AN EXPERIMENTAL APPROACH TO INJECTION MOLDING WITH POLYESTER RESINS FOR INDUSTRIAL ARTS CLASSES

by

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TABLE OF CONTENTS

AN EXPERIMENTAL APPROACH TO INJECTION MOLDING WITH POLYESTER RESINS FOR INDUSTRIAL ARTS CLASSES

CHAPTER I

INTRODUCTION

> "The typical new materials of the age definitely belong to the curriculum of school shops. Plastics have won a place as one of the important segments of industrial effort in a comparatively few years, so much so that few students in our shops today will not have need of more specific knowledge about them in the years ahead." (3, p. 14)

The plastics industry, while definitely out of its infancy, is surely and unmistakably "a growing boy", (see graph). The editorial column of the January, 1956, <u>Modern Plastics</u> magazine contains this statement, "There is not now and never will be any limit to the future of plastics." (11, p. 5)

Our schools should meet pupil needs. As consumers of a multiplicity of plastics products we ought to know them better.

> "To be able to say 'it's plastic', for most of us is no longer enough. It would be as descriptive to say 'it's metal', when referring to steel girders, iron pipe, copper wire, silver table ware, lead shot, gold jewelry, or an aluminum teakettle." (17, p. 6)

Harry R. Wilson, teacher in the Adult Education Center, Lansing, Michigan, wrote an article for <u>School Shop Magazine</u>. Within the article were these statements:

> "Tool designers, electricians, production and process engineers, all are returning to school in evening courses to obtain knowledge of basic electronics, practical hydraulics, and pneumatics. They are all wanting to know 'What makes these new machines tick.' Our training in industrial education is moving from the 'know how' to the 'know why' with the greater emphasis on the latter." (21, p. 25)

Skills are important -- but it seems as though related information is finding a place of increased importance.

Liquid plastics may be used in the Industrial Arts program in a number of ways. This has been aptly described and illustrated by Alexander Bick in his series of articles on polyester cold-setting resins which have appeared in the Industrial Arts and Vocational Education Magazine.[1]

The injection molding of polyester resin compounds could present to the students many problems of an industrial nature. Areas and pressures, clearances and tolerances involve mathematics. Color, shape, and texture of moldings bring the aesthetic side of life into play. Mold design and construction would necessitate a knowledge of strength and properties of materials. Simple chemistry finds application in the formulation of resin mixes. A scientific attitude is needed for accurate measurement of materials (fillers, resin, catalyst, etc.) in order to predict and control the molding cycle.

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1. The series begins with the December, 1954, issue.

The work contained in this thesis is an attempt to fabricate a new material by adaptation of an industrial method to industrial arts facilities. The problem grew out of a synthesis of experience with zinc die casting, intermittent experimentation with polyester resin, and reading from current industrial magazines. Motivation was sparked by articles such as this:

> "Take a piece of glass fiber and a plastic known as polyester. Mate them and you breed the most promising, perhaps the most versatile material to pop upon the industrial scene in a generation.
>
> "The two together are called reinforced plastics. And if you still haven't looked into their myriad application, you'd better. No other material possesses the same combination of high strength, low weight, dimensional stability, weather resistance, permanent colorability, and electrical properties." (15, p. 84)

An endeavor has been made to illustrate and describe the methods, materials and equipment needed to produce injection moldings of polyester resin compounds. It is hoped this thesis will serve many shop teachers and students as a guide for further study and development of the technique.

CHAPTER II

HISTORY OF PLASTICS

"The word plastic comes from the Greek language. It means fit for molding." (13, p. 6404) Clay, pitch, wax, gold, and silver were some of the earlier moldable materials used by man. The term plastic as it is used today, however, refers not to a material found in or on the earth's crust, but rather to a man-made material: a synthetic. By synthetic it is meant that the material in question is a product of chemistry. Through research and experimentation various elements are combined in such a manner that an entirely new material is produced. Combinations of hydrogen, carbon, oxygen and nitrogen are important in most of the plastics. "The chief source of raw material is from coal, petroleum, and agricultural products." (22, p. 486)

The plastics industry began in 1868 with the discovery of cellulose nitrate better known as celluloid. John Hyatt, American inventor and printer, stimulated by an offer of $10,000. to anyone who could produce a suitable substitute for ivory billiard balls, produced the first commercial plastic.

> "He developed a cellulose base material which, when molded under heat and pressure, could be made into a smooth hard ball. Thus the first synthetic plastic was born." (17, p. 3)

Celluloid stood alone for more than thirty years as the only synthetic plastic of commercial importance. This one plastic found numerous applications.

> "Combs, brush handles, piano keys, toys, trays, jewelry boxes and many other articles of celluloid were put on the market. The gentleman of the Gay Nineties, to be well dressed though not too comfortable, wore stiff celluloid collars and cuffs.
>
> "Although celluloid was very flamable, became brittle with age, and tended to turn yellow and lose its transparency, it served very well until the advent of the glass-enclosed car." (17, p. 3)

Forty years after Hyatt produced the "billiard ball" plastic, the second plastic of commercial importance was made available to industry. Dr. Leo Baekeland produced the first thermosetting plastic in 1909.

> "Bakelite, as this phenol-formaldehyde resin was called, under heat and pressure could be formed into useful articles. When molded, it became a hard insoluable mass which would not soften again when heated.
>
> "Strong, inexpensive, and of excellent appearance, Bakelite could be sawed, turned, drilled, punched, in fact machined much the same as wood or metal. Here was a plastic workhorse suitable for many industrial uses. The transmitters and receivers of phones, distributor caps and other automobile ignition parts, switch panels, instrument housings, machine tool parts, lighting fixtures, office equipment, composition board -- these are but a few of the first uses for Baekeland's phenol-formaldehyde plastic. Today phenol-formaldehyde resin retains a position of leadership in the plastics industry." (17, p. 3)

During the 1920's and 30's the plastics industry made great advances (chronological chart pp. 8-9). New materials were produced, formulations were modified to meet specific needs, new techniques for molding were developed, equipment was improved. In general, plastics began to be recognized as materials of great importance and potential.

The plastics went to war! Under the pressure of war needs the development and production of plastics mushroomed. The industrial growth was phenomenol. Production however, was limited to essential goods. Civilians received only limited contact with the many new plastics during the war years.

> "Thus, during these four years, out of public view, the plastics industry was coming of age. When this industry's many war-proved abilities began to find expression in civilian products, plastics were found in the most unexpected places doing the most surprising jobs." (17, p. 5)

The polyester resins are one of the newest members in the plastics family. Before being processed into products, polyesters may be liquids, powders or granules. They are versatile. They may be used for castings, coatings, laminates, moldings, fibers and films.

