pulled by the take-off roll around a chilled roll which cools the film.

The physical properties of calendered film do not vary as the width of the sheet changes. At all times, the longitudinal physicals are relatively constant across the sheet, while in any extrusion process, the highest physical strengths are apparent in the center of the sheet, and they get lower as the edges are approached.

Calendering has other advantages over extrusion. When extruding different colored films, the extruder has to be cleaned and purged when changing colors. A calender requires a minimum of cleaning between colors. Calendered sheeting is less glossy than extruded material. It may be preferable for some applications where high tensile properties and unusually close gage control is required. Popular calendering applications are electrical tape and window shade stock. Embossing can also be achieved on calendering equipment.

Calendered films are often used for thermoforming. Calendering is also used for applying a resinous coating to a fabric or other backing material by simply squeezing the resin film and the backing material between the heated rolls.

The cost of calendering equipment is very high and therefore it is not economical for small producers to utilize such equipment.

5.2 Coating.

5.2.1 *General.* The field of coatings is very broad and is generally considered to include any type of coating that is applied to any type of substrate in order to protect, identify, or decorate the surface.

The goal in formulating and applying a protective coating is to form a coherent and adherent film on the substrate surface. The film forming ingredients may be either thermosetting or thermopastic which have been suitably modified with pigments, plasticizers, solvents, etc., to obtain the coating which will give the desired performance.

Some films are formed by mere evaporation of solvent, some by a combination of solvent evaporation and/or an oxidative or polymerization process and others by fusion bonding the polymer to the substrate.

5.2.2 *Fluidized Bed Coating.* The fluidized bed coating system consists of dipping a preheated object into a bed of dry fluidized thermoplastic or thermosetting powders which melt and fuse on the heated surface to form a continuous uniform film.

The parts to be coated are preheated above the melting point of the fusion bond coating to be applied. The heated parts are then immersed with suitable motion in the fluidized bed. A rising current of air passing through a porous plate at the bottom of a specially designed tank fluidizes the plastic powder. In this condition, the powder looks and acts much like a liquid. If the tank is tipped or rocked, the level of the powder moves and changes as a liquid would.

As the powder particles contact the heated part, they fuse and adhere to the surface. After removal from the fluidized bed, the parts are often briefly postheated in an oven to completely fuse the coating and to obtain the best surface appearance. If a thermosetting resin is used, this postheating will cure the resin.

The process is adaptable to automatic processing of large parts in volume because cycle times are short. Also, relatively few operations and a minimum of labor are required. Total cycle time is short contrasted with the time required for applying a similar film thickness with most conventional coating processes. Immediately after cooling, the parts can be packaged, shipped or used. No additional drying or baking time is required.

The process can be used with batch equipment for coating small quantities of parts or for processing large and heavy parts. The equipment cost is lower than for conventional coating systems. Different fusion bond finishes can be applied to a variety of substrates using the same equipment line. A coating line usually includes precleaning, priming and handling equipment, preheat and postheat oven, fluidized bed tank, dipping jig and an exhaust system.

Parts must be moved quickly to minimize heat losses, particularly in the transfer from the preheat oven to the fluid bed tank. Conveyors and ovens must be designed to operate at 300 to 750°F.

Fixtures for holding parts are extremely important and may control the economics of the entire process. A room temperature fixture holding a preheated part can be dipped into the fluidized bed without being coated. Masking can be combined with holding by special fixture design. Special fixtures constructed of materials with different thermal characteristics are used to reduce heat loss from the hot part. Contract area with the part should be minimized.

Cleanliness of the part to be coated is just as important as in coating with paint. Alkaline cleaning, degreasing acid cleaning, sand blasting, wire brushing, and phosphatizing are all used when required.

Liquid primers, especially formulated for the process, should be used to obtain maximum adhesion. These solvent type primers, which are applied by conventional techniques also provide the needed underfilm corrosion resistance for most parts if the film is broken.

Selection of heating equipment for both preheating and postheating is dictated by the part to be coated, plant facilities and economics. Heating may be accomplished by convection oven, radiant heating, induction or resistance heating.

Actual coating is usually applied during a five to fifteen second immersion in the fluidized bed tank. The controlling parameters of of the coating process involve necessary motion of the part during immersion, time of immersion and heat content of the part when immersed. Control of these variables are necessary to achieve reproducibility and can best be accomplished by automation which eliminates the human factors for error, besides increasing the production rate. Some systems have been designed which elevate the fluidized bed tank to meet the conveyorized part and then drop the tank to its original position after a timed interval.

Touch-up Systems for fluidized bed coatings are commercially available and are essentially simple containers with a uniformly porous plate located several inches above the bottom. The fluidizing air or inert gas at 5 psig enters the container below the porous plate and should be free of dirt, oil and moisture.

Since fluidizing powders are very fine it is desirable to have some sort of exhaust system collector above the tank which may return the fines to the tank.

