EXPANDED PLASTICS USED AS SCULPTURAL PATTERNS FOR BURN OUT IN CERAMIC SHELL MOLDS

DISSERTATION

Presented to the Graduate Council of the
North Texas State University in Partial
Fullfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

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Denton, Texas
August, 1976

Penland, Lilburn C., Expanded Plastics Used as Sculptural Patterns for Burn Out in Ceramic Shell Molds. Doctor of Philosophy (Art), August, 1976, 219 pp., 5 tables, 93 illustrations, bibliography, 75 titles.

The purpose of this investigation was to develop a method of burning out expanded plastic patterns invested in ceramic shell molds. Technological information suggested that the procedure was not feasible because plastic expansion or gas combustion invariably spoiled the mold. However, burning out expanded plastic patterns would provide a practical method of using such materials in the sculptor's studio; combined with ceramic shells, the patterns would promote accurately detailed castings with ease and convenience. Developing the procedure was desirable.

Developing such a procedure and several other facets of combining expanded plastic patterns with ceramic shells were considered. Among those interests were the identification of families of expanded plastics and their physical characteristics which would be suitable for sculptural metal casting, the range of temperatures and times which would most effectively burn out the molds, the influence which pattern size, volume, and configuration would have on the molds, and eight different surface finishes to alter the surface texture of the castings. The two expanded plastics families identified were expanded

polystyrene of low density and expanded polyethylene of low and medium densities. The finishing materials were micro-crystalline wax, flour and glue paste, epoxy resin, Thiem (c.) styro fill 42.1, polyethylene film, polyester resin, paper mâché, and burlap.

The study was conducted in two parts: a pilot study eliminated families without potential, determined pattern-configuration refinements, and made preliminary tests of the finishing materials; the main study tested the two families in ten patterns for five configurations commonly used by sculptors in metal casting. Patterns were constructed of a single expanded plastic or some combination of densities or families, were surfaced with two finishing materials, were invested in ceramic shell molds, and were burned out. All ten molds were cast in aluminum to test their potential for producing bright, clean casts.

A procedure for vaporization/burn out of expanded plastics invested in ceramic shell was developed by this study. Patterned molds are placed in a muffled furnace and subjected to a slow rise in heat over a period of two hours and forty-five minutes. Slowly raising the furnace heat from room temperature begins vaporization of the plastics at approximately 175 degrees Fahrenheit; gases are combusted at 425 degrees, and any residue is eliminated at 1000 degrees. The final temperature of 1200 degrees Fahrenheit sinters the ceramic mold. Medium and low density expanded polyethylene and low density expanded polystyrene successfully burned out leaving clean, carbon- and ash-free molds when submitted to the procedure outlined above. Size, volume, and configuration had no effect on the molds. All finishing materials except burlap produced acceptable cast surface texture.

The results of the study recommend that further study of other families and densities of expanded plastics, other finishing materials, other types of furnaces and ovens, and a more precise range of time and temperature of burn-out periods be investigated. Finally, it is suggested that some attention be given to the establishing of a periodical in the sculpture discipline emphasizing procedures and technology as well as aesthetics so that artists may share what they discover with their fellows.

The report is organized into six chapters including the introduction, review of related literature and techniques, methodology, analysis of data, development of ten patterns, analysis of data, and the summary and conclusions.

ACKNOWLEDGEMENTS

A list of all those from whom advice, help, and encouragement was sought or given during the period of this investigation would be extensive. Elden C. Tefft of the National Sculpture Center was most encouraging and helpful. In the list, three men of industry stand out. Special gratitude and appreciation are due to Henning B. Dieter and Angelo J. Paoli, engineers, for their encouragement and availability, their freely shared information, and especially their critical examination of the draft of this dissertation. Gratitude is due to Bill Wooster and his colleagues at Consolidated Castings of Dallas for their numerous consultations.

Appreciation is also due to Paul Rainwater for his technical advice and persistance in seeking the best possible presentation of the photographs with which he had to work.

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CHAPTER I

INTRODUCTION

That the production of sculptured objects has been a concern of man may be seen in artifacts since the paleolithic era; his continued interest in pieces formed by his own hands is demonstrated in our heritage of sculptured works from older cultures such as the Egyptian, Chinese, Greek, Roman, and Anglo-Saxon. Prior to the Renaissance, sculptured articles had a predominately religious significance; since that time, however, sculpture has functioned primarily as ornament. Although two-dimensional art has always exceeded sculpture numerically as ornament, sculpture has occupied a more dramatic position in its environments, perhaps because it intrudes into our three-dimensional space.

One method of producing sculptured objects is the process of casting in metal, a technique which has been available in principle throughout most of the history of art. The process of casting involves pouring a liquid which will solidify into the cavity of a mold. Sand and earth molds were used as early as seven thousand years ago. The more sophisticated investment casting using a wax pattern (that is, encasing a wax form in a material capable of holding that shape until the liquid poured into it solidifies) extends back to the time of the Babylonians and Egyptians (5, p. 122); that process was "lost" and "rediscovered" several times during ancient ages. Benvenuto Cellini is credited with the re-application of the principle during the Renaissance. Metal casting, employing molten metal as the liquid, had changed very little from Cellini's era until about twenty-five years ago (8, p. 4).

Traditionally, patterns for casting have been made of wood or of wax. Patterns are packed firmly in sand to shape the cavity or are coated with materials which solidify. The cavity of the mold is next evacuated: wooden forms are lifted out while wax patterns are burned out. Each type of pattern material has advantages. Artists, who tend to use the casting technique for single, unique castings, find the use of expendable materials adequate. On the other hand, the industrial need to produce multiple castings from a single pattern dictates the use of some permanent pattern material such as wood.

For artists in the United States, the casting of metal sculptures is a comparatively recent experience.

> For over 5000 years, except for a brief interval during the Dark Ages, art casting in Europe, Asia and the Far East has been a dynamic and flourishing enterprise. In America, however, preoccupation with daily living and the scarcity of artisans has kept interest and enthusiasm in art casting from rivaling that of the older cultures (3, p. 801).

Moreover, before World War II, instructions in the use of special equipment and about the technical problems of foundry processes were omitted from formal educational programs for artists. As a result, few artists knew or understood the fundamental processes involved in metal casting. The increase in production of individual works and experimental metal casting came when post-war college youth sought advice, experimented with new and ancient crafts in art departments and commercial foundries, or discovered European foundries which had long been devoted to cooperative partnerships between foundry and artist for the production of works of art (6, p. 15). In the United States, the fabrication, by factories especially designed for that purpose, of artists' plans indicated an upsurge of cooperation between industry and art during the 1960's (4, p. 88).

That renewed interest in experimental metal casting parallels technological progress in the field of plastics. Beginning with the discovery of cellulose nitrate in 1868, experimentation and invention led to the wide variety of plastics which have become available during the past thirty years (1, p. 67). Plastics which had been developed for industrial use became materials which artists could manipulate and shape with their hands. In 1958, Harold Shroyer introduced expanded plastics as workable pattern material for metal casting (7). Since that time, many methods of employing expanded pastics as patterns in casting have been devised. Such progress was hailed as "the biggest stride forward in hot metal casting since the invention of the lost wax process . . ." (5, p. 122).

Following World War II, industry produced a second significant development which proved useful to the sculptor--shell molding. Light, thin shell molds made accurate production of pattern details possible; that accuracy contributed to more efficient production of cast pieces with less labor (2, p. 85).

The development of cermaic shell refactory and of expanded plastics which could be used as patterns provided artists with interesting and useful alternatives to traditional materials. The focus of three National Sculpture Conferences, in 1964, 1966, and 1968, and the participation of artists and craftsmen in such conferences furnish ample evidence of the renewed interest in the metal casting craft and in shell molding and expanded plastics for patterns. The development of those two areas has also played a significant part in the metal casting techniques introduced in this study.

Statement of the Problem

The purpose of this study was to determine the feasibility of using expanded plastics as patterns for a ceramic shell molding process which includes burn out for depatternization. Should a technique for combining the two, previously believed incompatible, be successfully developed, a number of other concerns would be considered. The following series of questions gave direction to the investigation:

1. What are the physical characteristics and properties of two families of expanded plastics--expanded polyethylene and expanded polystyrene--which make them suitable for use by the artist?

2. Which members of the two families of expanded plastics would be suitable for forming patterns?

3. Which members of the two families of expanded plastics would burn out in ceramic shell molds, leaving clean, carbon- and ash-free molds?

4. What temperatures would be most effective for the burn-out process of members of the two families of expanded plastics invested in ceramic shell molds?

5. What influence would size, configuration, and volume of patterns made from members of the two families of expanded plastics have upon the burn-out process of the ceramic shell molds?

6. Which of eight finishing materials used on the patterns to vary the surface texture of the cast pieces would undergo burn-out and produce clean, carbon- and ash-free molds?

These questions guided the pilot study as well as the main investigation of the present study.

Scope and Limitations of the Study

The research was limited to the following material and processes:

Expanded Plastic Patterns

Pattern construction was limited to trying four families of low and medium density expanded plastics in the pilot tests in order to determine which of these materials were most appropriate for use as patterns for making sculptural patterns.

The patterns were constructed in five general configurations established for the study (in Chapter IV) ranging in lengths up to twenty-four inches and volumes up to 840 cubic inches.

Finishing Materials

Patterns were finished with eleven finishing materials which were first tried in the pilot tests in order to establish which materials were effective in altering the texture of patterns and as cast surfaces.

Ceramic Shell Molding

Test patterns were invested in Nalcast (c.) ceramic shell refractory. Five coats of slurry and four coats of stucco were applied. Each mold was slit vented with one-half inch vents at eight-inch intervals.

Burn-out Procedure

Depatternization of the molds was limited to developing a burn-out process established in the pilot tests. It included establishment of a time and temperature schedule and the use of a bottom-loading burn-out furnace for burning out the pattern tests.

Successfully burned-out molds were cast in aluminum in order to test the strength of molds and effectiveness of finishing materials.

Significance of the Study

Throughout the long and varied history of metal casting, artists and industry have experimented with many combinations of pattern and shell molding materials and depatternization techniques. However, this study reports on the first successful and extensive combining of ceramic shell molds and expanded plastics as patterns depatternized through the technique of burn-out. The combination of ceramic shell molds with expanded plastics as patterns has been successfully employed; however, some evacuation technique other than burn out was employed, for it has been generally held that the burn-out process could not be successful due to one of two different conditions which exist when expanded plastics are burned out: either the gases which are generated in burning or the expansion of the plastic pattern due to the heat will cause the ceramic shell to crack. The technique for successfully burning out expanded plastics used as patterns in ceramic shell molds, therefore, contributes appreciably to sculptors' possibilities for achieving fine art castings. Previously, the most direct method of casting metal from expanded plastic patterns had been the full mold (sand casting) process; the improved techniques introduced in this report promise to be more efficient, although not as direct, with less finishing of the castings, better production of details, and less distortion of attenuated forms (the result of the force necessary to ram up sand cast models). It is hoped that further experimentation will extend the techniques being introduced.

The present report has been organized to include a review of those materials and techniques and the related literature which are significant to the study, a detailed examination of the pilot study and the main study, and recommendations for future studies. In addition, a glossary of technical terms is included in Appendix A, p. 193.

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CHAPTER II

A REVIEW OF RELATED LITERATURE

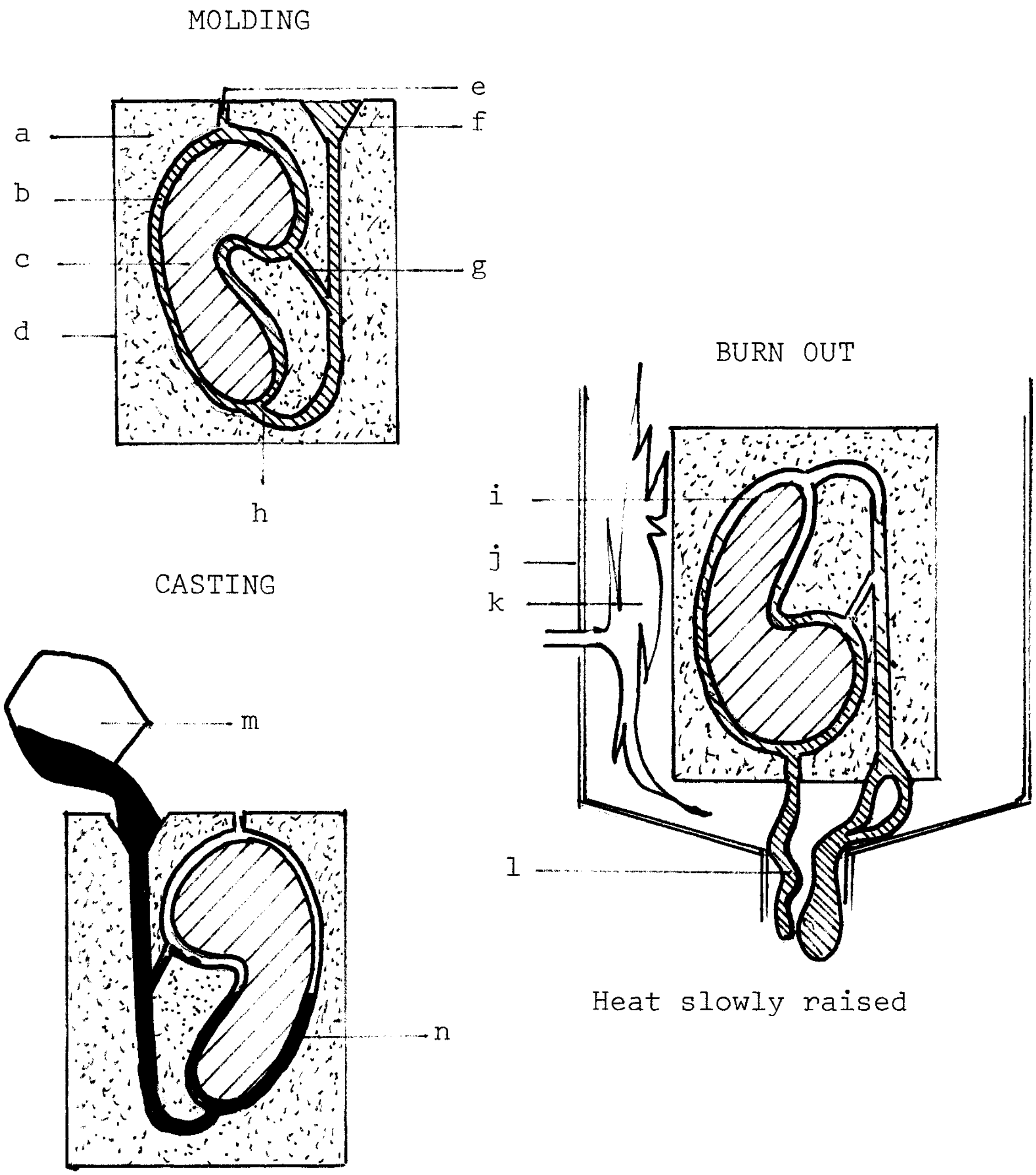
In the many centuries during which techniques and materials for metal casting have been employed by both artists and industry, experimental and innovative uses of those materials and processes which became available have resulted in productive discoveries. Each improvement, while it solves some problems, creates others. Yet new ideas continue to grow out of past mistakes in a slow accumulation of knowledge. The present study must, of necessity, build upon that base of experience and knowledge which other sculptors and even industry have discovered about the art of metal casting. A review of the literature related to that body of knowledge reveals information available about the materials and techniques employed in metal casting.

Mold Making and Mold Materials

Solid investment molding is an ancient technique. Prior to the advent of shell mold casting, solid investment molding was one of the most popular ways to produce castings. Wood (71) provides a history and highly technical description of investment casting; Chapman (7) discusses those technical developments which promoted the growth of investment casting. A simplified description explains that an investment of refractory material and plaster encases a wax pattern and is burned out at approximately 1000 degrees Fahrenheit; as may be seen in Figure 1, p. 12, the cavity which results from losing the wax pattern is then filled with molten metal. Although the technique is quite old, Granata (36) concludes that it remains the most frequently-used method of casting metal sculpture.

Certainly as late as 1966, sculptors at the fourth National (International) Sculpture Casting Conference, meeting in Lawrence, Kansas, were still interested in the technique, for one of the discussion seminars was concerned with problems of size limitation and such (32). At the 1970 National Sculpture Conference Colson (12) and Walsh (69) also discussed problems in ceramic shell. On the surface, then, solid investment molding appears to be a standard and time-proven technique, but problems do exist. Size and weight of the molds are often prohibitive. Because investment materials are relatively weak after burn out, molds must be made very thick, thus adding to weight and expense. Extensive fuel consumption may result because burn-out periods can extend for several days. Disposing of excess mold refuse adds still another problem. Continual experimentation with other materials and processes has resulted from the problems which exist for solid investment molding.

The development of shell molding techniques provided solutions for many of the problems of solid investment



[a]mold: plaster and sand

[b]pattern: wax

[c]core

[d]flask

[e]vent

[f]pouring basin

[g]riser

[h]bottom gate

[i]cavity

[j]furnace wall

[k]flame

[l]melted wax

[m]crucible

[n]metal

Fig. 1--Solid investment molding (cross section)

processes. Although shell molds of various types are now popular in both American and European industry, acceptance of the innovation was somewhat slow. Middleton (45, p. 48) states that an early process for shell molding was developed in 1944 by Johannes Croning in Germany; that shell mold process was employed primarily in core production. The first shell system of casting in the United States, according to Bauman (1, p. 21), was developed by the Corning Glass Company during the 1950's. By 1959, shell molding was beginning to be accepted tentatively as a foundry process. However, Fallows and Worthington (28) observe that the use of the technique reached a degree of significance during the 1960's. Currently, the different shell molding processes are standard production methods.

The shell molding process which was developed by Corning Glass Company uses powdered phenolic resin mixed with sand. As detailed by Brown (4, p. 23), a resin and sand mixture is brought into contact with a heated split metal pattern plate. The split pattern plate attracts the formation of a shell mold of the resin and sand mixture over its surface. When the quarter-inch-thick piece molds have been removed from the pattern plate and have been joined together, the mold is heated in order to give sufficient strength to the shell for handling and casting. A number of variations of the method, including the use of resin-coated sand, have proved successful, Halsey (37, p. 67) reports.

Of primary concern to sculptors and industry alike are the qualities of the shell molding material. Such material must register pattern detail accurately, must not adhere to the pattern, and must be capable of being built up; furthermore, the material must not crack during either the drying or burning out stages. Quigley and Bovarnick (54, p. 34) comment that the material must also have enough green strength for hardening and must be able to retain dimensional stability during firing and sintering. Shepherd and Lewis describe some of the problems of shell molding:

> Initially, suggestions were made in industry for making shells which were backed up by lightly bound or unbound sand when cast. This cannot utilize to the full the advantages which may be gained by using a thin-walled mold. Ceramic shells of sufficient strength not to need backing up were developed. The main obstacle to the successful development of such techniques was the failure of the shells to withstand the stress arising from the expansion of the wax pattern, when the pattern was removed by the normal method employed for block moulds, namely, melting out at a relatively low temperature. Two [general] approaches to this problem have been made. One was to employ a pattern material having a negligible expansion on removal, and the other was to remove the wax in a manner which would overcome the expansion difficulties (61, p. 549).

The first practical technique for using ceramic shell molds with wax patterns in metal casting was patented by Turnbull (66) in 1955. Unlike the Corning-developed shell molds, ceramic shell molds are formed by investing the patterns in a ceramic slurry by dipping them any number of times. Turnbull depatternized his molds by dissolving the wax rather than burning it out. Shepherd (60) reports on several other methods of removing wax patterns, including the use of the Monsanto Autoclave.

Variations of ceramic shell molding techniques generally require similar methods of formation. Schlinkmann (57) describes Nalcast ceramic molds; Herrmann (39), Collins (10), Dunlop (25, 26), Coleman (11), Snelson (64), and Verhelst (68) also describe procedures for ceramic shell molding processes. In addition, Walsh's slide presentation, presented before the fifth National Sculpture Casting Conference in Lawrence, Kansas, in 1968, shows the molding operation along with several other aspects of this particular type of investment. One may describe the process in a simplified manner as follows: the shell is formed around the pattern by coating, bonding, and stuccoing; the finished mold is dried or hardened before the pattern is removed. Then the mold may be cast with molten metal; subsequently, the mold is broken away from the cast.

Several commercially-prepared coating materials, differing only minimally, have these essential characteristics in common: the capability of quick application, of self-support, and of producing relatively thin, porous, highly refractory shell walls according to Schlinkmann's analysis (57, p. 66). The refractory slurry into which the pattern is first dipped contains one of two different bonding agents and a filler. The bonding agents are, Shepherd and Lewis state, ethyl silicate and colloidal silicate sol.

Ethyl-silicate dip-coating is a bonding medium formed of ethyl silicate hydrolised in water and a "small amount of strong acid such as hydrochloric acid to form a mixture of polysilicic acids" (61, p. 550). Colloidal silica dip-coatings, i.e., silica sols, are available commercially in two particle sizes; they are used as commercially prepared and contain a thirty per cent silica concentration. Silica sol bonding agents have better coating qualities than ethyl-silicate agents do because they are slightly thixotrophic (that is, gel-like at rest but fluid when agitated); furthermore, silica sols are stable and have longer storage lives; the specific gravity of silica sol is higher than that of the ethyl-silicate bond dip-coats. Both agents, however, must be stirred while in use (61, p. 552). Colson and Walsh (13), in a question session of the fifth National Sculpture Casting Conference in Lawrence, Kansas, in 1968, answered a number of questions concerning the consistency of the slurry, different dip-coating products, and the size of the wax patterns. Haskin (38) has also examined and evaluated the materials for ceramic shell molds as have Diskar and Gabriel (21); Haskin's presentation of his findings includes an excellent illustration of a bottom-loading burn-out furnace for shock burn out of wax patterns, a method of depatternization which was developed some time after Turnbull's original patent.

The wet slurried pattern is removed from its coating bath and dipped into a fluidized bed in order to prepare it to receive a dry powdered refractory coating. Halsey (37) describes in some detail the design and operation of the fluidized bed as well as methods of applying the stucco coating including stucco rain. The stucco layer is used to provide bulk and strength to the mold and to prepare the surface to accept further coatings of the ceramic slurry. Those refractory materials which are suitable for stuccoing include silica sand, calcined clay, alumina, and fused quartz. Shepherd and Lewis have found that

> silica sand stuccoed shells have high thermal expansion, moderate strength and, although inexpensive, require careful formulation to prevent cracking during de-waxing and firing. Calcined-clay shells . . . are reported to have moderate-to-good strength, medium-to-low thermal expansion and moderate cost. Alumina produces shells of high strength, moderately-high thermal expansion and is fairly expensive. . . . The strongest, lightest shells are produced from fused quartz, . . . the most expensive refractory (61, p. 552).

A graduation of stuccoing particle size is recommended.

The desired thickness of the ceramic shell is acquired by alternating the dip-coating and stuccoing processes. Hermann (39, p. 84) observes that the number of coatings to achieve the desired thickness depends upon the complexity and size of the pattern. He finds that, most often, five to seven coatings will produce a mold three-sixteenths to one-half inch thick. Halsey (37, p. 163) believes that the uniform thickness of the stuccoed coatings over the pattern produces homogeneous structures with strength and permability.

Acceleration of drying time between coats and before burn out has been of considerable interest to Davis (16). Simply raising the temperature of the molds is not feasible because of the undesirable wax expansion which results. There are three acceptable methods of drying ceramic shell molds: air exposure, addition of electrolytes for gas setting, and alternate dip procedures. Davis states that "air drying can be accelerated by increasing the rate of air flow and also by raising the humidity" (16, p. 171). Shepherd and Lewis (61, pp. 554-555) describe the second alternate method for drying and setting ceramic shell molds by the addition of an electrolyte for gas setting of mold materials. The electrolytes include ammonia ethyl-silicate, ammonia silica sol, and carbon dioxide silica sol. Drying and setting are achieved by exposing the stuccoed slurry coat to an appropriate gas. The third method for drying or hardening molds involves alternating dip procedures. Alternate acidic and alkaline baths may be applied and the previous coat set in the process of applying the next coating (61).

A composite molding technique used by industry which may be useful for sculptors is the Shaw process. In a paper presented to the Society of Manufacturing Engineers, Brismead detailed the process which employs a thin facing of coarse ceramic aggregate or sand bonded by sodium silicate as backing for the ceramic shell mold. The pattern is invested in a hydrolised ethyl silicate solution combined with a gelling accellerator. After the mold has gelled, it

> is stripped from the pattern . . .[and the]. . . gelled ceramic mold is ignited immediately after stripping to produce [a] microcrazed structure . . . (3, p. 1).

The ceramic shell molding process has solved many problems of solid investment molding. This technique has gained popularity in industry both in the United States and in a number of European countries. The process was not widely used in academic institutions during the 1960's (32, p. 89), a fact reported during a seminar "International Comparison of Foundry Techniques" held during the fourth National (International) Sculpture Casting Conference in 1966.

The advantages of using ceramic shell molding include ease of preparation, lack of shifting and cracking, lightness of weight, variable temperature requirements, and metallurgic quality control. Several advantages are discussed in detail in "New Ceramic Shell Casting Process" (48), which appeared in 1960. Among the advantages cited, fidelity of detail was considered an important asset. This asset is attributed to a progressive build-up of thin layers of the casting material. Ceramic shell molds also preserve well and have a consistent surface finish. Such surfaces require much less finishing than those produced by solid investment casting. The process also eliminates the need for flasks or containers. In addition, the problems of vibration and bulk usually associated with solid investments are settled. Finally, the process of mold making is simplified because of the limited number of steps required; the gating system permits a simple, direct top-pour into the mold, and vents are used as support during investing and depatternization. Thus, the entire operation is easier than mold-making procedures in solid investment molding.

Ceramic shell molding is particularly applicable to sculpture casting. Schnier outlined some of the aspects of the technique which should recommend it to sculptors in a paper read before the third National Sculpture Casting Conference in Lawrence, Kansas, in 1964:

> Perhaps the greatest advantage of all in the use of ceramic shell molds is the remarkably short time that is required to prepare them for casting. The wax melt-out and burn-out time for these molds may be as short as twenty minutes. This, of course, results in a great saving of time and especially of fuel. It is possible to prepare these molds for casting, i.e., to de-wax and burn out the residue while the bronze is being melted in the crucible furnace. And because of their high resistance to thermal shock, small molds can be cast unsupported in sand and shot poured around them for support. Removal of the mold from the casting is simply a matter of a few light blows with a hammer. Where undercuts and depressions occur in the cast it is more difficult to remove the hard ceramic material than it is to remove the softer investment used in solid molds. But by using sharp points the material can be eventually picked out (58, p. 2).