> "The polymerizable polyesters are relatively a new class of resins that first appeared commercially during World War II. They are noted especially for their ease of handling, good physical and electrical properties, and speed of cure. Initial applications were in combination with fibrous glass in radomes, body armor, and miscellaneous non structural aircraft parts. After World War II, civilian applications grew slowly. Gradually, lower

> resin costs, better technical know-how, and improved production techniques have resulted in an increasing number of applications.
>
> "Polyester resin volume in 1955 was approximately 48 million lb., about 75% increase over the 27 million lb. sold in 1954. This class of resins now is used for matched-metal molding, premix materials, laminates and hand lay-up applications, casting, and encapsulation." (12, p. 139)

How will the plastics industry affect us ten years from now? Optomistic engineers predict plastic houses and cars, among other things. The plastics possess great potential for improving our standard of living. In time they may change our way of life.

CHART I

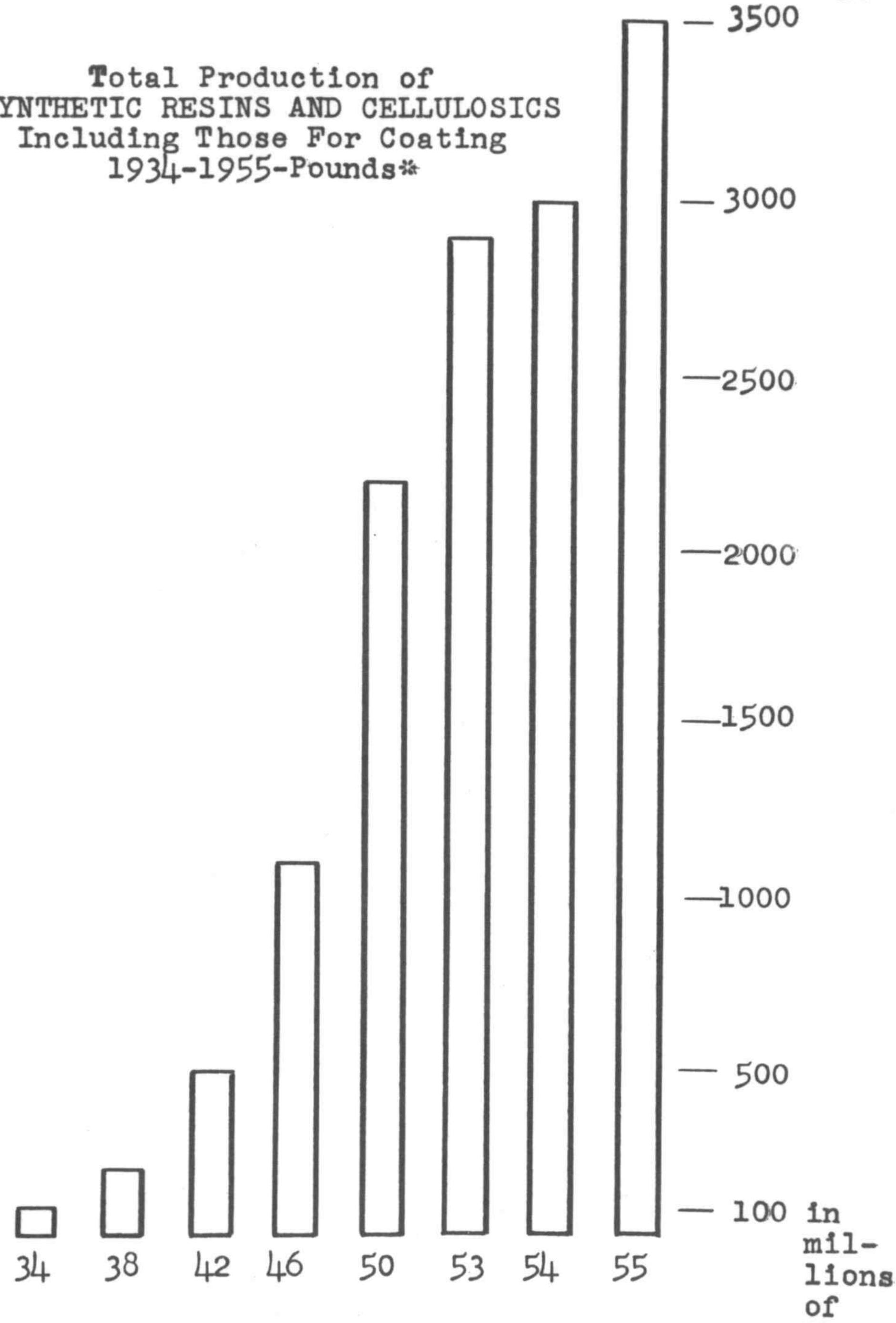
PROGRESS IN PLASTICS

Approximate Dates When Commercial Products Were Introduced In The United States

Date	Plastic	Form
1850	Rubber	Molded forms
1870	Cellulose nitrate (celluloid)	Sheets, rods and tubes
1895	Shellac compositions	Molded forms
1909	Bitumen compositions	Cold molding compounds
1909	Phenol-formaldehyde resin	Cast blanks, rods and tubes
1910	Phenol-formaldehyde lacquers	Brass coatings
1910	Phenol-formaldehyde	Molding powders
1919	Casein	Sheets, rods and tubes
1919	Cumar resins	Molding compositions
1919	Vinyl acetate polymers	Adhesives
1923	Phenol-furfural	Molding powders
1926	Alkyd resins	Coating materials
1926	Aniline formaldehyde	Resins, laminates, molding powder
1927	Cellulose acetate	Sheets, rods and tubes
1927	Thiourea formaldehyde	Laminates molding powders
1928	Urea formaldehyde	Cast forms
1928	Modified phenol-formaldehyde	Cast blanks, rods and tubes
1929	Urea-formaldehyde	Molding powders
1929	Vinyl Chloride-acetate copolymer	Sheets, rods, films and powder
1929	Modified vinyl acetate	Powders, films and sheets
1929	Cellulose acetate	Injection molding powders
1931	Acrylic esters	Castings and coatings
1932	Methacrylic esters	Castings and moldings
1932	Polybutene	Extruded forms and crumbs
1933	Benzyl cellulose	Sheets, rods and tubing

Date	Plastic	Form
1934	Celluloid and cellulose acetate	Continuous extruded sheet
1936	Ethyl cellulose	Sheets and powder
1936	Urea-formaldehyde	Transparent molding powder
1936	Methyl methacrylate	Cast sheets
1937	Polystyrene	Castings, transparent molding powders
1937	Cellulose acetate propionate	Powders
1937	Methyl methylacrylate	Molding powders
1938	Protein (including casein)	Molding powders
1938	Vinyl butyral	Safety glass
1939	Cellulose acetate butyrate	Molding powders
1939	Methyl cellulose	Molding powders
1939	Lignin-phenol-formaldehyde	Laminates, powders
1939	Vinyl chloride-acetate copolymer	Fibers
1939	Polyamide (nylon)	Fibers
1939	Vinylidene chloride	Extruded strips
1940	Melamine-formaldehyde	Laminates, molding powders
1941	Polyethylene	Extrusion compositions
1942	Polyethylene	Molding powder
1942	Allyls	Cast sheets
1943	Silicones	Coating resins, oils and greases
1943	Vinyl alkyds	Low pressure laminates
1944	Nylon	Molding powder
1945	Polystyrene	Foam
1945	Poly dichlorostyrene	Molding powders
1945	Tetrafluoroethylene	Sheets, blocks
1946	Vinyl chloride acetate copolymer	Floor coverings
1946	Polyesters-cross linked	Sheets coatings
1946	Silicones	Laminates
1947	Plastisols and Organisols	Coatings, sheets
1947	Diallyl benzene phosphonate	Resins (19, pp. 6-7)

Total Production of
SYNTHETIC RESINS AND CELLULOSICS
Including Those For Coating
1934-1955-Pounds*



*Source: U.S. Tariff Commission & Modern Plastics estimates.

