N 69-39623

NASA.TMX 61894

S&E-ASTR- R

August 18, 1969

GEORGE C. MARSHALL SPACE FLIGHT CENTER

CASE FILE COPY

PRESSURE MOLDING

FOR

ELECTRONIC COMPONENTS

By

Bobby W. Kennedy

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PRESSURE MOLDING FOR ELECTRONIC COMPONENTS

By

Bobby W. Kennedy

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

Pressure molding is an excellent process for producing electronic components. Many parts may be molded from a variety of plastic materials and electrical components may be encapsulated utilizing the same method. There are limitations to molding some electrical components, because some components cannot withstand the heat and pressure required for molding with some compounds.

Three primary methods of pressure molding are discussed in this report; transfer, injection, and compression. Transfer and compression molding are used for forming parts from thermosetting materials and injection molding is the most practical process for molding with thermoplastic materials. Materials, mold design, equipment, and processes for all three methods are discussed along with transfer molding encapsulation of stators and injection molding of cable connectors.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

PRESSURE MOLDING FOR ELECTRONIC COMPONENTS

SUMMARY

Pressure molding is an excellent process for producing electronic components. Many parts may be molded from a variety of plastic materials and electrical components may be encapsulated by the same method. There are limitations to molding some electrical components, however, because some components cannot withstand the heat and pressure required for molding with some components.

The primary methods of pressure molding are transfer, injection, and compression. Transfer molding is a process that transfers a hot thermosetting material from a pot or container into a heated mold by means of a plunger. The material is held under pressure until the cure cycle is complete. Only sufficient material to fill the cavity is heated with each cycle. Heat is maintained at a level sufficient to completely melt the charge before final compression is applied. Transfer and compression molding are the two main processes used for forming molded parts from thermosetting materials. Both processes can be performed in the same molding press, but different type molds are used. It is possible to mold thermosplastics by these processes since the heated material will flow to conform to the mold cavity shapes when under pressure, but these processes are impractical for thermoplastic molding because the mold requires cooling to solidify the thermoplastic part. The properties of the thermosetting materials are high-thermal stability, resistance to deformation under load, high-dimensional stability, and excellent rigidity and hardness. These properties make thermosetting materials excellent for molding of electronic components.

Injection molding is the most practical process for molding thermoplastic materials. The excellent electrical properties of thermoplastic materials and the ease with which they can be processed make them valuable for use in the electronic field. Thermoplastic materials also have outstanding mechanical properties such as strength and stiffness combined with toughness. The size and shape of the parts determine the design and fabrication of the molds. The design of the mold also depends upon the type of molding process and the type of material to be processed.

INTRODUCTION

The art of molding dates back to prehistoric man, when he learned to form articles from clay with the pressure from his hands. During the nineteenth century an application of compression molding was used as a manufacturing process, and the first patent on a process of molding in the United States was issued in 1870.

With the space age and the rapid development of atomic reactors, materials are needed for high-temperature applications. Several years ago, plastic materials were limited to approximately 100 degrees Celsius ($^{\circ}$C) for an extended period of time. Through research, thermal stability has been increased to 300 degrees C., and above; and for short periods of time can withstand temperatures to 1300 degrees C. Polyimides are the most highly developed group of the heat-resistant polymers and are suitable for the molding of electronic components.

Space exploration will continually demand materials which will accommodate the increasing complexity of aerospace design and technology. One of the most demanding trends of specialization is found in the field of electronics, particularly with the aspects of insulating and packaging.

TRANSFER MOLDING

Transfer molding is used to mold thermosetting plastics that require heat to cure. Transfer molding is a process whereby a dry, solid molding compound is heated to the point of compound plasticity. The material flows, under pressure, from a container, or pot, into a mold cavity that is shaped to the dimensions and configuration of a desired part. Transfer molding is used to encapsulate electronic units as well as many other parts.

Multicavity molds are common in transfer molding, and represent the major points of economy for large volume operations. Multicavity molds can be filled as rapidly as a single cavity, thereby reducing labor and equipment costs. When using multicavity molds, the heated plastic material is forced from the transfer cylinder, or pot, through two or more separate channels, or runners, into a separate cavity at the end of each runner.

Preheating the plastic compound is a very effective means of securing a fast operating cycle. Some compounds are heat plasticized to the flow point before being placed in the mold, so that flow will commence as soon as pressure is applied. Preheating, secured from high-frequency units or from steam heaters and infrared lamps, may reduce molding time as much as 75 seconds. It is important when using transfer molds to make certain that the preheated material temperature and the heating area of the chamber are adequate to flow the compound around fragile components without damaging the components.

Typical components that are encapsulated by transfer molding are diodes, resistors, chokes, capacitors, pulse transformers, glass diodes, modules, and stators. A typical transfer molded module is shown in figure 1.

There are numerous material application processes, methods, and techniques of encapsulation. Many of the techniques used in other processes are applicable to the process of encapsulation. The type of encapsulant used may be either opaque or transparent, provided the additives used to achieve this condition do not affect such specified requirements as shrinkage and expansion.

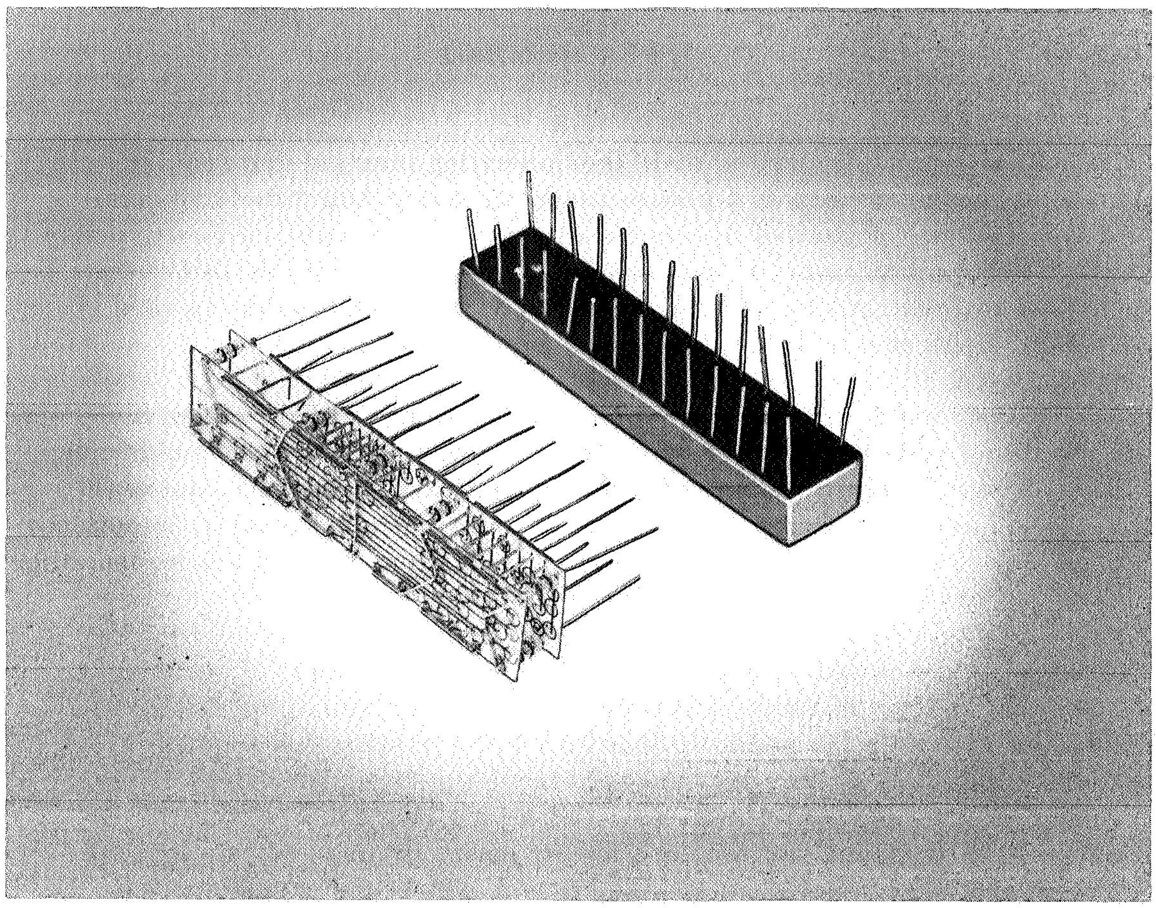


FIGURE 1. TYPICAL TRANSFER MOLDED MODULE

Transfer Molding Materials

Transfer molding materials are organic plastics of high molecular weight, which are usually referred to as a polymer or as the basic resin. The component acts not only as the binder in contributing adhesion to the plastic mass, but is also responsible for the properties of the end material. In some thermosetting plastics, the resin content is less than that of the other constituents. In other thermosetting plastics, the resin content makes up almost the entire composition.

Thermosetting resins are condensation polymers, formed through the reaction of the functional groups of organic compounds with the possible elimination of water or similar by-products. Reactivity of the starting compounds, in terms of the number of functional groups involved in the reaction, determines the type or structure of the polymer formed. In order for a polymer to be formed, the reaction components must each have at least two reactive functional groups. For thermosetting, or crosslinked polymers, it is necessary that at least one of the reactants be trifunctional or tetra-functional to provide three or more points of attachment to the molecule for the network structure. In early stages of the formation of this type of polymer, a deliberate attempt was made to limit the reactivity to only two reactive groups per molecule; thus, forming a linear, or thermoplastic polymer that can be compounded with other ingredients to form a plastic molding compound. During the cure cycle of the molding operation, complete polymerization takes place and the completely cross-linked polymer is formed, thus making it thermosetting or nonfusible. The intermediate thermoplastic polymer is referred to as the "B-stage" resin.

Epoxy molding compounds with mineral fillers are suitable for transfer molding of components that require good electrical and mechanical properties (table I) at high temperatures. This material has good flow properties at relatively low-molding pressures (1.72×10^5 to 5.17×10^5 N/m^2) and permits molding and encapsulation of delicate components.

TABLE I. PROPERTIES OF TRANSFER MOLDING EPOXY

Property	Rating
Electrical	
Dielectric Strength	510V/mil
Volume Resistivity - ohms - cm	5.1×10^{12}
Dielectric Constant at 60 Hz	4.6
Dielectric Constant at 1000 Hz	4.5
Mechanical	
Coefficient of Expansion 23 °C to 100 °C	25×10^{-6} cm/cm/°C
Specific Gravity	1.65
Tensile Strength - N/m^2	8.95×10^7
Flexural Strength - N/m^2	1.30×10^8
Shrinkage on Cure	1 percent
Machinability	Good
Heat Dissipation Temperature	200 °C

Some mineral-filled epoxy molding compounds in grandular form have low melt viscosity and excellent flow properties when transfer molded at pressures as low as 1.70×10^5 N/m^2; and uniquely combines into a single product with excellent dimensional stability, alkali resistance, and retention of electrical properties under heat and humidity.

Phenol-formaldehyde and melamine-formaldehyde molding compounds are the materials most used in transfer molding. Urea-formaldehyde materials have been transfer molded quite successfully in some cases, principally for small articles; but because of their reactivity and critical behavior in dielectric preheating, urea-formaldehyde materials have not been found as satisfactory as phenolics and melamines for transfer molding. Improvement in behavior of the urea-type plastics in transfer molding has been achieved, and research is continuing in this direction. Alkyd, or polyester, molding materials have been tested extensively in transfer molds. In some cases, they have proved suitable for molding smaller articles, but their extremely fast rate of reaction has prevented their use in molding larger articles where considerable plastic flow is required.

1. Phenol-Formaldehyde. For satisfactory use in transfer molding, a phenolic material must have a low viscosity at molding temperature to flow readily through runners and gates to form dense, homogeneously molded articles. For most production, this flow should be accomplished in the shortest time; and the material should have a rapid flow rate. Phenolic materials are now available that possess these properties; and, with the aid of dielectric or steam preheating, provide excellent results in all types of transfer molds.

2. Melamine-Formaldehyde. Good results have been obtained from using mineral-filled, cellulose-filled, and fabric-filled melamine materials for transfer molding. Certain melamine-urea formulations have also shown good characteristics in transfer molding. To produce the best flow in transfer molding, melamine materials may require some modification of basic properties. These compounds, as a class, have greater shrinkage than phenolics. This tendency exists independently of the method of molding and can be reduced by proper control of the resin and its compounding and by preheating before molding.

3. Silicones. Glass-filled silicone materials are molded by the transfer method for special high-impact, heat-resistant applications. Dielectric preheating is recommended to improve the flow. As with other fiber filled molding materials, precautions must be taken to use gates of adequate cross section to

maintain proper strength. Baking at 200 degrees C. is recommended to obtain optimum strength and heat resistance.

4. Diallyl Phthalates. Diallyl phthalates are used as transfer molding materials to mold fuel tank standoffs and spacers used in the Saturn module headers and connectors. This material offers excellent mechanical and electrical properties and is extremely easy to mold. They can be filled with fiberglas to provide additional mechanical properties.

5. Epoxy Molding Powders. A wide range of pressures and temperatures may be used when molding epoxy molding powders. Molding cycles as short as 30 seconds may be used successfully. When short molding cycles are used, it is recommended that parts be cured for one hour at 150 degrees C. to obtain ultimate physical and electrical properties.

The design of molds to be used for epoxy molding powders is essentially the same as those used with other thermosetting molding powders. The low viscosity flow of epoxy molding powders requires that the molds be designed to very close tolerances to keep flashing to a minimum. Typical physical properties are presented in table I.

The properties of epoxy resins are ideal for use in casting, potting, encapsulating, and sealing. The terms "potting, encapsulating, and sealing" are overlapping designations that pertain to the protection of components by the application of the exterior-resinous sheath. Definitions of these terms are as follows:

Casting - embedded by using a removable mold, which is separated from the unit after the material has been cured

Potting - embedded by using a shell or housing, which remains as an integral part of the unit

Encapsulating - to surround an item with insulating material, using either external molds that are removed to reveal the final product, or a thixotropic dipping sealant

Sealing - to close off a device against the environments.