Complicated patterns frequently require cores. In ceramic shell molding, problems of core shifting are easily prevented by the low expansion factor of the refractory mold material, according to Herrmann (39, p. 84). Other problems associated with flat, thin surfaces, inclusions and finning, are minimized because of higher mold permability.

Ceramic shell molds require very little mold material and are, therefore, light in weight and easy to handle. Furthermore, raw material handling is simplified. The material is stored in bag and drum containers rather than the conventional sand and luto storage and handling, Herrmann adds (39).

Another advantage of ceramic shell molds is the fact that both mold and casting temperatures may be varied from room temperature to the highest temperature required without damaging the mold. It is therefore possible to use any casting alloy such as magnesium, aluminum, and copper-based alloys, and all types of steel and cast iron, each of which requires the employment of temperature different from all the others. Temperature control also assists in obtaining optimum metallurgical properties and increased metallurical quality control, Dunlop (25, p. 534) reports, facilitated by optimum uniform solidification. Rapid cooling of the thin molds of ceramic shell prompts a finer grain size which promotes metallurgical quality increase, Dunlop further observes (26, p. 287).

Ceramic shell molding materials are also used by industry in various methods of operation which differ from those described above. Snelson (64) reported about these methods which do not appear to be particularly suitable for use by the sculptor; they are, however, cited here to illustrate the versitility of this highly stable refractory material: block molding for casting heavy section dies using solid ceramic shell molds; contour/back-up molding which uses permanent, cast-iron flasks or back-up molds; and composite molds made of a pre-formed sand mold which is contoured to approximately the dimensions of an expendable pattern. Ceramic slurry is poured or injected into the space between the pre-formed mold and the pattern.

Patterns and Pattern Materials

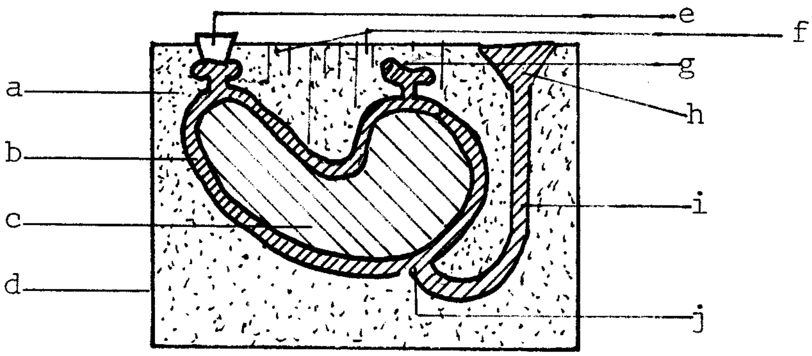
Although traditionally wooden or wax patterns were used in molding processes, the problems created by the combinations of pattern and investment materials have caused artists and industry to investigate other materials for each element. One method of relieving the expansion problem involved the use of frozen mercury patterns instead of wax ones, Shepherd and Lewis (61, p. 549) note; however, that procedure has been of little use for most sculpture projects. In recent years, plastics have been added to the list of materials artists use because plastics have certain qualities of workability, appearance, and strength which are desirable. Just as wood, stone, and metal have offered and continue to offer unique possibilities, Roche (55, p. 13) observed, plastics with their unique qualities are being explored and used. The use and advantages of expanded plastics as patterns for metal casting have been explored since 1956. Couzens and Yarley (14) provide an informative history of the "most popular expanded plastic," styrene, from which polystyrene is derived. It was first synthesized from ethyl-benzene in 1866. Its polmerization was being studied in 1909;

> . . . it was the so-called instability of styrene monomer--which remained liquid with difficulty and tended to change to the solid 'meta' -styrene--which held up the development of this potentially useful material for several decades. Although styrene itself had been synthesized by . . . 1866, the nature of the resin still remained unknown until [Herman] Staudinger [a German chemist] showed, by an examination of the viscosities of its solutions, that it consisted of styrene units joined by their vinyl groups into an assembly of macromolecular chains of different lengths, which he named collectively 'polystyrene' . . . (14, p. 69).

However, the problems of stress, aging, and discoloration were not overcome until 1937. The growth in manufacture of plastics was brought about by the shortage of rubber in Germany and the United States during World War II (14, p. 70).

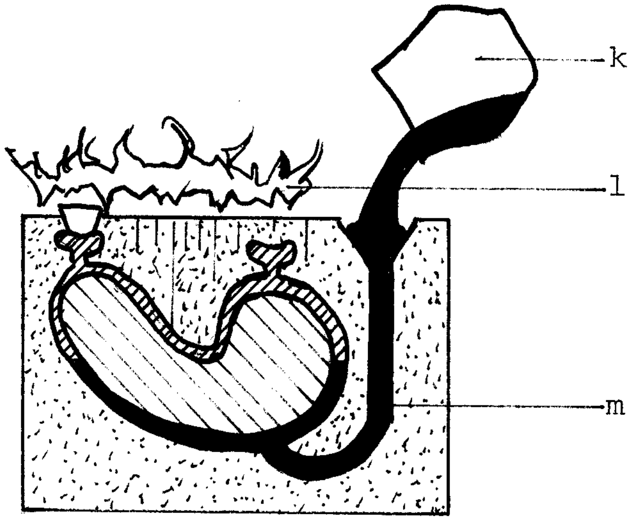
Polystyrene (not to be confused with expanded polystyrene, which is of more recent development) has been used as an expendable pattern material in the "lost polystyrene" process (43, p. 465). Small patterns may be made by injecting the warm plastic into dies. After Shroyer (62) patented the full mold process (illustrated in Figure 2, p. 24) in 1958, expanded polystyrene began to be used for patterns in metal casting. The full mold and CO_2 processes are similar to solid investment casting (illustrated in Figure 1 above);

MOLDING



BURN OUT AND CASTING

Pattern vaporized as metal is poured into the mold.



[a] mold: green sand or CO^2 process

[b] pattern: expanded plastic

[c] core

[d] flask

[e] blind feeder cap or plug

[f] vents

[g] blind

[h] pouring cup

[i] sprue

[j] bottom gate

[k] crucible

[l] combusting gas

[m] metal

Fig. 2--Full mold process (cross section)

however, green sand or CO_2-impregnated sand is used to invest an expanded plastic pattern. The pattern is vaporized by the heat of the molten metal being poured into the mold during the casting operation. The mold material itself is vented rather than the pattern cavity, and blind feeders may be employed to prevent combustion of the pattern. Because the molten metal vaporizes the pattern as it advances into the mold, the mold is always full. Emerson (27) and Newman (50) describe the process and its development.

The full mold process was adapted for casting sculpture by Duca, Flemings, and Taylor at the Massachusetts Institute of Technology, as reported by Newman (49), Duca (22, 23), Duca, Flemings, and Taylor (24), and two articles--"Fine Arts in the Foundry" (29) and "Foamed Plastic Patterns for Making Art Castings" (30). When Shroyer's patent became known, similar works which had been done by others earlier than Shroyer's experiments were disclosed, Dieter stated,

> including an article on the casting of an aluminum telescope mount by D. W. Howorth which is of particular interest as an early example of aluminum casting made from foamed polystyrene patterns, with no special equipment or materials (17, p. 89).

The full mold process has been considered revolutionary by some because of the change in concept from making castings in cavities, a process carried on for some seven thousand years (17, p. 89).

One experiment conducted by Penland (52) employing the full mold process technology used expanded polystyrene and polyurethane which were finished with various substances such as those which are reported on in this study. The coarseness of the green sand permitted a satisfactory but not excellent reproduction of pattern details. The most serious problem encountered in that investigation, however, resulted from the need to core thin enclosing surfaces and to ram up thin, flat surfaces. The tendency to warp the thin planes of expanded polystyrene was difficult to overcome.

Expanded plastics have many qualities which are desirable for pattern making for sculpture as well as industry. Young discussed the economy, accuracy, and simplicity of using expanded plastic patterns in full mold processes, especially its application for commercial production. Schnier (58) and Percy (53) considered the advantages of expanded plastics for the sculptor. Roukes (56, p. 36) and Mills (46, pp. 106-113) listed the advantages of expanded plastics for sculptural medium; those same advantages are also appropriate to making patterns for burn out in ceramic shell molds.

The lightness of plastics is one of their important characteristics when they are used as patterns for casting in metal. These plastics are of extremely low density. Clay and wax are approximately four times as heavy, require armatures, and can sag, crack, or break because of temperature and moisture conditions. Expanded plastics are not affected by these environmental problems. Expanded polystyrene melts and burns like wax but can be fabricated at room temperature. This material can be formed into attenuated or projecting shapes, with high degrees of openess, without armatures. Main masses can be located high above the base or support. Shaping can be accomplished with standard wood and metal working tools. Expanded polystyrene can be cut with a knife, saw, or hot wire; contoured with a rasp or file; smoothed by sanding; textured by heat, hot tools, and solvents; and bent by steam or lamination. Working with plastics enables the artist to add as well as remove or alter shapes. Expanded plastics can be assembled by use of a number of glues or internal setting asphalt adhesives. Furlong (34, p. 39) believed that expanded plastics make it possible to cast the most intricate patterns in whatever size the artist requires. The use of expanded plastics for the pattern permits that pattern to be carved, molded, and cast in the same day.

Each of the expanded plastics has different properties and characteristics. Therefore each expanded plastic may have advantages or disadvantages for the sculptor who wishes to employ these materials as patterns. A descriptive analysis of the various properties and characteristics of the products which may serve as patterns for metal casting is appropriate. The Modern Plastics Encyclopedia is an excellent source for technical information about these and other plastics.

Loftis (42) commented that one of the most popular of the expanded plastics is expanded polystyrene. While having many of the characteristics of all expanded plastics, expanded polystyrene will decompose in the presence of strong oxidizing acids such as nitric and perchloric acids. Chlorinated and aromatic hydrocarbons, esters, and ketones attack polystyrene readily. Expanded polystyrene of one pound per cubic foot density will retain approximately a two per cent set when weighted to ten per cent initial deformation. Dieter and Paoli have provided data supporting the claim that "expanded polystyrene cells will begin to collapse at 170° F . . ." (20, p. 142). Duca, Flemings, and Taylor reported an advantageous use of the property for producing surface relief; they observed that one may

> . . . paint selected portions of the plastic model [expanded polystyrene] with any one of several solvent-free black paints. . . . Then the model is placed under a heat lamp for a short time. The white portions of the model reflect the light readily and are substantially unchanged. The darker portions absorb the heat and rapidly shrink back, leaving the unblackened areas in considerable relief. Considerable variations in surface design and texture are obtainable by changes in painting technique, radiating time, etc. . . . (24, p. 808).

Housiton (40) stated polyurethane has good dimensional stability, high compression strength, and low water absorption, resulting from its closed-cell characteristic. The material is less flexible than other expanded plastics used in this study; yet, it can be manipulated as pattern material using similar methods to those described above. It does, however, have a more sand-like surface, attaining a smoother surface than expanded polystyrene when sanded and generally acts more like wood than other expanded plastics used in this study. It may be purchased in plank, sheet, and volumetric shapes. The possibility of using expanded polyurethane as a molding material is an added characteristic of that family of plastics, according to Gadberry (36, p. 69). He explained that an unlimited number of reproductions can be formed in negative expanded polyurethane molds.

Expanded polyethylene (trade name Ethafoam) is resistant to many chemicals, tough, moisture resistant, and flexible according to Breeding (2). The material exhibits some degree of compression after being pressed for a period ot time. It comes in plank lengths, cylinders, and volumetric shapes. Ethafoam (c.) can be shaped using the processes appropriate to other expanded plastics; however, when sanded or rasped, the surface remains textured similar to a soft brushed wool fabric surface.

One expanded plastic which was used in the present study is described by the manufacturer, Uniroyal (67), as being made from polyvinyl chloride and nitrile rubber; it bears the Uniroyal trade-name Ensolite. This expanded plastic is a closed-cell material; sheets of this product were employed in the present study. Ensolite (c.) is slightly ductile and has good strength; however, it does not resist several chemicals which occur in such materials as lacquer thinner. Ensolite (c.) has somewhat the quality of leather, moreso than any comparable natural material. It can be shaped with scissors, knives, sandpaper, and band saw when it has been laminated.

Although expanded plastics have many characteristics which make them useful as pattern material in metal casting, the easy destruction of these materials has always been one of their least desirable properties. Nor are these plastics generally ductile. These materials cannot be surface molded or manipulated like clay or wax; for this reason, wax or an especially prepared filler or surfacing material is often used in conjunction with expanded plastic patterns. However, as Schnier (59, p. 23) notes, despite these disadvantages, expanded plastics exhibit extreme versatility as a sculpture medium.

Processes and Techniques of Combining Molds and Patterns and of Depatternization

Two processes are predominately employed in the industrial use of expanded plastics as pattern material: the full mold technique of casting, which was introduced by an artist and developed by industry, and unbonded sand casting which was an industrial innovation. In addition, there have been a number of experimental variations of the sand casting process which have used expanded plastic patterns. Finally, even the traditional solid investment molding technique and the more recently developed ceramic shell molding process have been combined with expanded plastic patterns. It becomes readily apparent that both industry and artist are trying these new materials in a continuous effort to produce better cast pieces.

The full mold process (illustrated in Figure 2, p. 24) above was patented by Harold Shroyer in 1958 (62). Both Percy (53, p. 618) and Knapp (41) record that the German firm of Grunzweig and Hartmann purchased Shroyer's patent and began to develop the engineering aspects of the full mold technique in 1962 (53, p. 618). When a number of foundrymen went to Europe to observe advanced patternmaking there, the full mold process attracted the most attention (31, p. 34).

One drawback to the process, however, was the extremely dense cloud of smoke produced by non-combusted gases eminating from vents and sprues in sand molds. In addition, sooty residue from combusted expanded polystyrene caused surface defects on castings, Dieter (17, p. 9) relates. Butler and Pope note that three major solutions to these problems have been developed:

> . . . (1) To complete the combustion of the vapors as they emerge from the vents by the use of 'after-burners" or chimneys; (2) to eliminate vents from the mould by the use of blind feeders and (3) to eliminate vents during filling by the use of blind feeders but arrange that these have plugs or caps which are lifted

> off by the rising level of liquid metal after the mould is filled (5, p. 657).

Furthermore, solid (not hollow) expanded polystyrene patterns, pouring the metal rapidly, and bottom gating so that the metal fills the mold smoothly and evenly and that vaporization of the expanded plastic pattern takes place progressively, Duca, Fleming, and Taylor (24, p. 804) report, are refinements of these three techniques. The discovery that expanded polystyrene could be vaporized completely in a vacuum leaving neither the smoke nor the residue which resulted from the oxygen combusted patterns, suggested that reduction of air contact with patterns and gating systems would also reduce smoke and residue and confirmed that the three previous processes would, in fact, solve the problems.

Dieter's conclusive experiments (19, p. 126) have shown that when these procedures and expanded polystyrene patterns are used in casting aluminum or zinc alloy, the plastic decomposes into styrene vapor which appears to condense into the sand. Emerson (27, p. 114) states that penetration of the sand by higher-temperatured metals has been prevented by using zircon or zircon and graphite washes. Young (72, p. 83) specified the use of acid-catalyzed furan sand distributed over the pattern to prevent this defect. Water putty applied directly to the pattern has been used to prevent the opposite kind of defect, that of sand penetrating into the pattern during displacement according to Granata (34, p. 39).

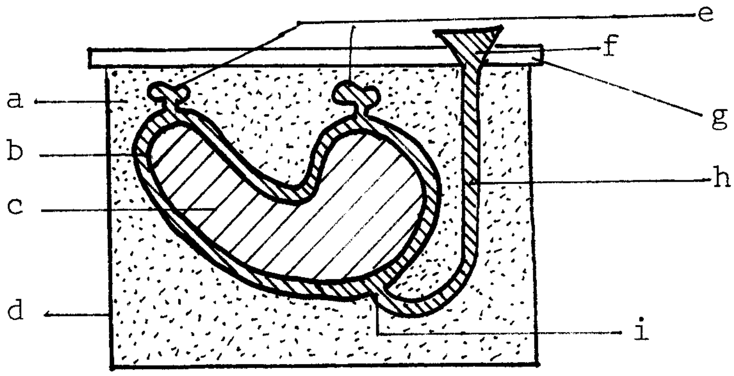
Dry sand casting was made possible by the combination of carbon dioxide and the full mold method of molding. Carbon dioxide-expanded polystyrene casting consists of packing an expanded polystyrene pattern, with attached gating system, in fine round grain sand bound with six ounces of solium silicate per pound, tempered with water. Carbon dioxide gas is used to set the mold material, Penland (52, p. 8) reports. The process was developed by Alfred Duca at Massachusetts Institute of Technology. He claimed that the method was simpler to carry out than the lost-wax method. The organic vitality of patterns is also claimed to be preserved (30, p. 463). Maxlow and Dewitte (44) patented a process very similar to the full-mold process several years after Shroyer's original patent. The Maxlow-Dewitte process differs from Shroyer's full mold process in the addition of ports of ingress and egress from the expanded plastic pattern. Heated gases, capable of degrading, decomposing, and melting the pattern are applied through the ports.

Dieter (19, p. 124) declares that Smith, Wittmoser, and Hamilson are credited with discovering the amazingly simple concept of using unbonded sand as an investment. Smith was observing the process of setting and drying sand molds using carbon dioxide at the Maytag Company in Newton, Iowa, in 1964.

He questioned the need for sodium silicate being added to the sand and the use of carbon dioxide gas, for it appeared to him that the expanded polystyrene would support the dry sand while simultaneously being replaced by metal. Figure 3, p. 35 shows a simplified illustration of unbonded sand molding. Butler and Pope (6, p. 186) provide a detailed description of the process including preparing the molds, compacting the sand by vibration, the use of lids and weights, and the refractory pouring basin. Molten metal advancing into the expanded polystyrene pattern vaporizes partly-depolymerized styrene out into the sand where it condenses. As the metal cools, additional heat is liberated which pushes the styrene farther out into the sand. The results of this procedure, Gadberry (35, p. 7) suggests, produce clean casting; no burn out is required, and there is little metal penetration. Clarke (8, 9) and Dieter (18, 19) provide many of the same details.

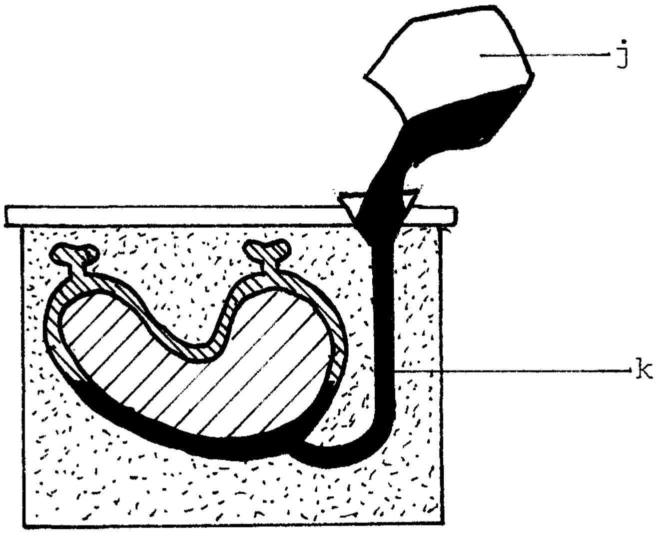
Low density expanded polyurethane was cast in the same unbonded sand process. However, Gadberry notes (35, p. 69), bronze or iron work better with expanded polyurethane because a very hot metal is required to collapse the plastic material. Butler and Pope states that "it has proved impossible to cast aluminum into polyurethane, at least where the section thickness has been below one-half inch" (6, p. 179). Dieter and Paoli report that

MOLDING



BURN OUT AND CASTING

Pattern vaporizes as metal is poured into the mold.



[a]mold: unbonded sand

[b]pattern: expanded plastic

[c]core

[d]flask

[e]blind riser

[f]pouring basin

[g]weighted top

[h]sprue

[i]bottom gate

[j]crucible

[k]metal

Fig. 3--Unbonded sand molding (cross section)

> expanded polystryene cells will begin to collapse at 170 F (77 C), gradually decreasing in volume to about 1/40 of their original size. The resulting molten plastic mass will start to vaporize at 400 F (204 C) and if oxygen is present to support combustion the gases will burn (20, p. 142).

Thus, the metal to be cast may determine the expanded plastic material which is used for the pattern. Spinagesh and Govind (65) believe that the finer-grain size and coating of the plastic patterns produce stronger castings.

Several experimental sand casting processes which employ expanded plastic patterns have been tried recently. Such experiments were of particular interest in this study. In 1958 and 1959, Jan Zach (73) of the University of Oregon cast expanded polystyrene in sand mixed with different organic materials. He reported success with corn meal, flour, and silica sand, bound with fish oil. Expanded polystyrene was enclosed in the sand and organic material mold and baked, then cast. The expanded plastic and organic materials burned out leaving a sturdy mold, which also easily released the casting. Zach records (73, p. 1) another experiment produced interesting effects by using pitch and sand (silica with powdered pitch) around the pattern made of expanded polystyrene. The results of in place burn out of the expanded polystyrene and intense heat ". . . caused holes of all sizes in the expanded polystyrene through which pitch sand sifted before solidifying" (73, p. 2).

Solid investment molding using expanded polystyrene patterns has been employed by industry and by such artists as John Rood. The expanded plastic is burned out according to the conventional lost wax procedure, mentioned by Mills (47, p. 86) but Darby (15, p. 32) reports that it takes 50 per cent longer time to burn out than wax. Two significant experiments made with expanded plastics as pattern material in solid investment are detailed here. Expanded plastic was used as armatures for buildup of wax, cloth, and other burnable materials by Nick Kiolis and Dale Eldred of the Kansas City Art Institute according to Gadberry (35, p. 75). They built such patterns and used hand-built chicken wire reinforced investments which supported the expanded plastic; subsequently the form was set on fire. Most of the rags and wax dropped out in the burning process. Final preparation of the mold was done by melting the wax with steam, then slush waxing, coring, burning out, and casting in the traditional solid investment method.

A lesser use of expanded plastic is as a transitional core coated with about one-fourth inch of wax. The core is shaped in expanded polystyrene to the approximate dimensions of the final sculpture. Then the surface is coated with wax. Various methods are used for applying the wax. After the surface is molded, the expanded polystyrene core is dissolved using solvents such as acetone, lacquer thinner and perchloroethylene. The wax pattern is subsequently attached to a gating system, invested in conventional solid investment material, and cast by the lost wax method (68, p. 32).

Although wax modeling or construction is the usual method of preparing patterns for ceramic shell molding Schnier (58, p. 7) reports that some significant experiments with expanded plastics covered with wax have been performed. Handled much like lost wax casting in solid investment molds described above, the wax is built up to the desired thickness of the cast metal over an expanded polystyrene core or armature. After pouring basin, sprue, and gates are attached, the pattern is molded in ceramic shell. Subsequently the core is vaporized using solvents for the plastic. Then a ceramic shell core is slush poured, sprayed, or applied by hand. Use has also been made of solid investment material to replace the expanded plastic core. Wax remaining in the mold is burned out before casting (59, p. 24).

Depatternizing became a problem for the early experimenters with ceramic shell molds over wax patterns when they tried to burn out the wax patterns in the same manner as was used with lost wax solid investment molds; the wax expanded with the slowly rising heat and cracked the ceramic shells. Several methods of depatternizing other than burn out were suggested.

Turnbull's original patent suggested the use of a trichlorethylene bath to solvenize the wax. Tricholorethylene permeated the shell and immediately reduced the wax to a solution whereupon it was drained off. However, Davis (16, p. 171) suggests this method does not appear to have been widely adopted.

A second method of depatternization is the shock burn-out process (illustrated in Figure 4, p. 40). The ability of the ceramic shell mold to withstand considerable shock permits high temperature shock melting as Davis specifies,

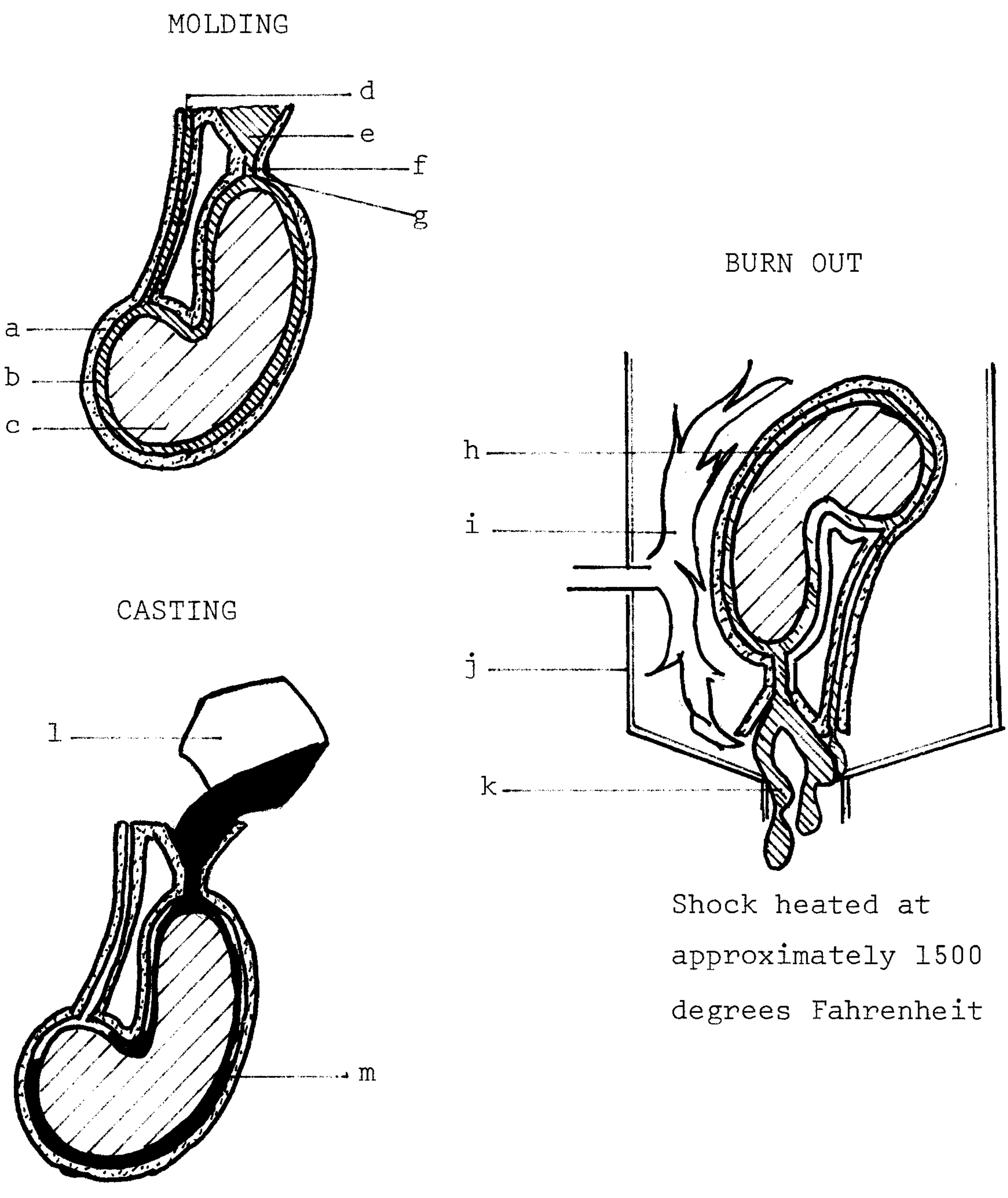
> The mold is plunged into a furnace maintained at more than 900°C. The wax at the mould/pattern interface melts immediately, penetrating the mould and leaving sufficient room for expansion of the pattern before melting (16, p. 172).