CHAPTER III

THE PLASTICS FAMILY

"The most common classification of plastics is under thermoplastic and thermosetting materials. The thermoplastics are those which when heated begin to soften at temperatures as low as 140 degrees F., then can be molded without any change in chemical structure. The thermosetting materials undergo a chemical change when molded and cannot be resoftened by heating to reshape them. Listed below are most of the common plastics designated according to these general categories:

Thermoplastic	Thermosetting
Acrylics	Alkyds
Cellulosics	Epoxides
Flurocarbons	Furau
Natural	Inorganics
shellac	Melamines
asphalt	Phenolics
etc.	Polyesters
Nylon	Silicones
Polyethylenes	Ureas
Polystyrenes	
Polyvinyls	
Protein substances	(22, p. 487)

Thermosetting resins in powder or granulated form may be softened when heated to the proper temperature but subjected to continued heat they set or harden. This hardening represents a chemical change which is permanent and irreversible. One author describes the change this way, "Helpful, though possibly far-fetched, might be the comparison right in our own kitchen of the action of the heated waffle iron on the plastic batter, sending this thermosetting material on a one-way trip." (17, p. 12)

Thermoplastics are similar to wax in that they can be softened, molded, and softened again if necessary. Thermoplastic materials are generally molded at lower temperatures and pressures than the thermosetting resins. Special compounds of thermosetting resins withstand temperatures in excess of 400 degrees F. Most of the thermoplastic compounds are heat-sensitive above 180 degrees F. Few will with-stand temperatures of 400 degrees F.

Liquid cold-setting polyester resins belong to the thermosetting plastics. When they harden they cannot be remelted. The chemistry of these resins is complex; the terminology used to describe their formation and character is highly technical. However, the following quotation is inserted with the belief that it may help to clarify the nature of these materials.

> "A polyester, as the term is used here, refers to an unsaturated polyester-base resin dissolved in a polymerizable monomer. The base resin component can be prepared from innumerable chemical combinations. It is this base component that usually is modified to obtain the various properties of the finished polyester.
>
> "Essentially, dibasic acids and dihydric alcohols are heated to sufficiently high temperatures to react, split out water, and form ester linkages. As the reaction proceeds, many ester linkages are formed in one linear

> molecule. It is essential that at least a portion of the dibasic acids or the dihydric alcohols be unsaturated, i.e., contain double bonds, to provide for the function of copolymerization. It is through the connecting of these double bonds with those of the monomer that curing takes place. . . .
>
> "Under the influence of heat and/or peroxide catalyst, the monomer and unsaturated polyester base copolymerize. No gas or liquid is evolved during the cure. The curing reaction is exothermic and the heat evolved aids in speeding the cure." (12, p. 139)

Two techniques are utilized to form liquid polyester resins in matched metal molds: The <u>preform</u> or <u>mat molding</u> technique and the <u>premix</u> technique.

> "Preform or mat molding utilizes heated, matched-metal molds. The mat or preform is placed into the heated mold, the catalyzed polyester is poured in, and closing the mold forces the resin throughout the reinforcement. Conventional molding cycles are 2 to 4 minutes at 220 to 260 degrees F. and 50 to 200 p.s.i.
>
> "Premix molding provides a rapid method of making less critical parts at considerably lower cost than mat or preform molding. . . . In this method, resin, reinforcement, filler and catalyst are mixed in a dough type mixer. The resulting material varies from a putty to straw-like mass, depending on composition. Typical molding cycles are 3/4 to 2 minutes at 270 to 300 degrees F. and 500 to 1500 p.s.i." (12, p. 140)

The pressures required for these two techniques are relatively low. The pressure increases as the viscosity of the resin is increased by the addition of fillers, reinforcement and colorants. Liquid resins can be molded at relatively low pressures and temperatures.

Fillers

Most plastics whether thermosetting or thermoplastic are composed of two or more materials.

> "The resin is the principal component of the compound, gives the compound its name and classification, and imparts the primary properties to it. It is the cohesive and adhesive agent which provides rigidity, and binds together the filler particles." (22, p. 487)

The role of fillers is well described and summarized by Robinson.

> "Rock, gravel, sand, and cinders are common fillers in concrete. Used in various proportions with the cement binder and water they give concrete the desired physical characteristics. Too, they are much cheaper than cement and their use decreases the cost but improves the physical properties of the concrete. Wood flour, cotton, fabric, graphite, asbestos, mica, and cord are some of the fillers used with plastic resins. Each imparts particular physical characteristics to the finished part and at the same time decreases the cost of the finished article. The fillers are most commonly used with thermosetting resins." (17, p. 21)

The liquid polyesters are easily combined with fillers. The operation is as simple as combining the ingredients for a cake. When close quality control of the molded piece is desired, reasonable care must be exercised in measuring out the materials.

Most of the liquid polyesters range in color from water white to dark straw or pink shades. When catalyzed and allowed to harden they are semi transparent, hard and quite brittle. The addition of a filler and/or reinforcement greatly changes the physical properties of the solidified mass. (See Chart II, p. 16)

Reinforcement for Molding Compounds

Reinforcement added to polyester molding compounds can greatly change their physical properties. Glass and sisal fibers are the most common reinforcing fibers.

> "For applications requiring increased impact strength, but no greater flexural strength than that imparted by the resin, sisal fibers are indicated. They have a lower specific gravity than glass and cost approximately one-half as much as glass. The maximum loading with sisal is approximately 20%, with 5 to 10% being in a more easy-to-handle range. The fibers do not appear to wet as well as glass and a noticeable straw like pattern develops on the molded surface. . . . sisal fibers should be straight and 1/4 to 1/2 inches long." (16, p. 126)

Glass fiber reinforcement in polyester moldings provide dimensional stability, toughness, high strength, and excellent weathering resistance.

> "In premix molding, optimum physical properties are obtained with a fibrous glass length of 1/2 inch. The selection of 1/2 inch fiber length is based upon the fact that shorter fiber lengths do not provide sufficient reinforcements, whereas fiber length in excess of 1/2 inch have the disadvantage of not dispersing as well in the mix and of being susceptible to a higher degree of degradation during mixing." (16, p. 126)

CHART II

COMMON FILLERS AND THEIR USES

Filler	Purpose	Remarks
Wood flour	Low-cost bulk; improved flexural and impact strength	White pine usually used up to 60% -- high percentage decreases luster
Mica	Electrical and heat resistance	Ground mica used
Alpha cellulose	Improved flexural impact -- strength	Especially valuable in translucent ureas
Cotton flock	Improved strength	Poor finishing properties
Paper	Impact strength	Pulp usually used
Macerated cloth	Impact strength	Not as high impact strength as woven cloth but also less expensive
Rosin	Dilutent	Low cost
Asphalt	Binder	Low strength
Talc	Acid resistance	
Asbestos	Insulating properties, heat and fire resistance	Poor finishing properties
Graphite	Internal lubricant	
Carbon	Chemical resistance, conductivity	
Gypsum	Flame proofing	
Canvas	Resilience, strength	Used in silent gears
Rock flour	Cheap bulk and weight	(22, p. 438)

Internal Mold Lubricants

Certain materials when added to the premix compound improve the flow characteristics and expedite removal of the molded piece from the mold.