Epoxy-resin castings can be used for patterns, molds, and finished products. Shrinkage is slight and dimensional stability good. The epoxy liquid systems surpass most conventional materials in ease of handling. Epoxy resin can be cast and cured quickly, and the smooth, void-free surfaces give excellent draws. Epoxy-molds are useful for short-production runs in molding electrical parts.

Because of the high degree of fill obtainable and the nature of the cured resin, the epoxies are widely used for encapsulating electronic components. For nearly all encapsulating and sealing operations; liquid, low-molecular-weight epoxy resins are used. Powders and preformed pellets may be formulated from higher-molecular-weight resins and anhydride curing agents for a limited number of molding applications.

The maximum operating temperature required for a specific application will determine the class of curing agent to be employed. Rigid systems, resistant to heat-distortion temperatures as high as 300 degrees C., may be formulated with anhydrides. Aromatic amines are resistant to heat-distortion temperatures up to about 180 degrees C., and postcured aliphatic amines are resistant to heat-distortion temperatures in the range of 120 degrees C.

It is difficult to predict the exact performance of a resin and curing agent under all conditions. The resin, percentage of curing agent, and the curing cycle are important in determining performance. Resins with higher function groups appear to give higher heat-distortion values and better strength retention above the heat-distortion temperature.

Selected properties of an epoxy-resin system can be improved by considering the cost, viscosity, exothermic heat shrinkage, pot life, and coefficient of thermal expansion.

a. Cost. Cost can be reduced by using only a minimum amount of material that is consistant with the specific application. This can be accomplished, where practical, by the incorporation of large loading volumes of inexpensive fillers or resinous modifiers.

b. Viscosity. Viscosity is most critical for potting operations where a high degree of impregnation is required and for casting operations where large volumes of fillers are necessary. If the resin-curing-agent system is at its lowest natural viscosity, it can be further reduced by working the catalyzed mix hot, or by adding either a reactive or nonreactive diluent. High-viscosity may easily be achieved by the use of thickening agents or high loading volumes of more conventional materials.

c. Exothermic heat. Exothermic heat may be reduced by the incorporation of fillers, resinous modifiers, and selected curing agents, although, the practical minimum value is about 50 degrees C. for reasonable cure times. Excessive exothermic heat can cause volatilization of the curing agent or resinous modifier and produce molding of unsatisfactory quality, which may adversely affect the temperature-sensitive components and subject the compound to too great a thermal cycle during cure.

d. Shrinkage. Shrinkage may be reduced by the incorporation of fillers and modifiers. For molding applications involving delicate components, the shrinkage of an unfilled epoxy may be sufficient to damage the components.

e. Pot life. Pot life can be increased with fillers, diluents, and resinous modifiers; although, usually only at the expense of increased cure times or higher cure temperatures. In the case of certain acid anhydrides, where pot life is too long, the pot life may be reduced and the cure time shortened by the addition of amine accelerators.

f. Coefficient of thermal expansion. The coefficient of thermal expansion of unfilled epoxy resins can be extremely rapid during temperature cycling and can result in damage to components that have different expansion coefficient. It is possible to match the value of the involved material by the use of suitable filler loading volumes. When high loading volumes cannot be used, it is often possible to formulate a satisfactory ductile compound that is capable of absorbing resultant strains. Such a system is feasible if several materials are involved and it is necessary for the epoxy resin to absorb varying stress levels within the system. Ductile systems do not give satisfactory performance at higher temperatures. Care should be taken to assure that modifications do not greatly degrade the desirable properties.

Transfer Mold Designs

The initial step in mold design is to review the product drawing to establish the parting line, ejection location, gating location, and venting areas.

The parting line is designated at the perimeter, which permits the best location for mold construction and operation in accordance with press movement, ejection, and ease of finishing after molding.

Ejection pins should be located to release the molded part from the mold after the curing cycle has been completed. A sufficient number of pins located in strategic locations insure ejection without damage to the part. A secondary function of the ejection pins is to permit the venting of air and gas at these positions through the medium of machined areas of the ejection pins or mold sections.

Venting must be provided in areas where gas and air will accumulate. Such areas may be vented by the use of ejector pins, with clearance areas between the pins and mold section. The parting line area should be vented opposite the gating area for small molds and intermittently around the top surface of the cavity at the flash line for larger molds. To produce good moldings, venting areas in the mold must be located so that air or gas will easily escape into the atmosphere. Any obstruction in this area will appear as a flaw on the molded part. The parting line vents shown in figure 2 are essential because this area of the mold cavity is the last area to be filled.

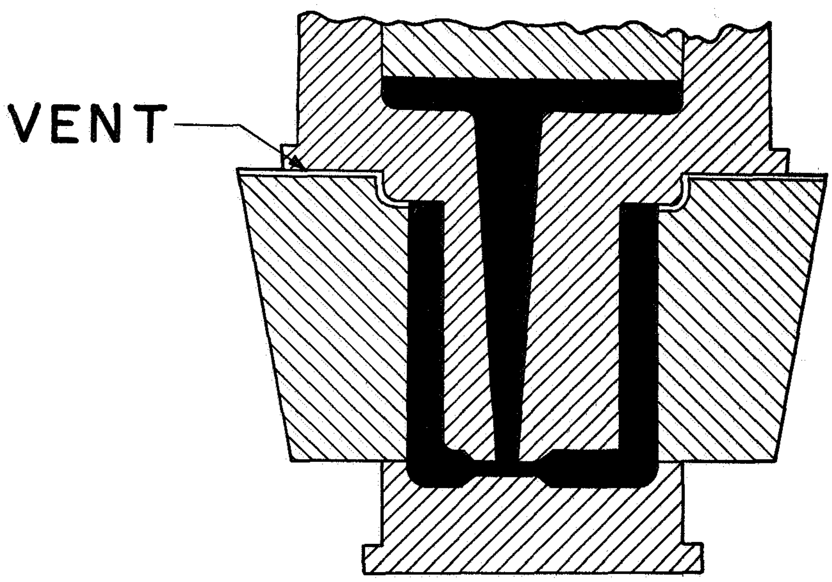


FIGURE 2. TYPICAL VENTING METHOD

General practice and broad experience is needed in designing molds. Some techniques are: main runners are from 0.635 to 0.953 centimeter with auxiliary runners approximately 30 percent smaller. Round runners provide a maximum volume-to-surface ratio that gives the least possible resistance to material flow.

Gating presents design problems for which it is impossible to state specific design and size information; therefore, experience and practice offer the most reliable design guidance. Normal practice is to position the gate at the thickest section of the part. Materials having long fillers generally require a boss molded in front of the gate area to facilitate finishing the part by removing depressions or voids caused by tearing the fillers when the runner is removed.

Gate removal and final finishing must be considered because of their potentially large effect on product cost. Final finishing costs are reduced by using gates that may be removed by breaking or a product may often be designed to permit the gate to be a depressed area on the side of a part to further reduce finishing costs. When this method is used and the inset gate is broken off, the extension will not protrude beyond the outside contours of the part and interfere with fitting to adjacent parts. Gates should be located, when possible, on a hidden area of the product.

The gate scar remains on the finished part at the point where the plastic molding compound is forced from the runners into the cavity. The scar, which is small and unobjectionable, results when the finished part is parted from the runner.

Although low pressures are utilized in transfer molding of embedded electronic components, it is strongly recommended that transfer molds for direct encapsulation be constructed of high-quality, hardened tool steel for protection. It has been found that maintaining dimensional stability and achieving a trouble-free production operation is possible only with heavy duty molds, although less expensive molds can be built from aluminum, beryllium-copper, or soft steel. The molding press should be capable of delivering pressures in excess of those normally required, but it should also be capable of sensitive adjustment to lower pressures, particularly in the transfer circuit, to achieve optimum results in the process. The mold should contain heaters that are sufficient to heat the mold to 150 degrees C. within one hour. Molds with a projected mold area of approximately 38 by 38 centimeters generally require 3 kilowatts per mold half to meet this requirement. Adequate temperature control should be provided by using thermostatically controlled heating units.

Hard-chrome plating is recommended for all sections of the mold that will come in contact with the molding compound. This includes the entire parting surfaces of the mold, since some material will come in contact with the non-working surfaces. Any cam-actuated surfaces, sliding sections of the mold, or hydraulically-actuated core pins should be thoroughly chrome plated and polished. The plating not only tends to minimize compound adhesion, but also facilitates cleaning of the mold and minimizes wear. Chrome plating is relatively inexpensive and can be removed easily if further mold machining is required. Before plating, the surface should be polished to a finish of 40 microcentimeter, or smoother.

The hard-chrome mold surface provides good wear characteristics, preserves the molding surface while the mold is not in use, aids in release of the molded product, and the products do not require additional sanding or machining to remove mold release or other foreign matter that is left on the surface of the molded part.

Chrome plating on a finished mold surface reduces the original surface finish to a certain degree, but after this degree of reduction has been reached, the chrome will maintain that final finish for a longer period of time.

Chrome plating will not harden the material upon which it has been applied, nor will chrome give the mold surface a smoother or finer finish. The advantages and disadvantages vary with the amount of chrome applied. Best results are achieved with a deposit of from 0.0038 to 0.0050 centimeter.

The designer must consider many factors in designing a mold. The mold contemplated must be correct in order to produce parts economically, and tough in order to withstand the hard use to which it will be subjected. The cost of the materials used in mold making is the least important consideration, but the hours of labor used in constructing the mold represent an expensive investment that will be lost if the design is poor or the materials unsuitable. The final design represents many compromises in achieving a suitable balance of styling, engineering, and cost factors. The four general classes of steel used in mold making are as follows:

Low carbon, (less than 0.20 percent carbon) - this steel does not contain enough carbon to cause it to harden to any appreciable extent when heated and quenched

Medium carbon - 0.20 to 0.60 percent carbon

High carbon - 0.70 to 1.30 percent carbon

Alloys - steel of this classification contains various elements besides carbon, each element serving to contribute a definite property to the materials.

Steel may be machined in a relatively soft state and then hardened by heat treatment to achieve improved wear resistance, toughness, strength, and dimensional stability. The pressure in the mold may ramp to a very high value under certain conditions and crush or distort the steel mold section. Unhardened molds will not withstand the high production rates in most molding processes because of the lack of compressive strength.

Some grades of steel are more adaptable to certain machining operations than others, depending on the annealing process. It is possible to custom anneal a piece of steel to provide better machinability for a given process. The machinability of a given stock will vary with the type of machining to be employed, and will, to some extent, be determined by the type of annealing to which the stock has been subjected. Mold steels are usually annealed to result in the best average machinability.

Steel that is used for making molds must possess the following qualities:

Cleanliness - the steel must be clean and should not contain nonmetallic inclusions that will cause pitting during polishing.

Structure uniformity - the steel must be uniform in structure and relatively free of alloy segregations. It must be uniform in chemical composition.

Machinability - machinability depends upon the hardness of the steel and upon its microstructure. Softness is not necessarily an assurance of machinability; and extreme softness is as undersirable as extreme hardness. Steel that machines easily and uniformly is required for economical mold construction.

Capable of being hobbed - steel that is to be hobbed must be clean, ductile, and very soft when annealed. Mild steel, Swidish iron, and boiler plate may be hobbed easily, but the specially developed hobbing steels are preferable. They offer the maximum in cleanliness and uniformity. Ingot iron and the low alloy steels are easiest to hob. The higher alloy content steels offer some difficulty, but give the best results in service.

Hardenability - good mold steel must acquire the desired hardness during the heat-treating process, be uniform in composition, have a hard surface, and a tough strong core. Ingot iron and low carbon steel will harden in water, but may distort and become useless. Alloy steels harden in oil or air and show a minimum amount of dimensional change during hardening.

Strength and toughness - molds require a hard surface and a tough core. The larger the mold, the greater the core strength required to resist distortion.

Heat-treating safety - an important characteristic of a good mold steel is its ability to be hardened satisfactorily in a wide range of sections by a variety of methods while producing uniform results.

Finish - mold steel must be capable of accepting a mirror-like finish easily, although a dull surface is often used as the desirable finish.

Wear resistance - wear resistance is a fundamental requirement of a good, general-purpose, mold steel. (Some plastics cause little tool wear; others, such as glass-filled plastics, require a maximum amount of wear resistance.)

Many materials other than steel have been used for molds; however, for certain work, none of these substitute materials have proven as satisfactory as steel and merit selection only for short-run jobs, or for sample-production runs. Some of the dense, non-metallic materials are suitable for sample molds if handled carefully and if soft, free-flowing compounds are used. In some cases, steel is combined with other materials for mold making.

A variety of plastic materials are used for cast molds. These include the silicones, epoxy, and polyester resins. Metallic fillers are often used in such cast molds to increase strength. Steel wool may be included as a filler to obtain thermal conductivity. Such simple cast molds are commonly used in prototype development work.

Beryllium-copper alloys can be used successfully for many types of molds. This material may be cast, which eliminates costly machining of intricate mold design. The best physical properties of beryllium-copper molds; such as good surface finish, uniform density, compressive strength, and greatest hardness, are obtainable only by high-pressure casting against a heat-treated hob. Beryllium-copper molds will not withstand continued use in compression molding, but are satisfactory for many injection molds and for some transfer molds.

Properties such as dimensional stability, cold flow, moisture absorption, flammability, hardness, electrical, chemical resistance, impact resistance, and mechanical strength may require a change of material or an alteration in product design.

The preparation of a mold for use involves cleaning, drying, and preparing the mold for release of the molded item. Many suitable cleaning solvents and release agents are available. Cleaning is necessary to obtain the true configuration of the mold on the molded item. A thin film of release agent is usually applied to all mold surfaces, which eliminates the need for knockout pins in many simple configurations.