With autoclave dewaxing, the wax pattern is exposed to steam superheated in an autoclave for fifteen to twenty minutes.

> A technical disadvantage of the solvent method of de-waxing is the inability to dewax molds dried in an ammoniacal atmosphere without cracking. Such moulds can be successfully dewaxed in both thermal shock and autoclave units (16, p. 173).

Snelson (64, p. 36) reports that one other depattern-ization has been used. Combination patterns of wax and some permanent "part" are assembled and invested as a unit in a ceramic shell to form this type of pattern. After the ceramic shell has jelled or set, the permanent part of the pattern is removed. Then the wax is evacuated using one of the methods described above. This process seems to have little applicability to sculpture making.

There are reports of using materials for patterns other than wax, including natural objects and flammable materials.



[a]mold: ceramic shell

[b]pattern: wax

[c]core

[d]vent

[e]pouring cup

[f]sprue

[g]top gate

[h]cavity

[i]flame

[j]furnace wall

[k]melted wax

[l]crucible

[m]metal

Fig. 4--Shock burn out method (cross section)

Such reports are of special interest to this study because of the question of burning out expanded plastics in ceramic shell molds. Frazier (33, p. 80) reviewed experiments using pine cones, gated with wax and invested in ceramic shell molds. They were burned out using the conventional wax shock-burn-out method and cast in bronze. Castings were reportedly of "extreme accuracy," with no mold fracturing or other irregularities.

Although the previously cited experiment was of special pertinence to the present study, examples of other experiences with burning out natural materials suggest the wide scope of burn-out depatternization. Several materials are commonly used for strengthening wax patterns which have been invested and burned out in the conventional lost wax process. Corrugated cardboard, burlap, and cheesecloth produced clean molds when burned out at 1000 to 1200 degrees Fahrenheit. Schnier (59, p. 19) reports the use of balsa wood to support wax patterns also being burned out successfully.

Solid investment molds have apparently been used to burn out wood, plant forms, and fabric in the production of sculpture, according to O'Hanlin (51, p. 71). An example of using wood involved coating an oak chair with wax modeling. He discussed his observation that one of Jacques Lipschitz's sculptures included forms resulting from burn out of felt hats.

However interesting experiments with burning out natural materials used as patterns may be whether in solid investment or ceramic shell molds, experiments and problems which involve expanded plastic patterns in ceramic shell molds are of prime concern to this study. In a paper presented to British Investment Casters in 1961, C. H. Waxman (70) discussed injection molded polystyrene used as a pattern material and referred to the problem of shell molds cracking when invested with such patterns. In subsequent discussion of the paper, there was speculation that shape of particular patterns, type of shell, thickness, and strength could be influences which could contribute to shell mold cracking. Waxman referred to the influence of expansion on the cracking shells, and he observed that

> this was one aspect where there was probably room for a certain amount of research. Variable expansion might have something to do with cracking troubles. On the other hand it might be that the gases given off were causing the trouble rather than the expansion of the polystyrene itself. Of course, the polystyrene expanded much less than did wax. . . . [Waxman] had calculated that one would have to take polystyrene up to about 700 deg. C. in order to get the equivalent expansion one got from wax up to its melt-out point. On this basis, . . . there must be something else involved (70, p. 717).

One successful attempt to combine ceramic shell molds with expanded plastic patterns which were depatternized by burn out has been reported by V. A. Skazhennik and others (63) in the periodical Russian Casting Production. Since that report is of vital importance to the present study, efforts were made to obtain additional information about the various sizes of the expanded polystyrene patterns which were tested and the furnace temperatures; however, no further information has been ascertained to date. From the rather abbreviated information regarding sizes of patterns and exact temperatures employed, it appears that the experiments performed by Skazhennik, Antipenko, Dyagelets, Konotopov, and Chernov were not extensive enough to reveal certain problems both revealed and solved in the present study. Essentially Skazhennik and the others employed both burn-out depatternization and different solvents to evacuate the molds; however, according to tables and charts which illustrate the article, maximum dimensions of the samples of expanded polystyrene were 62.1 x 53 x 94.1 millimeters (or about 2½ x 2 x 2-3/4 inches). In addition, the report that expanded plastic patterns "can be combined with the mould firing cycle" dictates that the furnace loading temperature "must be at least 450 degrees C" (63, p. 93) (or about 850 degress Fahrenheit). As the pilot study of the present report will show, temperatures as high as 450 degrees Centigrade are not consistently successful; small patterns of 2 x 3 x 1 inches burned out more consistently than larger or more voluminous patterns. It is therefore assumed that the process attempted by Skazhennik and his colleagues was not extensive enough to determine the exact limitations of expanded plastics used as patterns. The present study is thus the first successful extensive investigation of this matter.

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CHAPTER III

PROCEDURES AND METHODOLOGY

This study proposed to combine the elements of ceramic shell molds for fine detail with expanded plastic patterns for ease of fabrication with a burn-out technique in order to develop another alternative for the sculptor. A review of related literature revealed that previous attempts to combine these two elements and burn out the molds had been relatively unsuccessful; however, that literature also suggested that a technique might be developed which would utilize the low density of expanded plastics and would have little or no effect on the molds in a burn-out process.

In order to define the processes and generate data for the study, it was necessary to conduct pilot tests. The pilot tests examined four families of expanded plastic patterns coated with nine finishing materials. The tests examined size, volume, vents, and burn-out techniques. Photographic records were made to provide a permanent record and to confirm personal observations. In addition, a journal and time and temperature charts for each test were kept to provide evidence of results. Details of implementation of the procedures appear in the pilot tests.

Pilot Test I: Shock Burn Out of Identified Expanded Plastics

Preparation for Burning Out

The first pilot test was designed to determine which of four families of expanded plastics (consisting of twelve varieties) and which of nine finishing materials would burn out successfully. The four families of expanded plastics--expanded polyethylene, polystyrene, polyurethane, and polyvinyl chloride and nitrile rubber--were chosen because all are readily available to artists.

Twelve varieties of these four families were tested. The three examples of expanded polyethylene were from two examples of low density Ethafoam (c.), 2.2 and 2 pounds per cubic foot (hereafter noted as p.c.f.), and one medium density Ethafoam (c.) sample of 9 p.c.f. (2). Six relatively low density examples of expanded polystyrene were used (4); the densities of these samples were 1.0, 1.8, 2.1, and 3.3 p.c.f. One sample of Styrofoam (c.) of 2.0 p.c.f. was added because of its texture and surface difference from the others. Thin sheets of one-eighth inch thick mini-cell expanded polystyrene were laminated to make material of a thickness comparable to the other expanded plastics used as patterns. Two examples of rigid urethane, of 1.5 and 8 p.c.f., were used because of their wide range in density. The 8 p.c.f. sample was composed of one-eighth inch thicknesses of the material laminated to make one-half-inch-thick boards, which was the thickness of other materials used as patterns. Finally, one-eighth-inch-thicknesses of Ensolite (c.), a flexible material, were laminated to make material of comparable thickness to the other plastics used in this test.

Nine sets of patterns from the twelve varieties of expanded plastics were made by use of a band saw. Each shape was approximately four and one-half inches long and two inches wide, cut in a wedge shape, gradually coming to a sharp edge at the bottom of the length, from one-half-inch thickness at the top. Each set consisting of twelve sample patterns was sanded to a medium smooth surface and finished (coated) with materials listed below, or left unfinished, as indicated:

1. Microcrystalline wax, on both sides;

2. Flour and Elmer's (c.) clue, on one side, and paper mâché on the other side;

3. Acrylic paint, on both sides;

4. Thiem (c.) styro fill 42.1 a commercial finish used in industry, on both sides;

5. Gesso, on both sides;

6. Fiberglas (c.) laminated with polyester resin. (Because polyester resin solvenizes polystyrene, this test was not performed on the set of polystyrene).

7. Epoxy resin, on both sides;

8. Bondo (c.), a commercial filler made for filling auto bodies, on both sides;

9. Left as sawed on the band saw, uncoated.

Following the finishing step, all nine sets of patterns were arranged with wax sprues using gates of the same type of expanded plastic as the patterns. Each set was then coated with five layers of slurry and stucco; the first coating of slurry was stuccoed with fine-grain silica sand while the second through the fourth coatings were stuccoed with medium-grain silica sand. The final coat of slurry was left without stuccoing. Each coating was allowed to dry for twenty-four hours before the next coating was applied or, in the case of the fifth coating of slurry, before burn out.

Burning Out and Casting

The bottom-loading, open-flame furnace used was a type closely resembling one described by Donald Haskin (3, p. 46), for example see Figure 5, p. 55. The furnace was constructed of a steel frame, lined with fire brick consisting of a thirty-six-inch-diameter cylindrical chamber, forty-five inches high. The furnace was equipped with one burner, fed by a three-inch gas line and a portable electric squirrel-cage blower. Temperatures were recorded using a portable pyrometer. Each of the ceramic shell molds was vented at the bottom with two one-half-inch slits sawed through the mold surface near the corners. The slits were cut with a hacksaw blade. Subsequently, the nine molded sets of patterns were anchored on a rack for quick loading in the burn-out

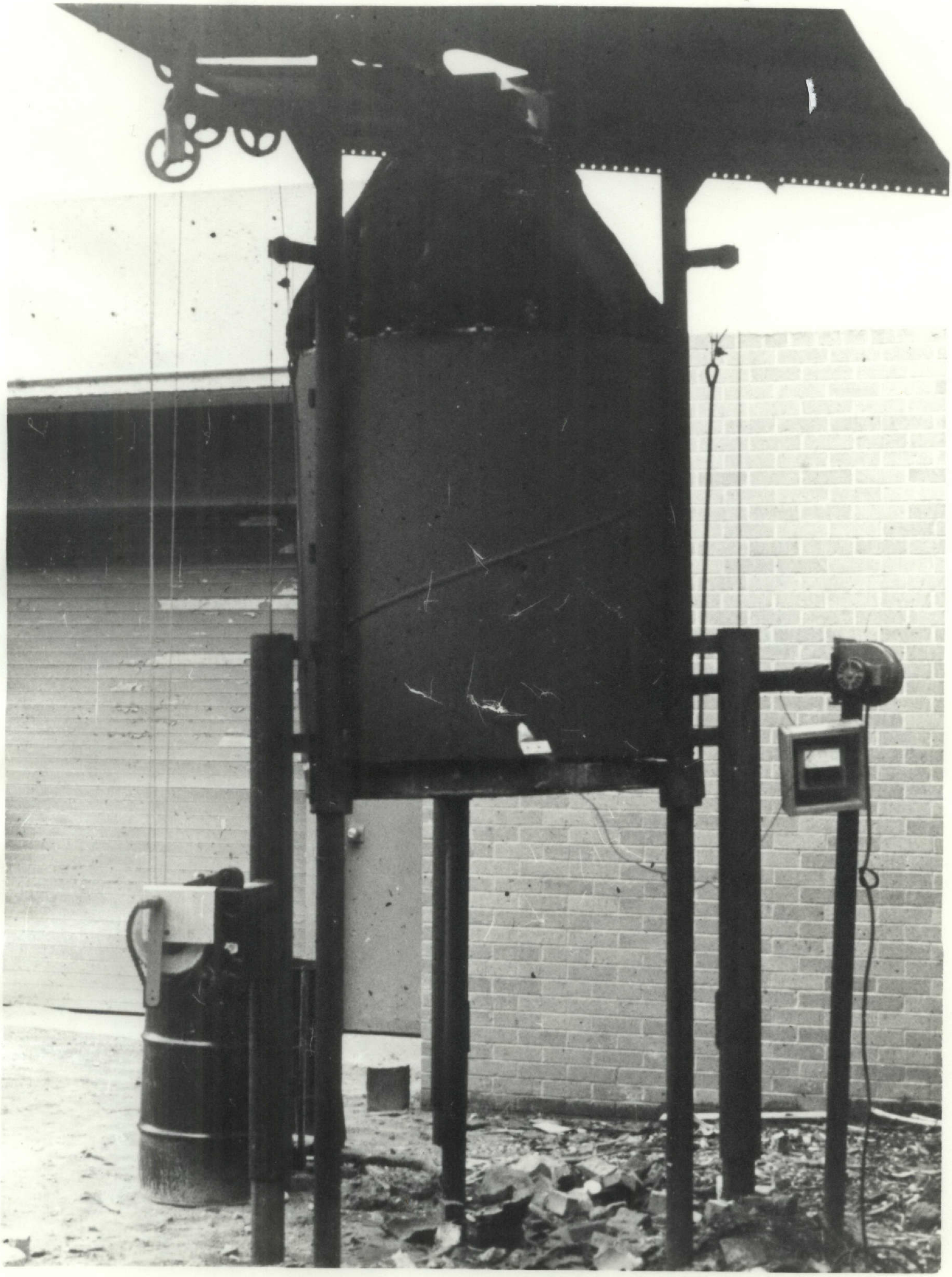


Fig. 5--Bottom loading burn out furnace

furnace. The furnace was pre-heated to 1850 degrees Fahrenheit. The door was lowered and the racks of sets placed in position. Molds were immediately raised into the furnace flame as the bottom-closing door was raised. After the resultant temporary reduction in heat, the temperature quickly rose to 1,500 degrees Fahrenheit.

During the first five minutes, billows of black smoke were emitted from the furnace. After five minutes the temperature was lowered to 1,200 degrees Fahrenheit and kept at that temperature for twenty-five minutes.

Subsequently, the furnace was shut off and the door lowered. An example of the appearance of the molds as they were withdrawn from the burn-out furnace is shown in Figure 6, p. 57. Figure 7, p. 57, indicates a closer view of an individual set of molds after burn out utilized in pilot test.

After patching molds to prevent the metal from escaping through broken sections (see Figure 8, p. 58), the molds were preheated to 1,000 degrees Fahrenheit and cast with aluminum as shown in Figure 9, p. 58.

Results of Pilot Study Test I

The procedures which were described above do not differ from normal practice in the burning out of wax molded in ceramic shell. In fact, the purpose of following the wax burn-out procedure was to determine whether and/or which patterns would crack molds under such conditions. The results

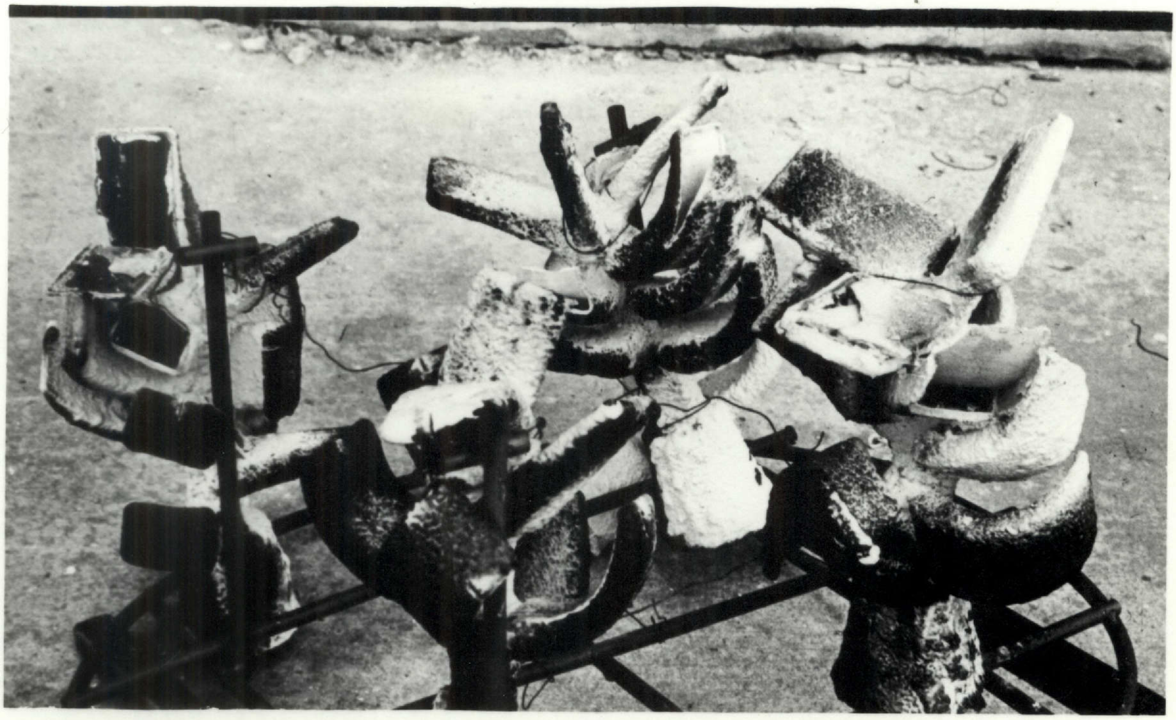


Fig. 6--Four sets of molds utilized in pilot test I

Fig. 7--Molds for Bondo (c.) finished patterns

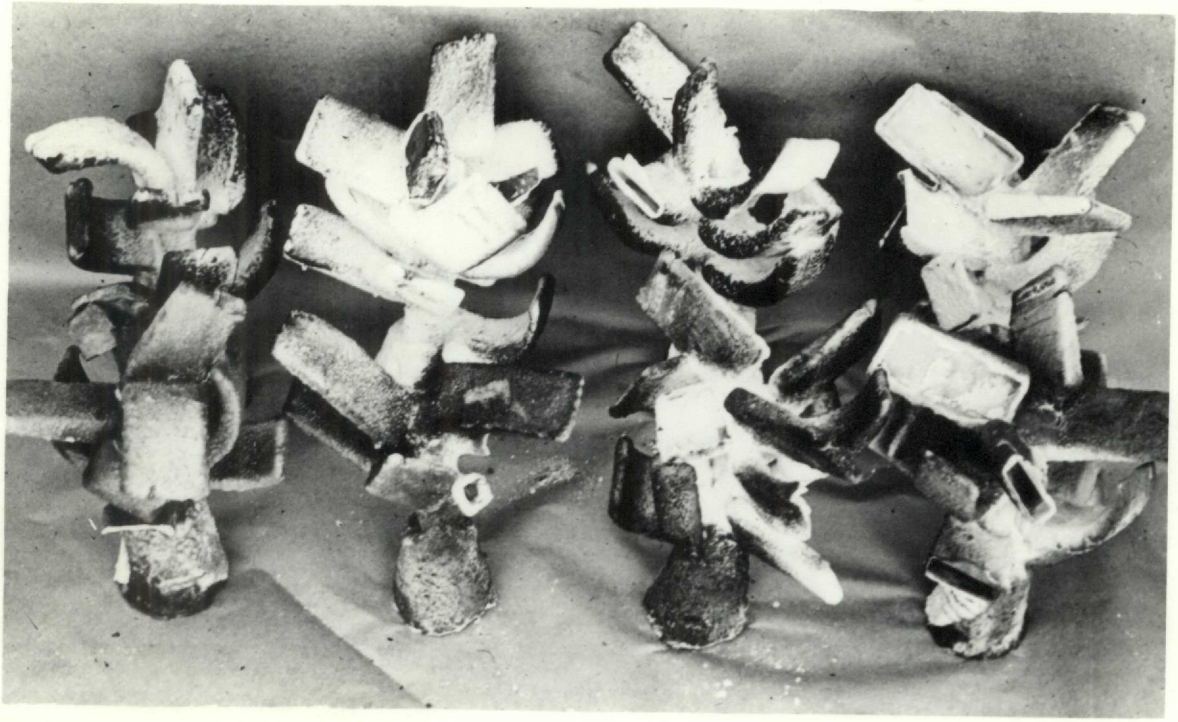


Fig. 8--Patched pattern sets utilized in pilot test I

Fig. 9--Casting sets of molds utilized in pilot test I

of the pilot study test, burn out, and casting of the ceramic shell molds are shown in Table I, p. 60. Pilot Test I indicated that ten of the expanded plastics samples were the most successful as patterns and produced satisfactory castings. Five of the finishing materials burned out successfully.

All densities of expanded polyethylene (Ethafoam) (c.) and polystyrene were determined acceptable for burn out under the same conditions. Although the pattern made of expanded polystyrene, 1.0 p.c.f. did crack, it was determined that a definite explanation for such occurrence could not be deduced. Since the pattern was the least dense of its family of plastics, it was decided that the pattern material would continue to be considered until more definite proof of its unacceptability was found.

The goal in applying the finishing materials was to have a smooth, lustrous surface. As can be seen in Figure 10, p. 61, wax, flour and glue, paper-mâché, epoxy, and Thiem (c.) styro fill 42.1 produced the best surfaces. Such evidence is proof of their burn-out capability and suitability as finishing materials.

However, Pilot Test I indicated that two of the expanded plastics samples were unsuccessful as patterns molded in ceramic shell. Four of the finishing materials did not burn out satisfactorily as shown below.

Expanded polyurethane of low density such as the 1.5 p.c.f. used in this test is unsatisfactory for burn out since

TABLE I

RESULTS OF BURN OUT AND CASTING OF CERAMIC SHELL MOLDS UTILIZED IN PILOT TEST I

Family and Variety of Expanded Plastic	Wax	Flour and Glue/ Paper Mâché	Acrylic Paint	Gesso	Epoxy Resin	Thiem(c.) Styro Fill 42.1	Fiberglas and Polyester Resin	Uncoated	Bondo
Expanded polyethylene (Ethafoam) 2.2 p.c.f.	*	*	A	A	*	*	A	*	A
Expanded polyethylene (Ethafoam) 6 p.c.f.	*	*	*	*	*	*	A	*	A
Expanded polyethylene (Ethafoam) 9 p.c.f.	*	*	A	A	*	*	A	*	A
Expanded polystyrene 1.0 p.c.f.	*	X	A	X	X	X	/	*	A
Expanded polystyrene 1.8 p.c.f.	*	*	A	A	*	*	/	*	A
Expanded polystyrene 2.1 p.c.f.	*	*	A	*	*	*	/	*	A
Expanded polystyrene 3.3 p.c.f.	*	*	A	*	*	*	/	*	A
Expanded polystyrene (Styrofoam) 2.0 p.c.f.	*	*	A	A	*	*	/	*	A
Expanded polyurethane Rigid 1.5 p.c.f.	X	X	X	X	X	X	X	X	X
Expanded polyurethane Rigid 8.0 p.c.f.	*	*	A	X	*	*	X	*	A
Expanded polystyrene Mini-cell	*	*	A	*	*	X	/	*	A
Polyvinyl chloride & Nitrile rubber (Ensolite)	X	A	A	X	X	A	X	X	X

*Acceptable burn out   XBroke during burn out

AAshes   /Not tested

EXPANDED
PLASTICS

Ethafoam
2.2 p.c.f.
Ethafoam
6.6 p.c.f.
Ethafoam
9 p.c.f.
Polystyrene
1.0 p.c.f.
Polystyrene
1.8 p.c.f.
Polystyrene
2.1 p.c.f.
Polystyrene
3.3 p.c.f.
Styrofoam (c.)
2.0 p.c.f.
Polyurethane
1.5 p.c.f.
Polyurethane
8 p.c.f.
Polystyrene
mini-cell
Ensolite

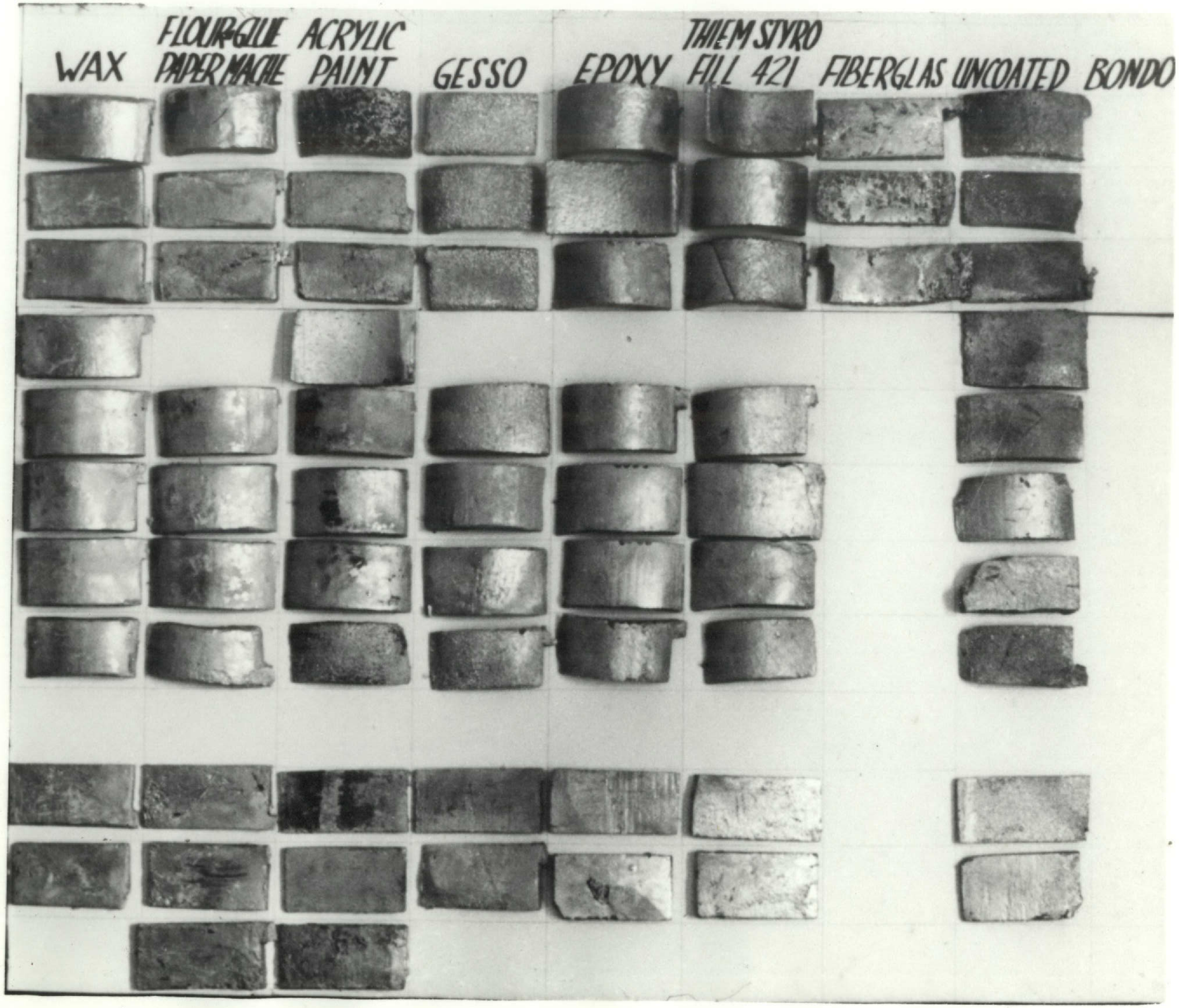


Fig. 10--Casts from pilot test I

it breaks the shell molds. Expanded polyurethane, 8 p.c.f. did not break the molds consistently; however, the material has limited use in thin sheet form, the only form in which it was available. Since the mini-cell expanded polystyrene material was shown to burn out successfully, above, and was of the same thickness and more flexible, it appeared to be more useful for sculptural patterns.