> "The plastics molder, using the terminology of his trade, might say that the cook who adds an oil or grease to waffle batter to prevent the waffle from sticking to the waffle iron had added a lubricant." (17, p. 26)

Several internal mold lubricants are available for industrial usage. "For satisfactory mold release characteristics, the use of internal mold lubricants such as stearic acid and zinc or magnesium stearate is required." (16, p. 128) Powdered graphite is also listed as an internal mold lubricant. However, this material acts as a potent colorant. If a black finish is desired on the molded piece then graphite would be a likely lubricant since it is readily available in hardware stores at a nominal price.

While it is highly desirable for industrial operations to incorporate a mold release into the premix it would probably be more convenient in industrial arts applications to apply the lubricant directly to the mold. Paraffin, vaseline, margarine, olive oil, waxes and soap are the more common parting agents.

CHAPTER IV

MOLDING PLASTICS

The injection molding of plastics is limited to the thermoplastics. Another forming method using matched metal dies is called transfer molding. Thermosetting materials are successfully molded by the latter method. Both of these methods are illustrated and described.

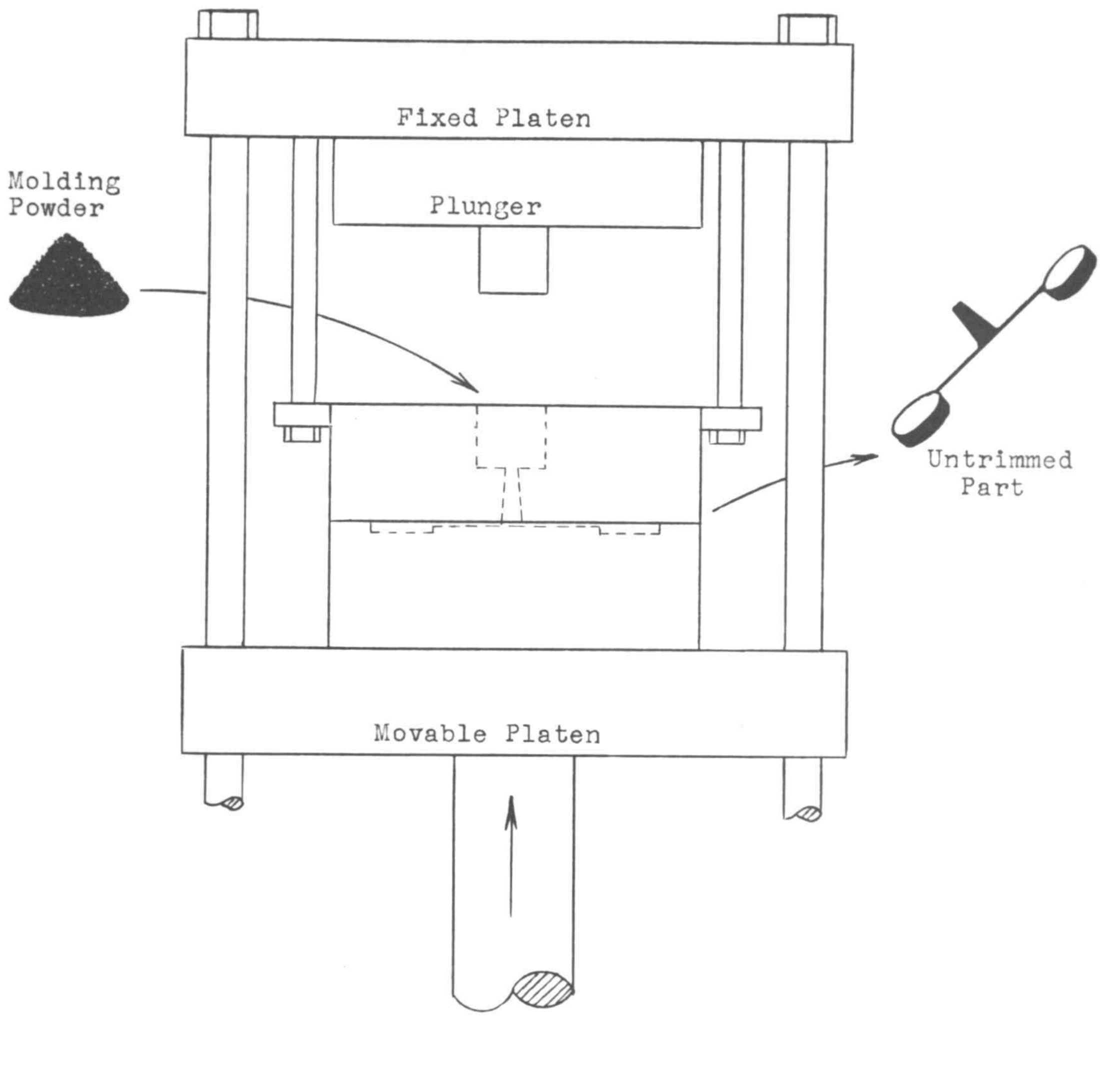
Injection Molding

"Since the thermoplastic resins set up or harden only when cooled, it is obvious that the mold in which they are formed should be kept cool. The molding material can best be heated and softened elsewhere and then shot under pressure into the cool mold. Here it is formed and in but a few seconds becomes cool enough to permit the mold to be opened, the part removed, and the mold closed again to receive another charge of the hot thermoplastic material. This is just what happens in injection molding. . . . A supply of the compound is kept at molding temperature in a heating chamber fed from a hopper. When the mold is closed and ready to receive a charge, a ram or plunger forces the hot semiliquid out of the heating chamber, through the nozzle, through the moldgate, and into the cavity. Pressures up to 25,000 pounds per square inch force the semiliquid into every part of the cavity." (17, pp. 32-33)