Module Encapsulation

The demands of modern technology have produced requirements for electrical and electronic assemblies of smaller sizes whose components have greater physical protection and better electrical insulation. Encapsulation by transfer molding is a means of providing these qualities, and is especially beneficial in protecting fragile components (figure 1). The introduction of new polymer materials has made transfer molding more accepted and more desirable.

There has been some question as to what effect encapsulation by transfer molding would have on cordwood modules composed of glass-sealed diodes, glass-sealed capacitors, resistors, transistors, and other components that make up a module. For this reason, a study was conducted to determine whether encapsulation of modules would cause failures to occur.

The first step of the study was the selection of the module circuits to be encapsulated, such as an amplifier or an inverter, which normally contain fragile diodes, resistors, and capacitors.

In addition to the selection and design of the circuits, consideration was given to the materials that comprise the circuits. All materials do not behave in the same manner when subjected to hot encapsulating compounds under pressure.

The design of modules is of importance in several aspects. The design parameters of packaging size and parts layout are joined with a necessary choice of materials to be employed in molding operations; therefore, the following criteria have become necessary for the design of components to facilitate molding operations.

The assembly must be centered in the molding cavity. To obtain good insulation properties and to produce a unit with good appearance, a wall of equal thickness should surround the assembly upon completion of molding. In a cylindrical capacitor, this is achieved by clamping the two axial wires tightly between the two mold halves on the loading fixtures. This method is undersirable for encapsulating assemblies with fragile components.

For the encapsulation of delicate components, one solution that has been suggested is to mold a support for the assembly having extensions that rest on at least three sides of the mold cavity. Such a support, if made out of a carefully chosen thermosetting material, would not only adhere well to the encapsulating compound, but could eliminate distortion during the molding operation.

Undercuts or protrusions should be avoided. These produce weld lines and voids in the finished products.

Coils should be wound tightly; however, both sharp edges and flat bobbins must be avoided in winding coils. A coil wound on a flat bobbin, or one wound with loose wire tension, will tend to entrap more air than a tightly wound cylindrical coil. Air entrapment will cause blisters and voids that will result in a poor appearance of the finished product.

Materials containing volatile substances should not be used, if at all possible. Many adhesives and tapes fall into this category. If they must be used, the selection of thermosetting varieties is urged.

Tapes should be applied in the same direction as the flow of the material. Likewise, adhesive joint and solder connections should be oriented to have optimum strength in the direction of the material flow. Welding is favored over soldering, but if soldering proves more economical, or must be used, a high-temperature solder with a melting point at a minimum of 50 degrees C. above that of the molding temperature must be used.

If the module contains solder connections, it is also necessary to ensure that all flux is removed before encapsulation. If it is not removed, it may react chemically with the molding compound, and is invariably detrimental to the electrical and physical properties of the compound. Also, flux tends to migrate to the surface, leaving it gummy and forming excellent paths for arcing.

All connections, tapes, adhesives, and solder joints must have sufficient strength to withstand the temperature and flow of the encapsulating compound.

If the module contains any fragile parts, a reinforcing section should be placed on the bottom and, if necessary, on the top of the module for protection during the ejection process.

Cordwood modules chosen for the study were D2A-Delay Circuit 300 Series and SI-2 Signal Isolar Modules, fabricated by the Sperry Utah Company. The materials used for the encapsulation process was two different mineral-filled epoxy molding compounds numbered 1 and 2. These materials were selected for use because of their low coefficient of thermal expansion (tables I and II).

1. <u>Module Encapsulation With Compound No. 1.</u> Ten D2A-Delay Circuit Series 300 Electronic Modules were encapsulated and used for this test. These modules were composed of glass-sealed resistors, diodes, capacitors, and transistors; chosen to determine the effects of transfer molding on each glass-sealed component.

The modules were electrically tested before encapsulation (table II), after encapsulation (table III), and after thermal shock (table IV).

TABLE II. D2A MODULES TEST DATA BEFORE ENCAPSULATION

Ser. No.	Logic Level "0"	Logic Level "1" Volts	Fall Time	Pulse Width	Pin No.	Specification Values
1	0.2	6.0	0.2	1.5	D	>3.0V <0.5V <0.5 Micro. Sec. 1.8 ± 0.5 Sec.
1	0.3	7.5	0.2	1.5	F	>3.5V <0.5V <0.5 Sec. 1.7 ± 0.5 Sec.
2	0.2	6.0	0.2	1.0	D	
2	0.3	7.5	0.2	1.5	F	
3	0.2	6.0	0.2	0.5	D	
3	0.3	7.5	0.3	0.5	F	
4	0.2	6.0	0.2	1.0	D	
4	0.3	7.5	0.2	1.5	F	
5	0.2	6.0	0.2	1.0	D	
5	0.3	7.5	0.2	1.5	F	
6	0.2	6.0	0.2	1.0	D	
6	0.2	7.5	0.2	1.5	F	
7	0.2	6.0	0.2	1.0	D	
7	0.3	7.5	0.2	1.5	F	
8	0.2	6.0	0.2	1.0	D	
8	0.3	7.5	0.2	1.5	F	
9	0.2	6.0	0.2	1.0	D	
9	0.3	7.5	0.2	1.5	F	
10	0.2	6.0	0.2	1.0	D	
10	0.3	7.5	0.2	1.5	F	

The following molding procedure was used with the D2A modules.

The modules were placed in the mold, the mold transferred to the molding press, and the temperature of the mold raised to 150 degrees C.

TABLE III. D2A MODULES TEST DATA AFTER ENCAPSULATION

Ser. No.	Logic Level "0"	Logic Level "1" Volts	Fall Time	Pulse Width	Pin No.
1	0.2	3.5	0.1	0.5	D
1	0.2	5.0	0.1	0.5	F
2	0.2	4.0	0.1	0.5	D
2	0.3	5.0	0.3	1.5	F
3	0.2	3.0	0.2	1.0	D
3	0.3	5.0	0.2	1.5	F
4	0.2	3.0	0.2	1.0	D
4	0.3	5.0	0.2	1.5	F
5	0.2	3.0	0.2	1.0	D
5	0.3	5.0	0.2	2.0	F
6	0.2	3.0	0.2	1.0	D
6	0.3	5.0	0.2	1.5	F
7	0.2	3.5	0.2	1.0	D
7	0.3	5.0	0.2	1.5	F
8	0.2	4.0	0.1	0.5	D
8	0.3	5.0	0.2	1.5	F
9	0.2	3.0	0.2	1.0	D
9	0.2	5.0	0.2	1.5	F
10	0.2	3.0	0.2	1.0	D
10	0.3	5.0	0.1	1.5	F

A premeasured amount of compound 1 was placed in the mold cavity and the transfer ram brought down on the material at a pressure of 5.20×10^5 N/m^2. After 30 minutes at this pressure, the mold was taken from the press and allowed to cool prior to removal of the module.

When the D2A modules had been thermal shocked, they were visually inspected under a 10x microscope to determine whether thermal shock had caused any cracks in the molding material. No cracks were noted; however, a discoloration or bleaching of the material was observed. The thermal shock test consisted of placing each module in water at 100 degrees C. for 10 minutes and then immediately transferring the module to a dry ice and alcohol bath at minus 65 degrees C. for 10 minutes. Both D2A and SI-2 modules were subjected to a thermal cycling test, which consisted of 10 cycles.

TABLE IV. D2A MODULES TEST DATA AFTER THERMAL SHOCK

Ser. No.	Logic Level "0"	Logic Level "1" Volts	Fall Time*	Pulse Width	Pin No.
1	0.2	2.0	0.3	1.5	D
1	0.2	2.0	0.3	1.5	F
2	0.2	4.0	0.3	1.5	D
2	0.2	5.0	0.3	1.5	F
3	0.2	3.5	0.3	1.5	D
3	0.1	5.5	0.3	1.5	F
4	0.2	4.0	0.3	1.0	D
4	0.2	5.0	0.3	1.0	F
5	0.2	4.0	0.3	1.5	D
5	0.2	5.0	0.3	1.5	F
6	0.2	4.0	0.3	1.5	D
6	0.2	5.0	0.3	1.5	F
7	0.1	4.0	0.3	1.5	D
7	0.2	5.0	0.3	1.5	F
8	0.2	4.0	0.3	1.0	D
8	0.2	5.0	0.3	1.5	F
9	0.2	3.5	0.3	1.0	D
9	0.2	5.0	0.3	1.5	F
10	0.2	4.0	0.3	1.5	D
10	0.3	5.0	0.3	1.0	F

* All time in microseconds

2. Modules Encapsulated With Compound No. 2. Number 2 molding compound was used to encapsulate ten SI-2 modules. This granular molding compound is a mineral-filled epoxy resin with low-melt viscosity and long-flow properties when transfer molded as low as 1.92×10^5 N/m^2; and uniquely combines into a single product with excellent dimensional stability, alkali resistance, and retention of electrical properties under adverse conditions of heat and humidity.

The SI-2 module was placed in the transfer mold, the mold placed in the press, and temperature set at 150 degrees C. The press was closed and molding material inserted into the mold cavity and pressure was applied by the transfer ram at 5.20×10^5 N/m^2 for five minutes. Pressure was released and the mold was removed from the press and allowed to cool before removal of the encapsulated module. In production of molded modules, knock out pins would be used to release the module while the mold was hot, this eliminated cooling and reheating the mold after each module was molded. To facilitate easy handling, the module was located on a teflon insert in the mold.

The SI-2 modules were electrically tested before encapsulation (table V), after encapsulation (table VI), and after thermal shock (table VII).

TABLE V. SI-2 MODULES* TEST DATA BEFORE ENCAPSULATION

Logic Level "1" 7.5V	Logic Level "0" <0.5V	Rise Time <0.5 Sec.	Pulse Width >1 Sec.	Current <0.5 ma	Isolation Resistance >10 meg	Min "E" <3.5V
5.0	0	0.3	2.5	1.32	∞	2.5
5.0	0	0.3	2.5	1.36	∞	2.5
5.0	0	0.3	2.5	1.33	∞	2.5
6.0	0	0.3	2.5	1.34	∞	2.5
5.5	0	0.3	2.5	1.33	∞	2.5
5.0	0	0.3	2.5	1.33	∞	2.5
5.5	0	0.3	2.5	1.32	∞	2.5
5.0	0	0.3	2.5	1.32	∞	2.5
5.5	0	0.3	2.5	1.33	∞	2.5
5.5	0	0.3	2.5	1.33	∞	2.5

* Serial numbers 1 thru 10

After thermal shock and electrical test, each module was visually checked with a 10x microscope to determine whether modules had been cracked during thermal shock. No cracks were noted and the material retained good color and a glossy finish.

Workable modules may be obtained when electronic modules are encapsulated by transfer molding at low pressure and temperature. The low pressure will not be determental to glass components in the modules.

According to electrical test data, all components of both type modules withstood molding and thermal shock without cracking. All electrical values were within specified limits.

TABLE VI. SI-2 MODULES* TEST DATA AFTER ENCAPSULATION

Logic Level "1" 7.5V	Logic Level "0" <0.5V	Rise Time >1 Sec.	Pulse Width >1 Sec.	Current <0.5 ma	Isolation Resistance >10 meg ohm	Min "E" "1" <3.5
5.0	0	0.3	2.0	1.35	∞	2.5
5.0	0	0.3	2.0	1.40	∞	2.5
5.0	0	0.3	2.0	1.40	∞	2.5
5.5	0	0.3	2.5	1.36	∞	2.5
5.5	0	0.3	2.0	1.40	∞	2.5
5.0	0	0.3	2.0	1.40	∞	2.5
5.5	0	0.3	2.5	1.35	∞	2.5
5.0	0	0.3	2.5	1.38	∞	2.5
5.5	0	0.3	2.5	1.40	∞	2.5
5.5	0	0.3	2.5	1.40	∞	2.5

* Serial numbers 1 thru 10

TABLE VII. SI-2 MODULES* TEST DATA AFTER THERMAL SHOCK

Logic Level "1" 5V	Logic Level "0" <0.5V	Rise Time 0.5 Sec.	Pulse Width 1 Sec.	Current <0.5 ma	Isolation Resistance 710 meg ohm	Min "E"for <3.5V
5.0	0	0.5	2.7	1.24	∞	2.5
5.0	0	0.5	2.5	1.26	∞	2.5
5.0	0	0.5	2.6	1.25	∞	2.5
6.0	0	0.5	2.6	1.24	∞	2.5
5.5	0	0.5	2.7	1.25	∞	2.5
5.0	0	0.5	2.5	1.25	∞	2.5
5.5	0	0.5	2.7	1.24	∞	2.5
5.0	0	0.5	2.6	1.24	∞	2.5
5.5	0	0.5	2.8	1.24	∞	2.5
5.5	0	0.5	2.5	1.25	∞	2.5

* Serial numbers 1 thru 10

INJECTION MOLDING

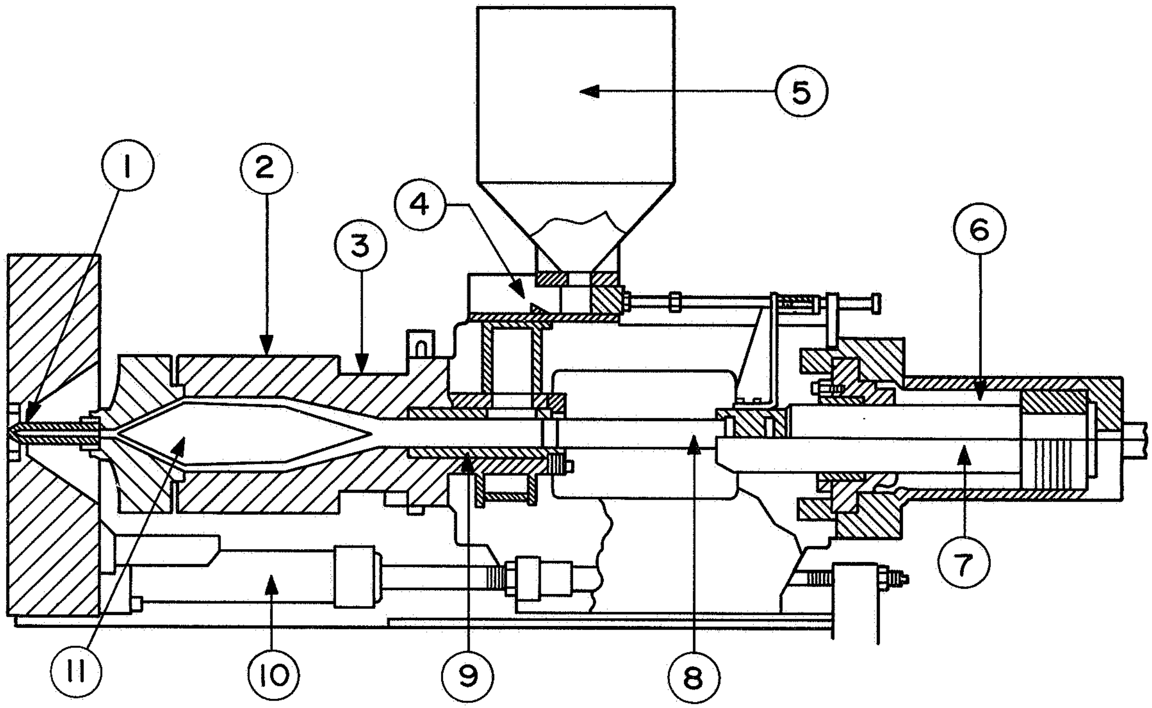
Injection molding is the most practical process for molding thermoplastic materials and is much faster and usually cheaper than transfer or compression molding.