Ensolite (c.) i.e., polyvinyle chloride and nitrile rubber, either cracked its molds or left deposits of ash, making it unsuitable for burn out and casting. Acrylic paint, gesso, and Fiberglas (c.) leave deposits of ash, making them unsatisfactory for burn out and casting. Bondo (c.) left so much ash in the molds that they were discarded and not cast. See Figure 7, p. 57.

Pilot Test II: Test of Volumetric-Organic Shapes

Preparation for Burning Out

Whether expanded plastic patterns of greater volume than that of the shapes made for Pilot Test I would also burn out successfully prompted Pilot Study Test II. Six varieties of expanded plastics were selected from those which had burned out successfully in Pilot Study Test I: expanded polyethylene, Ethafoam (c.)--9.0 p.c.f., expanded polystyrene, Styrofoam (c.)--2.0 p.c.f., and expanded polystyrene 1.0, 1.82, 2, 1 and 3.3 p.c.f. Each example was made into similar patterns of approximately 100 cubic inches and gated and sprued with material of the same kind as the pattern. See Figure 11, p. 64, which shows from left to right: Ethafoam (c.), Styrofoam (c.), expanded polystyrene, 1.0, 1.8, 2.1, and 3.3 p.c.f., respectively. Those patterns were then molded in five coats of ceramic shell slurry and stuccoed as in Pilot Test I.

Burning Out and Casting

Prior to burn out, each mold was vented with four one-half inch slits sawed through the surface of the molds for the purpose of assisting in escape of excess gases. The furnace described in Pilot Test I was preheated to 1,850 degrees Fahrenheit. The test patterns were burned out at 1,500 degrees Fahrenheit for five minutes and then at 1,200 degrees Fahrenheit for twenty-five minutes.

Slits used for vents during burn out were repaired using ceramic shell slurry. The molds were then preheated and cast with aluminum. As Figure 12, p. 64 shows, from left to right: (1) Ethafoam (c.) and Styrofoam (c.) produced satisfactory casts; (2) expanded polystyrene, 3.3 p.c.f. broke the mold; and (3) the remaining casts were satisfactorily produced from expanded polystyrene, 1.0, 1.8, and 2.1 p.c.f., respectively.

Fig. 11--Patterns utilized in pilot study test II

Fig. 12--Pilot study test II casts

Results of Pilot Test II

Results of the test are demonstrated graphically in Table II, p. 65 below. Four of the test examples burned out satisfactorily: Ethafoam (c.), 9.0 p.c.f. and expanded polystyrene, 1.0, 2.0, and 2.0 p.c.f. Expanded polystyrene, 1.8 p.c.f., cracked its mold during burn out, and it was repaired, producing an acceptable casting.

TABLE II

RESULTS OF BURN OUT AND CASTING OF PILOT TEST II: VOLUMETRIC-ORGANIC SHAPES

Family of Expanded Plastic	Variety of Expanded Plastic	Burn Out	Cast-ing
Ethafoam,	9.0 p.c.f.	*	+
Polystyrene,	1.0 p.c.f.	*	+
Polystyrene,	1.8 p.c.f.	=	+
Polystyrene,	2.0 p.c.f.	*	+
Polystyrene,	2.1 p.c.f.	*	+
Polystyrene,	3.3 p.c.f.	X	X

*Acceptable burn out =Cracked during burn out

XBroke during burn out +Acceptable casting

On the other hand, the densest of the tested expanded plastics did not burn out satisfactorily; expanded polystyrene, 3.3 p.c.f., broke the mold. Evidence of breaking the mold of the pattern described above suggested that greater density material apparently needed more venting in order to allow for escaping gases.

It was also noted that the expanded polystyrene, 1.8 p.c.f., cracked the mold during burn out; however, two examples of greater density did not crack the molds. These irregularities contributed to the deduction that the test was inconclusive and further testing was necessary to determine the correspondence of vents to large, voluminous, or dense patterns.

Pilot Test III: Relationship of Vents and Density to Volume of Expanded Plastic Patterns

Preparation for Burning Out

In order to test the relationship of venting and density to volume of expanded plastic patterns used in previous tests in this study, six patterns, each of approximately 100 cubic inches were prepared, using three patterns of expanded polystyrene, 1.8, p.c.f., a relatively medium-density material for this study, and three patterns of expanded polystyrene, 3.3 p.c.f., a relatively dense material for this study. See Figure 13, p. 67. Each of the patterns was provided with a vent constructed of plastic soda straws at the high end of the pattern. These soda-straw-constructed vents were to assist in escape of gases in the process of casting. The patterns were sprued and gated with material of the same

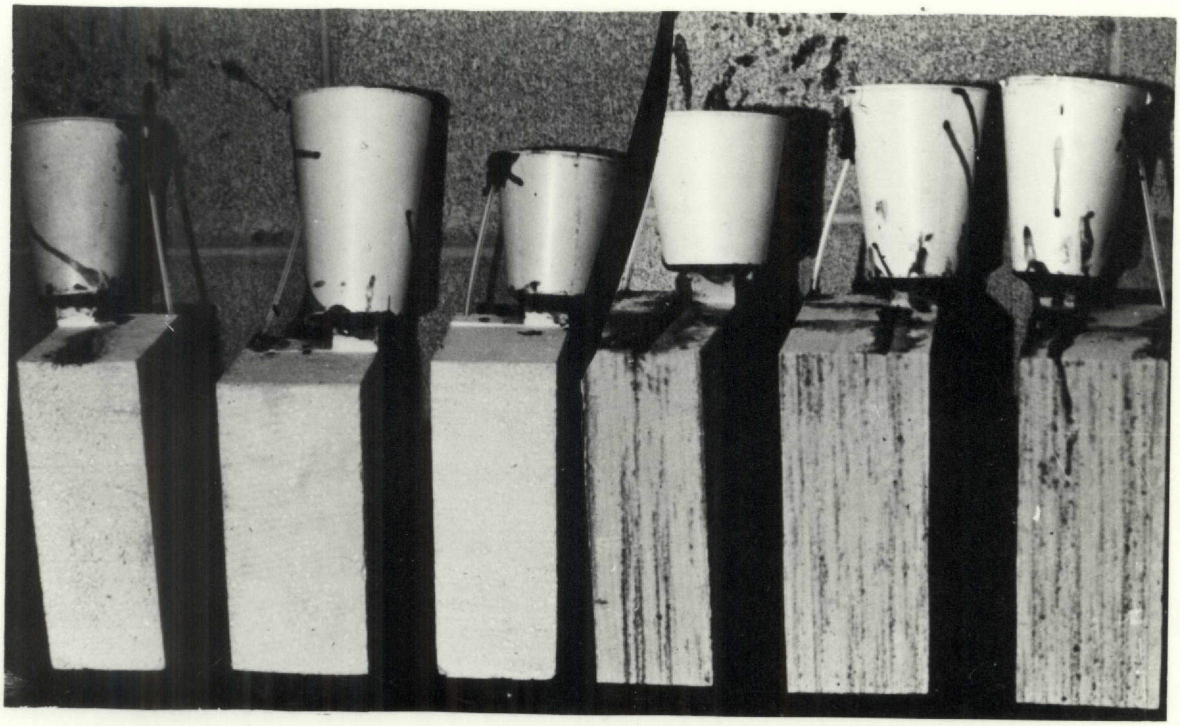


Fig. 13--Patterns utilized in pilot study test III

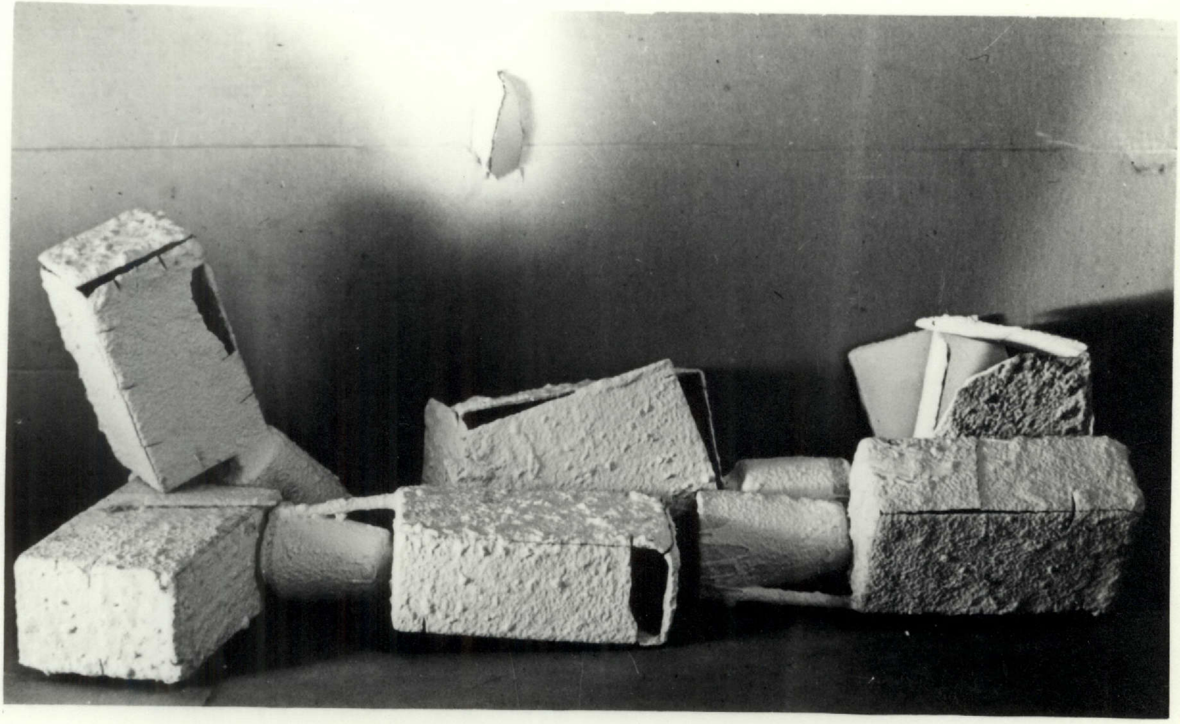


Fig. 14--Burned out molds utilized in pilot test III

variety as the patterns. Each of the patterns was molded in ceramic shell following the same procedures as for Tests I and II above.

Burning Out and Casting

Two patterns which consisted of one from each of the two densities of expanded plastic were selected for testing in three separate and successive burn out operations. All three burn-out operations utilized the furnace previously described, preheated to 1,850 degrees Fahrenheit. The temperature dropped to 1,500 degrees Fahrenheit when the furnace was opened to be loaded with the molds. It was left at 1,500 degrees Fahrenheit for five minutes. When burn out of the patterns began, as was apparent from the smoke, the temperature was then reduced to 1,000 degress Fahrenheit and left at that temperature for twenty-five minutes.

Each of the patterns had already received a soda straw constructed vent. In addition, the three sets of molds were prepared for burn out by sawing one-half inch slits through the ceramic shell molds as follows: set one received four additional slit vents; set two received ten additional slit vents; and set three received fourteen additional slit vents. However, no casting was possible.

Results of Pilot Test III

Results of the three burn-out procedures is shown in Table III, p. 69 below, and Figure 14, p. 67 above, showing from left to right: two molds each, with five, ten and fifteen vents, representing burn outs one, two, and three, respectively. These results indicated that in the first burn-out procedure, the test sample of expanded polystyrene 1.8 p.c.f. cracked the mold along all four side edges, and the test sample of expanded polystyrene 3.3 p.c.f. cracked and broke the mold containing it. These results indicated the need for further testing using more vents.

TABLE III

RESULTS OF TEST FOR RELATIONSHIP OF VENTS TO VOLUME AND DENSITY OF EXPANDED PLASTIC PATTERNS

Family and Variety of Expanded Plastics	5 Vents	10 Vents	15 Vents
Expanded Polystyrene, 1.8 p.c.f.	||	|| X	|| =
Expanded Polystyrene, 3.3 p.c.f.	|| X	|| X	X

||Cracked along edges during burn out

=Cracked across side during burn out

XBroke during burn out

Results of the findings for the second burn out utilized in Pilot Study Test III indicated that both the molds in the second set broke during burn out, as shown by the third and fourth molds in Figure 14, p. 67 above. It appeared that more vents would be necessary to provide for escaping gas during burn out of the expanded plastics used as patterns.

The set of molds on the right of the illustration (Figure 14, p. 67 above) shows results of burn out three utilizing molds which received fourteen slit vents. These results indicate that the test sample of expanded polystyrene 1.8, p.c.f. cracked its mold along six edges and across one side. The test sample of expanded polystyrene 3.3 p.c.f. broke its mold completely into small pieces.

These tests indicated that there was a condition (other than venting for escape of gases) operating in the test envirnoment which caused cracking of the ceramic shell molds. Fifteen vents on a 100-cubic-inch-pattern could be considered to require excessive patching before casting in addition to the obvious chances of more blemishes on the cast. For this reason, additional venting did not appear to be practical.

Upon the basis of Dieter and Paoli's findings, reported above, which indicated collapse of polystyrene cells at 170 degrees Fahrenheit and vaporization of the styrene at 400 degrees Fahrenheit (1, p. 142), it was assumed that the temperature of the burn out furnace might have caused the molds to crack as a result of combustion of the patterns. It was further assumed that no acceptable amount of venting would alleviate the pressure of such combustion.

Based also upon Dieter and Paoli's findings, it was assumed that expansion of the patterns was not a contributing factor. The problem appeared to be that of rapid combustion brought about by pressure of expanding gases which were suddenly exposed to intense heat. In effect, it appeared that a minor explosion occurred inside the shell molds resulting in their cracking or breaking to relieve the pressure.

In response to a request for an opinion of these assumptions, Paoli replied:

> . . . 1. Expanded Polystyrene breaks down at a very low temperature (175°F).
> 2. Expanded Polystyrene will create no ash or residue if it is allowed to vaporize. If it ignites and burns, it creates three to four times more gas than when vaporized, and a small amount of ash. . . .

He went on to say the burn out could be accomplished by

> . . . A. A low-temperature initial firing of the mold (about 400° to 425°F) in a muffle or core oven unit. This should prevent ignition of the pattern and allow the vapors to exit through the gate system or systems.
> B. Allow ample initial cure time to allow mold to be thoroughly warmed to 400°F or so, or until the pattern is entirely removed.
> C. After the initial cure you may go ahead and high temperature fire your mold in the normal fashion (5).

Pilot Test IV: Vaporization/Burn Out of Selected Expanded Plastics

In order to test the practical application of Paoli's information and suggestions, Pilot Test IV was designed. The test was conducted to determine which of the different varieties of expanded plastics used in Pilot Test I would vaporize by low heating, then continue to burn out at 1,200 degrees Fahrenheit, as required in curing ceramic shell molds. The test was also designed to incorporate a re-test of the effect of finishing materials and thicknesses and volume, in order to be more representative of an average-sized sculpture pattern invested in ceramic shell molding material.

Preparation for Vaporization/Burn Out

Four families consisting of nine varieties of expanded plastics were used because these families represented basic chemical polymers deemed important to this study; the families were expanded polyethylene, expanded polystyrene, expanded polyurethane, and polyvinyl chloride and nitrile rubber.

The densest sample of expanded polyethylene (Ethafoam (c.)) was employed in Pilot Test IV. Ethafoam (c.) 9.0 p.c.f. was acceptable as pattern-making material because of its closed cell structure and relative rigidity as compared to samples of less density. It also required less filling than the lower density varieties.

Five samples of the expanded polystyrene family were used. Expanded polystyrene 1.0 and 1.8, Styrafoam (c.) of 2.0 and expanded polystyrene 3.3 p.c.f. were selected because of the variation in their density. All are relatively low density examples of this family of expanded plastics. Thin sheets of polystyrene, mini-cell material about one-eighth inch thick were laminated to make a board-like thickness comparable to the other plastics used. Two examples of rigid expanded polyurethane 1.5 and 8 p.c.f. were again used in this test. The 8 p.c.f. sample was composed of one-eighth inch thicknesses of the material, laminated with Elmer's (c.)

glue to make boards one inch thick. Finally, polyvinyl chloride and nitrile rubber, approximately one-eighth inch thick, was laminated using Elmer's (c.) glue to make slightly flexible boards about one inch thick.

Test patterns were prepared by cutting one rectangular patterns from each variety of expanded plastic. Each pattern was four inches wide, sixteen inches long, and one inch thick, or sixty-four cubic inches in volume. It was thought that these patterns would incorporate a more typical example of the size and volume of average patterns molded in ceramic shell than Pilot Test I. In addition, such patterns incorporated testing the problems which Pilot Test I and II had tested, material and volume burn out, under different conditions.

The patterns were then divided into eight two-inch-wide bands across the width of the patterns. One band on each pattern was finished with material indicated below (see Figure 15, p. 74):

1. Microcrystalline wax
2. Flour and Elmer's (c.) glue
3. Paper mâché
4. Epoxy resin
5. Thiem (c.) styro fill 42.1
6. Polyester resin (This resin was applied in a thin layer permitting it to dissolve only the top surface of the expanded polystyrene samples. The irregular dissolving action

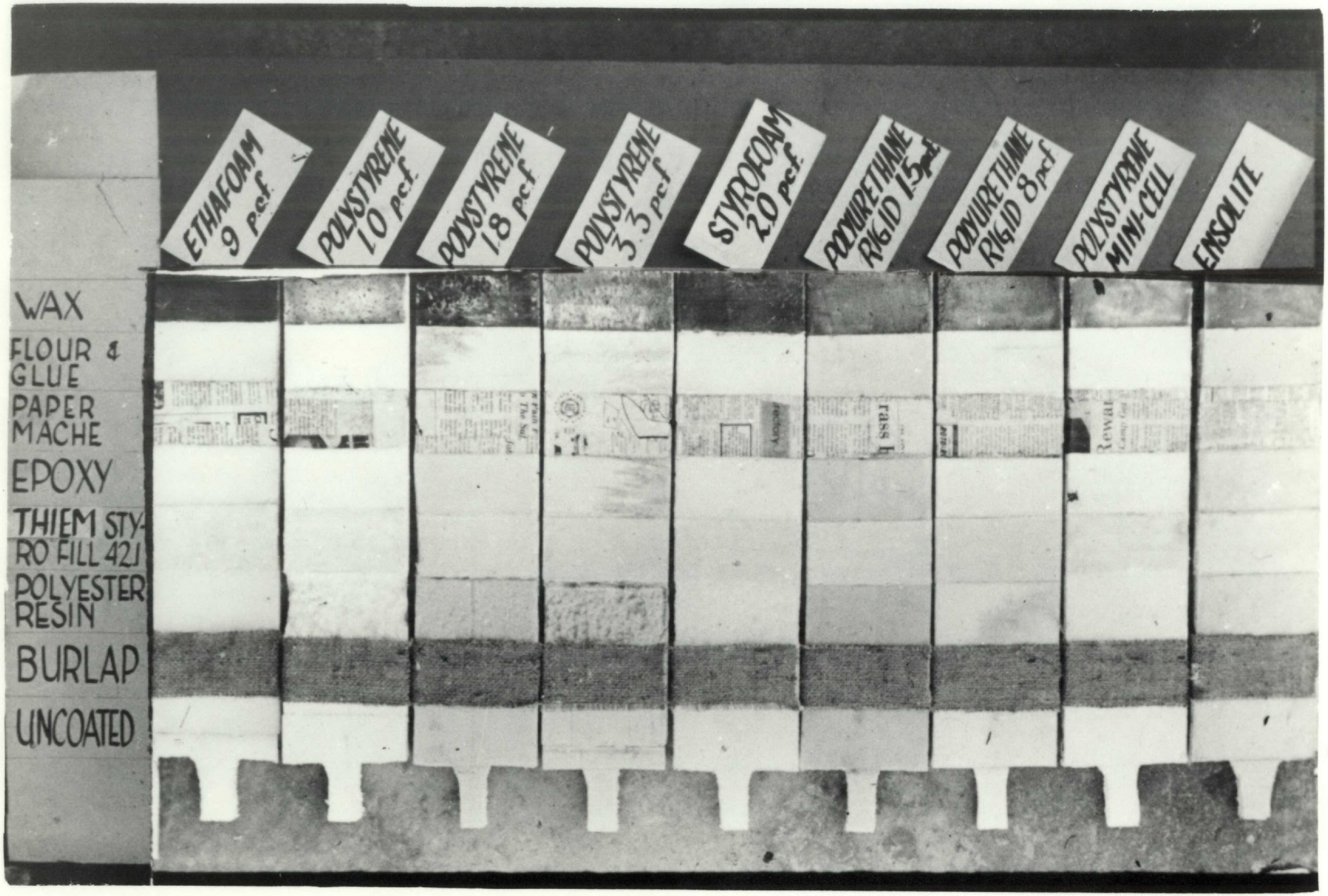


Fig. 15--Finished expanded plastic patterns utilized in pilot test IV

resulted in a unique texture. Other families of plastics used were not reactive to the resin).

7. Burlap adhered with Elmer's (c.) glue, and

8. One band left uncoated.

The nine patterns, finished with materials stated above, were made with gates and sprues of the same material as the patterns. After attaching a pouring cup made of mini-cell expanded polystyrene, each pattern received five coats of Nalcast (c.) slurry: (1) the first coating of slurry was stuccoed with fine grain sand; (2) the second, third, and fourth coatings of slurry were stuccoed with medium-grain sand, and (3) the fifth coating of slurry was left to air dry without being stuccoed, following molding procedures used in ceramic shell molding of wax patterns (see Figure 16, p. 76 below). Each coating was allowed to dry for twenty-four hours.