This process is finding extensive use in the application of "integral" insulation to armatures and fields of electric motors in addition to providing corrosion preventive coatings.

5.2.3 *Electrostatic Coating.* The theory of electrostatic deposition is fairly simple. Two forces, attraction and adhesion are involved. The electrostatic charge that can be put on a particle is a function of the surface area of the particle, while the forces to be overcome such as gravity and inertia, are functions of the volume of the particle. Therefore, electrostatic attraction is enhanced with small particles having the larger ratio of surface area to volume. Thus, the small charged particles are attracted to any electrically grounded object immediately in their vicinity.

This phenomenon is commonly explained in terms of "image" theory. That is, the particles "see" their oppositely charged particles on the other side of the grounded object. Since oppositely charged materials attract, the negative particles will be attracted to the grounded object in which they see their image. They will also adhere to the grounded object.

Using non-conductive plastic particles, a point is reached in coating thickness where the charge on the surface of the coated substrate equals the charge on the particles in the surrounding air. At this point, attraction no longer occurs, and new particles are repelled from surface.

However, there is a way around this problem. Insulators normally have lower insulating resistance as their temperature increases. In the case of plastics, this is approximately a reduction of the resistivity by a factor of 2 for each 10°C. rise in temperature. This allows thicker coatings for a particular plastic powder by preheating the substrate. Or, more than one coat can be applied to a substrate by successively coating the melt plastic surface.

The powder coatings adhere to the substrate anywhere from two hours to two days depending on the powder and particle size. To apply a permanent continuous coating film, the particles are fused and bonded to the base material by curing the powder coated part in an oven.

The charge particles envelop and adhere evenly to objects without regard to corners, perforations, or uneveness of surface. Uniform pinhole free coatings can be applied, even in thin coats on irregular and complex shapes, sizes or contours. Powder utilization is nearly 100 percent; powder can be recycled and reused without treatment. The electrical discharge is harmless to operating personnel. In addition, no toxic or flammable solvents are involved.

Because of the superior properties of plastics and the relative ease of coating objects electrostatically, they have replaced other coating materials in many applications. These include protection against corrosion, weather, moisture, and contamination; electrical insulation for motors, printed circuit boards, mounting surfaces, and electrical and electronic components; lubrication of metals and other materials, casting of film on male or female molds; where it is uneconomical to use injection molding or rotational molding techniques; and in the decorative coating of a number of materials.

Among the materials known to provide good coatings via electrostatic deposition are

PVC, PVAC, polyethylene, tetrafluoroethylene, cellusosics, acrylics, nylon, polypropylene, acetals and chlorinated polyethers. However, any commercial thermoplastic polymer of the right particle range should be equally acceptable.

Among the thermosetting materials, two part expoxies, "B-Stage" phenolics, as well as silicones also give good coating results.

For plastics having a specific gravity in the neighborhood of 1, powder sizes up to 50 mesh can be handled by the electrostatic deposition method. Heavier powders should in general be slightly finer. For best results, powders below 100 mesh are preferred. To prevent packing, the powders must also be dry and kept dry.

One type of equipment used for electrostatic spraying consists of a hand gun having a grounded handle, an insulated barrel and a charging nozzle at 90,000 volts d-c negative. The d-c power supply and powder reservoir are connected to the guns by means of flexible wires and tubes. For most powders the maximum flow rate is 30–40 pounds per hour. A trigger on the gun handle controls the turning on and off of the high voltage and the powder flow. The powder is conveyed from the reservoir by means of compressed dry air. A second stream of compressed air is used in the gun nozzle to assure that the powders pass over the charging surface of the nozzle.

An electrostatic fluid bed system is also available. The bed is particularly suited for continuous production line coating of grill work, channels, wire pipe and similar parts. The fluid bed system employs an electrostatic generator which creates an electrical field capable of charging the powder particles, causing them to be deposited quickly and uniformly on any object passed through the charged powder cloud.

5.3 Casting. Casting is a process which differs from all other processes of shaping a plastic in that a liquid mix is poured into an open mold, where it is shaped without the application of pressure.

The simplest technique would be to melt a thermoplastic polymer and pour it into a mold, however, most polymers degrade and discolor when heated sufficiently to become fluid.

Dissolving the polymer in a solvent is also unsatisfactory because of the excessive shrinkage which occurs during solvent evaporation. For these reasons, both thermoplastic and thermosetting monomeric materials are used for casting operations. Some of these materials may be partially polymerized prior to casting.

Phenolic resins were the first to be used in the casting of plastics. They were found to be useful for small volume production which could not justify the use of an expensive mold. The early phenolics would crack and discolor with age, but subsequent formulation improvement has led to the widespread use of phenolics for casting.

Later, acrylic resins and styrene became available, and, because of their optical clarity and good mechanical properties they have become very popular for cast applications.