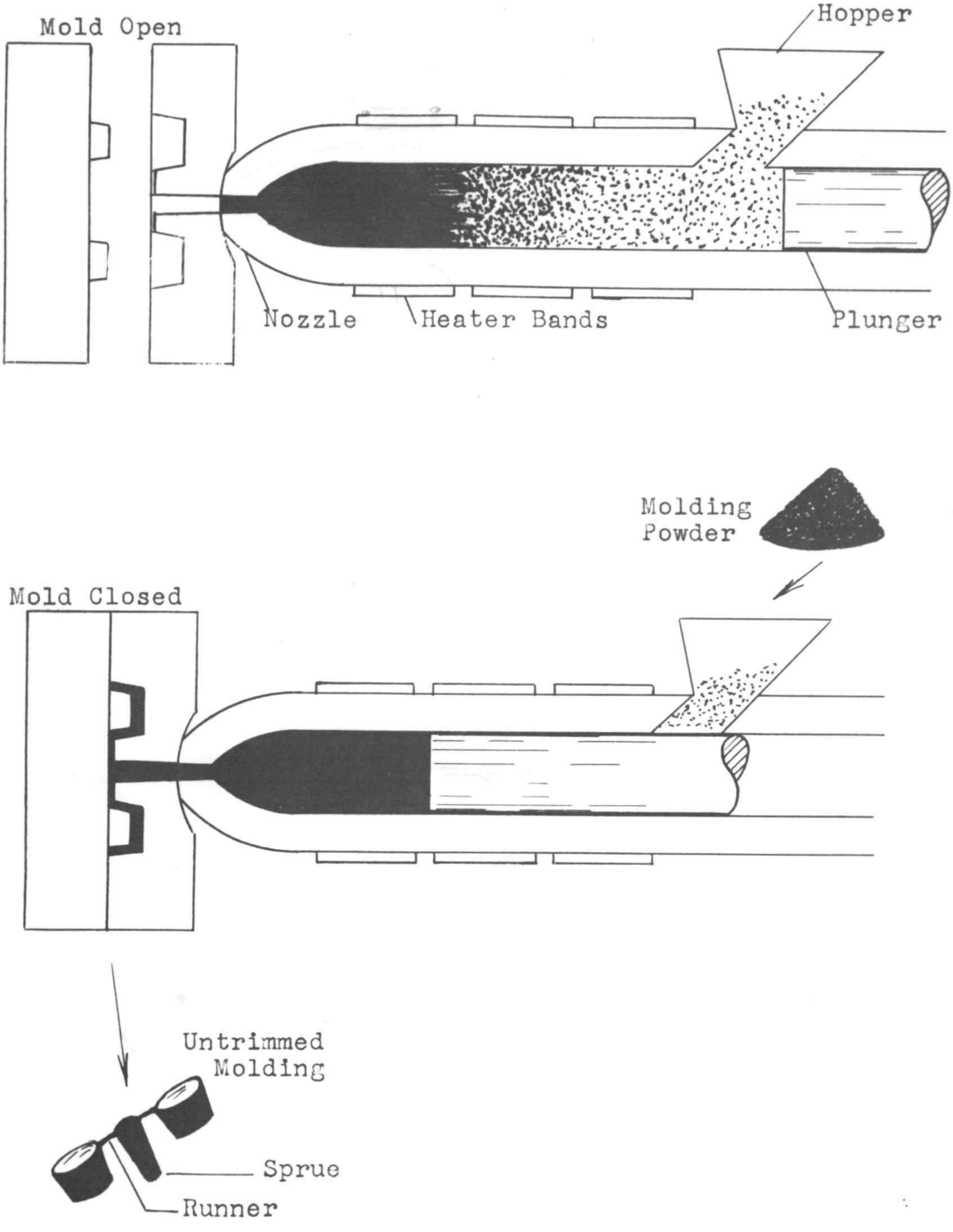
Transfer Molding

"Compound for a single charge is heated in a chamber adjoining the mold cavity. In

Schematic Diagram of
A Transfer Molding Press



Schematic Diagram of an
Injection Molding Machine



> order that it shall not set up in this heated chamber, the whole charge is quickly forced into the hot die where the curing continues and the resin binder sets or hardens."
> (17, p. 36)

The Experimental Injection Mechanism

The mechanism constructed for this experimental work was termed an "injection machine" but it really follows more closely the principles of a transfer molding press. (See p. 19)

Two 3/8 inch steel plates are supported in a fixed position by four 3/4 inch cold rolled steel rods threaded for a 5/8 inch N. F. nut on each end. The top plate is threaded to receive the injection cylinder, lever pivot post, and numerous hold down bolts which may be positioned as needed.

The location of the injection cylinder and the pivot post are arbitrarily chosen with due consideration given to the leverage factor. Other factors to be considered are: 1) height of pivot point, 2) height of cylinder, 3) length of piston connecting rod, 4) position of the connecting rod pin in the lever, 5) length of piston. The basic things to consider are the leverage ratio and diameter of the piston.

To do successful molding with premixes, pressures of 300 p.s.i. on the material should be available. Piston diameters of not less than 3/4 inch seem most practical with an upper limit somewhere around 1 1/2 inches. These dimensions of course can vary greatly depending upon the leverage ratio and the size of the mechanism. A cylinder of 1 inch diameter is more easily loaded with the premix material than one of a smaller diameter.

Experience would seem to indicate that a clearance of about .003-.004 between the piston and the cylinder wall is most desirable.

The hold-down bolts position and secure the mold to the top plate. The cylinder extends through the plate and fits flush with the underside so that the mold may fit snugly against it. The cylinder is threaded to the plate so it can be removed easily for cleaning or replacement. The pivot post is also threaded to the plate. The pivot post can rotate so as to either align the piston with the cylinder or swing to one side while the premix is placed in the cylinder.

Caution must be taken to remove the piston either before or during gelation when molding. If the piston remains in the cylinder after the resin paste has solidified, it may be very difficult to withdraw.

CHAPTER V

PRODUCING A MOLD

Most of the matched metal molds used in industry for molding plastics are constructed of steel. Precision equipment and skillful operators are prerequisites for superior molds. The production of a steel mold is beyond the scope of most industrial arts programs. For this reason other materials and methods of producing a mold were sought.

Premix molding requires a pressure range of approximately 100 to 500 pounds per square inch on the material and molding temperatures ranging from 180 to 320 degrees F. Under these conditions molding cycles of 15 to 25 seconds are not uncommon. The molding temperature can be reduced to room temperature but this will result in great sacrifice in the number of pieces which can be produced in a given time. The molding cycle would be extended to approximately 15 to 30 minutes, depending upon the amount of catalyst added to the premix. With these facts in mind there followed a considerable period of experimentation in mold construction. Three materials were used -- Keene cement, polyester compounds and lead -- all in an attempt to produce a mold by the casting technique.

A pattern was made of the desired article. The mold was cast in two halves, in much the same manner that a green-sand mold is made in a foundry. The pattern, either split or flatback in this case, was laid upon a smooth surface. A retaining barrier of sheet metal determined the outside dimensions and shape of the mold. After the mold had been cast, a hole was drilled in a predetermined location and taper reamed with a pipe reamer to provide a sprue opening. The runner and gate were made with a rat-tail file.

Locating pins for matching the halves can be inserted either when the mold is cast or after it has solidified.

The various materials used for casting the molds are discussed and the success with each is described herewith.

Keene Cement Molds

The material is low in cost, can be purchased at many building supply houses, and is fairly easy to handle so far as mixing and pouring are concerned. It can be drilled, filed, and sanded with ease. Its chief disadvantages lie in the fact that fine detail cannot be retained and it is very low in flexural strength. Moisture inherent in the casting mixture also has an adverse effect upon wood patterns. Keene cement molds of very simple shapes may be practical if they are saturated with hot paraffin or a similar parting agent after they have thoroughly dried.