Vaporization/Burn Out and Casting

The open-flame, bottom-loading, burn-out furnace described in Pilot Test I was muffled by placing a fifty-five gallon steel oil drum upon the bottom-loading furnace door. The barrel was prepared with the top end cut out and a four-inch diameter hole cut in the bottom to permit drop out of styrene or wax. The burn-out furnace was equipped with a portable pyrometer. It should be noted that the pyrometer did not measure the temperature inside the muffled chamber

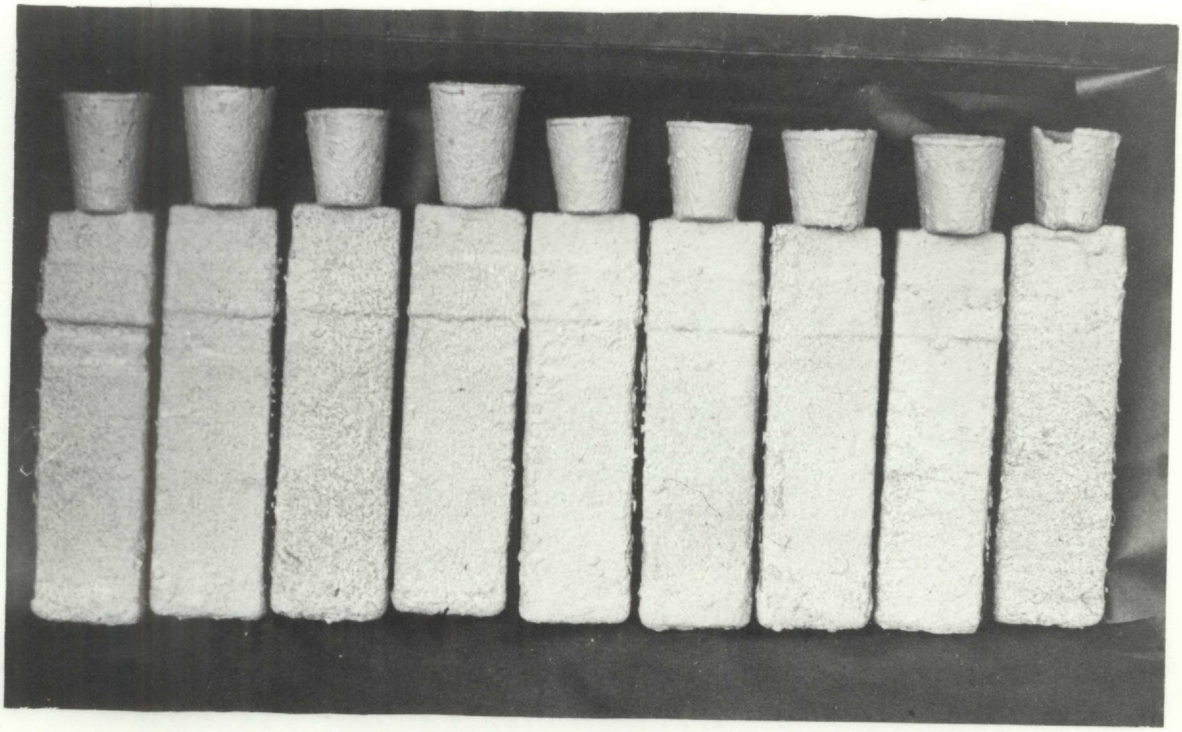


Fig. 16--Invested patterns utilized in pilot test IV

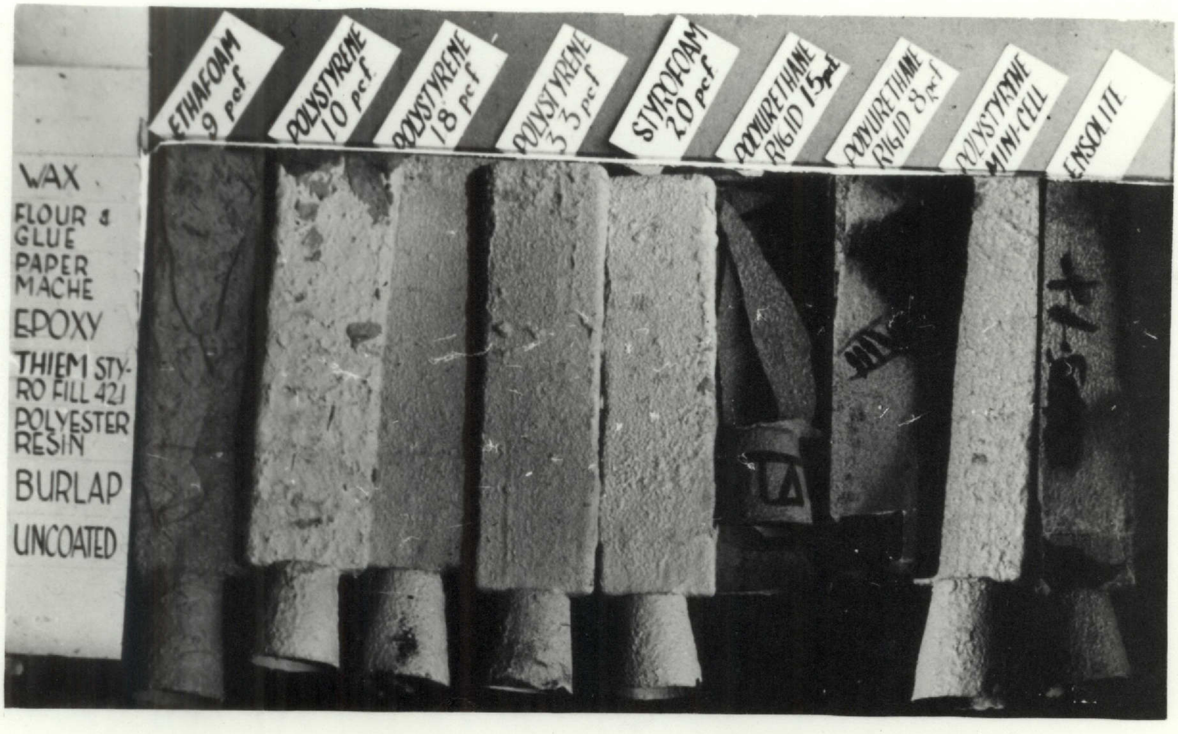


Fig. 17--Burned out molds utilized in pilot test IV

created by the oil drum; specifically, it measured the temperature in the open-flame chamber between the outside wall of the furnace and the portable muffle chamber, i.e., oil drum. The ceramic shell molds were given burn-out vents by cutting two one-half inch slits in the bottom end of the patterns near the corners. Then the ceramic shell molds were arranged in the drum which was sitting upon the bottom-loading furnace door. The pilot light to the furnace was lighted. The drum containing the molded patterns was then raised into the furnace burn-out chamber.

The following schedule was used for vaporizing the patterns and for proceeding directly into burn-out and the sintering of the molds:

1. the temperature was gradually raised over a period of one and one-half hours until it reached 500 degrees Fahrenheit;

2. the temperature was increased to 800 degrees Fahrenheit within the next thirty minutes;

3. the temperature was increased to 1,000 degrees Fahrenheit within fifteen more minutes;

4. the temperature was rapidly increased to 1,200 degrees Fahrenheit to sinter the molds for thirty minutes.

The flame was then extinguished and the patterns lowered on the door of the furnace to cool for examination. See Figure 17, p. 76.

The slits cut to vent the molds were patched with Fiberglas (c.) laminated in ceramic shell slurry to give added strength to the patch. Those molds which did not crack during burn out were again heated to approximately 1,000 degrees Fahrenheit and cast with aluminum.

Results of Pilot Study Test IV

The results of this test are shown in Table IV, p. 79. These results indicated that two of the four expanded plastics families which were tested burned out successfully, i.e., these families of materials did not crack the ceramic shell molds. Expanded polyethylene, Ethafoam (c.), and low density expanded polystyrene including the mini-cell expanded variety such as was used in the test appeared to be usable pattern material under this burn-out procedure. In addition, all of the finishing materials were successfully burned out, leaving little or no apparent residue. Castings were bright and appeared to be exact duplicates of the pattern surfaces as molded, as shown in Figure 18, p. 80.

Two families of expanded plastic, however, were not deemed acceptable for use as patterns in a burn out procedure. The test indicated that expanded polyurethane and polyvinyl chloride and nitrile rubber, Ensolite (c.) not only cracked and broke the ceramic shell mold but also left excessive ashes.

TABLE IV

RESULTS OF BURN OUT AND CASTING OF CERAMIC SHELL MOLDS UTILIZED IN PILOT TEST IV

Finishing Material	Expanded Polyethylene (Ethafoam) (c.) 9 p.c.f.	Expanded Polystyrene 1.0 p.c.f.	Expanded Polystyrene 1.8 p.c.f.	Expanded Polystyrene 3.3 p.c.f.	Expanded Polystyrene (Styrofoam) 2.0 p.c.r.	Expanded Polyurethane Rigid, 1.5 p.c.f.	Expanded Polyurethane Rigid, 8.0 p.c.f.	Expanded Polystyrene Mini-cell	PVC and Nitrile Rubber (Ensolite) (c.)
Wax	*	*	*	*	*	X	X	*	X
Flour and Glue	*	*	*	*	*	X	X	*	X
Paper-Mâché	*	*	*	*	*	X	X	*	X
Epoxy	*	*	*	*	*	X	X	*	X
Thiem (c.) Styro Fill 42.1	*	*	*	*	*	X	X	*	X
Polyester Resin	*	*	*	*	*	X	X	*	X
Burlap	*	*	*	*	*	X	X	*	X
Uncoated	*	*	*	*	*	X	X	*	X

*Acceptable burn out
(No ashes or carbon was apparent)

XBroke during burn out

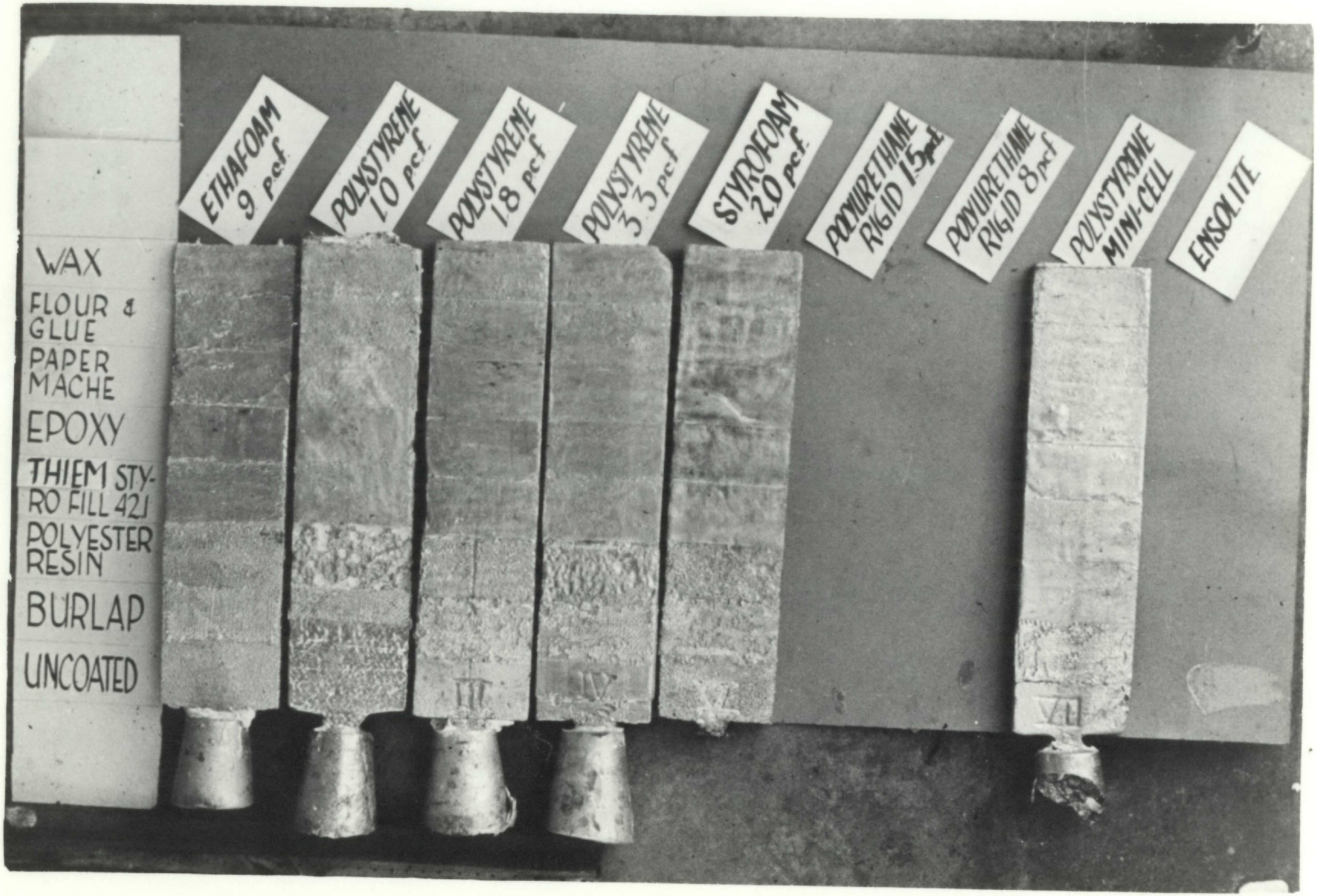
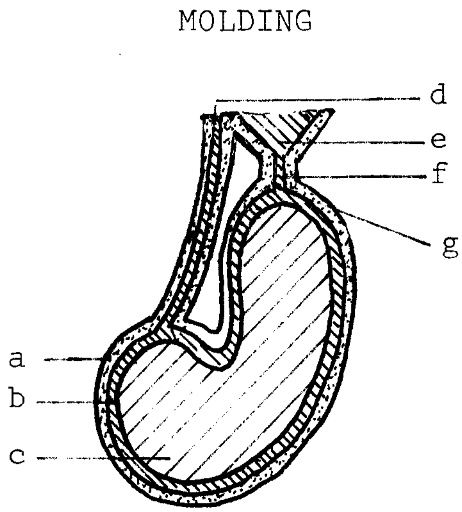
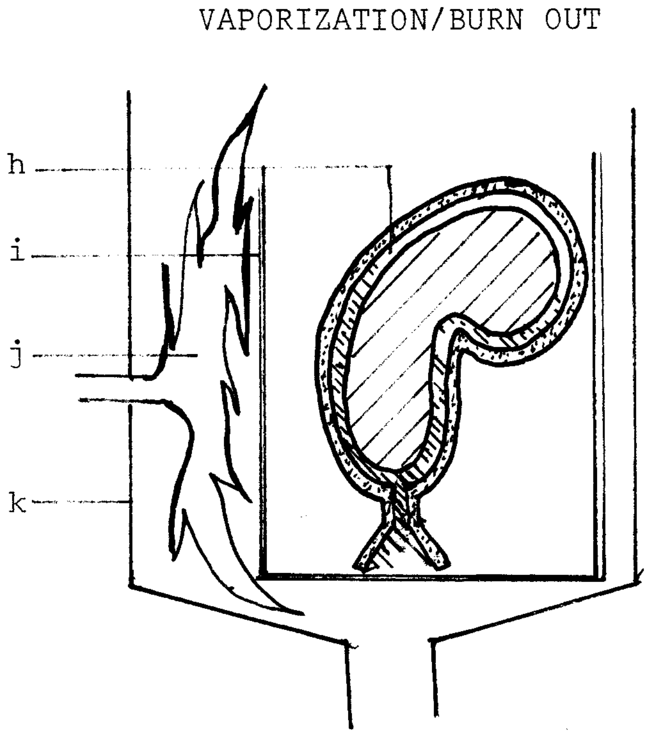


Fig. 18--Casts of patterns burned out in pilot test IV

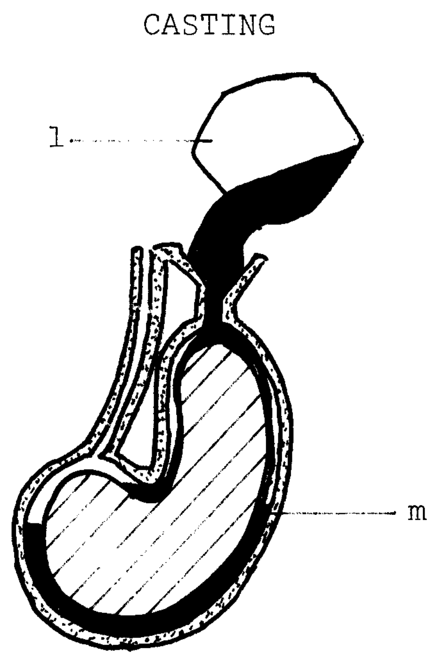
Synthesis of the Major Findings of the Pilot Tests

Pilot Test IV indicated positive preliminary findings with reference to the central questions of the present study. Specifically the vaporization/burn out procedure (illustrated in Figure 19, p. 82 below) of slowly raising the temperature in the furnace until all of the expanded plastic pattern has been decomposed appears to provide a solution to the problem of burning out expanded plastic patterns encased in ceramic shell molds. The initial low temperature of the burn-out furnace can be raised to a burn-out and sintering level in order to finish the mold after the expanded plastic patterns have been eliminated. Thus, this process can combine evacuation of the mold and firing in one process, saving time as compared to solvenizing the pattern and then burning out and sintering the ceramic shell mold, a technique which had been employed previously. Although not all of the families of expanded plastics can undergo the process without cracking or breaking the mold, the fact that members of two families can do so and that those two families are dissimilar in properties and characteristics permits the assumption that both would be useful under different circumstances. The greater flexibility of expanded polyethylene, Ethafoam (c.), suggests further that material might be quite interestingly used in combination with the less flexible expanded polystyrene.





Heat slowly raised in order to vaporize the pattern and then burn out the residue.



[a]mold: ceramic shell

[b]pattern: expanded plastic

[c]core

[d]vent

[e]pouring cup

[f]sprue

[g]top gate

[h]cavity

[i]muffle chamber wall

[j]flame

[k]furnace wall

[l]crucible

[m]metal

Fig. 19--Vaporization/burn-out method (cross section)

Although the density of the expanded plastic patterns seemed to be a contributing factor to each expanded plastic's ability to undergo burn out successfully, the apparent dominate characteristic for a successful burn out seemed to be the chemical makeup of the material. Whether that appearance is true or not may be determined by future investigations.

Finally, there was no difference between the appearance of the ceramic shell molds used on expanded plastics in these tests and those used which are produced with wax patterns; nor were any differences observed during casting. Molds of substantial size or attenuated shapes were partially supported by loose sand in the Pilot Test I. Others were anchored in a bed of sand to maintain their stability during casting. Figures 20, p. 84, and Figures 21, p. 84, show representative examples of the casting techniques used in these tests.

Conclusion

The information derived in the pilot tests established the procedures and identified the materials to be employed in the main pattern tests, reported in Chapter IV. For the main study, ten test patterns were designed. The test situations examined volume, size, configuration, constructing from different numbers of pieces, lamination, finishing materials, and, most importantly, the technique of vaporization/ burn out. Molds which burned out successfully were, as in the

Fig. 20--Casting utilizing a box of sand

Fig. 21--Casting utilizing a bed of sand

pilot tests, cast in aluminum as verification of the effectiveness of the technique. Photographic records of all phases of the tests, as well as journal notations and time and temperature charts were again made; these physical records were kept as evidence of the results of the tests, as confirmation of personal observations, and as a permanent means of judging the results. Details of those ten test situations appear in the following chapter.

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CHAPTER IV

DEVELOPMENT OF TEN PATTERN TESTS

One of the purposes of the present research was to develop a technique for burning out expanded plastics used as patterns in ceramic shell molds for metal casting; such a technique, it was hoped, would be suitable for the sculptor's studio. Preliminary findings indicated that such a technique might be possible. Some expanded plastics had been vaporized during the pilot study by raising the temperature of a muffled burn-out furnace slowly over a period of time; residue was then burned out as the heat was increased in order to sinter the ceramic shell mold. In order to verify those preliminary findings, the second and principal series of experimental tests was planned. The set of criteria by which pattern shapes and sizes were selected and a general review of the procedures which were used in all tests precedes a presentation of the data which was derived from the tests.

Criteria for Selecting Pattern Shape and Size

Although the pilot study had furnished some information about the influence of configuration and size of pattern upon successful burn-out in ceramic shell molds, further testing was deemed necessary. In order to facilitate development of a technique for burning out patterns of expanded plastics which would be practical and useful to the sculptor, ten patterns or sets of patterns were designed; the designs included a variety of shapes representative of the configurations typically found in sculpture patterns and reflective of the sizes of patterns most commonly cast in ceramic shell molds. The five general configurations and sizes which were selected were as follows:

1. Small, irregular shapes; for the purpose of this study, dimensions of less than ten inches were considered small;

2. Organic patterns, varied in thickness;

3. Long, slim, and attenuated shapes, flat and rectangular; for the purpose of this study, lengths over twenty inches were considered long;

4. Large, voluminous, and organic shapes; for the purpose of this study shapes over ten inches in any dimension and volumes over 500 cubic inches were considered large and voluminous;

5. Wide, curved patterns, varied in thickness; for the purpose of this study, patterns over six inches across and longer than six inches were considered wide.

Criteria for Construction

Members of families of expanded plastics vary widely in density, physical make-up, and properties. Determining whether individual patterns might employ more than one type of expanded plastic suggested that diversity in structural make-up should be tested. In order to examine the possibilities for combining, fabricating, and tooling the expanded plastics which were selected for the present series of tests, patterns were constructed in the following ways: of one piece of expanded plastic; of more than one piece combined in one pattern, including members of different families and different densities of expanded plastics; and from laminated expanded plastics.

Patterns constructed of one piece.--Patterns were made from a single piece in order to test the suitability of expanded plastics for the subtractive method of constructing sculptural forms, i.e., cutting and rasping away of the excess material used for a pattern. In such procedures, toughness and strength of the expanded plastics were noted in order to provide data about these critical characteristics of sculptural pattern-making materials.

Patterns constructed of more than one piece.--Patterns were made of more than one piece of material to test the versatility of expanded plastics for combinations of different densities and families into one pattern. The ability to make up larger sizes from smaller pieces, joining methods, and capabilities for finishing of jointed areas were considered essential to the development of a method of burning out expanded plastics used as patterns for sculptural forms.

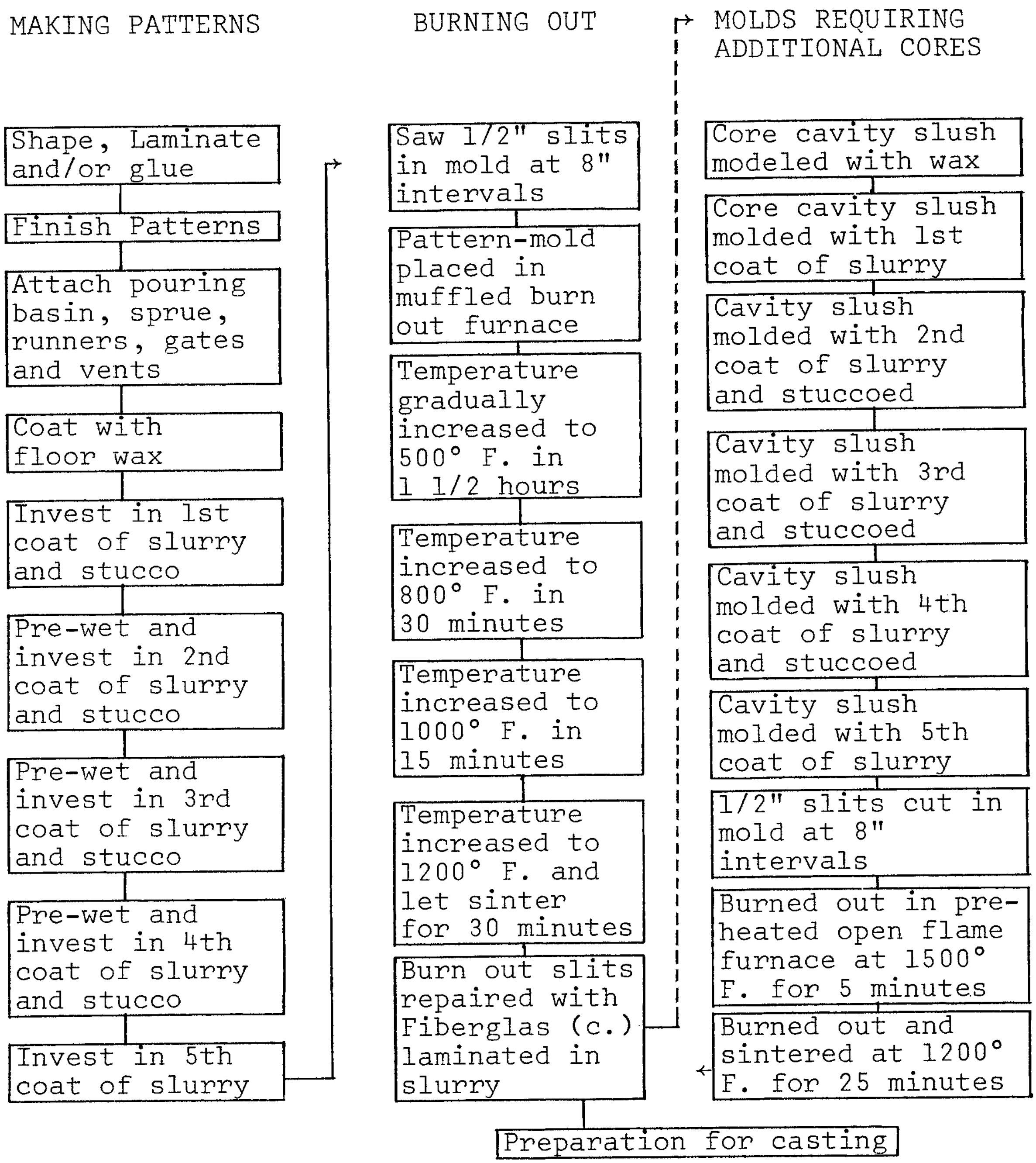
Patterns constructed by lamination.--Patterns were constructed of laminated varieties of expanded plastics in order to test the utility of surfacing one variety of expanded plastic with another in order to achieve a desired texture and to enhance contour surfaces needing more bulk or curvature. Furthermore, lamination added strength to pattern edges and built-up areas of protruding shapes.

Procedures

The naturally-ordered steps of preparing the pattern, finishing and modeling the pattern, burning out the mold, and casting the mold were systematized as shown in Figure 22, p. 91, so that identical procedures would be utilized in each of the ten pattern tests. In addition, each sequential step of the first pattern test was photographed to serve as illustrations for the procedures in all ten tests. Figure 22 also shows a series of steps which may be taken after the initial burn-out for any pattern whose volume or configuration is so thick as to require additional coring. A brief, general description of the sequence of procedures is given at this point to avoid repetition in the presentation and analysis of actual test data.

Constructing the Patterns

Three-dimensional patterns were made from the two pretested families of expanded plastics, i.e., polethylene and polystyrene, which demonstrated the most consistent burn out



_____ indicates regular procedure

----- indicates additional procedure required for coring cavities resulting from burn out of solid patterns.

Fig. 22--Procedures for making expanded plastic patterns and burning them out.

in the pilot study. Patterns used in the study were constructed using the following materials and tools, illustrated in Figure 23, p. 93:

1. expanded plastics sawed with a band saw (not illustrated) (a process well understood) or a hacksaw blade or cut with a matte-knife;

2. patterns shaped with a rasp and sandpaper;

3. pattern pieces joined together with Elmer's (c.) glue and sharpened match sticks which were used to strengthen joints; and

4. slivers of aluminum sheet material which were used to hold pattern pieces as the glue dried.

Finishing the Pattern

Eight finishing materials were tested in order to determine their burn-out capabilities; seven of the finishing treatments had proved successful in the pilot study. The eight materials which were tested are as follows:

1. microcrystalline wax;
2. flour and glue paste;
3. paper-mâché;
4. epoxy resin;
5. Thiem (c.) styro fill 42.1;
6. polyester resin;
7. burlap cloth;
8. polyethylene film.