Other cast plastics were developed during World War II, among the most important of which were the unsaturated polyester resins. Both the acrylics and unsaturated polyester resins were used in large quantities during the war and subsequently for airplane cockpit enclosures and similar uses.

At about the same time, the class of casting resins known as hot melt compounds began to be used in appreciable quantities. These include ethyl cellulose, cellulose acetate-butyrate, and, more recently, polyamide and polyethylene resins. The hot melt compounds are the only class of casting materials which are already in the polymerized state before casting. Used either alone or in combination with waxes, plasticizers, heat stabilizers, etc., their characteristics are such that they can be liquified and cast satisfactorily. The epoxy resins are the most recent members of the cast resin family. They produce a superior casting because they shrink very little during curing, and properly formulated castings are not subject to cracking, have excellent electrical characteristics, and are resistant to a wide variety of chemical reagents.

Many types of molds may be used in casting operations. The choice is dependent on the resin being cast, the type of molding required, and the volume of production.

It is desirable that casting resins be in the liquid form, yet be in a stage such that final polymerization or cross linking is accomplished in a short time. Except for the hot melts, which are already polymerized, this is accomplished by partially polymerizing thin monomers to a syrupy consistency. They must retain enough fluidity that all recesses of the mold may be completely filled.

Thermosetting phenolic casting resins are poured at the syrupy A stage and the castings are cured at 60 to 80°C. Days or even weeks are required for cure, depending on the thickness of the casting. Slow curing is required to prevent occlusion of bubbles and to prevent cracking. In the case of unsaturated monomers, such as acrylic and allyl types, much more polymerization is required. It is for this reason, as well as to reduce heat of reaction, that prepolymers are often made.

In the preparation of methyl methacrylate polymers and copolymers, one can mix equal parts of monomer and polymer (finely divided). Pigments, lubricants, acclerators, etc., can then be incorporated. As the polymer dissolves, the mixture thickens and can then be poured into a plaster mold of the impression one may wish to reproduce. The mold may be lined with tin foil, cellophane, or an alginate for good release of the impression. Curing is accomplished by heating at 80°C. for a few hours.

Although unsaturated polyesters can be cured by the proper chemical initiator at room temperature, most of them are heated in closed molds to prevent surface tackiness caused by the inhibiting effect of oxygen in the air. Epoxies may be cured in open molds since they are not subject to this type of inhibition.

Hot melts may be poured directly into the molds as hot, liquid melts. Upon cooling they are ready for use, since no polymerization occurs during casting. These products as well as many of the preceeding types are used in ever increasing amounts for plastic tooling.

A variation of casting procedure is known as embedding. Many objects are embedded in transparent plastics for the purpose of preservation, display and study. For electrical and other industrial purposes, two other processes known as potting and encapsulation are used. The latter is the covering of a device with an insulating or protective material, while potting involves the complete penetration of the voids in the device with a plastic substance.

Phenolic casting resins and, somewhat later, urea resins were among the early materials used for embedding, but were not at first successful because of the discoloration of the phenolics and the cracking of both types. The methyl methacrylate resins were probably the first ones to be used on a large scale. Subsequent improvements in phenolic resins have since led to their wide spread use. More recently, epoxy resins have been markedly successful.

For electrical potting and encapsulation uses, the phenolics, unsaturated polyester, silicone, polyurethane and epoxy resins are of greatest value. Potting can be accomplished simply by heating the object in a mold above 105°C. to drive off moisture, allowing the mold to cool, and then pouring in the liquid resin. After curing for about an hour, the casting is usually postcured outside the mold. In order to make sure that the liquid resin is forced into all voids in potting electrical devices, vacuum or pressure or centrifugal force is frequently utilized.

5.4 Foaming. Cellular structural materials of low apparent density can be made in the form of "solid foams from a large variety of plastics and elastomers." A foamed material is one which may be defined as a solid whose volume contains an appreciable fraction of uniformly dispersed voids or cells.

There are about five general ways for the preparation of foamed materials: (1) Incorporation of a "blowing agent" into a liquid resin or elastomer mixture which, upon heating, liberates a gas by chemical reaction; (2) incorporation of certain compounds into an unsaturated liquid polyester which not only form a gas, but also cross-links the resulting foam into a flexible or rigid structure, (3) whipping air into a colloidal suspension and subsequently setting the porous mass, as with foamed latex, (4) injection of a gas into a mix under high pressure in an autoclave; and (5) flash vaporizing a solvent from a liquid mix. All of the above methods are used commercially; however, only the first two use blowing agents.

Blowing agents are chemical compounds which liberate an inert gas by decomposition or chemical reaction at room temperature or, more often, upon the application of heat. Ammonium compounds and inorganic carbonates have been used for many years in the manufacture of sponge rubber. However, organic blowing agents are usually more advantageous in that gas evolution can be closely controlled by regulation of temperature and pressure. Most of these blowing agents are organic compounds which release nitrogen gas upon heating.