The thermoplastic material is maintained in a heated reservoir of the injection molding machines. This hot, soft material is forced from the reservoir into a cool mold shaped to the desired form. The mold is opened as soon as the material has dissipated enough heat to hold its shape and allow repetition of the cycle. The speed of each cycle is determined by the thermal conductivity of that material. Acrylics are slow performers and styrenes are among the fastest.

The injection molding machine is usually one of two types: (1) straight ram; (2) screw automatic, or semiautomatic; whose bore determines the capacity. Within the bore is a piston that opens a hole in the top of the cylinder when the piston is retracted. Material enters the mold cavity through the hole and new material can be added to replace the charge shot into the mold. The cylinder is heated by electrical bands which permit temperature variation along the cylinder length. Inside the exit end of the cylinder is a torpedo over which the hot material is forced before injection by the nozzle into the channels leading to the cavities. This causes a final churning action that provides thorough heating of all particles. The mold opens and closes automatically and the entire cycle is controlled by timers. An injection machine is rated by the number of grams it will inject per stroke of the piston and by the square centimeters of working area that can be clamped against the injection pressure. A straight ram injection molding machine is depicted in figure 3.

In general, the reciprocating screw injection machine has made the plunger-type press obsolete and has been a great help in the growth of injection molding and the use of molded products. Figure 4 shows a screw injection machine.

The reciprocating screw press, often identified as an in-line press, utilizes a reciprocating screw to move and melt the granules of material as they are milled by the screw and passed through the heated injection cylinder. Complete melting is achieved by mechanically working the molding compound. When melted, the material builds up in front of the screw, forcing it to retract. At this point, the screw stops and becomes the plunger, which moves forward forcing the plasticized material into the mold.



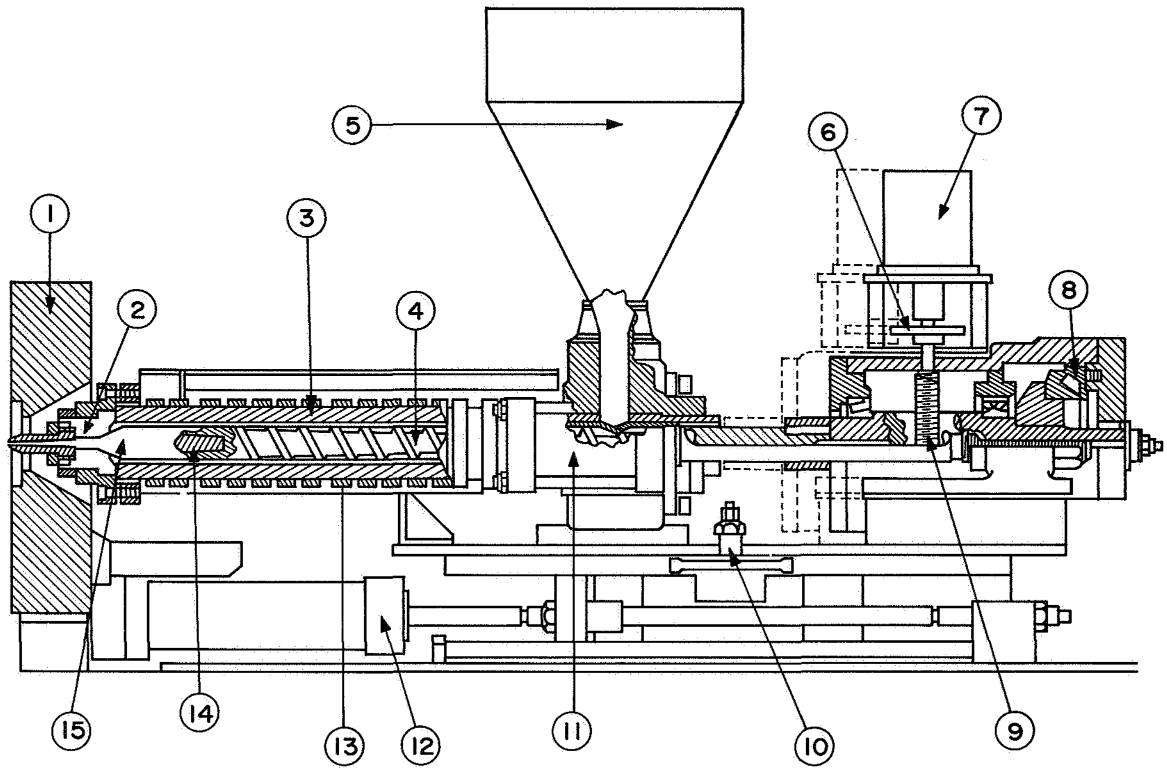
1. Nozzle Tip
2. Heating Bands
3. Plasticizing Chamber
4. Feed Chute
5. Material Hopper
6. Hydraulic Injection Cylinder
7. Injection Ram
8. Injection Plunger
9. Injection Sleeve
10. Pull in Cylinder
11. Heated Torpedo

FIGURE 3. STRAIGHT RAM INJECTION MOLDING MACHINE

The function of the injection mold is to shape the part and confine the molten material under pressure until it is sufficiently rigid to permit ejection. It must perform this function repeatedly in continuous production on minimum cycles without sticking, distortion, wear, component breakage, or excessive maintenance. The mold must also provide a rapid and efficient transfer of heat.

Injection Molding Material

The most important properties of the thermoplastic materials are their excellent electrical properties and their adaptability to use by the injection



1. Die Head
2. Standard Extruder Head
3. Extruder Barrel
4. Extruder Screw
5. Hopper
6. Tachometer Drive
7. Hydraulic Motor
8. Thrust Bearing
9. Screw Drive System
10. Pivoting Device
11. Two Hydraulic Cylinders
12. Pull-in Cylinder
13. Heating Bands
14. Non-Return Flow Valve Assembly
15. Injection Chamber

FIGURE 4. SCREW INJECTION MACHINE

molding process. Certain of the thermoplastic materials such as teflon, polystyrene, polyethylene, and polypropylene offer low electrical losses normally unobtainable with thermosetting materials. When produced in high volumes, parts made of thermoplastic materials can be produced much more economically than parts made of thermosetting materials.

Acetals are a relatively new class of thermoplastic material with outstanding properties of mechanical strength and stiffness, toughness, excellent resilience for the stiff nature of the material, and excellent dimensional stability.

Abrasion resistance is generally superior to thermoplastics other than nylons, and their electrical properties are good at most frequencies. They maintain these characteristics under high humidity exposure and at temperatures up to 125 degrees C.

Nylon is a thermoplastic material for which there exists a considerable number of distinct variations. The nylon designation refers to the number of carbon atoms in the amine and the acid-based materials, which are used to produce the nylon. Nylon is easy to process and is very widely used. All nylons have good electrical properties, but there are variations in the processability, moisture absorption, weather resistance, and thermal resistance of the various formulations.

Polycarbonates are a relatively new thermoplastic material whose outstanding properties are dimensional stability and toughness. They have excellent electrical properties, which change very little when subjected to elevated humidity conditions and temperatures up to 125 degrees C. This combination of high mechanical strength, particularly impact strength, and good electrical properties make polycarbonates an excellent choice for many electronic packaging applications.

Fluorocarbons, such as polytetrafluoroethylene (Teflon TFE), are widely used in electronic packaging because of their resistance to high temperature and their low electrical loss characteristics. Several grades of teflon are available. All have a low dissipation factor and dielectric constant, which is essentially unchanged from frequencies of 60 hertz to 10,000 megahertz. Electrical properties undergo only slight alterations when subjected to temperatures up to 260 degrees C. The primary advantage of teflon is its low coefficient of friction; its major disadvantage is the relatively high cost and non flowing properties, which make processing difficult and costly.

Teflon FEP is a copolymer of tetrafluoroethylene and hexafluoropropylene. FEP has most of the excellent properties of the TFE but exhibits a lower melt viscosity, which makes possible conventional injection molding. Teflon FEP has a lower temperature capability and is more costly than TFE, but for large volumn applications the reduced processing cost can make FEP less costly for molded parts.

Polychlorotrifluoroethylenes (Kel-F, Halon, CTFE) represent a well established group of fluorocarbon resins. CTFE resins exhibit the same general properties as the teflon materials, but the electrical losses of CTFE are higher and the resistance to heat is lower. This material is easily processed and offers relatively low cost for this high class of material. CTFE is also harder than TFE or FEP.

Two thermoplastics that resist heat from 205 to 260 degrees C. are TFE and CFE fluorocarbon. The long-term thermal stability of TFE polymers exceeds 260 degrees C. and their chemical inertness is unmatched by any other organic polymer. CFE polymers have less chemical inertness and thermal stability, but are easier to process by conventional forming methods. Fluorocarbon resins have no appreciable moisture absorption characteristics and their electrical insulating qualities are unexcelled in the plastics field. The unusual properties, coupled with their thermal stability, indicate their wide use in the electronics field.

Although TFE is technically classed as a thermoplastic, its properties are unique in that it does not become fluid even as the temperature is increased beyond its fusion temperature. The crystaline structure of TFE at or near ambient temperature changes to an amorphous, transparent gel when heated above the transition temperature (325 degrees C.). The material is quite sticky in the gel stage and will weld together under light pressure.

The thermal stability of TFE is shown by the temperature versus weight loss in table VIII.

TABLE VIII. TFE WEIGHT LOSS IN AIR

Temperature ($^{\circ}$C)	Weight Loss (percent/hr.)
200	0.0002*
260	0.0002*
315	0.0002*
360	0.0001*
390	0.006**
420	0.09**

* Test on granular molding powder
** Test on molded sheet

Some outstanding features of molded TFE are thermal stability, resistance to chemicals, electrical insulation properties over a wide range of frequencies and temperatures, lowest coefficient of friction, and serviceability at extremely low temperatures.

Molded TFE mechanical and electrical properties are presented in table IX.

TABLE IX. MECHANICAL AND ELECTRICAL PROPERTIES OF MOLDED TFE FLUOROCARBON

Property	Rating
Mechanical	
Tensile Strength ($N/m^2 \times 10^7$)	1.50 to 3.00
Elongation (percent)	100 to 200
Flexural Strength (6.90×10^6 N/m^2)	No break
Stiffness ($N/m^2 \times 10^8$)	3.45 to 6.20
Compressive Stress Deformation ($N/m^2 \times 10^6$	4.15
Coefficient of Linear Thermal Expansion, 25 to 60 $^\circ C$ (cm/$^\circ$C)	11.66×10^{-4}
Thermal Conductivity, 0.045 cm (cal/cm/sec/cm^2/$^\circ$C)	0.0005
Specific Heat (gram calories/gram/$^\circ$C)	0.25
Heat Distortion Temperature, 4.55×10^5 N/m^2 ($^\circ$C)	120
Water Absorption, 24 hr (percent)	0.005
Flammability (cm/min)	Nonflammable
Specific Gravity	2.1 to 2.2
Resistance to Weathering	Excellent
Electrical	
Dielectric Strength (V/mil)	400 to 500
Surface Arc Resistance (sec)	Non-tracking
Volumn Resistivity (ohm-cm)	10^{15}
Surface Resistivity, 100 percent RH (Megohms)	3.6×10^6
Dielectric Constant, 60 Hz to 10^8 Hz	2.00
Power Factor, 60 Hz to 10^8 Hz	0.0003

TFE polymers may be considered completely inert to practically all chemicals and solvents with the exception of molten alkali metals and fluorine at both elevated temperatures and high pressures. Samples of TFE have been immersed in boiling aqua regia, hydrofluoric acid, nitric acid, sulfuric acid, and strong alkalies without weight loss or property change.

TFE is one of the most useful organic materials available for use at cryogenic temperatures. Strength increases substantially at low temperatures, and some degree of elongation and resilience is retained. TFE parts have been used successfully at temperatures as low as minus 240 degrees C.

Polycarbonate resin has excellent properties such as high impact strength, good dimensional stability, resistance to high temperatures, good electrical and self-extinguishing characteristics, and creep resistance. Many of these properties are enhanced by reinforcement with glass fibers. For good results, cylinder and nozzle temperature should be from 275 to 315 degrees C., and the heated mold temperature should be in the range of 75 to 95 degrees C. Typical injection pressures used with polycarbonates are 1.05×10^8 to 1.40×10^8 N/m^2.