Fig. 23--Construction materials and tools

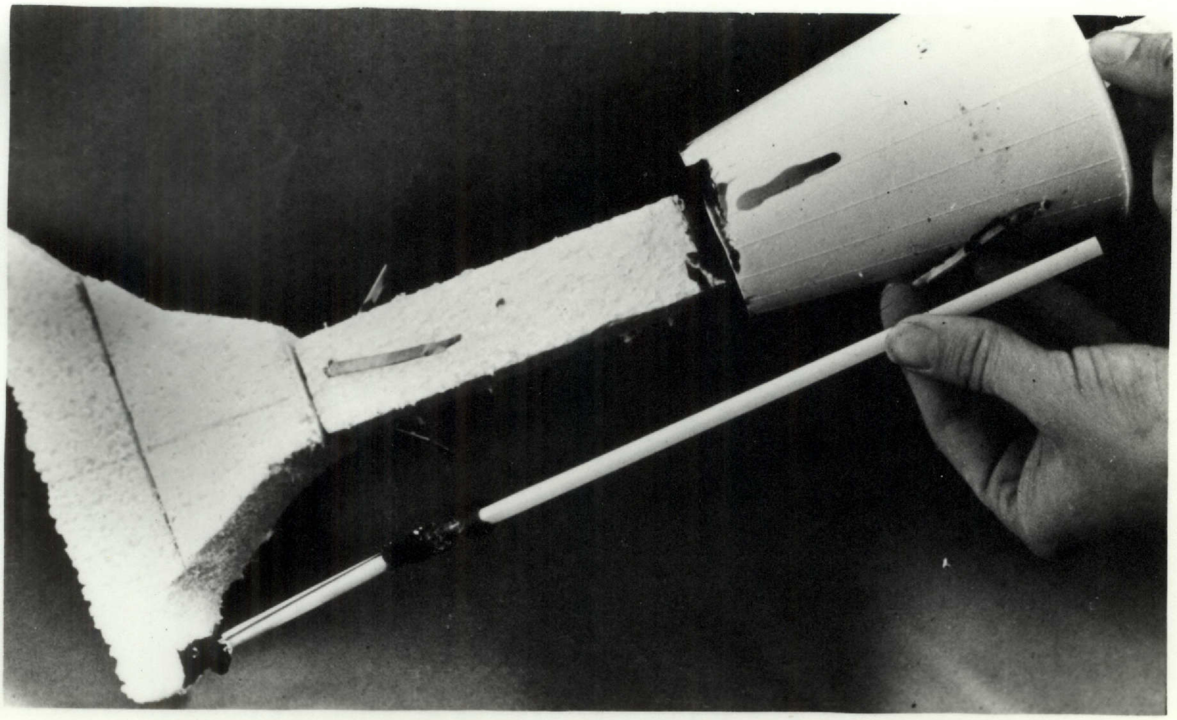


Fig. 24--Installation of vents and gating system

Because the texture of expanded plastics often presents undesirable characteristics, alteration of the texture of patterns was considered important to the study. These eight finishing materials offered a diversity in materials ranging from industrial products, produced specifically for finishing patterns, to household goods. Microcrystalline wax is used in industry and art for making and for finishing expanded plastic patterns molded in green sand. Thiem (c.) styro fill 42.1 is an industrial product, developed by industry to fill or finish expanded polystyrene patterns also used in green sand molding. The other materials are readily available to artists and were selected for their potential diversity in filling, covering, and texturizing. Each of the patterns was finished with two different surfacing materials in two different areas. The areas to be covered and the desired surface texture sought for each sculptured form dictated which material was used in each examination.

Molding the Patterns

The following techniques were used in molding the patterns: installing the vents, attaching the gating systems, cleaning the patterns, and coating the patterns.

Installing the vents.--Soda straws were used as vents when vents were necessary and were attached to the patterns as shown in Figure 24, p. 93 above. The vents provided cavities in molds being made for the escape of the gases during casting, eliminating the possibility of trapped gases preventing casting in the corners. After investment, such vents also furnished support for handling patterns in subsequent operations.

Attaching the gating system.--Mini-cell expanded polystyrene cups were used throughout this study in order to form pouring cups for casting the molds. The gating systems were made of expanded polystyrene and filled with wax (see Figure 24, p. 93 above).

Cleaning the patterns.--Patterns, with gating systems attached, were coated with vinyl floor wax in order to clean the patterns. This procedure was necessary in order to insure an even coating of ceramic shell slurry; slurry would not adhere to oily or soiled surfaces on the pattern.

Coating the patterns.--All patterns which were examined in this study were dip-coated in five coatings of Nalcoag (c.) ceramic shell slurry. The first coating of slurry was stuccoed with fine-grain sand. The second, third, and fourth coatings were stuccoed with medium-grain sand. The fifth coating of slurry was not stuccoed. This entire step follows the usual practice in application of ceramic shell moldings. For a complete description of the molding materials, see "slurry" and "stucco" in Appendix A, Glossary, p. 199.

Burning Out the Patterns

The vaporization/burn-out procedures included the following two steps: slit-venting the patterns and the burn-out schedule.

Slit-venting the patterns.--Prior to burn out, all patterns received additional vents in the form of slits, approximately one-half inch long, cut with a hacksaw blade in order to allow gases to escape during the burn-out process.

Burn-out schedule.--Pattern/molds were placed inside a fifty-five gallon oil drum which served as a muffle for the furnace to prevent direct contact between furnace and molds; the oil drum was put on the bottom loading door of the burn-out furnace previously described in the pilot study. The temperature of the furnace was then raised according to a schedule. Although times and temperatures were scheduled, actual time and temperature, which varied with the prevailing atmospheric conditions, were recorded on burn-out charts (see Figure 93 in Appendix B, p. 201). The times and temperatures were sequenced as follows:

1. The temperature of the furnace was gradually raised from atmospheric temperature to 500 degrees Fahrenheit during a period of one-and-one-half hours. At approximately 175 degrees Fahrenheit, the expanded plastic patterns began to vaporize; at approximately 425 degrees Fahrenheit, the gradual combustion of the remaining styrene was initiated. The

gradual rise in temperature eliminated sudden combustion and the accompanying expansion of gases.

2. Within the next half-hour, the temperature was raised to 800 degrees Fahrenheit; this intensification of heat burned out any styrene which had not been decomposed by the previous temperatures.

3. The temperature was raised to 1000 degrees Fahrenheit during the next fifteen minutes in order to burn out ash residue left by burned styrene.

4. The temperature was quickly raised to and maintained at 1200 degrees Fahrenheit for approximately thirty minutes in order to sinter the ceramic shell mold.

Casting the Molds

The procedure for casting the molds of patterns used in the study included repairing the slitted vents, preheating the molds, and casting the molds.

Repairing the slitted vents.--The slits which were sawed into the molds and which acted as vents during burn out were repaired in order to prepare the molds for casting, using a piece of Fiberglas (c.) cloth dipped into ceramic shell slurry and pressed into the slitted area.

Pre-heating the molds.--The molds were placed in the open-flame burn-out furnace used throughout the study and pre-heated to 1000 degrees Fahrenheit preparatory to casting. Pre-heating was done to insure against freeze out; i.e., premature solidification of the molten metal until all cavities were filled.

Casting the molds.--Molds were placed on a pad of sand or were partially covered with sand in order to anchor and support the mold during casting.

Documenting the Processes

Three methods of documentation were used in the study: notation of critical incidents, photographing procedures and techniques, and charting the burn-out procedures for each pattern on burn-out schedules forms.

Notation of critical incidents.--Critical incidents observed in the study were noted and used as one item in this report.

Photographing procedures and techniques.--Color slides were made during the study in order to record pictorally the procedures and techniques used. These photographs were reproduced in black and white and used to illustrate the processes which were reported and to support analysis of data.

Burn-out schedules.--The burn out of each pattern was recorded in order to analyze the burn-out schedule established for this study. These charts are included in this report as Figure 93, p. 202.

Data and Analyses for Ten Pattern Tests

Ten patterns were created from expanded plastics according to the criteria for selecting patterns cited previously. Each pattern was then processed by performing the steps outlined in Figure 22, p. 91 above, and described in general in the test. The three methods of documentation were practiced for each of the ten tests. In the following sections, further description of the procedures as they apply to the individual pattern tests are presented.

Pattern One

Pattern one was designed to satisfy the requirement of a small, irregular shape. In addition, the pattern was constructed from two pieces of expanded polystyrene, 1.0 p.c.f., glued together. Sawing the pattern from a small block of expanded polystyrene, using a hacksaw blade illustrated in Figure 25, p. 100 below, was followed by the gluing of an eight-inch handle-like piece to the 8 x 6 inch rectangular base, which resembled a concave-sided truncated pyramid; Figure 26, p. 100 below, shows the two pieces as they were being joined together with glue. Match sticks were used to strengthen the joints, and slivers of aluminum sheet metal pinned the two pieces together until the glue had dried. Figure 27, p. 101, illustrates the use of a rasp for shaping the pattern while Figure 28, p. 101, indicates the use of sandpaper to give the expanded polystyrene pattern a medium smooth finish.

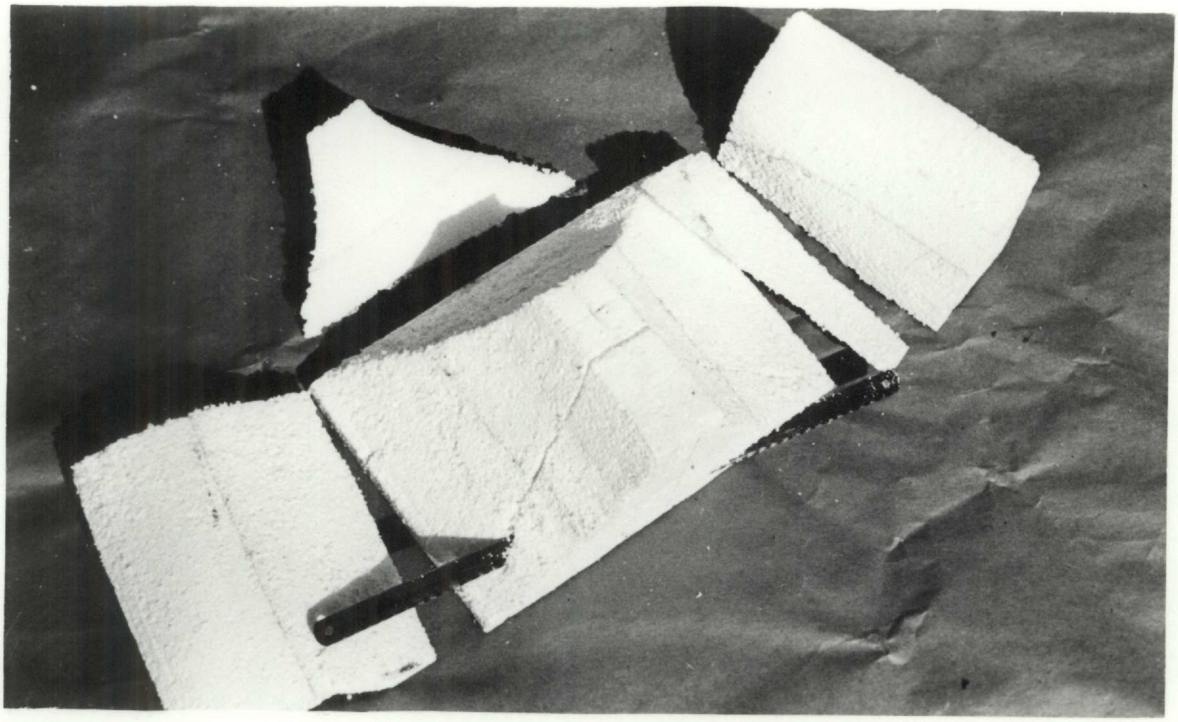


Fig. 25--Cutting out pattern one

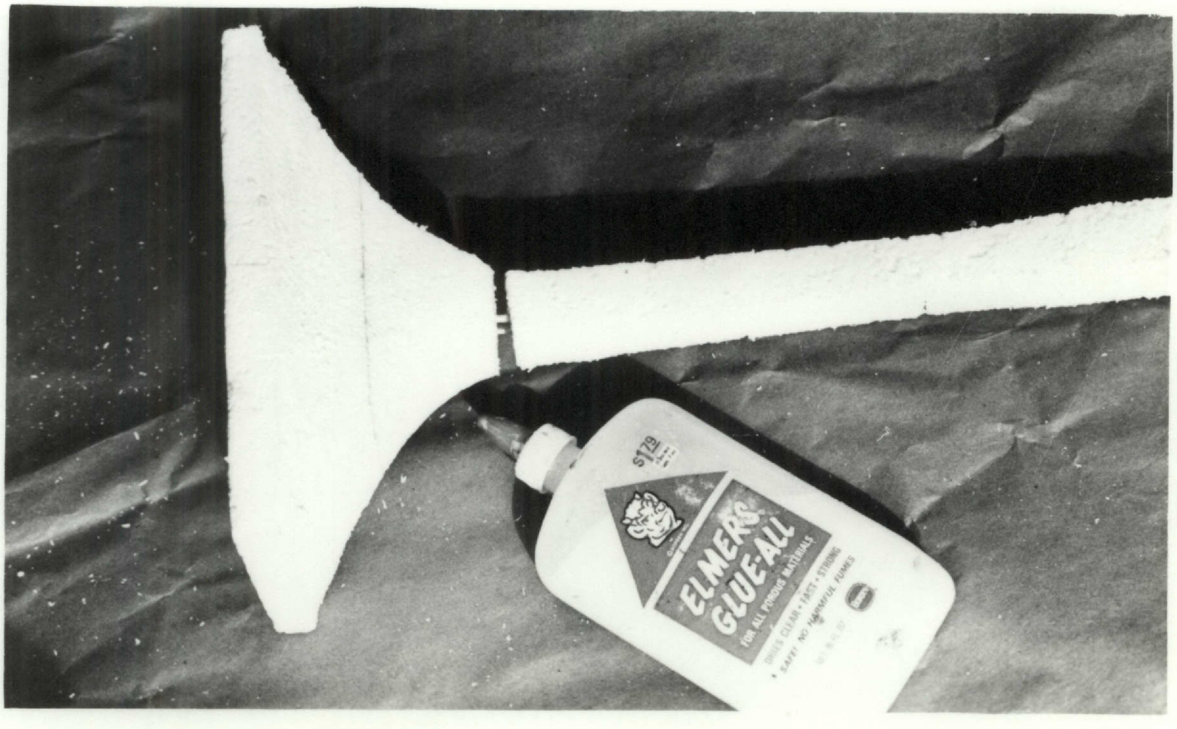


Fig. 26--Joining pattern one

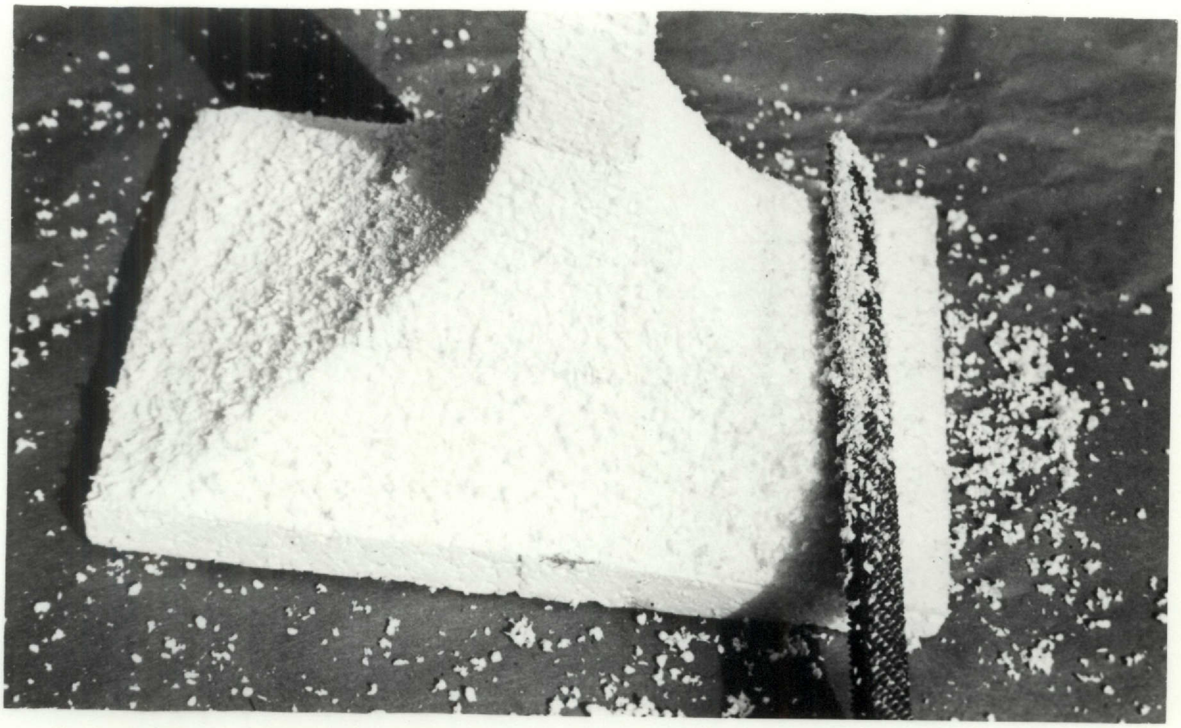


Fig. 27--Shaping pattern one

Fig. 28--Sanding pattern one

Finishing pattern one.--The face, or flat end of the pattern, was treated with a thin coating of polyester resin which solvenized the surface into an eroded texture (see Figure 29, p. 103). Flour and glue paste was used to finish the back side and remainder of the pattern, as illustrated by Figure 30, p. 103. These finishes were used because of the differences in textures which would result and to test their utility.

Molding pattern one.--The extended end of the handle-like shape was used as a sprue to which the pouring cup was attached. Subsequently, the pattern was cleaned with a brush coating of vinyl floor wax in order to prepare the pattern for accepting a smooth coat of ceramic shell slurry, as illustrated by Figure 31, p. 104.

The following steps provide a detailed description of the molding processes performed on Pattern One and duplicated for all patterns used in the study:

1. Dip-coating in slurry of Pattern One (Figure 32, p. 104);

2. Immediate stuccoing of the pattern with fine-grain sand (Figure 33, p. 105);

3. Air-drying for twenty-four hours (Figure 34, p. 105);

4. Pre-wetting the pattern in Nalcoag (c.) colloidial silica (Figure 35, p. 106);

5. Dip-coating the pattern into the slurry (Figure 36, p. 106);

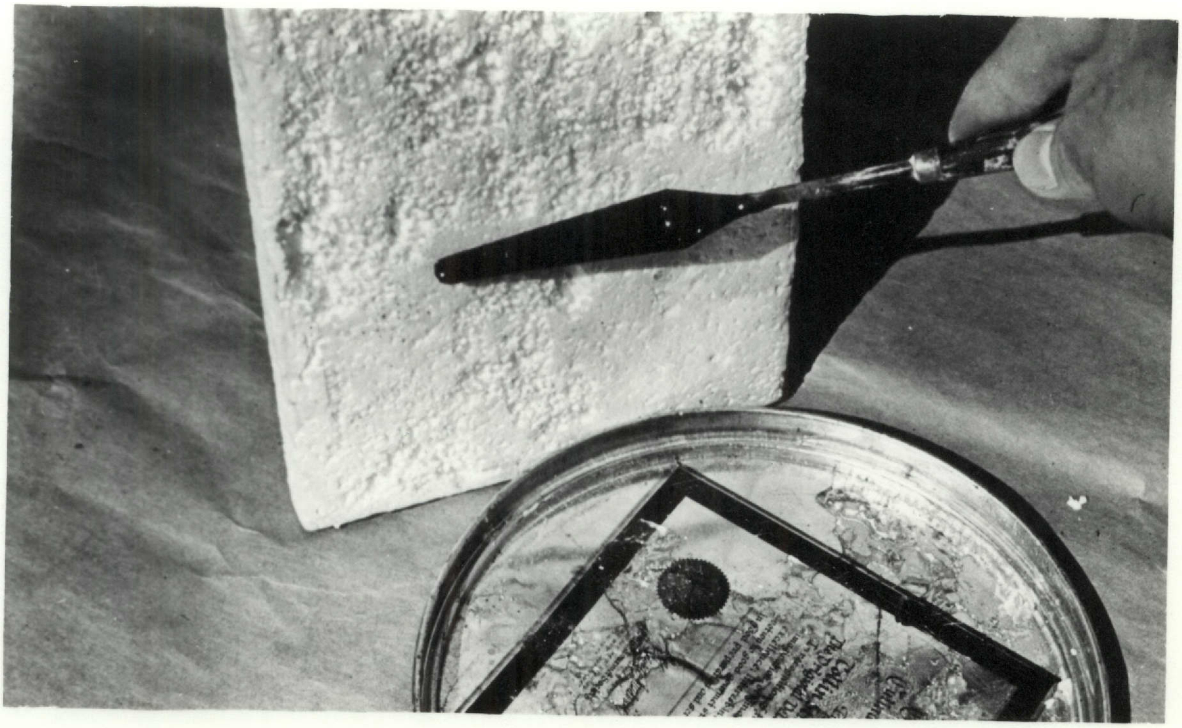


Fig. 29--First finish of pattern one

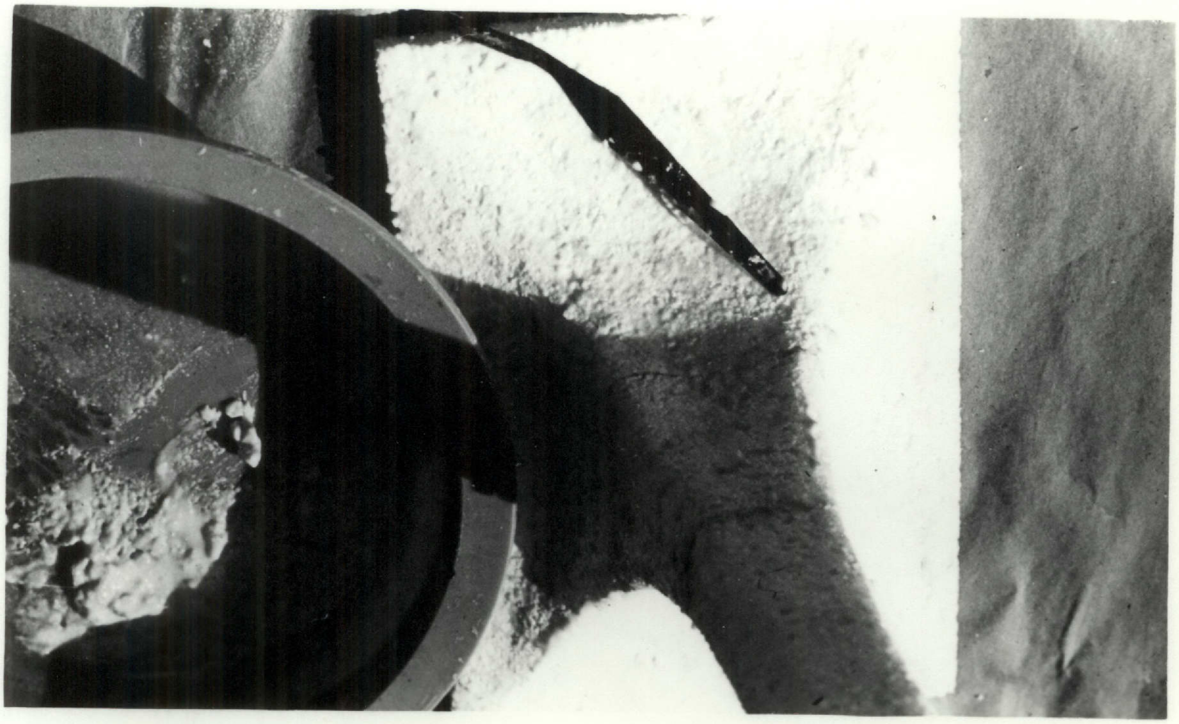


Fig. 30--Second finish of pattern one

Fig. 31--Cleaning pattern one

Fig. 32--First dip-coating of pattern one

Fig. 33--First stuccoing of pattern one

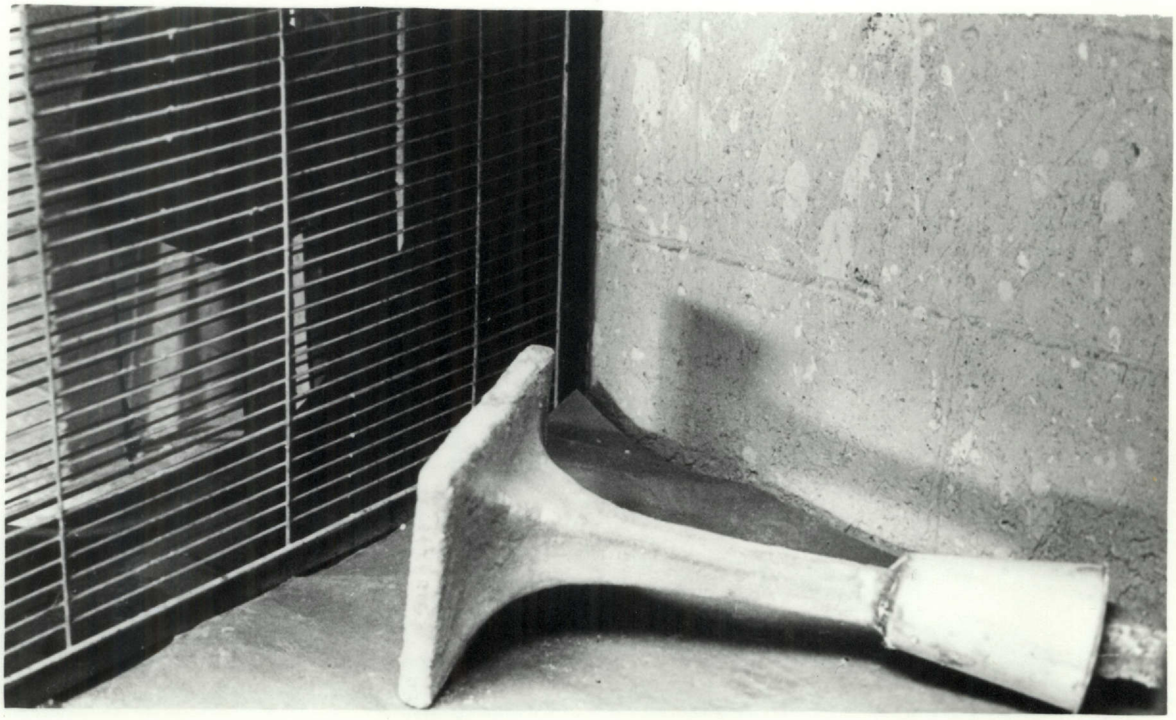


Fig. 34--First drying of pattern one

Fig. 35--Pre-wetting pattern one

Fig. 36--Second dip-coating of pattern one

6. Stuccoing with medium-grain sand (Figure 37, p. 108);

7. Air-drying the pattern for twenty-four hours (Figure 38, p. 108).

8. Steps four, five, six, and seven, above, were repeated twice in order to form coatings three and four;

9. Final coating of slurry before air-drying and preparing for molding (Figure 39, p. 109).

Burning out pattern one.--Pattern one was prepared for burning out by sawing three slits in the pattern using a hack-saw blade. This preparation is illustrated in Figure 40, p. 109.