Foamed materials may be classified either as an open celled, or closed celled (unicellular) type. The former, exemplified by a sponge, consists of interconnected cells which are capable of absorbing large quantities of fluid. The unicellular type contains discrete voids, each being surrounded by a thin envelope of resin.

The common expanded materials are phenol aldehyde and urea aldehyde resins, polystyrene, polyethylane, polyurethanes, plasticized polyvinyl chloride, cellulose acetate, and both natural and synthetic elastomers. They all possess low densities and low thermal conductivities which confer good insulating properties, good moisture resistance and the low flammability of many of the above make them particularly desirable for many structural applications.

A new method of producing foamed-in-place material is by the use of very small phenolic spheres (Microballoons), which may be bonded with a polyester, phenolic, or epoxy binder into a low density material known as "syntactic" foam. The spheres have an average diameter of 0.0013 inches and are filled with nitrogen.

Polystyrene may be obtained in the form of beads containing a chemical blowing agent and upon heating with steam, the material expands readily to form unicellular, intricate shapes in the mold.

Foamed plastics prepared from urethanes are unique in that one of the reactants (diisocyanate) which forms the resin provides the gas (carbon dioxide, in this case), as well as the cross linking medium. Expanded polyurethane foams may be produced in rigid or flexible types and are dependent on the nature of reactants. Reactants can be simultaneously combined in a high pressure mixing head and forced out of a nozzle in a spray pattern or into a container or mold in which the material foams and cures from its own heat of reaction. The density of the foam is controlled by the amount of water and excess polyisocyanate used.

Rigid foams are generally made by mixing two prepared components and pouring the product into a suitable mold. Two advantages of the two component system are: (1) It is not necessary to install the expensive equipment required to pre-react the diisocyanate with the polyesters under carefully measured and controlled conditions and (2) It is simple for the user to merely mix the two components and "foam in place."

5.5 Cellular Laminates. A cellular laminate or sandwich construction consists of a relatively thick core of low density bonded between two high strength faces or skin. The function of the core is to stabilize the skins of the sandwich so that they can develop a substantial portion of their ultimate compressive strength without buckling. This construction provides a very stiff structural panel of low weight which may be used for decorative as well as purely functional purposes. Such a panel may be fifty times as rigid in bending as a sheet of skin material of the same weight.

Core materials used include "honeycomb"; balsa wood; expanded plastic foams; sawdust board; and cellular rubber hard board. Honeycomb may be made from reinforced plastics, metal foil and paper. The skins are usually of glass reinforced plastics, metal or ply wood. Almost any combination of core and skin material may be combined depending upon the product desired. High strength adhesives which adhere well to skin and core are used for bonding.

Two general methods are employed in sandwich construction. The more usual method is to prefabricate skins and cores separately, then bond them together. This requires that the cores be machined or expanded to the correct shape in the initial core manufacturing operation. Plastic skins are molded by one of the techniques discussed earlier or by molding directly over the preformed core.

A less common method of fabrication consists in foaming or expanding the core in place inside prefabricated and positioned skins. Since preshaping of the core is eliminated, this process is often employed in the manufacture of aircraft radomes or wing tips where accurate preshaping of core material is very expensive or where location is difficultly accessible.

A very useful type of panel can be made by bonding a flexible, honeycombed, resin-impregnated glass cloth or paper core between thin laminates of glass cloth, metal or hardboard. Panels of extreme high strength and very low weight for use as structural members in automobiles and particularly in aircraft are thus made. Much thicker, built up structures, such as beams have also been manufactured.

By proper selection of components, specific nonstructural advantages can be obtained from cellular laminates.

5.6 Heat Sealing.

5.6.1 *General.* Heat sealing consists of fusing together two or more layers of thermoplastic film in select areas. Some seals are functional, and some are decorative. Decorative seals are referred to as embossing and can be accomplished on one or more layers of film. The advantages of sealing, as opposed to sewing or the use of adhesives are: (1) seal strength equal to or greater than the strength of the plastic itself; (2) greater repeatibility in the shape of the seal; (3) formation of surface decorative effects; (4) unskilled labor may be used; (5) tear seals may be produced.

All methods of heat sealing involve the use of heat and pressure, a die or heat applicator, and a carefully controlled timing sequence to assure that adequate control of heat level, heating and cooling cycle.

5.6.2 *Thermal Sealing*. Hot plates constructed with cartridge or strip heaters, employed on one or both sides of the work, are used in conjunction with some form of surface sensitive seal temperature sensing device and a good temperature controller. Effective temperature control of the sealing die face determines the seal strength and appearance.

The pressure required to form a seal may come from air, hydraulic, cam, mechanical or hand tools. Continuous sealing may be accomplished by the use of heated wheels. Heating die flatness and perfection of mating surfaces is important to insure the uniformity of the seal in all areas. It is wise to construct dies of similar material in order to eliminate distortions due to differences in thermal coefficient of expansion.