Injection Mold Design

Sizes and location of runners and gates play an important part in the success of an injection mold. The runners vary in size and shape with each job and each type of plastic used.

There is no set rule for predetermining how large a runner should be. A starting point for an average mold is a diameter of 0.635 centimeter; and 0.318 centimeter for a very small mold. If the runner is larger than necessary, too much material is used to fill it, sometimes taxing the capacity of the machine, and often lengthening the cycle in order to chill the unnecessarily thick section. If the runner is too small, resistance to flow is greater and the material is cooled too much before it reaches the cavity. The cylinder temperature can be raised within limits to allow for this drop, but the correct practice is to enlarge the gates and runners. Runners should be cut small initially, and then enlarged to optimum cross section on the basis of actual trial.

In turns, runners should be polished and rounded. The ratio of perimeter to cross-sectional area should be as small as possible. Whenever possible, they should be cylindrical, with one-half of the runner cut into each side of the mold. Where this is not practicable, they should be trapezoidal, with the depth almost equal to the width. In no case should they be wide and shallow.

The layout of a multicavity mold should be symmetrical, with all cavities equidistant from the sprue. This helps to fill all cavities at the same time, and with equal pressure. Where this is not possible, as in the case of family molds, filling rates of different cavities can be equalized by variations in the size of the gate and runner.

The gate, which is the opening through which the material enters the cavity of the mold, must be designated to meet the specific requirements of each job.

The smaller the gate, the easier it is to trim off, so it is wise to keep it as small as possible, consistent with good molding. Generally a large gate should enter the cavity of the mold at its widest section, but in many cases restricted gates work much better when they feed into the thinnest section, and best of all when the entering material impinges on a wall of the cavity before it spreads to the rest of the cavity, thus mixing the plastic and preventing molding strains and streaks.

Location of the gate through which the material flows into the cavity of the mold should be such that fewer flow marks, weld lines, and air pockets will occur.

If the cavity is not correctly vented, proper filling is difficult, a poor weld may result, or trapped air may even be compressed to the point of overheating and burning the material. The mold is tightly closed before the material is injected and provisions must be made to expel air from the cavity. If the last part of the cavity to fill is at the parting line, a groove from 0.005 to 0.010 centimeter deep can be ground from that point to the outer surface of the mold. If the last part to fill is not at the parting line, an ejector pin provided with several flats ground to a depth of 0.005 centimeter may be located at that point. In most cases, such vents can be effectively and accurately located only after the mold has been tried.

The location of water lines is very important for cooling of injection molds. Channels should be located in the initial design of the mold before supporting pillars, knockout pins, and other components of the mold are positioned.

The metals used in making injection molds should be the same as those used in making transfer molds. See Transfer Mold Design.

COMPRESSION MOLDING

Compression molding is a process by which a measured quantity of plastic material is given shape by heat and pressure applied to a hardened steel mold in which the plastic material has been placed. The steel mold is usually divided into two halves which are attached to the upper and lower platen of a press. The upper half is called the force, or plunger. The lower, or receiving half, is called the cavity. Heat is applied either directly to the mold or indirectly through the platen. Steam or electrical resistance may be used as a heat source. A typical compression mold is shown in figure 5.

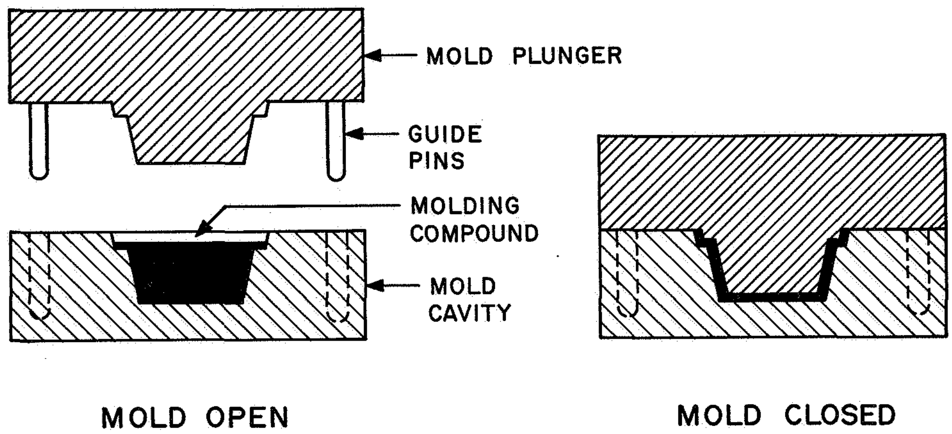


FIGURE 5. COMPRESSION MOLD

The powdered molding compound is placed in the mold cavity and the press is cycled. The mold closes to apply heat and exert pressure, causing the plastic material to soften and flow into the cavity. The temperature ranges from 120 to 190 degrees C. and the pressure ranges from 2.05×10^6 to 6.90×10^7 N/m^2, depending on the characteristics of the plastic material and the design of the workpiece. The mold remains heated and closed while the plastic material cures. A small clearance, usually 0.008 to 0.15 centimeter is allowed between mold halves to permit escape of excess material and volatile gases.

After the material has cured, the mold is opened and the part is ejected by knockout pins. The cure time will depend on the size and thickness of the part, usually from 20 seconds to 10 minutes.

Compression molding is characterized by simplicity of operation with relatively great latitude in molding conditions. This process is ideal for producing parts of large area and deep draws having relatively simple shapes. The wide range of typical parts made by compression molding is evidence of the versatility of the process.

The cost of finishing compression molded parts is high when compared to the finishing cost of injection molded parts. The relatively slow compression molding cycles require a greater number of cavities for a given production rate than is required by other molding processes. Compression molded parts require greater tolerances across parting lines, and inserts are often integral parts of the molded piece. It is difficult to hold delicate inserts in place during compression molding.

Compression is a major process used for forming molded parts from thermosetting raw materials. Thermoplastic materials may be molded by this process but it is not practical because the mold must be cooled to solidify the thermoplastic part. Since repeated heating and cooling of this large mass of metal and the long resultant cycle time per part produced are both objectionable, injection molding is commonly used to mold thermoplastic materials.

Compression molding of thermosetting materials has certain advantages over transfer molding. These advantages are: less material waste in the form of sprues and runners; no problem of erosion by material flowing through narrow gates into a closed cavity; less internal stress in the molded article because of the shorter and multidirectional flow of the material under pressure in the mold cavity; less finishing cost because there are no gates; maximum number of cavities can be used in a given mold base without regard to demands of a sprue and runner system; more adaptable to automatic loading of material and automatic removal of molded articles; no runners or culls to remove; with modern high frequency preheating, thicker sections can be successfully molded without central voids, porosity, or blistering.

Compression Molding Materials and Techniques

The most commonly used thermosetting materials are phenol formaldehyde, urea formaldehyde, melamine formaldehyde, alkyds, and silicones.

Phenolic molding powders are made by the interaction of phenol with formaldehyde in the presence of a suitable catalyst and in combination with various types of fillers. The filler in a specific compound is chosen because of the qualities it will impart to the finished product.

The nonreinforcing fillers are wood flour, cotton flock, silica, mica, and paper. The reinforcing fillers generally used are synthetic fibers, fiberglas, cloth, and asbestos cords or fibers. Fillers facilitate molding, add body, give additional strength, provide flame resistance, and greatly improve dielectric strength and dimensional stability.

Urea formaldehydes are light-weight plastics yielding hardsurfaced shapes which are rigid, dielectrically strong, odorless, and tasteless. Urea parts will break under heavy impact, but have adequate strength for most applications.

The hard glossy surface of melamine compounds is similar in appearance to that of the ureas, but the melamines are superior in resistance to abrasion, impact, chemicals, staining, and ability to withstand heat. Excellent dielectric qualities, arc and track resistance, and low moisture absorption rates have made melamines important in electrical application.

The name "alkyd" is accepted as a generic term designating resins made by reacting polybasic acids with polyhydric alcohols. True polyesters are unsaturated alkyds dissolved in liquid monomers, frequently styrene. Another type of alkyd in use is diallyl phthalate.

Alkyd molding materials are available in granular form, as putty, or in the form of rope. The fillers used in alkyds may be asbestos, glass, clay, cellulose, or a combination of these materials. Molding pressures range from 5.50×10^6 to 1.40×10^7 N/m^2. Recommended molding temperatures range from 135 to 180 degrees C.

Silicone resins are compounded for compression and transfer molding. Compounded resin may contain fillers, such as glass, asbestos, or other similar inert, inorganic materials. Silicones are used to mold electrical components, such as coil forms, terminal strips, and connector plugs.

1. Phenol-Formaldehyde Compounds. Details of the procedure for molding thermosetting materials can conveniently be covered by a description of the molding of phenol-formaldehyde compounds.

A mold is made in two parts which, when brought together, enclose a cavity representing the article to be molded. The two parts are registered and mounted in a hydraulic, pneumatic, or mechanical press, which serves to open and close the mold and to apply pressure to its contents. The mold should be made for circulation of steam under pressure, since steam provides satisfactory heating and automatically replaces itself as it condenses, thereby holding the mold at an even temperature. Electrical heating is often used, and gives good results with molds, which are adaptable to uniform distribution of heating elements of sufficient capacity.

In molding thermosetting material, a predetermined amount of material, either at room temperature or preheated, is placed in the lower half of the mold, which is heated to 145 to 200 degrees C. The mold is then closed under full pressure. The material, under these conditions, becomes plastic and flows under pressure into the cavity created by the two halves of the mold. The material filling the cavity is held under heat and pressure until the required degree of hardness is achieved, and then the mold is opened and the molded article removed. Thermosetting materials, having been hardened by a chemical change caused by heat, can be ejected after the proper curing cycle without need of cooling the mold. Occasional slight cooling of the mold is advisable with thermosetting materials in order to improve dimensional stability of the articles.

Gassing, or venting, the mold may be necessary when compression molding phenolic, melamine, or urea materials. These materials generate moisture when under molding heat. They also entrap and effectively seal air during compression. Venting is accomplished by releasing mold pressure just before or just after it has closed on the material charge. The mold should be opened sufficiently to allow entrapped air and gas to escape from each cavity. Certain molding compounds require a timed "dwell" in this open position before the mold is reclosed.

2. Urea-Formaldehyde and Melamine-Formaldehyde Compounds. The techniques employed in handling and molding urea-formaldehyde are, in general, similar to those used for phenol-formaldehyde, but some differences in practice are frequently required. These materials are of light color, so caution must be exercised to avoid inclusion of any contamination, which will be visible in the molded part. In molding urea and melamine, the design of the article and mold is important because the light color of these plastics fail to conceal flows and gas pockets that would be undetected in dark, opaque, phenolic materials. It is desirable to design both the article and the mold to minimize appearance defects.

3. Alkyd Materials. Techniques of molding alkyd thermosetting materials are similar to those employed for urea-formaldehyde and melamine-formaldehyde compounds. The chemical reaction is usually much faster and require a faster cycling press. In molding these materials, it is frequently necessary to vent or degass the mold slightly and briefly after it has been initially closed, to allow the escape of gas formed by the reaction of curing.

Compression Mold Design

The basic molding problem requires the use of a mold that will compress the compound to the desired shape and hold it under pressure and heat until the cure process has taken place. The mold must be designed so that the compound and inserts may be introduced easily and the part ejected without distortion. Since the mold is idle while it is being loaded and unloaded, the efficiency of these operations, the quality of the part, and the cost of finishing operations will be a true measure of the quality of the mold.

The molding pressures and heat may produce highly localized stresses in various parts of the mold and thereby cause serious mold breakage if the mold or parts are not properly designed. For example, assume that a mold for a certain part is needed. The part will be molded from one of two materials: black, wood-flour-filled phenolic, or gray urea-cellulose compound. The user wants a sample mold, built quickly for test. The quickest and least costly mold that can be built is a single-cavity hand mold.

The first step in the design of such a mold is the determination of the bulk factor and the shrinkage:

	Bulk Factor	Shrinkage (cm/cm)
Phenolic and wood flour	3	0.006 - 0.009
Urea-cellulose compound	3	0.008

Volume calculations may be made either by laying out the piece in sections and calculating the volumn of each section, or by computation from the weight of a model.

Weight calculations are obtained from the volume, using formula (1), which follows.

$$VW_U = WT \qquad (1)$$

Where: V = total volume of part

V_U = unit weight of material

WT = total weight of part.

When the total weight of the part has been determined, 10 percent addition is made for flash. Flash is the material that is squeezed out around the plunger and through the overflow slots as the mold closes. This allowance must be made in compression molding to prevent precure at the parting line and to enable material, which lies on the land, to escape outward and provide a good pinchoff. The overflow also compensates for variation in the load by permitting the excess compound to escape.

Formula (2) is a general formula used for calculating the total volume of loose powder or preforms.

$$\frac{W\,(BF)}{W_1\,(100)} = V \qquad (2)$$

Where: W = Gross weight of molded part per 100 pieces

BF = Bulk factor of compound

W_1 = Weight per cubic centimeter of compound

V = Total volume.

Determination of cavity well or loading space depth may be calculated, using formula (3).

$$\frac{V - V_1}{A} = D \qquad (3)$$

Where: V = total volume of material required (cubic centimeters)

V_1 = volume of actual cavity space (cubic centimeters)

A = hortizontal area of loading space plus area of all lands (square centimeters)

D = depth of loading space in centimeters from top of cavity to pinchoff land.

In this formula, V_1 must be considered the volume of any mold pins, inserts or projections that will subtract from the gross volume of the cavity space. The lands of A will generally be at least 0.318 centimeter wide. In cases where the lands are irregularly shaped, the land area may be computed by tracing or drawing an outline on cross-section paper and counting the number of spaces included in the outline; or a planimeter may be used for measuring this area.