Figure 41, p. 110, illustrates pattern one as it was placed in the muffle chamber, a fifty-five gallon oil drum, for burning out in the burn-out furnace previously described. Figure 42, p. 110, illustrates this drum sitting on the bottom loading door of the burn-out furnace as it was utilized throughout this study before being raised into the burn-out chamber.

The burn-out schedule described above was followed in order to test the utility of the procedure. Actual temperatures and times were recorded during the burning out process (see Figure 93, p. 202). This process was followed throughout the study. No significant fluctuations in times or temperatures were noted for burning out pattern one (see Figure 93).

Fig. 37--Second stuccoing of pattern one

Fig. 38--Second drying of pattern one

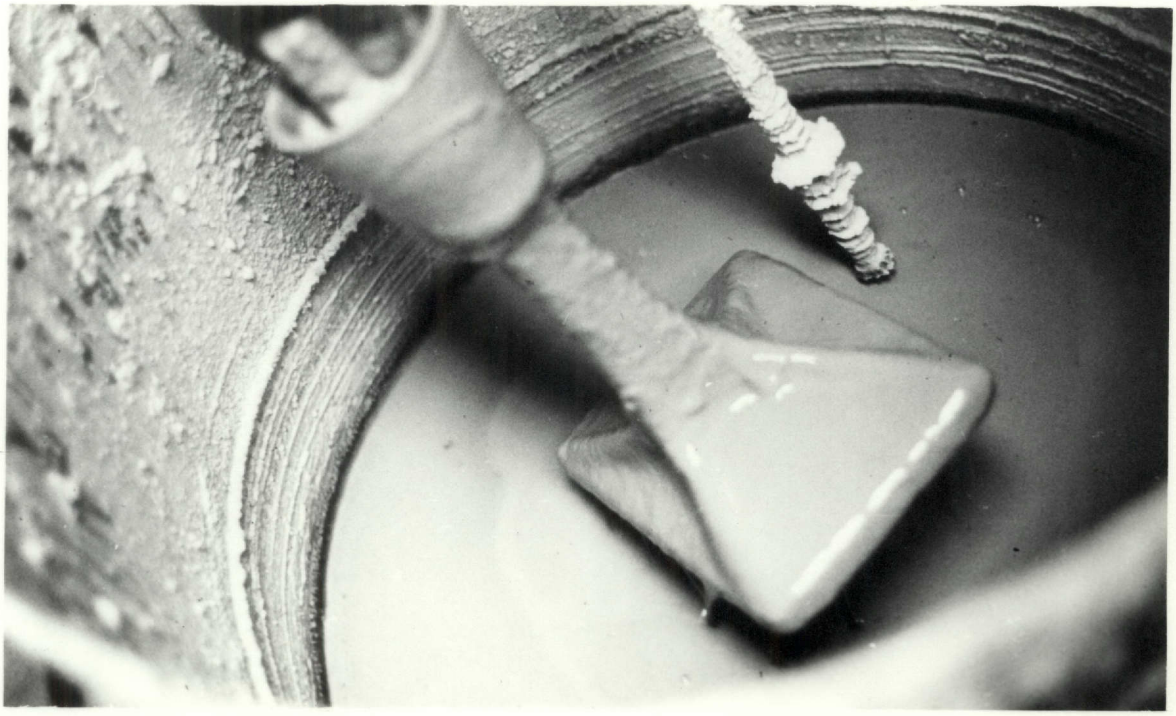


Fig. 39--Fifth dip-coating of pattern one

Fig. 40--Slit venting pattern one

Fig. 41--Burning out pattern one

Fig. 42--Muffle for burn out

After burn out, the mold was inspected and vent slits repaired for future casting using pieces of Fiberglas (c.) cloth dipped in ceramic shell slurry and pressed into the area of the slit. See Figure 43, p. 112.

Casting pattern one.--In preparation for casting, the mold for pattern one was pre-heated to 1000 degrees Fahrenheit in order to facilitate flow of the charge of molten metal, i.e., prevent freeze out, and cast in aluminum. Figure 44, p. 112, illustrates the cast mold as it sat in the loose sand bed after being cast. Figure 45, p. 113, indicates the cracking and breaking away of the mold as it cooled. In addition, the ease of removal of ceramic shell molds after casting in aluminum is illustrated.

Findings for pattern one.--The expanded polystyrene, 1.0 p.c.f. and polyester resin and flour and glue paste used to finish pattern one burned out satisfactorily, resulting in a clean and bright casting, as illustrated by Figure 46, p. 113. The textures created by the finishing materials were clearly differentiated by the apparent quality of the erosion of polyester resin on the expanded polystyrene. The polyester resin was applied to the pattern with a knife. The thick flour and glue paste was applied in uneven patches then smoothed with a knife dipped in water, which served as an effective way to apply the material. These materials were judged acceptable within the scope of the problem.

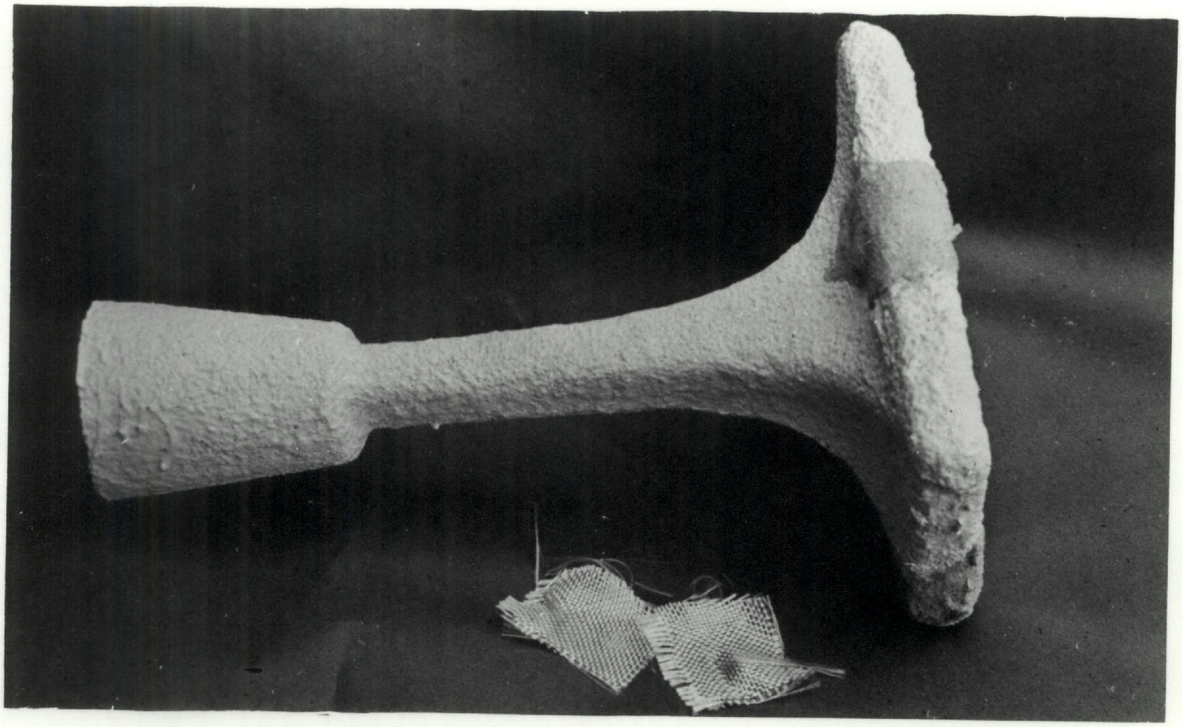


Fig. 43--Repairing slits in pattern one

Fig. 44--Casting pattern one

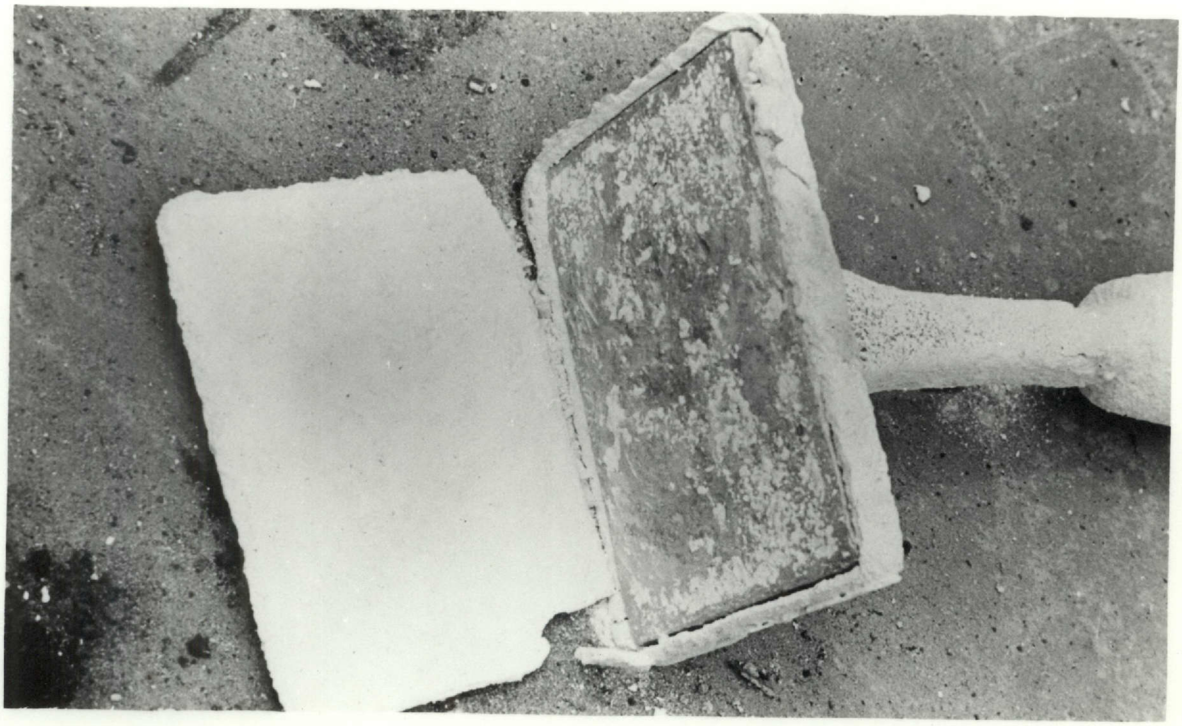


Fig. 45--Removal of molding from pattern one

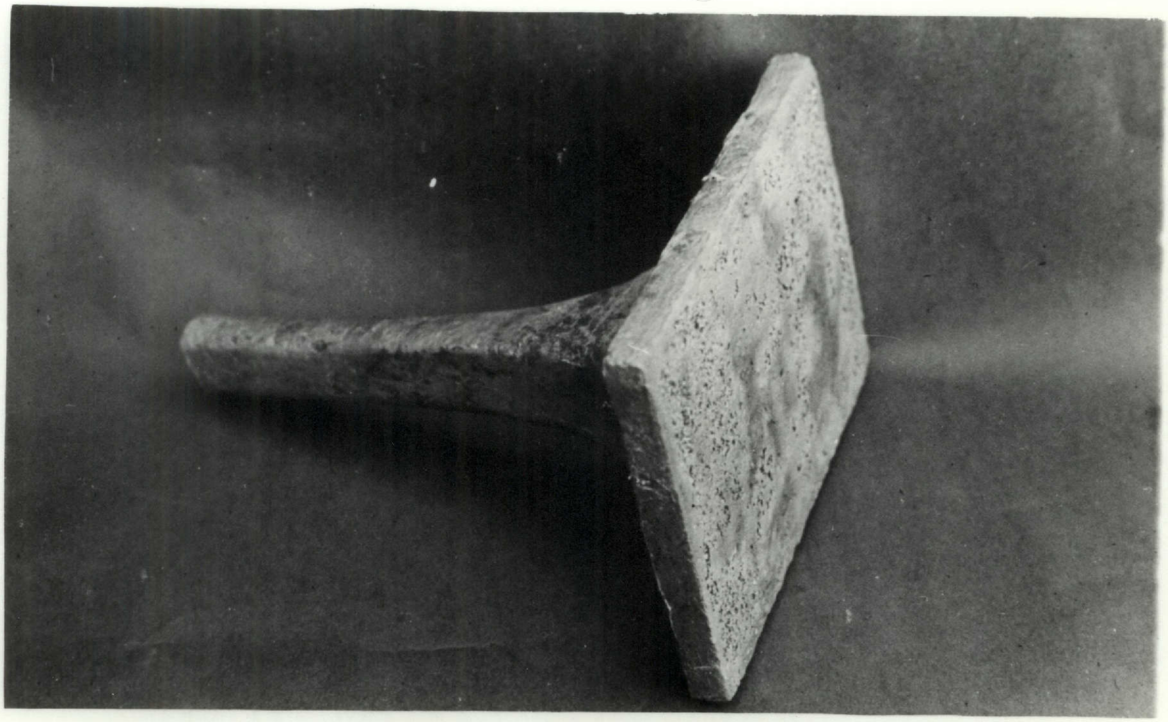


Fig. 46--Cast of pattern one

Pattern Two

For Pattern Two (hereafter referred to as pattern set two) a set of four small, irregular shapes were designed to satisfy the requirement for small, irregular patterns and to exploit varieties in pattern configuration. The set also helped confirm the feasibility of using this type of pattern. The shapes had sharp and soft corners. In addition, they were irregular in thickness and included curved surfaces as well as flat contours.

Constructing pattern set two.--The patterns were made from expanded polystyrene, 1.8 p.c.f. material. They ranged in size from 3 x 6 x 2 inches to 6 x 10 x 4 inches. Each pattern was cut from bulk material using a hacksaw blade. Each pattern was rasped and sanded as a process of shaping.

Finishing pattern set two.--Concave face surfaces of the patterns were finished with microcrystalline wax. Exterior back sides were finished with flour and glue paste (see Figure 47, p. 115). These materials offered two contrasting surface finishes.

Molding pattern set two.--One of the set of four patterns was furnished with vents. The gating system of the forthcoming molds was installed, and the patterns were invested in ceramic shell molds (see Figure 48, p. 115) in the procedure used for molding all patterns.

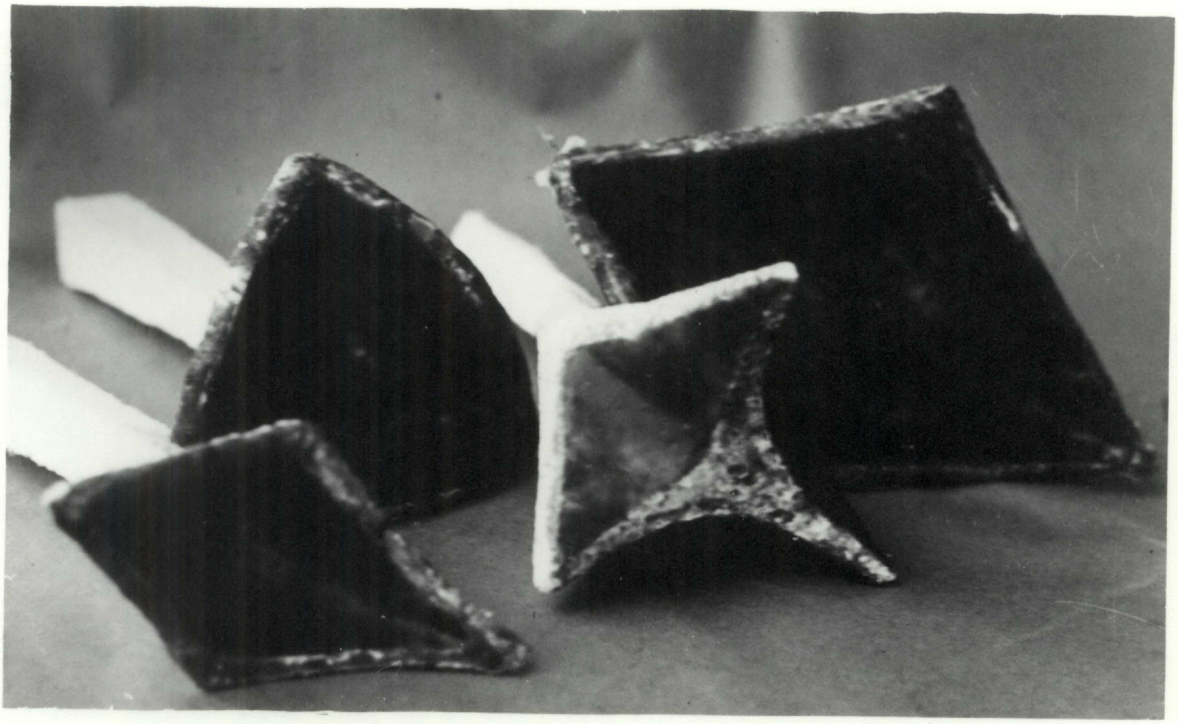


Fig. 47--Finished pattern set two

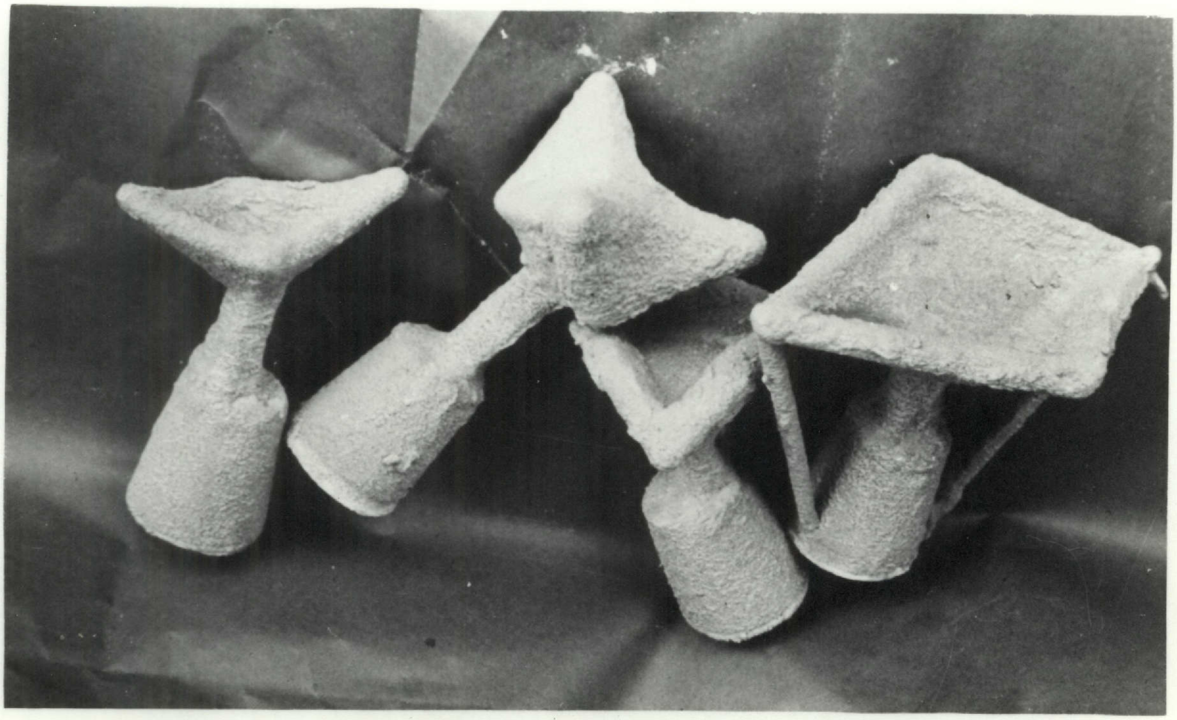


Fig. 48--Molded pattern set two

Burning out pattern set two.--All four patterns in the set were burned out simultaneously. Burn out proceeded according to the procedures established for the study (see Figure 93, p. 203).

Casting pattern set two.--The pre-heated molds were cast in aluminum according to the procedure established for the study, as illustrated in Figure 49, p. 117.

Findings for pattern set two.--The expanded polystyrene, 1.8 p.c.f., and microcrystalline wax used to finish these patterns burned out satisfactorily, resulting in a clean and bright set of castings with apparent textural differences in surfaces treated with wax and with flour and glue paste. The wax was heated in order to facilitate application; however, a smooth surface was difficult to attain. Flour and glue was difficult to apply because it tended to roll up if too dry or failed to fill if too wet. Flour and glue paste did shrink upon drying leaving a softly pocked surface. All materials were acceptable within the scope of the problem.

Pattern Three

Three pieces of expanded polystyrene, consisting of two different densities, were used to make this pattern which was selected because of its organic configurations which varied in thickness. Such differences in materials and configurations met the requirements of shape, size, and combination of materials.

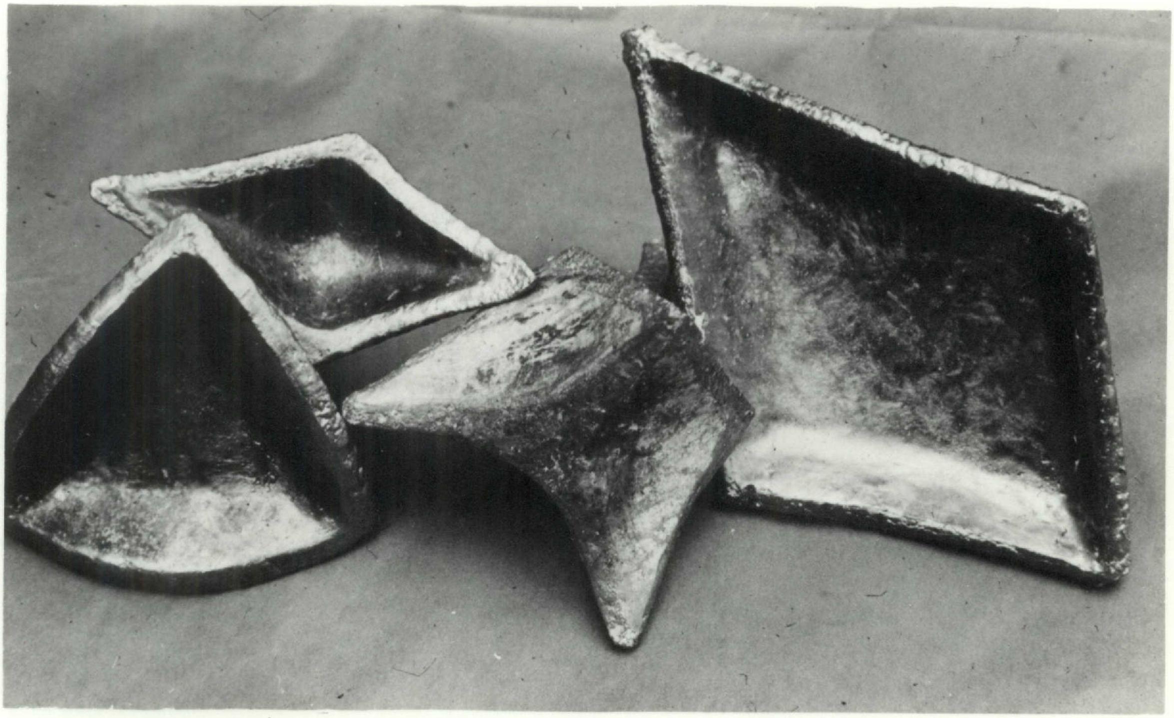


Fig. 49--Casts of pattern set two

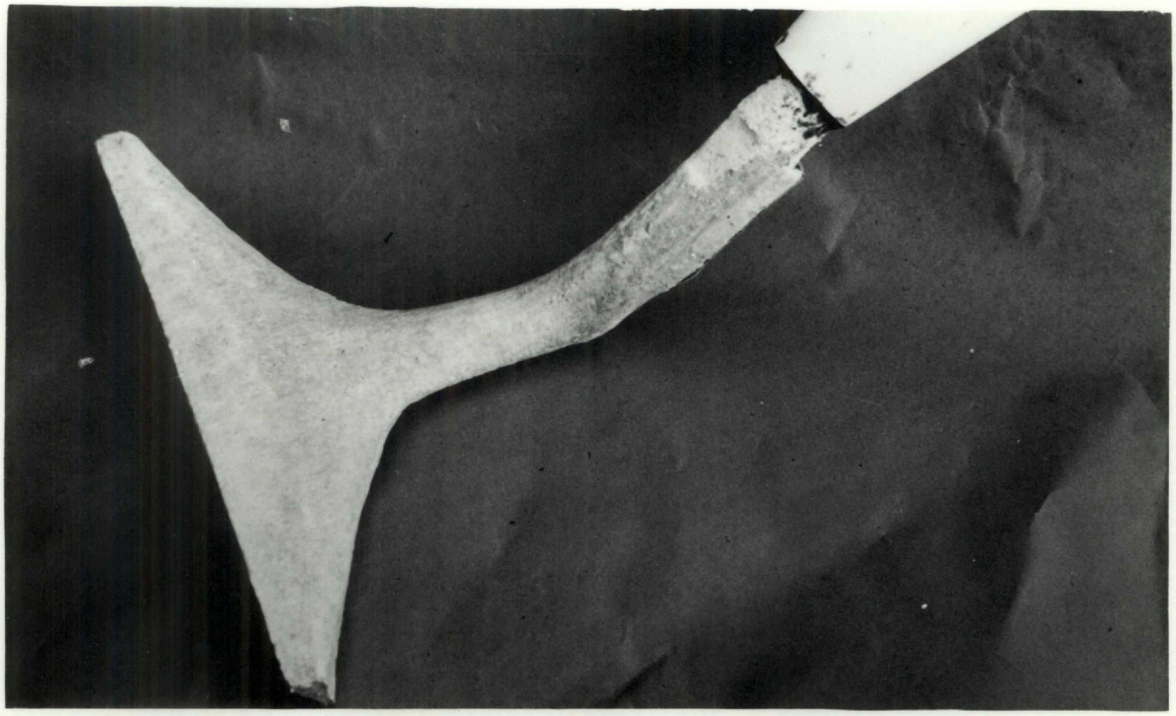


Fig. 50--Front side, finish of pattern three

Construction of pattern three.--The three pieces of expanded plastics used for the pattern were cut with a hack-saw blade. The handle-like section and the lower horizontal piece cut from 1.0 p.c.f. expanded polystyrene were glued together. A 1 x 1½ x 13 inch strip of 3.3 p.c.f. expanded polystyrene was laminated to the bottom edge of the pattern. The pattern, measuring 13 x 15 x 1½ inches, was shaped with a rasp and sand paper.