5.6.3 *Impulse Sealing*. In contrast to thermal machines, most impulse sealers seal only straight sections or at best gradual curves. This is due to the die construction. A Nichrome ribbon or wire tape is supported between thin webs of high temperature material, with a spring on one end of the wire to allow for the expansion of the nichrome during the heating portion of the cycle. In some applications, the outermost face of the heating wire is uncovered in order to permit the wire to cut through the work. In this form the heat is maintained at constant level at all times. In all cases of true impulse heating, however, the period of heating is followed by the cooling cycle, before the press is allowed to release the work. Seals may be made on a continuous basis, however, if the work is not allowed to cool under pressure.

The wire or tape is heated electrically from the cold starting position as soon as the press contacts the work. Most commercial machines do not attempt to measure the temperature at the work, as the heating cycle is much too short for accurate measurement. In order to obtain good results, trial and error procedures are employed on equipment with good reproducible voltage and tuning devices. Heating tapes must be mounted flat and must be light and well insulated from the supporting structure, otherwise, both long heating and cooling cycles will be encountered. The bed or flat plate which opposes the "dies," is often covered with a high temperature resilient material, to overcome any errors in the flatness of the tape. Press follow through can be achieved through this means for thin films.

5.6.4 *Dielectric Sealing*. The heat required to achieve the seal is induced within the film by agitating the molecules of the work. The ease with which agitation takes place is measured by dielectric loss characteristics of the material. A great advantage is that thick films may be sealed in a short period of time and post seal cooling may be obtained. A radio frequency is generated, and is electrically connected to an air or hydraulically operated press. The field of force is concentrated at the die face so that heat is induced only in this area. Tear seals may be obtained at the same time and with the same die used to seal the work, by stepping the height of the surface, and by sharpening to a knife edge those portions of the die which almost cut through the work. Temperatures are neither measured nor controlled. Heat level is regulated by a power control device which permits variable amounts of current to flow between the die face and the bed opposing it.

The work performed with dielectric heat sealers can be very much larger in area than those obtained with thermal and impulse sealers. In many cases the film to be sealed is separated from the bed by paper or other thermal insulation. This buffer acts as a source of heating the surface of the work which contacts it, and also limits the flow of heat from the work to the bed. In addition the buffer allows for less accurate dies as it is generally quite soft and pliable.

5.6.5 *Ultrasonic Sealing.* The ultrasonic machine employs small tools, either point contact or bars much smaller than those used in any other method of heat sealing. The advantage of this method lies in the fact that certain films, if they are not too thick, can be sealed, regardless of the loss characteristics of the work, without employing heated dies. Since the source of energy is mechanical vibration, thicker films will dissipate the power without allowing the vibrations to penetrate through to the interface to be sealed.

Power is obtained from an electronic oscillator, similar to that employed in dielectric sealers, except that the frequency used for ultrasonics is substantially lower. The generated power is supplied to a transducer (either a crystal or a coil surrounding a magnetostrictive core) fastened to an applicator. The applicator has a cross section of a hyperbolo so that the power may be more adequately concentrated at the tip of the horn. The tip activity is measured in displacement in thousandths of an inch. Should the tip be very firmly pressed into the work, damping of the motion of the tool may result, with a loss of applied power. Therefore, the entire horn assembly is floated off the bed and applied pressure is carefully used. The pressure of the head assembly and variations of the work in thickness and other mechanical properties can throw the tool to another operating frequency, making transfer of power to the tool an impossibility. Automatic frequency control of the generator to match the resonant frequency of the tool insures that the maximum power transfer takes place.

The heat generated within the transducer is often the limiting factor in the size of the unit which can be used. To date, machines of 500 watts output represent the practical upper limit with few exceptions. Since the applicator is cool, the amount of post seal cooling required is minimal. By pulling the work under a point applicator, the production of continuous seal lines may be obtained.

5.7 **Spinning.** The spinning of all modified natural and synthetic fibers is really an extrusion process. Spinning may be defined as the process whereby a polymer, temporarily fluid, is extruded from one or small orifices and is then returned to the solid state in the form of a fiber. The fluid state is obtained: (1) By putting the polymer into solution in an ionized form (2) by dissolving the polymer in a suitable solvent, or (3) by melting the dry polymer. The choice of method for fluidizing is dependent on whether or not the particular polymer can be melted without degradation.

As mentioned previously, the spinning process involves extrusion and subsequent stretching of the monofilaments. The latter step increases the axial strength of the monofilament due to molecular orientation. Yarns or threads are made from monofilament by twisting together a small number of coarse filaments or a large number of fine filaments, with the latter having greater strength and pliability.

In *wet or solution spinning*, a polymer is first dissolved in a suitable solvent. Water is frequently used as the solvent if the polymer is of such a nature that it can be water solubilized by prior reaction with an appropriate reagent. Such is the case of the solubilization of cellulose with carbon disulfide and caustic, also, the solubilization of proteins with caustic.