Molds for automatic molding require most of the features of those used for manual or semiautomatic molding; however, there are two major points in design that require special attention.

First, the molded article must be made to withdraw with the same half of the mold on every opening stroke. If bottom ejection is required, every precaution must be taken to assure that the molded piece will not stick to the top half of the mold on the opening stroke. Undercuts, or ridges, to grip the article are required. Top hold-down pins, essentially the same as knockout pins, are often used, but are designed to push the molded piece away from the top half of the mold as it is opened. When top ejection is required, bottom hold-up pins are used. The design of the molded part dictates whether top ejection or bottom ejection is to be used. When using automatic presses, the molded article must be under positive control at all times.

Second, there must be assurance that any flash will cling to the molded piece and not to the mold face, cavity, or force. Some presses use an air blast as a cleaning device to remove flash or excess powder from a mold prior to loading the new charge of material. The air cleaning method does not clean as effectively as an operator, so a concerted effort must be made to keep flash to a minimum and to assure that any flash, which does develop, is automatically removed with the molded part. Polished mold surfaces are necessary, chrome plating of the cavity and force is recommended, and all corners and sharp edges should be removed to reduce the accumulation of flash.

MOLDING EQUIPMENT

The press illustrated in figure 6 can be used either for transfer or compression molding. This press has a transfer pressure of 16,330 kilograms and a clamp pressure of 45,360 kilograms. Each mold half is electrically heated and temperature controlled.

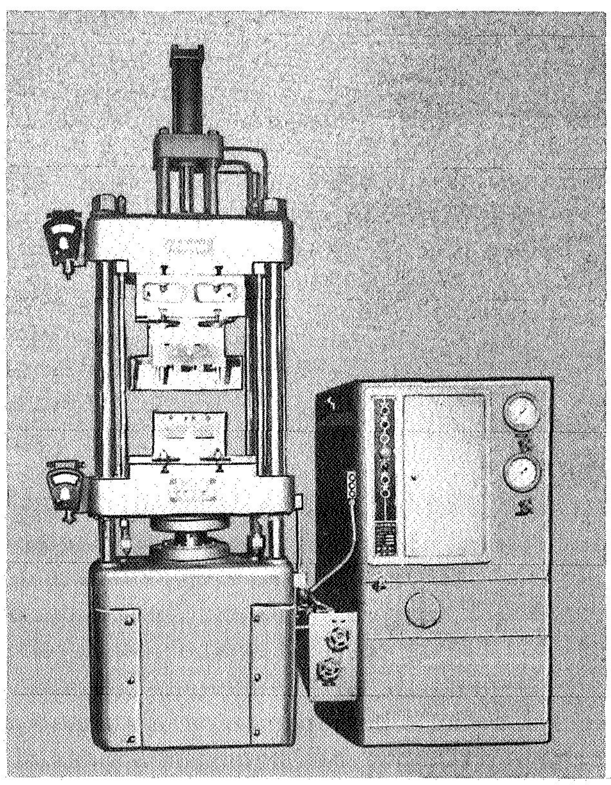
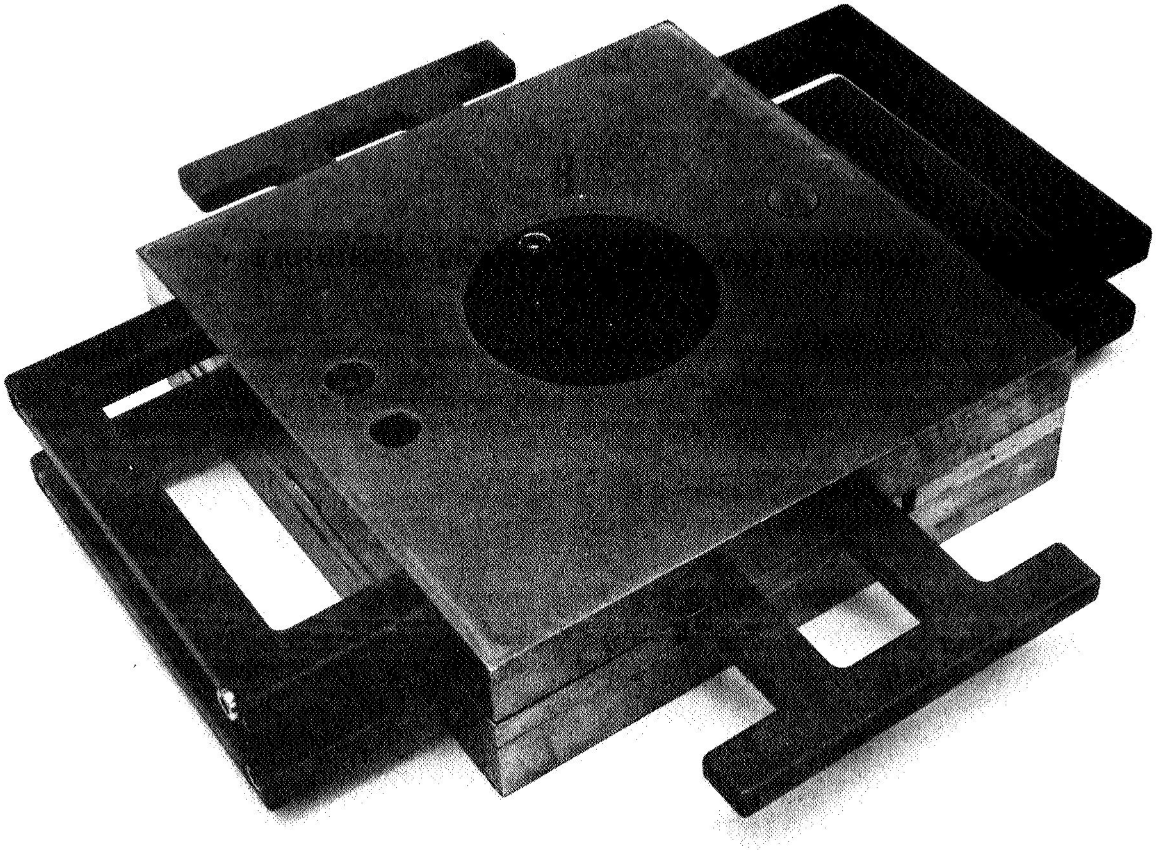
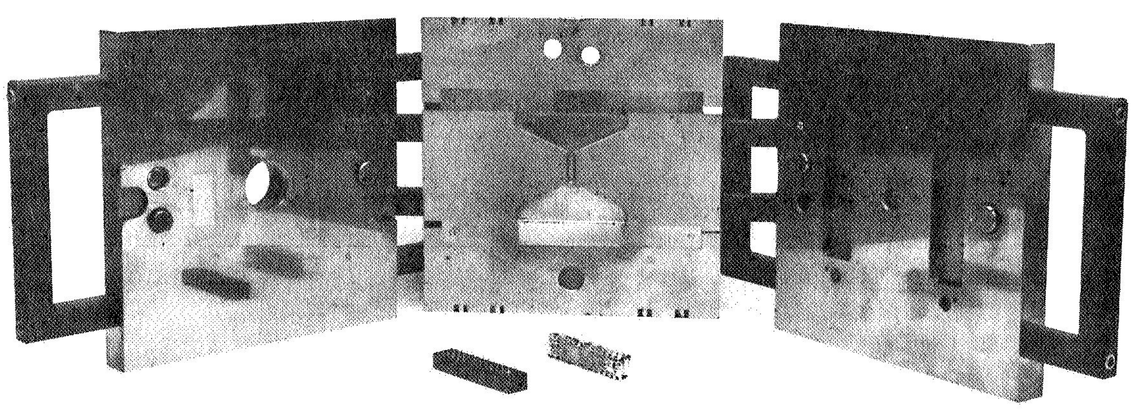


FIGURE 6. TRANSFER AND COMPRESSION MOLDING PRESS

A mold (closed position) used in transfer molding of electronic components is shown in A, figure 7. The open mold and modules are depicted in B, figure 7.



A



B

FIGURE 7. TRANSFER MOLD AND MODULE

The selection of transfer molding materials used to encapsulate modules is important where fragile components are involved. Most materials used are highly filled epoxies. A material with a coefficient of expansion equal to that of the most fragile elements (glass) and one sufficiently flexible to absorb shock and temperature change stresses should be selected.

The press shown in figure 8 was designed primarily to laminate printed circuit boards, but has been converted to perform transfer molding. It is used mainly to encapsulate modules and to mold test specimens.

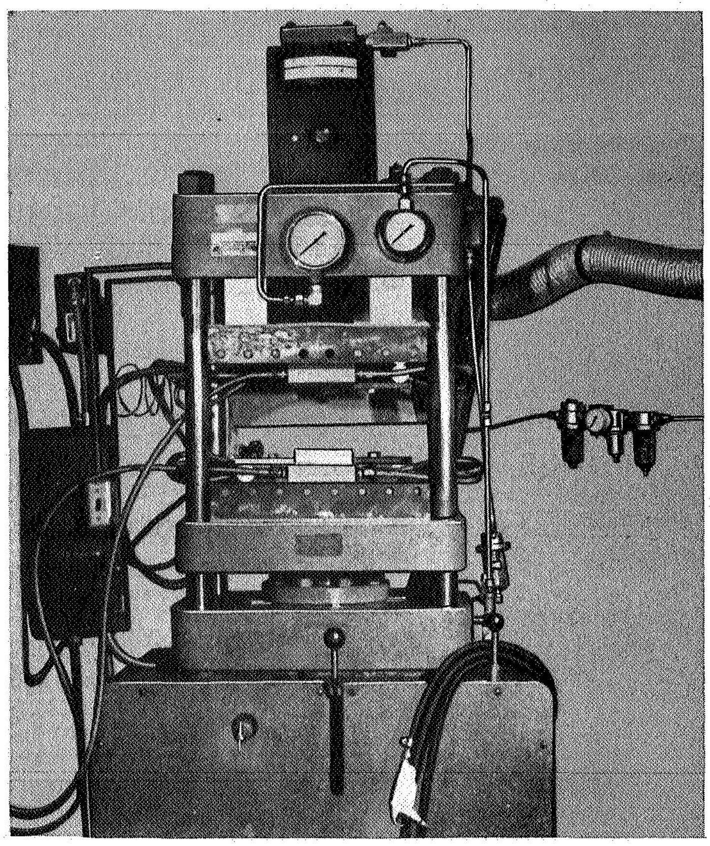


FIGURE 8. LAMINATING AND TRANSFER PRESS

Stator windings are encapsulated with a rigid, heat-resistance material to provide the necessary compactness and winding protection. Figure 9 shows transfer molds used for encapsulating stators and figure 10 shows a stator before and after encapsulation.

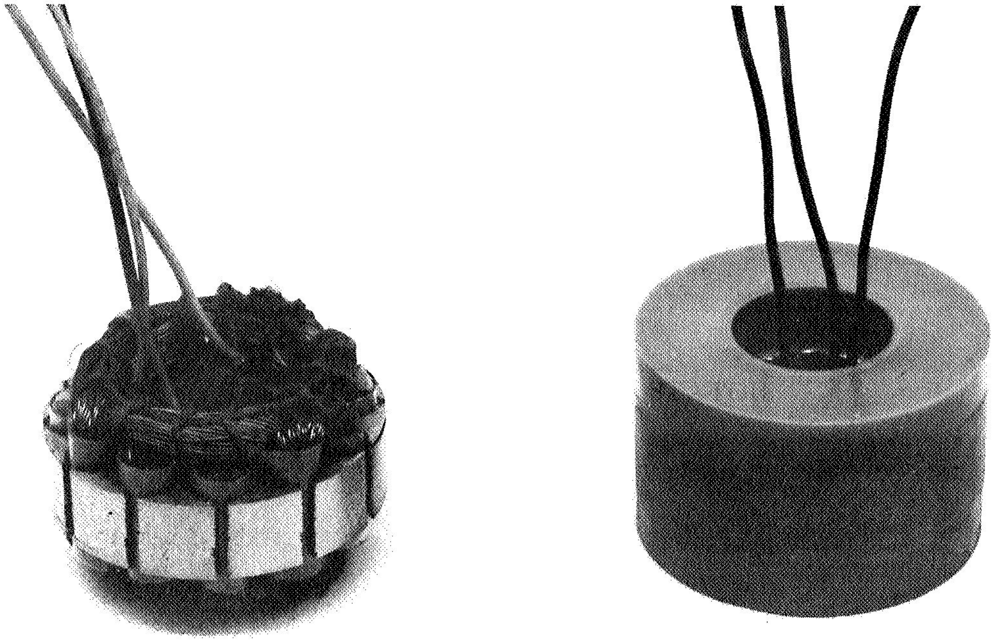


FIGURE 9. STATOR MOLD

The injection molding machine (figure 11) is used primarily for molding small parts such as flat conductor cable plugs (figure 12). The machine has a clamping pressure of 16,330 kilograms, and a maximum injecting capacity of 42.53 grams, depending on the injection pressure required.