Polyester Molds

Cast polyester molds gave the most satisfactory results. Very fine detail was obtained. Also it is possible to obtain a very smooth mold surface which is essential for ease in removing molded pieces. Various fillers and glass-fiber reinforcement were used in the resin. Listed below are the mixes tried and the results obtained.

1) Unfilled resin with glass fiber reinforcement. A high concentration of glass fibers tends to trap a multitude of minute air bubbles in the mixture. This results in a mold pocked with bubbles and voids. Glass fibers are most successfully used by adding them to the resin after it has been poured over the pattern. The fibers can be readily immersed in the resin using a small stick or wire. The glass helps to control fracturing which can occur during the curing stage if too much catalyst has been used.

2) Wood flour and resin. Wood flour is finely ground particles of wood. It acts as an insulator in the mix, which helps to control the exothermic action during curing. If too much flour is used

a surface texture develops causing poor mold release in subsequent moldings. Enough flour can be added to considerably thicken the resin but if it becomes paste-like in viscosity, then probably too much flour has been added.

3) Resin and powdered glass. Powdered glass added to the resin produces a casting which is not as brittle as straight resin. The powder will trap air bubbles and make it more difficult for them (the bubbles) to rise to the surface. Powdered glass is very fluffy and unless handled carefully particles of it will drift away in the slightest breeze. This may constitute a potential health hazard in the shop. It is a very good medium for thickening the resin and produces a mold which retains fine detail.

4) Resin and Keene cement. A good casting mixture was obtained using these materials. The cement provides control of shrinkage and the exothermic action during cure.

5) Resin and powdered bentonite clay. This mixture produced one of the best castings. Bentonite clay is one of the ingredients in ferrous casting sand and was obtained from the foundry. The

resulting material is fairly easy to work and shrinks very little.

Lead Molds

Several attempts were made to produce a good lead mold. Many difficulties were encountered. Some obstacles were overcome and one usable mold was produced. Wood patterns can be used with lead molds, if they are given a coating of whiting (chalk dust) and the temperature of the molten lead is kept as low as possible for satisfactory pouring. Tempered Masonite patterns proved superior and could be used two or three times if the first casting failed to turn out well. Powdered graphite also proved to be a good protection for the pattern.

When hot lead is poured over a wood or Masonite pattern, gases are produced. These gases must be released or they will bubble up through the lead, causing pocks and voids. Also the pattern will float if it is not secured. These two problems were overcome by holding the pattern down with an awl while pouring the lead. The lead solidified very rapidly around the awl. The awl was removed immediately and the gases which were forming escaped at the small hole left by the awl. This hole can be closed by soldering. The pattern and retaining barrier should be placed on a steel plate or smooth iron casting when the lead is poured. This helps to conduct the heat away and allows the lead to solidify faster. If the pattern is left in the hot lead too long it will burn excessively and render it unusable a second time.

Lead molds can be made but they are readily susceptible to damage from dents and scratches. Damaged or outmoded lead molds can be remelted to make new ones. There is some danger involved in handling the hot lead, which might make this means of producing a mold impractical in the school shop.

All molds should be made with ample draft to facilitate removal, both of the finished mold from the pattern and the finished molding from the mold. Seven degrees of draft was found to be a practical amount. In a deep draw (more than one inch) more draft is desirable. Multiple cavity molds are practical if the cavities are not too large (about the size of a walnut) and are close together.

A premix compound loaded with filler and/or reinforcing fibers will offer a great deal of resistance and will not flow properly if the sprue, runner, and gate are too small. A tapered sprue opening of not less than 3/8 inch is recommended and runners should be approximately 1/4 inch wide, 1/8 inch deep and half round in cross section.

Premixes containing more than 20% glass fiber content by volume should have somewhat larger gates and runners.

Vents should be made at strategic locations to provide escape of air. Good judgment, experience, and a study of the mold will dictate where to vent. Small "v" grooves made with a file are usually adequate. Very small (1/16 inch or under) holes may have to be drilled in the top of the mold to permit escape of bubbles.

When a mold is cast all possible precautions should be taken to eliminate air bubbles from the surface of the pattern. Voids can be patched later with a resin and powdered-glass mixture but this is time-consuming. Pour the resin over the pattern slowly. A bubble-free smooth coating is obtained by first brushing some of the resin over the pattern.

When mixing a polyester compound for casting a mold it is desirable to add the catalyst first. Addition of other ingredients insures adequate distribution of the catalyst. Measure and calculate the amount of catalyst accurately. If too much catalyst is added, a near violent exothermic action can produce fractures within the mold.

Experimental Molding Problems

There were a great many variables which could and did cause difficulties during the first attempts to produce molded plastics. The injection mechanism itself, although simple enough in its final form, caused many moments of frustration in its initial construction.

Several failures were experienced in the construction of molds and poor mold-release materials accounted for the loss of three usable molds before any moldings were produced. One application of a paste wax is usually not sufficient as a mold release. To be sure of being able to remove the molding it is best to use at least two coats. Paraffin is a good release agent but it is difficult to apply to most cavities in a thin even coat.

Polyvinyl-alcohol is an excellent proven material that is brushed on, but 20 to 30 minutes must be allowed for it to dry. A new coating must be applied each time the mold is used.

Oleomargarine, olive oil, and vaseline were recommended as good parting agents but there was insufficient time to allow experimentation with these materials.

Glass fibers in excess of 1/2 inch introduced into a premix produced an unusable mixture. The resulting stringy wad was an inseparable mass which could not be inserted successfully into the injection cylinder. Beware of glass concentrations which exceed the 20% mark and fibers more than 1/2 inch in length.

The first premix compounds tried were too fluid. This resulted in pocked surfaces and voids. Instead of the material forcing the air out of the vents, the trapped air tended to force the material out. When the premixes were thickened to a paste consistency best results were obtained. The paste viscosity required greater pressure to mold but it flowed quite well into sections as small as 1/8 inch thick.

If an insert or core is positioned in the cavity it is easier to remove the molded piece. This was especially true of the "C" clamp pictured on page 36. Good detail of the thread and easy unscrewing (removing) of the bolt were experienced. For strength and durability a nut should have been inserted on the bolt and molded permanently into the clamp body.

Industrial molds rely on stripper pins to eject the molding from the mold; but without this device, we must rely on the extra large draft allowances and/or projections on the molding to facilitate its removal from the mold.