Water in an inexpensive and convenient solubilizing medium, but not all polymers can be made water soluble. If possible, non water soluble polymers may be dissolved in a suitable organic solvent. In both cases, solutions of polymers are deaerated and filtered and are then forced through the holes of a spinneret into a spinning bath. The bath either contains a reagent which reacts almost instantaneously with the solubilized polymer to convert it to the insoluble form or contains a nonsolvent liquid for the polymer which so dilutes the polymer solution that the polymer is precipitated. The former technique is more commonly employed. Derivatives of naturally occurring polymeric substances (e.g., cellulose nitrate) were first spun by this method.

In *dry spinning*, the polymer is dissolved in a suitable solvent and, after proper treatment, is also forced through a spinneret. This method differs from solution spinning in that the fibers are not passed into a spinning bath but are instead dried very rapidly by blowing a current of hot gas through the chamber into which the filaments are extruded. The evaporated solvent is recovered and reused. In this process no chemical change is involved. Polymers such as cellulose acetate and vinyl chloride copolymers are spun in this manner.

For fibers which have reasonably sharp softening temperatures, are sufficiently fluid above these temperatures and are adequately heat stable above these temperatures, the process of *melt spinning* may be employed. In this process suitable fluidity is obtained by heat alone, no solvent being added to the polymer. Generally, fibers which are melt spun are produced in the form of somewhat coarser monofilaments. Examples of melt spun fibers are polyethylene, saran, nylon, dacron (and glass). Note that the above polymers are either insoluble or are only slightly soluble in common or inexpensive solvents at room temperature, hence are not amenable to spinning by either of the other techniques.

5.8 **Finishing of Plastics.** The term "finishing" is used to cover those operations subsequent to the actual fabrication process. The operations performed on fabricated articles involve smoothing of surfaces, removal of fins and parting lines produced in molding operations, the drilling and tapping of holes, the decoration of surfaces, and otherwise bringing the articles to the desired condition.

Regardless of the method used to fabricate an article, some finishing is generally required. Every time a new application for a plastic material is found, a new method or technique of finishing usually must be developed. The developed finishing operation must be studied in connection with the product design to insure minimum cost. Often, the finishing labor may exceed the molding labor, and a poorly designed fabricating process may result in excessive overall costs.

For molded articles, the process of finishing includes the removal of gates, spruces, runners, flash and fins. Other operations which are common to the finishing of plastics are hand filing, sanding, cementing, carving, punching, trimming, piercing, tumbling, buffing, polishing, lapping, machining, grinding, reaming threading, drilling tapping, turning milling, routing, sawing, stamping, embossing, metallizing, coating, and also annealing and post baking.

Probably the oldest and most commonly used method for removing fins from thermosetting articles is filing by hand. Another method employs a moving, flexible belt coated with abrasive. Although belt sanding may be either a wet or dry process, the former method is usually preferable, as the water absorbs frictional heat, decreases abrasive loading, increases cutting speed, settles dust, and prolongs the life of the belt.

The tumbling method removes the flash by placing parts in an octagonal barrel which rotates. The rubbing of the pieces over each other erodes away the flash. Breaking agents, such as wooden pegs, steel balls, jacks, or pieces of chain are sometimes added to the barrel to accelerate the deflashing operation. Sawdust is often added to provide cushioning to protect against breakage of parts.

Both gates and flash may be removed in a punch press which consists of a shaped stamping plate to hold the article and a cutting blade. Parting lines are frequently removed by a process known as ashing, which is accomplished by use of a buffing wheel, made of muslin disks, to which fine, wet pumice is applied. Ordinary hand shears, or snippers, for trimming thermo-plastic materials may also be used. Band saws and electrically heated wire can also be used for gate and flash removal.

Cold molded articles are usually finished by use of a carving spindle. A rapidly rotating cutter or burr on the end of a spindle quickly removes rough edges and fins.

Most plastic articles are subsequently polished to restore their inherent high surface luster. Both tumbling and buffing are employed. The tumbling operation is similar to the one mentioned previously except that polishing agents, such as pegs treated with waxes, are added, instead of breaking agents. Buffing is used for polishing small as well as large articles requiring unusually high surface gloss. Plastic articles are pressed against a rotating buffing wheel impregnated with such compounds as tripoli, lime, pumice, rough, and tallow.

Often a plastic piece must be cemented to another plastic or other material. The type of cement will vary, depending upon the composition of the plastic. Thermoplastic compounds are easily joined by the use of a cement composed of the plastic dissolved in a suitable solvent; the cement attacks the plastic and becomes part of the assembly. Thermoset articles are usually joined by cements which harden by polymerization; the final assembly is given an after bake to insure complete polymerization and to relieve stresses.