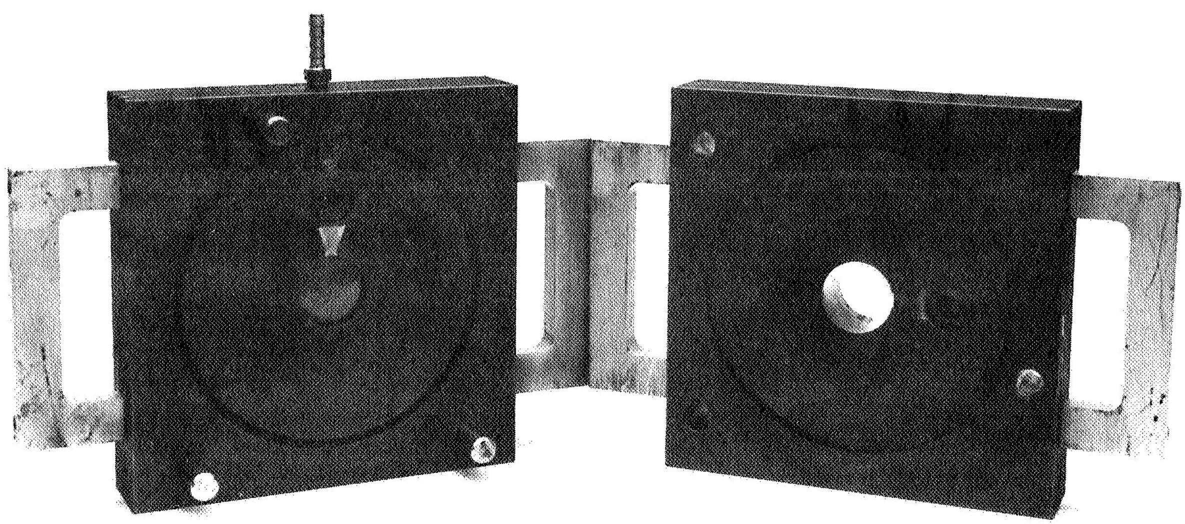


FIGURE 10. MOLDED STATOR

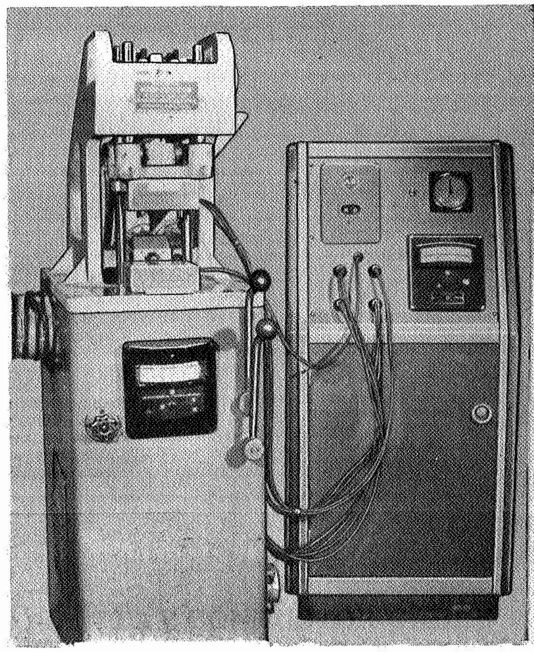


FIGURE 11. INJECTION MOLDING MACHINE

The screw injection molding machine shown in figure 13 is completely hydraulically operated with pushbutton controls. It has a controlled hydraulic injection pressure of 1.34×10^{8} N/m^{2} and a clamp pressure of 68,040 kilograms. The machine molds any thermoplastic material, and is capable of molding from 90 to 120 grams of material.

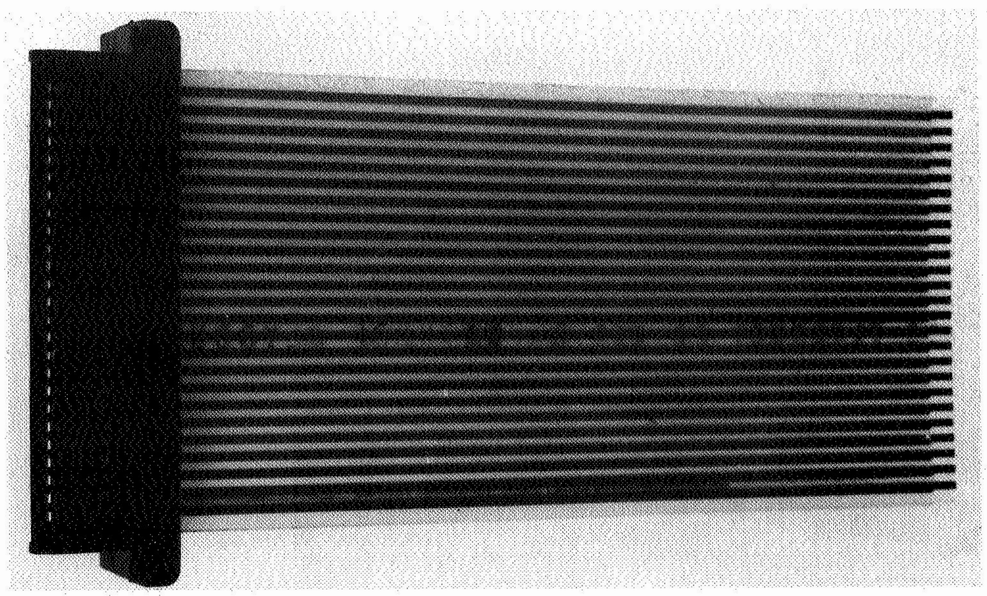


FIGURE 12. FLAT CONDUCTOR CABLE PLUG

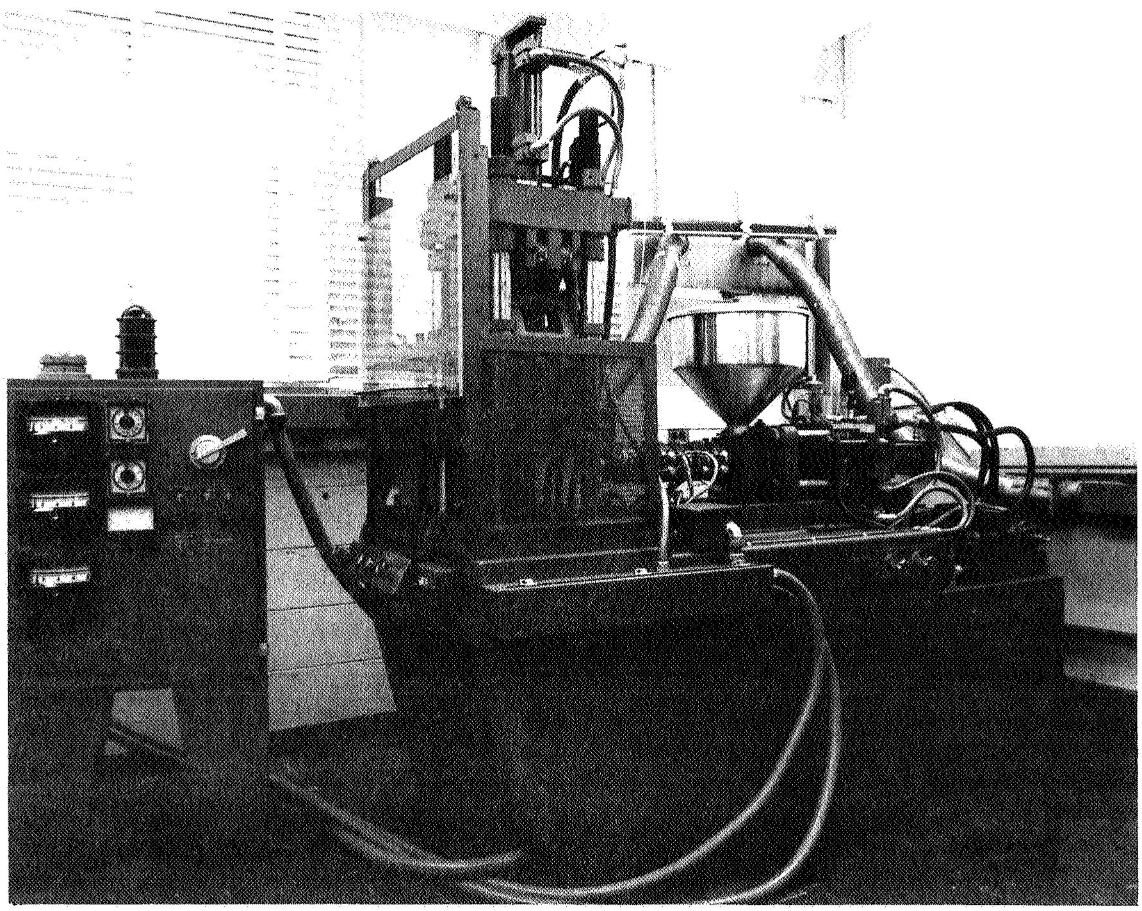


FIGURE 13. SCREW INJECTION MOLDING MACHINE

The mold (figure 14) used in injection machines is heated electrically, and the temperature is controlled to a very close tolerance. The mold is used to mold flat conductor cable plugs.

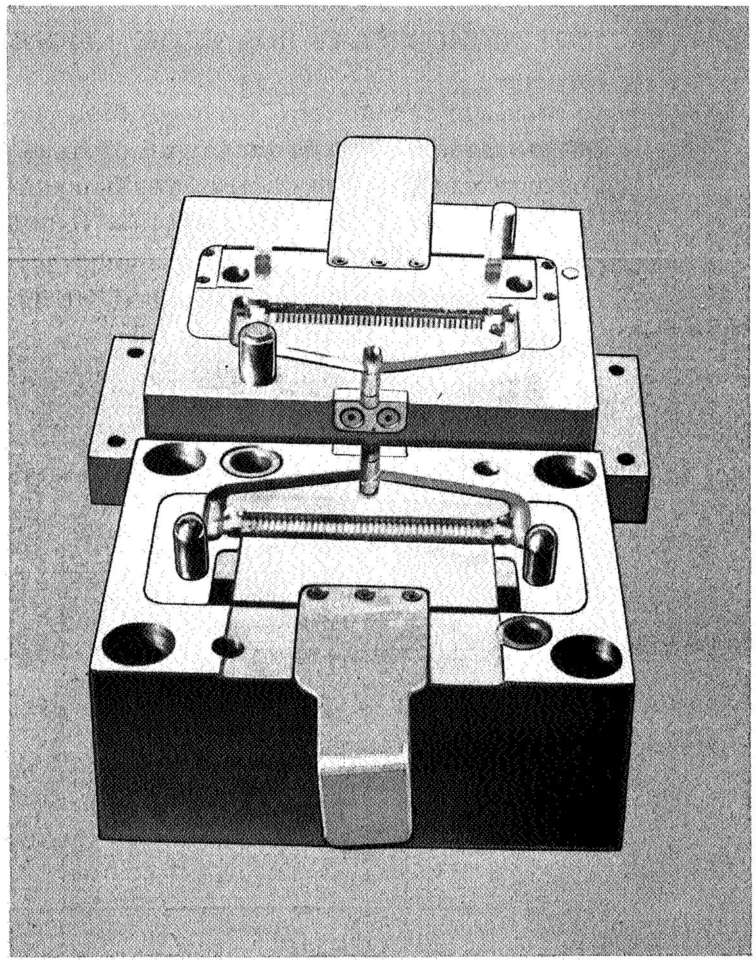


FIGURE 14. MOLD FOR FLAT CONDUCTOR CABLE PLUG

A spiral flow mold (figure 15) is used to evaluate encapsulating materials. The flow of material is important when encapsulating delicate components. The molding compound is placed in the mold cavity; and pressure is applied, causing the material to flow in a spiral form measured in centimeters. By applying a certain amount of pressure and measuring the length of flow material, the flow properties can be determined.

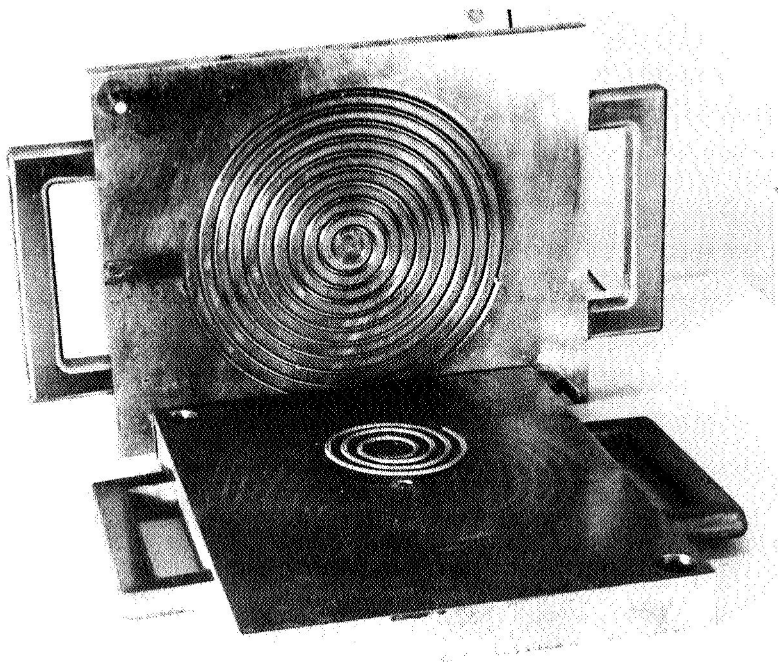


FIGURE 15. SPIRAL FLOW MOLD

Figure 16 shows a typical mold to obtain samples for the determination of the coefficient of thermal expansion of molding compounds.

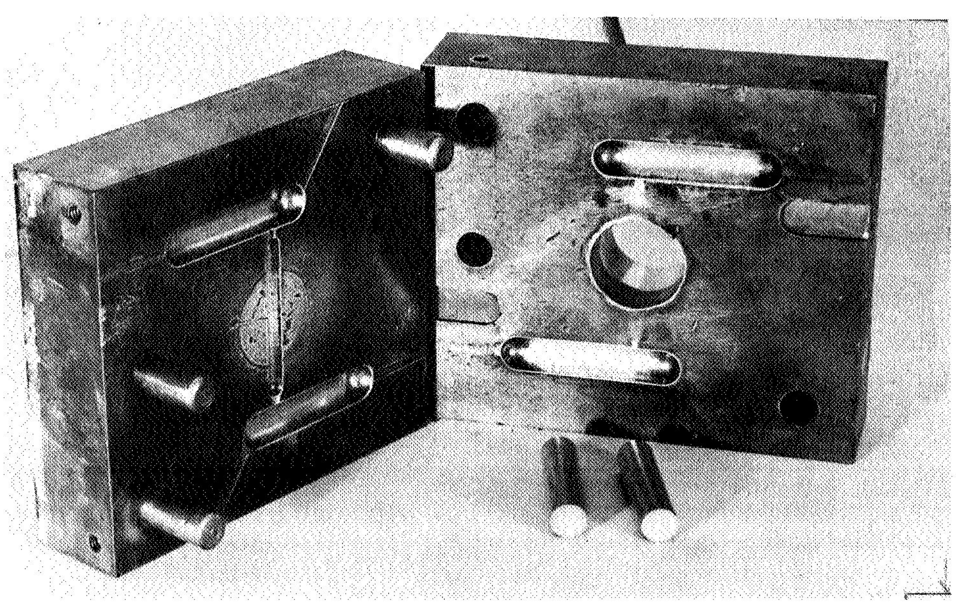


FIGURE 16. COEFFICIENT OF THERMAL EXPANSION MOLD

Figure 17 depicts a typical mold for molding tensile strength specimens of molding compounds.