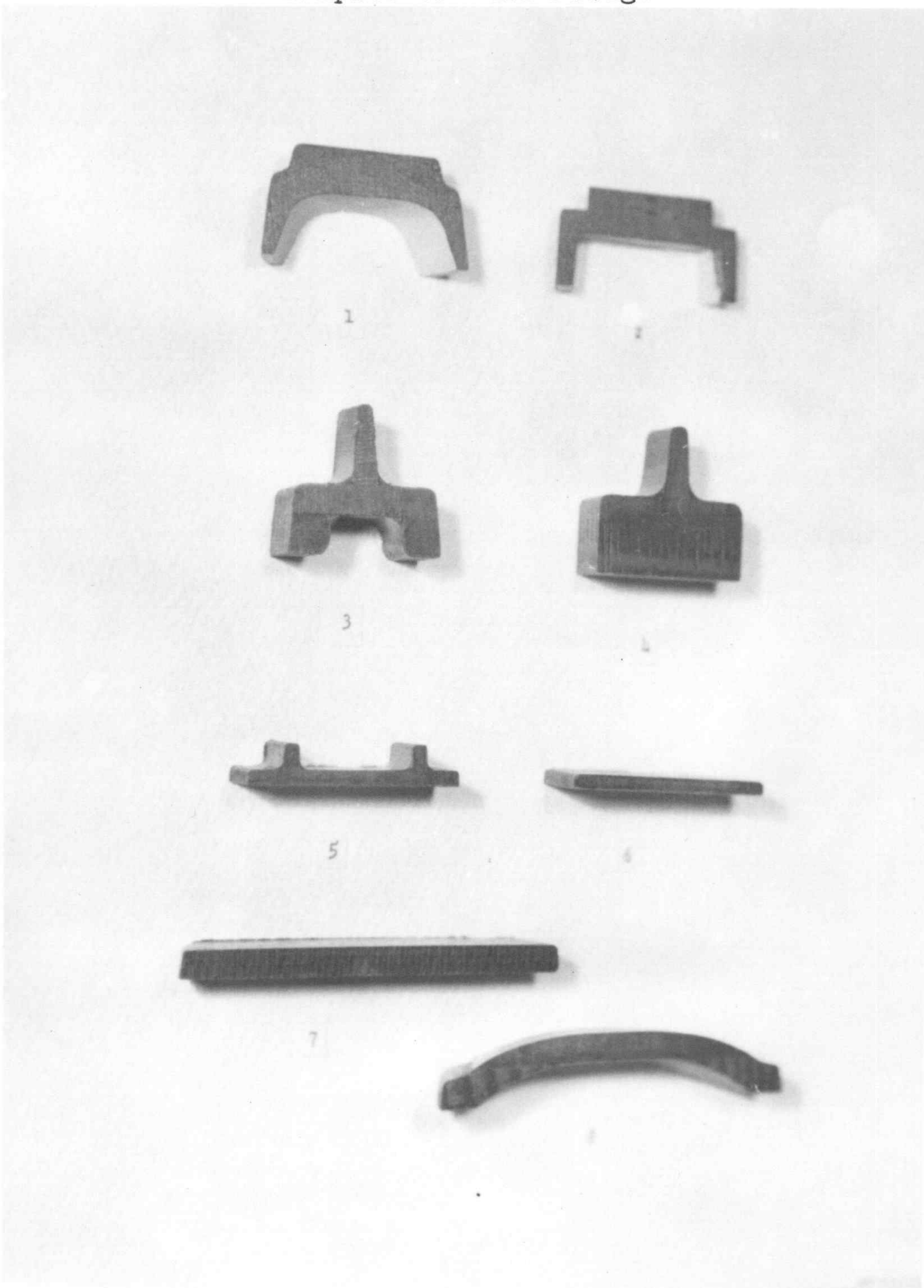
Polyester resin of the type used for hand lay-up work was used in the experimental premixes. It is available at many sporting goods stores or where boats are sold and repaired. It is also available through dealers listed in the industrial arts professional magazines.

The cost per gallon has declined from around $9.00 to about $7.00. The cost will vary with geographic location and the individual dealer. The price of the catalyst must also be figured in the overall cost. The resin purchased for the experimental work cost $6.80 per gallon from a local dealer. The catalyst for this amount of resin would cost about 80 cents.

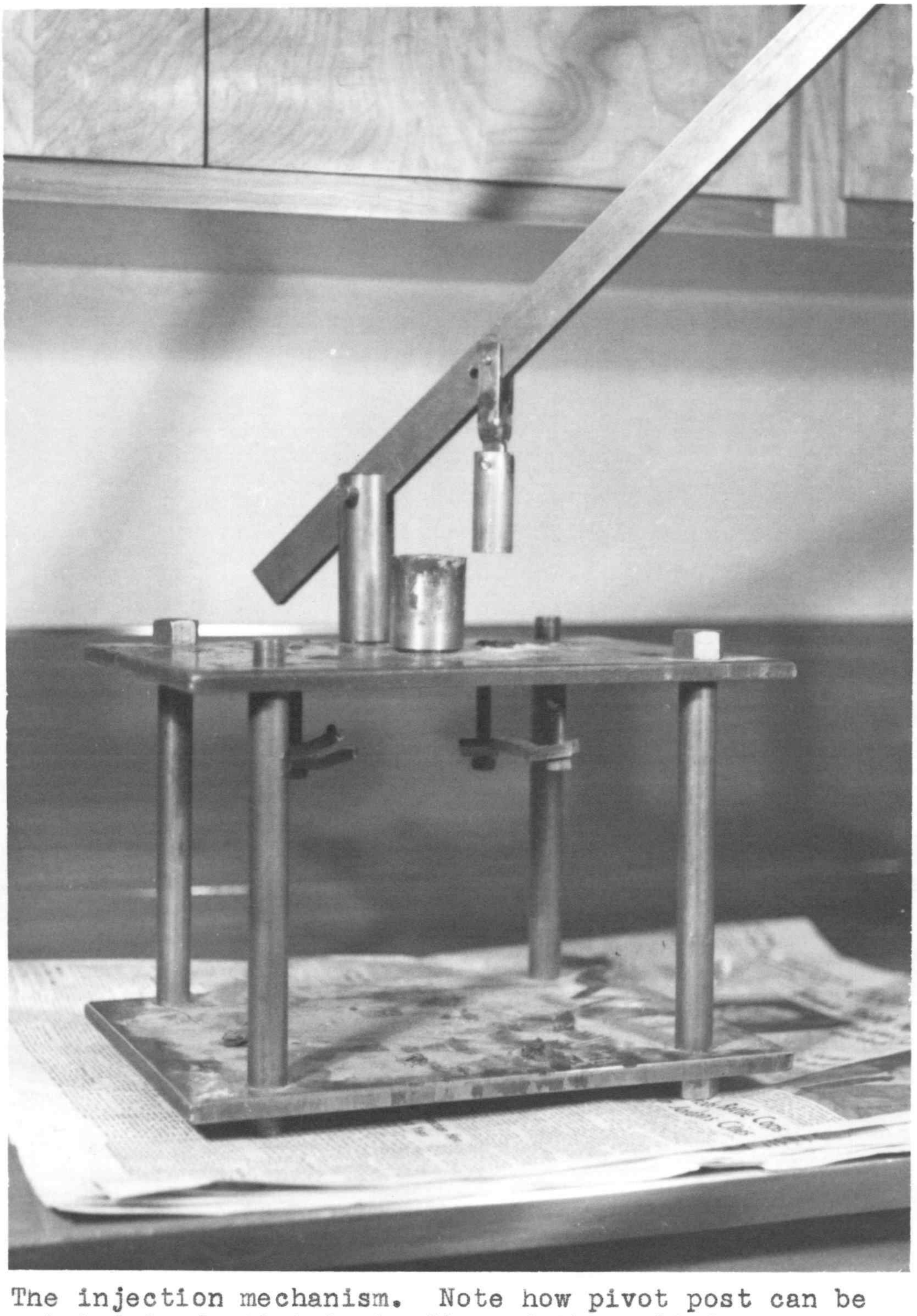
There are many types of polyester resin. Obviously the best type to use for matched molding would be one with characteristics especially suited to this work. These are available to industry. It is quite probable that better results would have been obtained by using one of the specially compounded resins, but such was not available in the smaller quantities used for this study.