Articles made by processes other than that of molding are finished somewhat differently because they vary more widely in form and material used. Among the most commonly fabricated materials are the laminated and cast phenolics, laminated ureas, and sheets, rods, and tubes of the various thermoplastic resins. Operations frequently used include sawing, drilling, turning, punching, tapping and threading, and polishing. Laminated articles require less polishing than molded ones. Since many laminated articles are relatively large, tumbling is usually not feasible and buffing is resorted to. Single sheet stock may be finished by any of the above methods. Routing is frequently used to make such stock conform to a particular pattern. Square holes in sheet stock can be made by a technique known as chopping, using a steel cutting die in a power press.

Hot-gas welding has become an extremely useful technique for joining thermoplastic materials to form articles which would otherwise be difficult or impossible to make. Polyethylene and vinyl chloride polymers are commonly used for fabricating by this technique. Methacrylates, styrene copolymers, nylon, saran, and polychlorotrifluoroethylene can also be welded successfully.

Hot-gas welding is similar in many respects to the gas welding of metals. The greatest difference lies in the application of the welding rod. In plastics welding, the rod instead of becoming molten, is only softened sufficiently, together with the sheet, that the two will fuse and make a permanent joint. Air (insert gas for polyethylene) at 200° to 300° C. is used to do the softening of the rod and sheet. Slight contact pressure of the rod in a V notch of the plastics to be joined is sufficient to do the job. This technique is used extensively for both consumer and industrial products. Plastic pipes are frequently joined by welded and flanged connectors. Plastic covered cables are often spliced by means of this technique.

Annealing is another operation performed on thermoplastic molded materials. This operation relieves "locked in" stresses. Unrelieved stresses cause poor dimensional stability, crazing by solvent and poor thermal shock resistance. For molded thermosetting parts one may post bake in order to improve dimensional stability by releasing strains and accelerating after-shrinkage. Moisture content is also thereby reduced and improved electrical characteristics will result.

The decorations of a plastic item is one of the most important and possibly one of the most complex of the finishing operations. Decorative methods may be generally broken down into dry and wet systems. Combinations of methods in both systems are frequently used to produce a finished part, particularly those requiring multi-color effects. The methods and systems available may be broken down into the following categories:

Hot Stamping—Hot stamping, roll leaf stamping, or gold leaf stamping requires a machine or tool incorporating a method of heating the decorative stamp so that it may be pressed in contact with the plastic part with a special pigmented, dyed, or metalized transfer foil interposed between the heated die and the part. Hot stamped parts may be used immediately, packed or otherwise processed without danger of smearing the imprint. Effects in highly pigmented colors, both matte and high gloss finishes, plus simulated bright gold imprints which cannot be visually detected from metallized items can currently be produced from the use of special metalized Mylar foils. This process can be automated and incorporated in a continuous processing line.

Vacuum Metalizing—This process provides an economical means of finishing plastic parts of all sizes and shapes with a metalic finish. These finishes simulate gold, chromium, silver, brass, stainless steel, etc., insofar as their surface is concerned. Normally, a base coat of gloss lacquer is applied to the plastic part prior to metalizing for screening and masking micro-scopic defects in the plastic surface and contributing the proper sheen and color to the finished part. The parts are loaded in a vacuum chamber, where under vacuum and high voltage, aluminum is caused to evaporate from the filament and be deposited on the plastic part. The aluminum film is of microscopic thickness and may be dyed to simulate any color. The film is subsequently protected by a lacquering or enameling procedure. Although equipment, jigs and fixtures are expensive, the system produces high volume work on complex parts at an extremely low unit cost. Where metalizing on a part is not desired, masking, spray painting, hot stamping and other applicable techniques may be used in conjunction.

Wet Decorative Systems—Paints and inks (other than flexographic) are similar to the extent that they incorporate pigments to obtain color and hiding power plus a vehicle or carrier to provide the fluid transfer and the power to bond the finished article and to obtain the surface finish desired. The vehicle loses solvent through evaporation and then polymerizes or oxidizes in contact with air or under low baking conditions. Paints, lacquers and ink may be formulated with a vast range of drying times. Solvents used in formulation may or may not attack the substrate plastic depending on what is desired. Wiping paint must not dissolve the plastics; otherwise smudge or blushes will be left after wiping. Printing and spraying applications prefer the vehicle to combine with or soften the plastic to produce firm adherence to the substrate.

Screen process printing was originally developed using silk as a screening material, but now metals including stainless steel are widely used for screen printing. Large parts such as signs and displays are made by this process in either automated or manual operations. Multi-color effects are produced in successive operations involving drying each coat laid down. The process involves preparation of a screen such that areas to receive the paint film are left open and other areas are blocked out or screened. The ink or paint is then forced through the open areas into contact with the plastic part. Both large block areas as well as relatively fine detail can be achieved by this process.

Offset printing is used for fine detail, where the necessity for high opacity is not required. Inks of relatively slow drying time are normally required, in that they must flow from a fountain through a distributor to a marking die and then be deposited on a flat or cylindrical transfer blanket and from this to the plastic part.