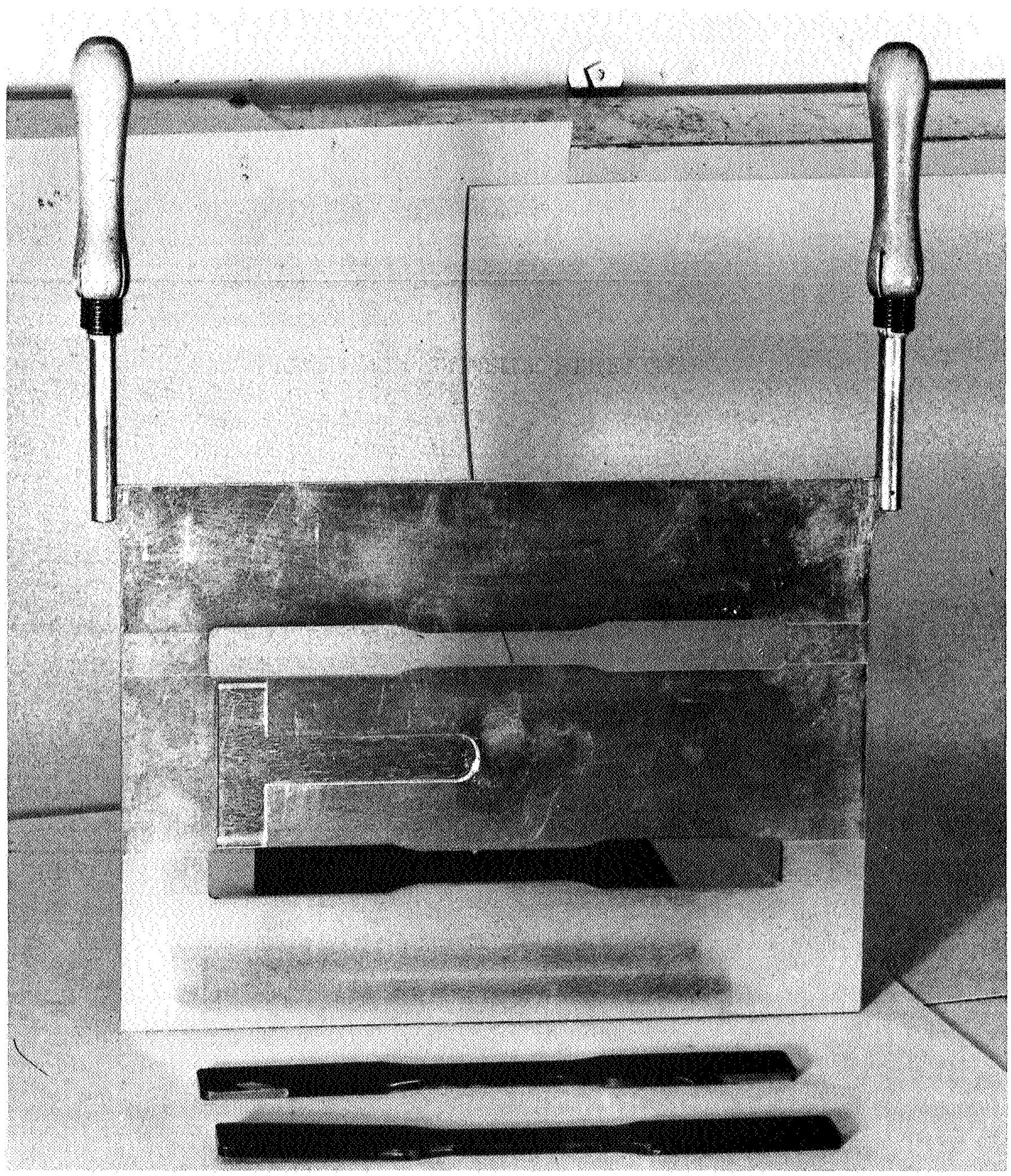


FIGURE 17. TENSILE STRENGTH MOLD

A mold for molding dielectric constant and dielectric strength samples is shown in figure 18.

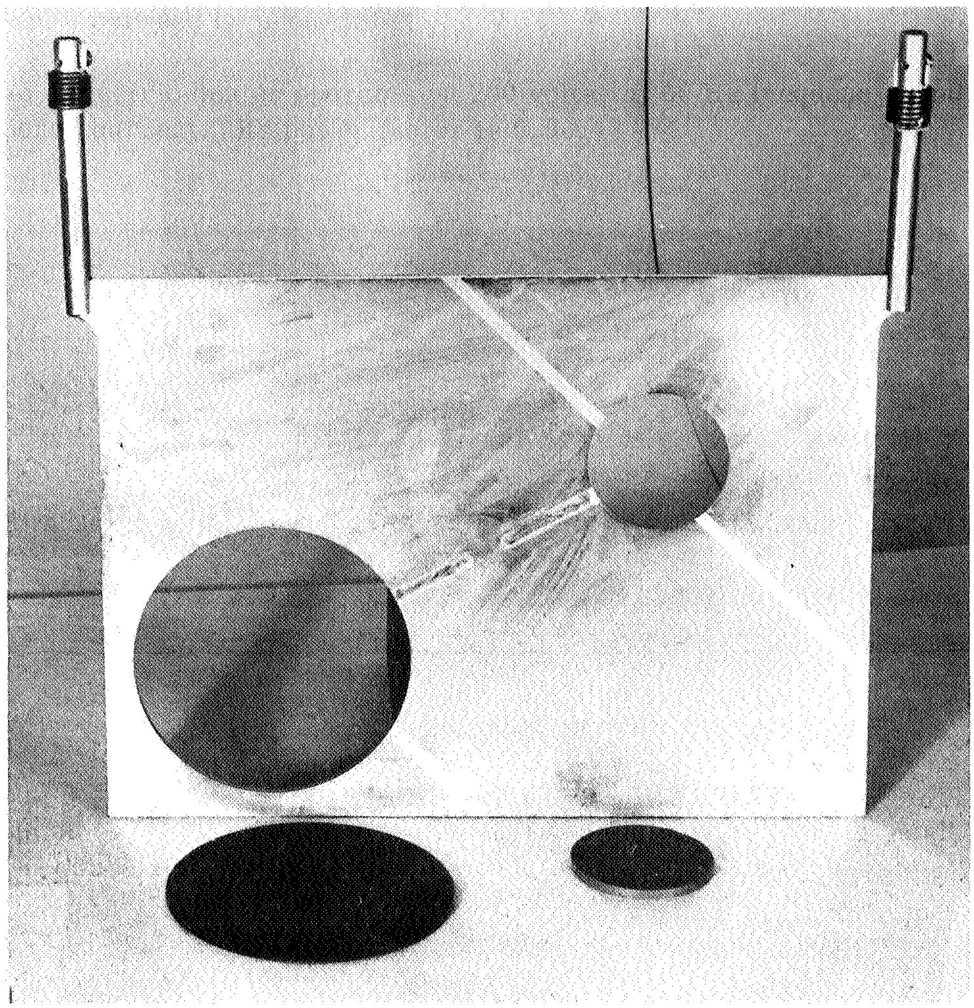


FIGURE 18. DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH MOLD

A dielectric heater (figure 19) is used to preheat plastic materials that are to be molded. This device uses varying electrostatic fields to heat the plastic. The material is placed between two metallic plates that act as a capacitor. The plastic material between the plates acts as a dielectric and is heated to a softened state by the dielectric losses of the setup. The flow characteristics of the materials are improved by preheating.

The dielectric heater operates on 230 volts, at 60 Hz frequency, and at 10 amperes current. Its power factor is 0.95.

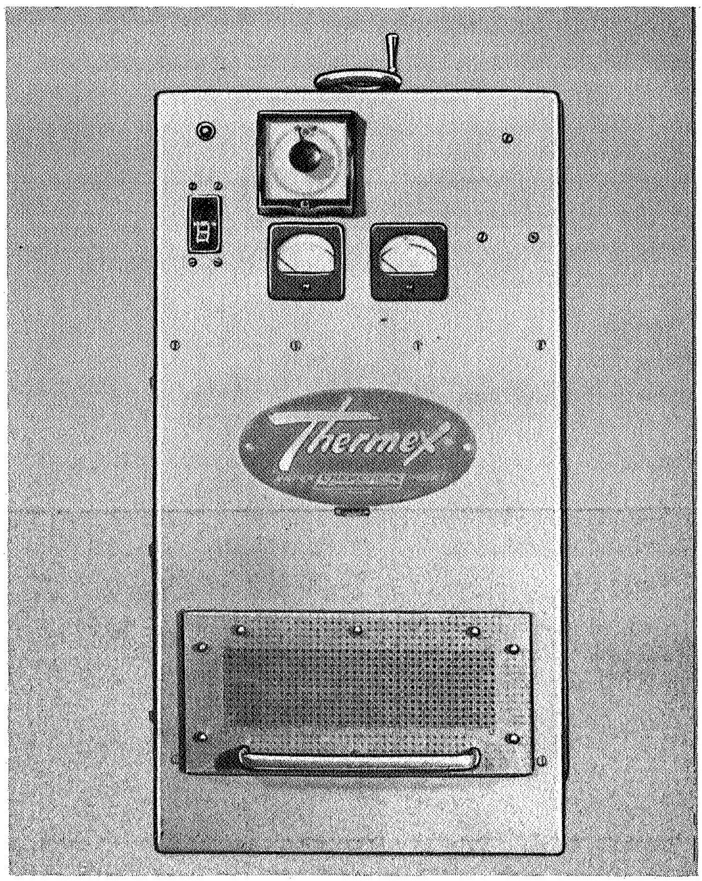


FIGURE 19. DIELECTRIC HEATER

CONCLUSIONS

Demands of modern technology require electrical components and assemblies to be small and reliable. These small components and assemblies can have greater physical protection and better electrical insulation through encapsulation by pressure molding. Formulations producing new polymer materials have made pressure molding desirable and accepted in the space industry.

Selection of molding materials is very important when fragile components are involved. Materials are usually confined to highly filled epoxies and urethanes, but other materials with similar properties are considered. A material with a coefficient of expansion equal to that of glass, and a compound sufficiently flexible to absorb shock and temperature change stresses should be selected.

Molds may be designed and built for items with many sizes and shapes. Many of these items are vital parts for use in space flight and ground support equipment. Many molded plastic parts require a high degree of precision. This precision is obtained through careful design and fabrication of the mold.

BIBLIOGRAPHY

Brenner, Walter; Lum, Dorey; Riley, Malcolm W.; High Temperature Plastics, 1962, Reinhold Publishing Corporation, New York, N. Y.

Dubois, J. H., Plastics Mold Engineering, 1965, Reinhold Publishing Corporation, New York, N. Y.

Harper, Charles A., Plastics for Electronics, 1964, Kiver Publications, Inc., Chicago, Ill.

Riley, Malcolm W., Plastics Tooling, Second Edition, 1961, Reinhold Publishing Corporation, New York, N. Y.

Simonds, Herbert R. and Church, James M., A Concise Guide to Plastics, Second Edition, 1964, Reinhold Publishing Corporation, New York, N. Y.

Skeist, Irving, Epoxy Resins, 1960 Reinhold Publishing Corporation, New York, N. Y.

The Society of the Plastics Industry Inc., Plastics Engineering Handbook, Third Edition, 1960, Reinhold Publishing Corporation, New York, N. Y.

APPROVAL

PRESSURE MOLDING FOR ELECTRONIC COMPONENTS

By

Bobby W. Kennedy

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

D. L. Anderson

D. L. Anderson
Chief, Microelectronics Branch

J. C. Taylor

J. C. Taylor
Chief, Technology Division

DISTRIBUTION

S&E-ME

Dr. Siebel
Mr. Wuenscher

S&E-QUAL

Mr. Grau
Mr. Trott

S&E-ASTN

Mr. Heimburg

S&E-ASTN-M

Mr. Schwinghamer

S&E-ASTR-DIR

Mr. Moore
Mr. Horton
Miss Flowers

S&E-ASTR-F

Mr. Hosenthien

S&E-ASTR-B

Mr. Kampmeier
Mr. Spears

S&E-ASTR-Z

Mr. Payne
Mr. Ackerman

S&E-ASTR-C

Mr. Swearingen
Mr. Lucas

S&E-ASTR-E

Mr. Aden
Mr. Youngblood

S&E-ASTR-I

Mr. Powell
Mr. Duggan

S&E-ASTR-S

Mr. Wojtalik
Mr. Gassaway

S&E-ASTR-G

Mr. Mandel
Mr. Doane

S&E-ASTR-M

Mr. Boehm
Mr. Barr

S&E-ASTR-R

Mr. Taylor
Mr. Reinbolt

S&E-ASTR-RM

Mr. Anderson
Mr. Kennedy (30)

CC-P

I-RM-M

MS-H

MS-IP

MS-IL (8)

MS-T (6)

Scientific and Technical Information
Facility (2)
P. O. Box 33
College Park, Maryland 20740
Attn: NASA Representative (S-AK/RKT)