The experiments would seem to indicate that premix molding of polyester compounds is possible and practical in the school shop. Developments had shown the possibility of real success when the time limitation curtailed further experimentation for this particular study but it is believed that a proper foundation has been laid upon which further developments can proceed favorably.

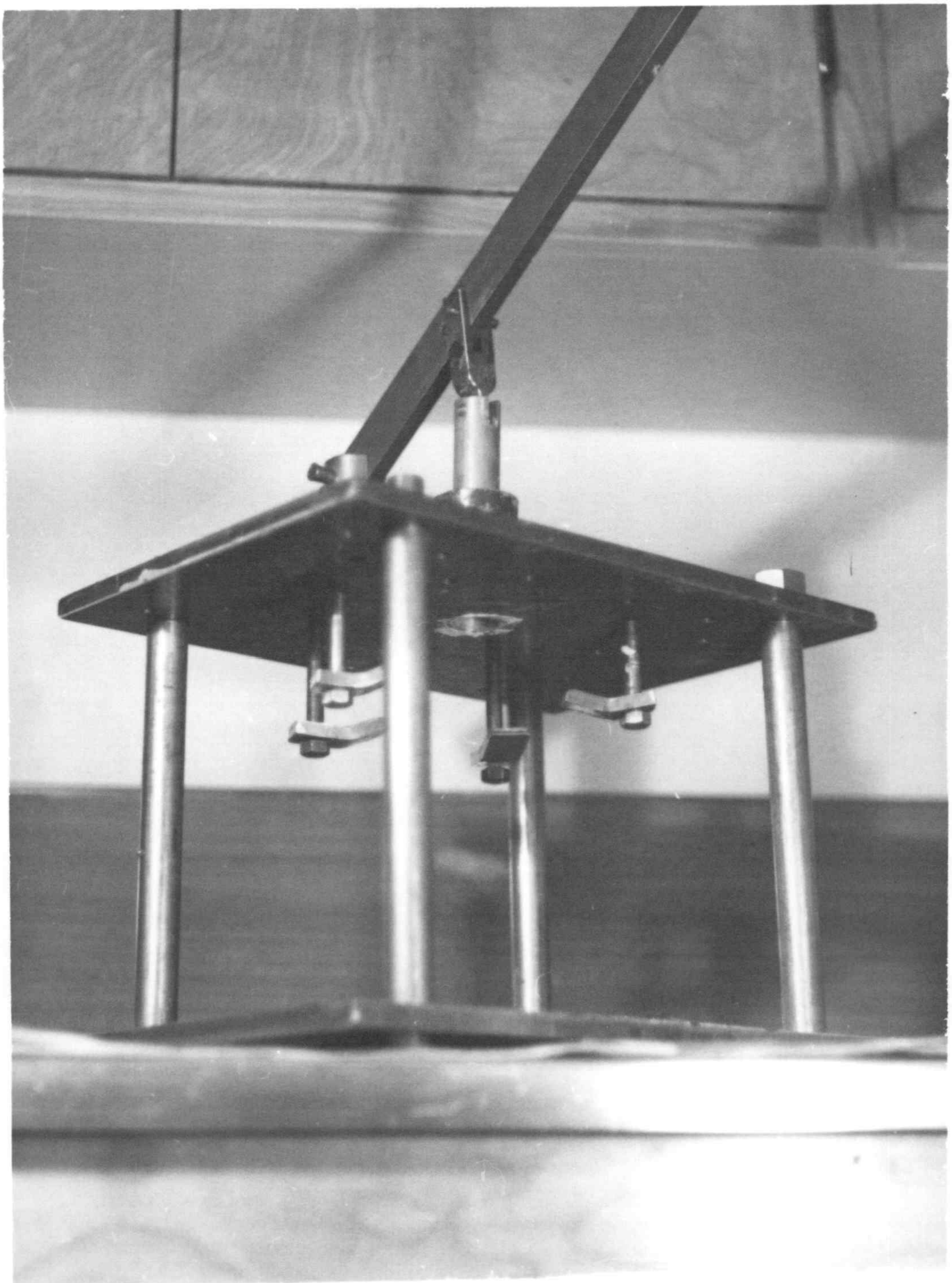
Examples of Mold Design



1-2 Adequate draft and fillets are necessary for good moldings. 3-4 Uniform cross-section reduces costs and shrinkage. 5-6 Webs reduce warpage. 7-8 Doming increases strength.



The injection mechanism. Note how pivot post can be rotated to facilitate loading of the cylinder.



The piston aligned with the cylinder. Hold-down bolts can be repositioned to accommodate size of the mold.

The "C" clamp mold and the molding.

The sheet metal retainer used while casting the mold, the pattern, and the finished mold.

CHAPTER VI

SUMMARY

The importance of plastics cannot be gauged alone by reviewing the annual dollar value of the industry or the production figures in pounds per year. Only as they are related to the progress of other industries which utilize them in their myriad applications and forms can we see their full impact upon our standard of living.

The plastics industry has grown at a phenomenal rate. It is continuing to expand. The men of the plastics industry state there is no limit to the future of plastics. If this is the case, and much evidence indicates that it is so, then we can but conclude that the plastics must be given a place of importance in the industrial arts program.

Plastics are more than sheets, rods and tubes which can be bent, formed, machined and joined; they are liquids, solids, films, fibers and foams which may be combined with a variety of materials to form an infinite number of products. They challenge and stimulate the most fertile imagination. The cost and availability of these materials is now within the range of most school shops.

As yet relatively few articles have been written for the teacher which describe the methods and equipment needed to utilize the newer plastics. This experimentation has been a search for a practical method by which liquid polyester plastics could be given industrial emphasis in the school shop. Many problems were encountered but from the information obtained through experimentation the molding of polyester premix compounds would seem to be practical in the school shop.

Another method of utilizing liquid plastics would be that of casting. From the experience gained in casting the molds it would seem that casting techniques might be more readily adaptable to the industrial arts program than is the case with the molding of premixes. A molding will usually represent a greater investment of man-hours than a casting. Also, molding requires more know how. Casting and encapsulating make use of the same materials as used in the molding technique but in general the operations are simpler and the results quicker.

The world of plastics is fascinating. The purchasing of a quart of polyester resin and its catalyst can bring anyone to the threshold of creative adventure. Plastics belong in the school shop. Polyester cold-setting resins are representative of the chemical age in which we live and they are readily adaptable to the industrial arts program.

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