Letter press printing uses conventional presses with either rubber or vinyl printing plates. The special inks required for use on the plastic end items may dictate the use of special transfer rolls and modification of press speeds from those used for printing paper stock. The process lends itself to the production of plastic charts, graphs, etc., for both moderate and high production. These parts are frequently covered with a lamination to protect the imprint.

Gravure printing involves transfer of ink from fine recesses in the printing plate to the plastic part. The engraved roller which is partially immersed in the reservoir is wiped clean on its surface by a doctor blade and then immediately contacts the film or sheet being pulled across its rotating surface. Ink in the recesses is thus transferred to the product. The process is widely used for printing continuous sheet and film with fine details in one or more colors, particularly where large runs are involved. A serious disadvantage lies in the comparatively high cost of the gravure cylinder itself.

Flexographic printing, while similar in some broad respects to gravure in that it is primarily used for film and incorporates a cylinder or roller process, uses a raised characteristic elastomer die, normally made of rubber or vinyl. Ink is transferred to this die from a liquid reservoir by means of a fine knurled or screened roller. Printing plates for the flexographic process are generally more economical than gravure cylinders; however, it is not generally conceded that as fine detail can be obtained as with the gravure process.

Rubber stamps may be used to mark fabricated parts of a nature or configuration which cannot be marked by a letter press, conventional offset, etc. In such cases, manually placed rubber printing plates or rubber stamps are used to imprint nomenclature, legends or numbers. Work falling into this category may include molded terminal blocks, cases or instrument frames. Special machines have been developed which incorporate rubber printing plates and which by unique mechanical linkages, permit reaching into otherwise inaccessible areas. This insures accuracy of location and uniformity of film deposit.

Dipping and dyeing methods of decoration are generally arrived at in conjunction with the manufacturer of the paint, ink, or dye. The processes are in relatively little use, particularly since they are overall covering media, and coloring agents are generally incorporated directly into the plastics at the molding stage.

Air brush as well as manual brushing are used in certain industries for particular end products desired.

Roller coating is frequently used to place a contrasting color on raised lettering, design, etc., on molded parts. Hand rollers may be used or production equipment automatically feeding the parts beneath rollers and an inking system are available. Manual methods may be used for roller coating the tops of letters and lines on knobs of both flat and contoured sections. Because of exposure to the air, paints or inks of relatively slow drying time are mandatory.

Spray painting; together with hot stamping and metalizing, is one of the primary processes for decorating molded plastic parts. Basically, the system consists of a mask which leaves exposed the areas which are to receive the lacquer or paint which is applied by a spray gun. Systems may run from manual hand-held units to automatic equipment which transports the part through stationary, swinging or multiple spray gun stations to an unloading area and to a washing unit to clean the mask for the next operation. Masks are normally made of metal and conventionally electroformed to insure close contact with the part. The electroformed shell is cut in those areas which are to receive the paint. Masks which are the key to the system can be manufactured to permit painting raised design or lettering, to keep recessed areas free paint or spray on immediately surrounding areas, and for combinations of these.

Hand filling is often used where it is required to obtain a three dimensional color effect on dials or name plates. This is most effectively obtained by molding the lettering or designs from the second surface and then filling and hand wiping pigment into this recessed area. The process must be set up for each individual part, the formulation of wiping material will depend upon the thickness of the film and the plastic to which it is applied. Filling and wiping is conventionally a manual process and where the filled areas are adjacent to side walls, flanges, etc., extreme care must be taken to avoid getting the paint into such crevices, where it is extremely difficult, if not impossible, to remove.

Miscellaneous decorating systems are used to enhance the appearance of plastic parts. Labels and decalcomanias are used for informative or directional purposes; however, they are generally expensive to apply and unless the adhesives are correctly formulated, their permanence may be questionable. Plastic parts may be covered with flock to resemble felt or suede, etc. This is applied by coating the area to be flocked with a suitable adhesive and then either dusting or dipping the item with the flock material. Tumbling is used to produce a polish or matte on molded articles. It is also used to cut extraneous enamel from the flat surface of molded items having a recessed design which has been sprayed or manually filled. Decorative foils may be preprinted and specially processed to leave a design in one or more colors, which is an indigenous part of the finished product and which is protected by a clear, curved overlay. Recent developments have made these foils suitable not only on flat or slightly curved items, but also on relatively severe curvatures. The thermographic transfer process involves the transfer of previously imprinted designs or images from a film to the plastic part by means of heat and pressure. Economical multi-color results can be obtained where volumes are large. Heavy film and sheeting is often enhanced by mechanical or heat embossing to produce a texture or design to the surface. This can be accomplished by platen press or, as is more commonly the case, by roll press where the sheet material is formed between mating embossing rolls. This process lends itself to the production of simulated leather grained material, etc.

The decoration of plastic parts while not, as yet, an exact science, is rapidly progressing from the days of the hand finisher and is more than keeping up with other developments in the plastics production field.

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