Finishing pattern three.--The front surface was finished with Thiem (c.) styro fill 42.1. The back side was finished with paper-mâché. These finishing materials produced a soft smooth surface, and their effects on the final cast would be easily compared. Figure 50, p. 117 and Figure 51, p. 119, illustrate these finishing techniques.

Molding pattern three.--The pattern was molded in the manner previously described for use in the study. Vents were not considered necessary due to the apparent lack of possibility for entrapment of gases in the forthcoming mold.

Burning out pattern three.--The burn out was conducted using the procedure established for the study (see Figure 93, p. 204). Upon removal from the furnace, small pieces of beige colored ashes were shaken from the mold. The ashes were light and collapsed to a fine powder when touched. The pattern was blown out with thirty pounds of air pressure per

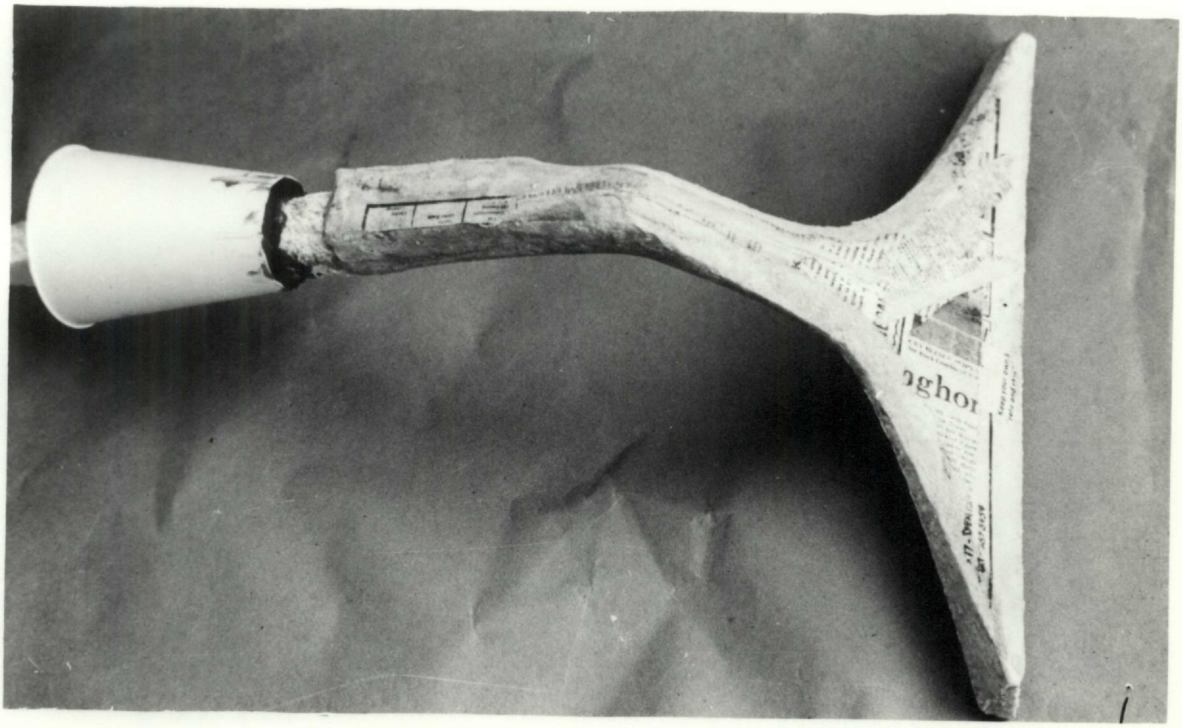


Fig. 51--Back side, finish of pattern three

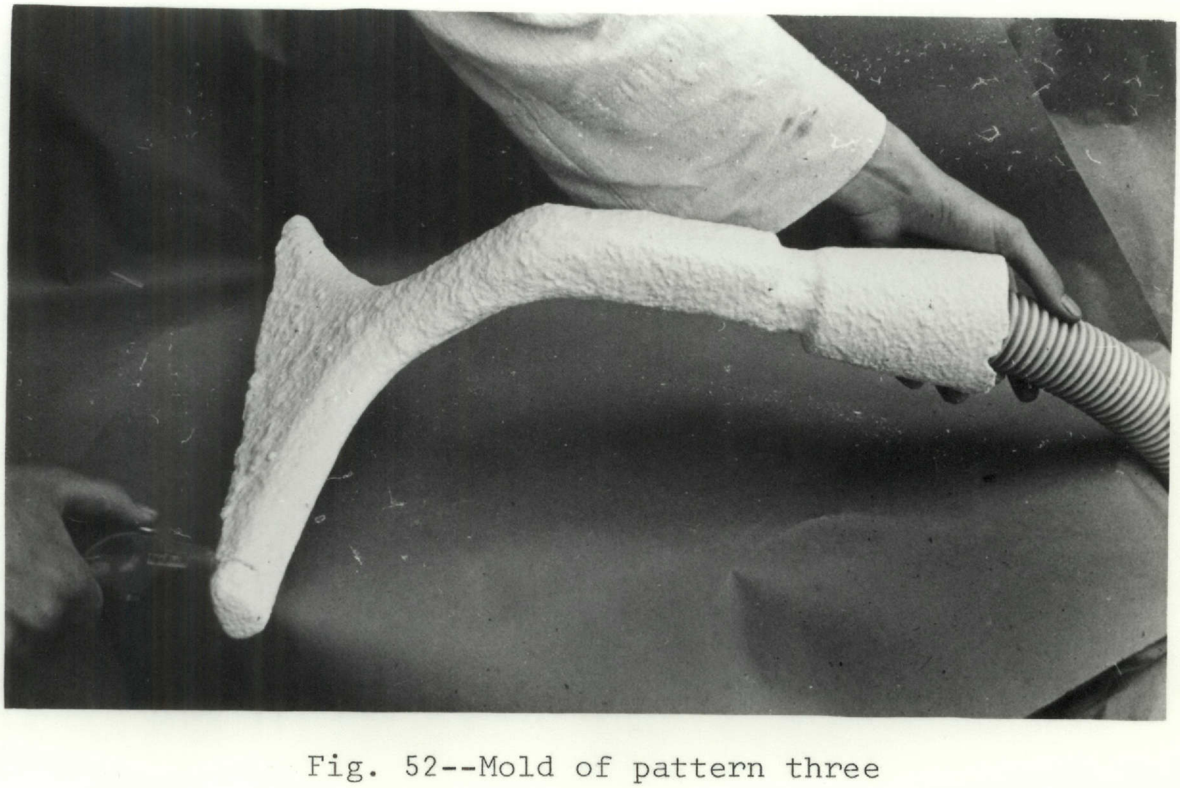


Fig. 52--Mold of pattern three

square inch and vacuumed at the same time in order to further evacuate the mold (see Figure 52, p. 119).

Casting pattern three.--The mold was pre-heated and cast in aluminum according to the procedures established for the study as shown in Figure 53, p. 121. The casting was clean and bright in appearance.

Findings for pattern three.--Paper-mâché was easily applied and adhered to the pattern. Thiem (c.) styro fill 42.1 was applied at about the consistency of wet plaster. It was not easily smoothed but could be sanded after drying. Approximately one teaspoon full of ashes was present in the mold after burn out. The residue appeared to indicate that the finishing material paper-mâché left the ashes. They were easily evacuated, however, using both air pressure and a vacuum. Expanded polystyrene 1.0 p.c.f. and 3.3 p.c.f. as well as the finishing materials were accepted as satisfactory pattern-making materials.

Pattern Four

This pattern was selected to test multi-coring and to retest both lamination and the utilization of an organic pattern which was varied in thickness. The design met the previously described criteria for the study.

Constructing pattern four.--The rough shape was cut with a hacksaw blade from two sections of expanded polystyrene 1.0

Fig. 53--Cast of pattern three

Fig. 54--Constructing patterns four and five

p.c.f. planking. The pattern dimensions were 14 x 13 x 3½ inches at the thickest point.

The top side of the lower flared shape was covered by a one-eighth inch piece of mini-cell expanded polystyrene sheet material. The two materials were laminated with glue. This procedure left a crevice or undercut to be cored in the regular molding process, illustrated at the top of Figure 54, p. 121 above. The arm section was hollowed out to avoid casting an unnecessarily bulky section, and a hole was cut in the base of the resultant cylinderical shape, which would facilitate anchoring the forthcoming ceramic shell core mold. These alterations were accomplished by burning the pattern to create a core or hole area with a small electric soulder-ing tool (see left side Figure 55, p. 123).

Finishing pattern four.--The pattern was finished with Thiem (c.) styro fill 42.1 on the arm-like section, diminish-ing to the smooth, uncoated mini-cell expanded polystyrene surface at the bottom. These two softly smooth surfaces were used adjacent to one another in order to compare their eventual influence on the texture of the casting. The pattern may be seen at the top of the illustration in Figure 56, p. 123. Upon drying, the Thiem (c.) styro fill 42.1 surfaces were hair checked, i.e., minutely cracked.

Molding pattern four.--A gating system was attached to the pattern as can be seen in the upper section of the

Fig. 55--Patterns four and five

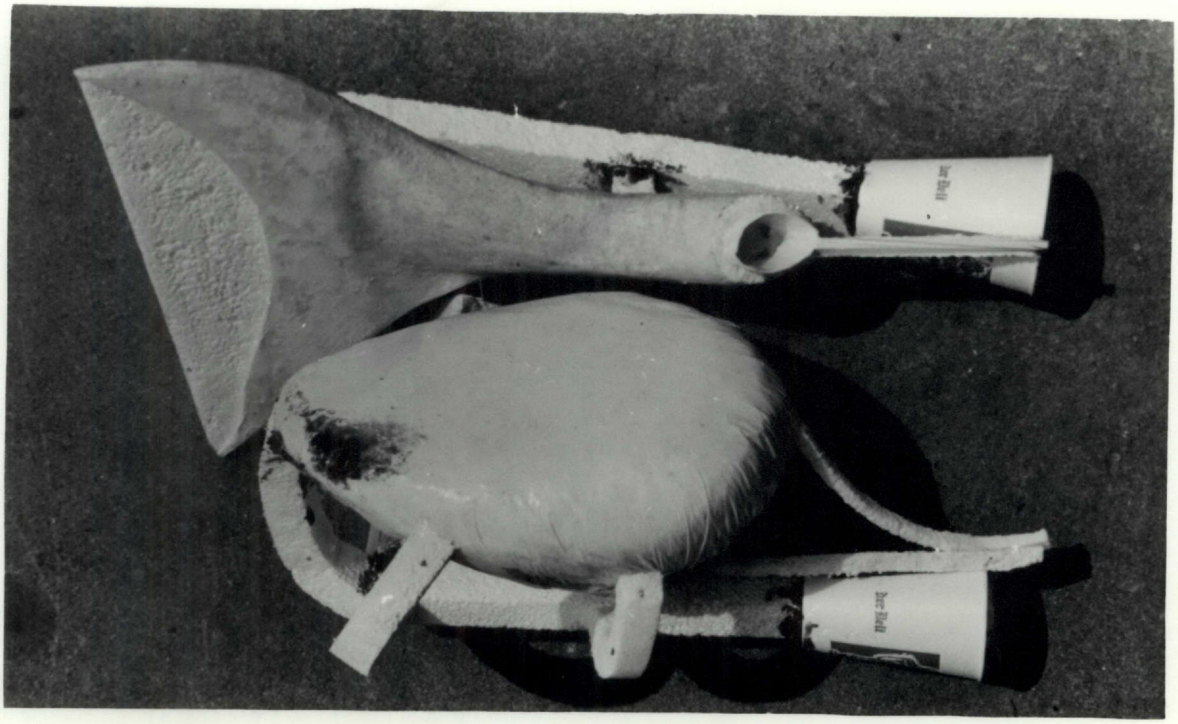


Fig. 56--Gating systems for patterns four and five

illustration in Figure 56, p. 123. The mold was formed following the procedures established for the study.

Burning out pattern four.--The pattern was burned out in the manner described previously. The burn out was slightly irregular as shown in Figure 93, p. 205, but was not considered significant. The mold was clean and carbon free.

Casting pattern four.--The mold was pre-heated and cast in aluminum following the procedure established for the study resulting in a bright casting. See Figure 57, p. 125.

Findings for pattern four.--The expanded polystyrene 1.0 p.c.f. and mini-cell expanded polystyrene used in constructing the pattern combined with Thiem (c.) styro fill 42.1 finishing material burned out satisfactorily. Thiem (c.) styro fill 42.1 was loosely applied with a spatula and smoothed with the edge of a knife adjacent to the mini-cell expanded polystyrene surface. These manipulations were easily executed. Except for the surface resulting from hair checking of the Thiem (c.) styro fill, the cast surface differences were not apparent.

Pattern Five

This large, voluminous and organic pattern was made from two families of expanded plastics selected in order to meet the needs of this study for testing such configurations and combinations of pattern materials.

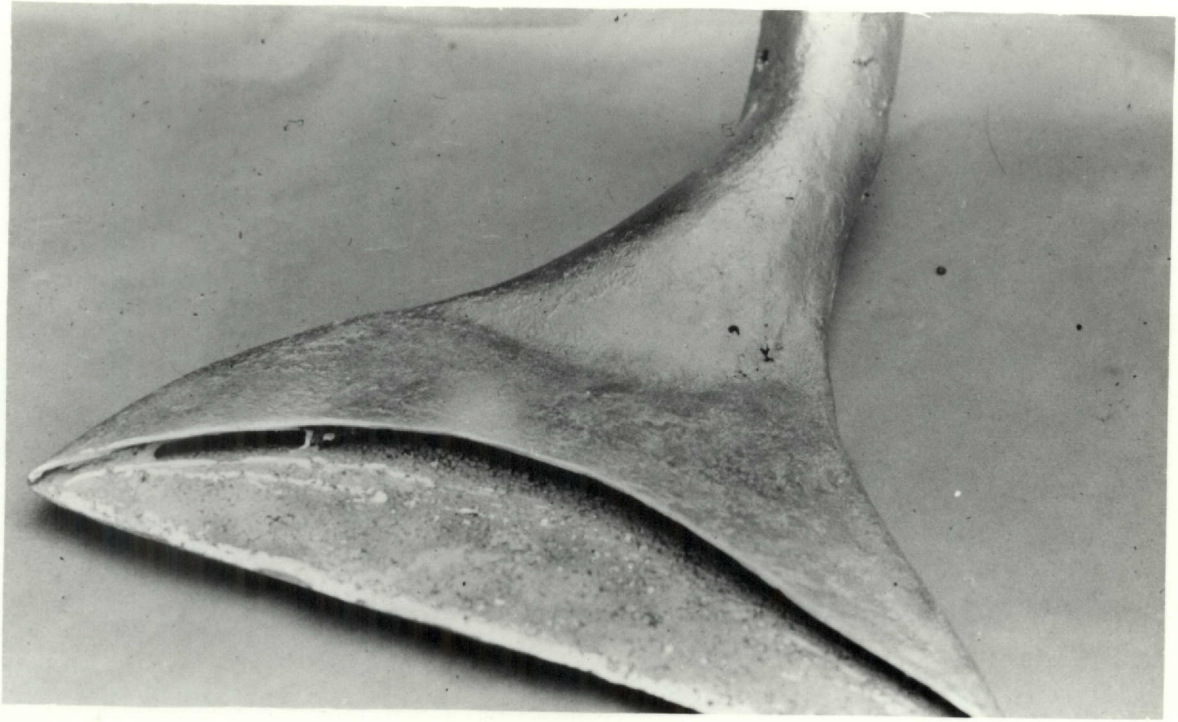


Fig. 57--Cast of pattern four

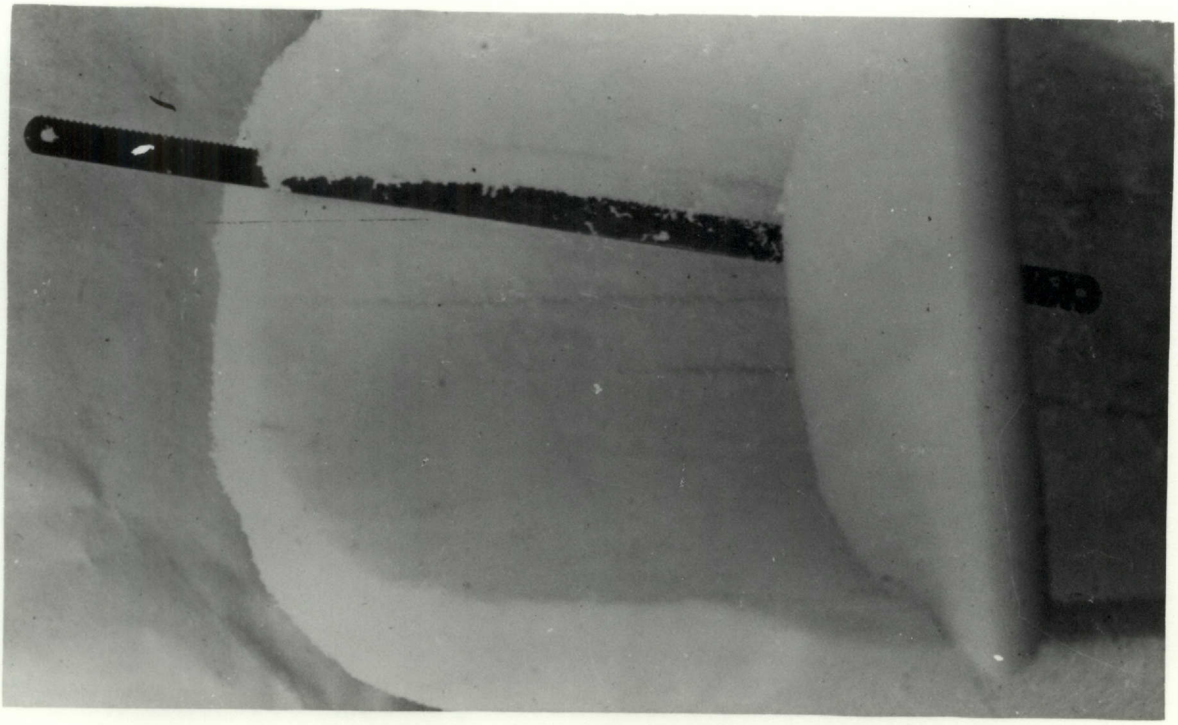


Fig. 58--Initial construction of pattern five

Constructing pattern five.--One cylindrical piece of expanded polyethylene 9 p.c.f. was cut down one side with a hacksaw blade and the core cut at one-inch intervals along its length, to allow the piece to fold open (see Figure 58, p. 125 above). Extraneous material was trimmed off and another cylinderical piece, e.g., the bottom piece in the illustration, Figure 59, p. 127, was placed inside to replace the initial volume, provide more bulk, and make the pattern solid. A truncated conical piece of expanded polystyrene 1.0 p.c.f. was added to the bottom of the pattern (see lower half of the illustration Figure 54, p. 121 above). The resulting pattern measured 10 x 12 x 7 inches or 840 cubic inches.

Finishing pattern five.--The pattern was finished by stretching a section of a polyethylene film bag over the pattern, taping it with cellulose acetate tape, and filling the underside with microcrystalline wax (see Figure 55, p. 123 above). The film was used to test capability of the material in rendering a polished smooth surface. The wax was used because it was deemed most practical for filling the folded layer of polyethylene film and taped areas.

Molding pattern five.--The pattern gating system was made of expanded polystyrene 1.0 p.c.f. including the vent which would also lend more stability to the anticipated mold than the soda straw technique for building vents (see Figure 56, p. 123 above).

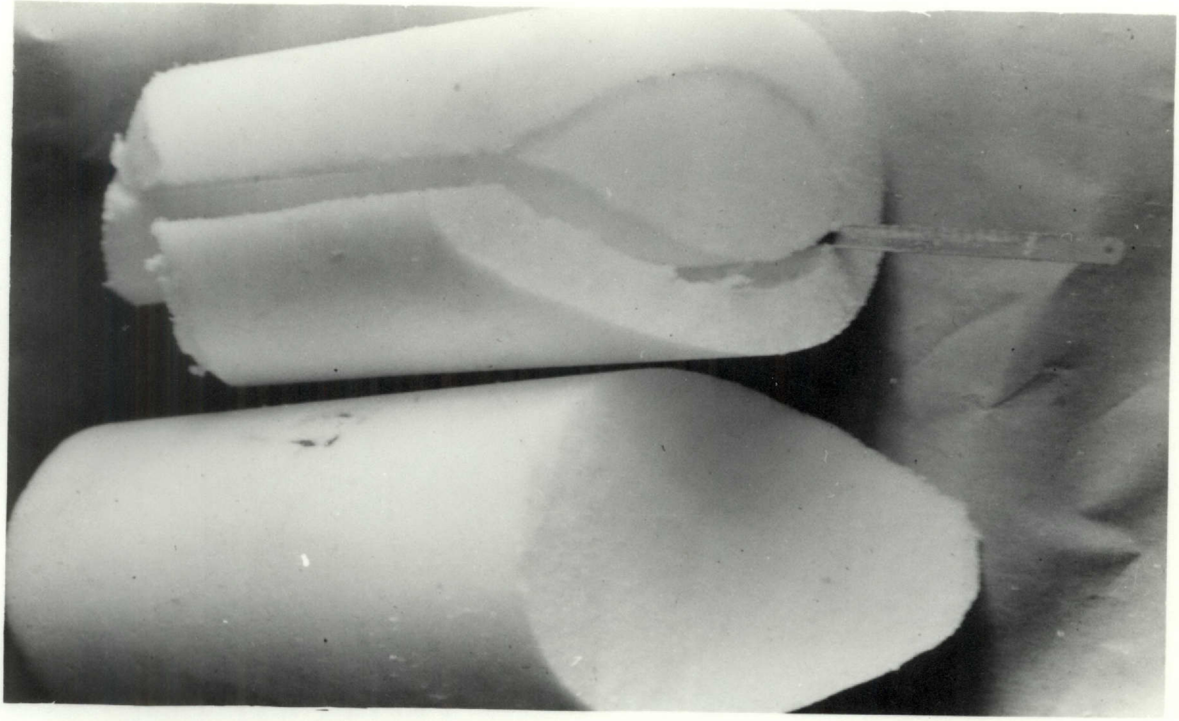


Fig. 59--Volume construction of pattern five

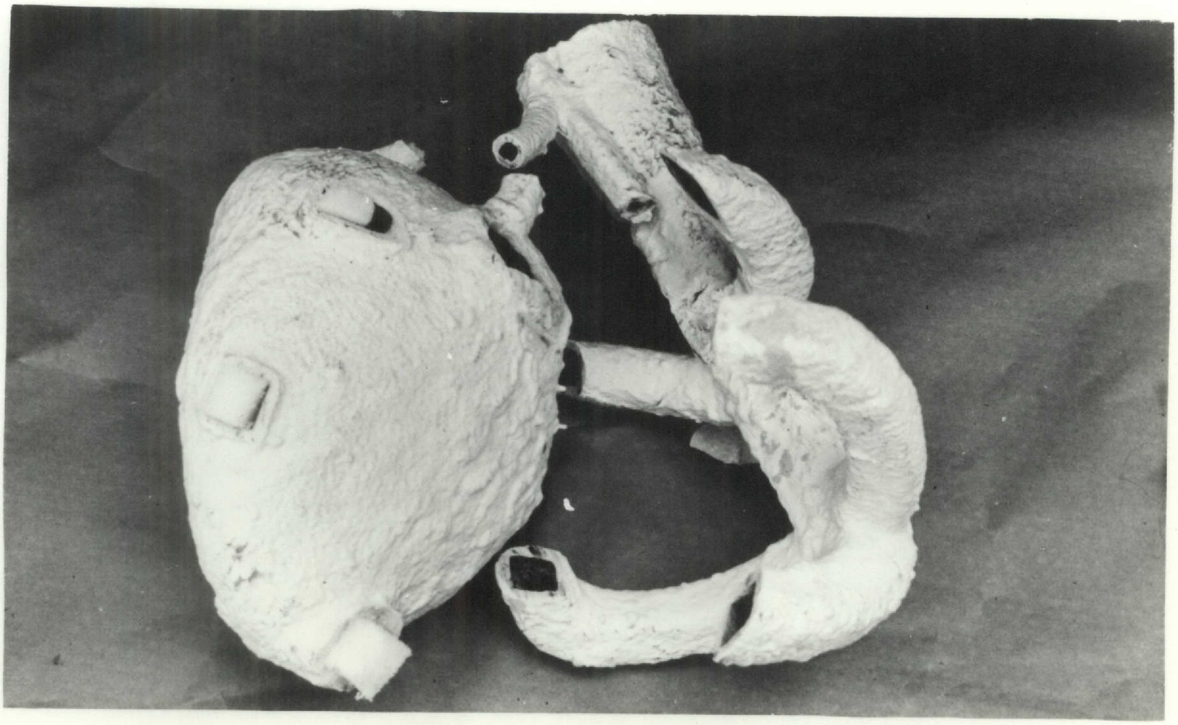


Fig. 60--Removal of gating system of pattern five

Burn out pattern five.--After initial burn out (see Figure 93, p. 206), the gating system was removed by sawing through the gates with a hacksaw blade and the mold slush-patterned with hot wax in order to form a second pattern surface inside the mold (see Figure 60, p. 127 above and Figure 61, p. 129, respectively).

Core pins were installed in the walls of the mold by drilling through the ceramic shell wall in order to hold the core in the wax pattern and mold. The core was molded following the procedure established for the study. After replacement of the sprue and gating system (see Figure 62, p. 129, showing the mold being assembled), the mold was burned out using the shock burn-out procedure normally used for burning out of wax patterns, as follows: (1) the open-flame burn out furnace was pre-heated to 1800 degrees Fahrenheit; (2) the bottom loading door was lowered; (3) the pattern was placed on the door and raised into the burn out chamber, where the temperature had dropped to 1500 degrees Fahrenheit; (4) and, after five minutes, the temperature was lowered to 1000 degrees Fahrenheit and the mold let sinter for approximately twenty-five minutes. There was no apparent residue remaining in the mold.

Casting pattern five.--The mold was pre-heated and cast in aluminum, following the procedure established for the study.

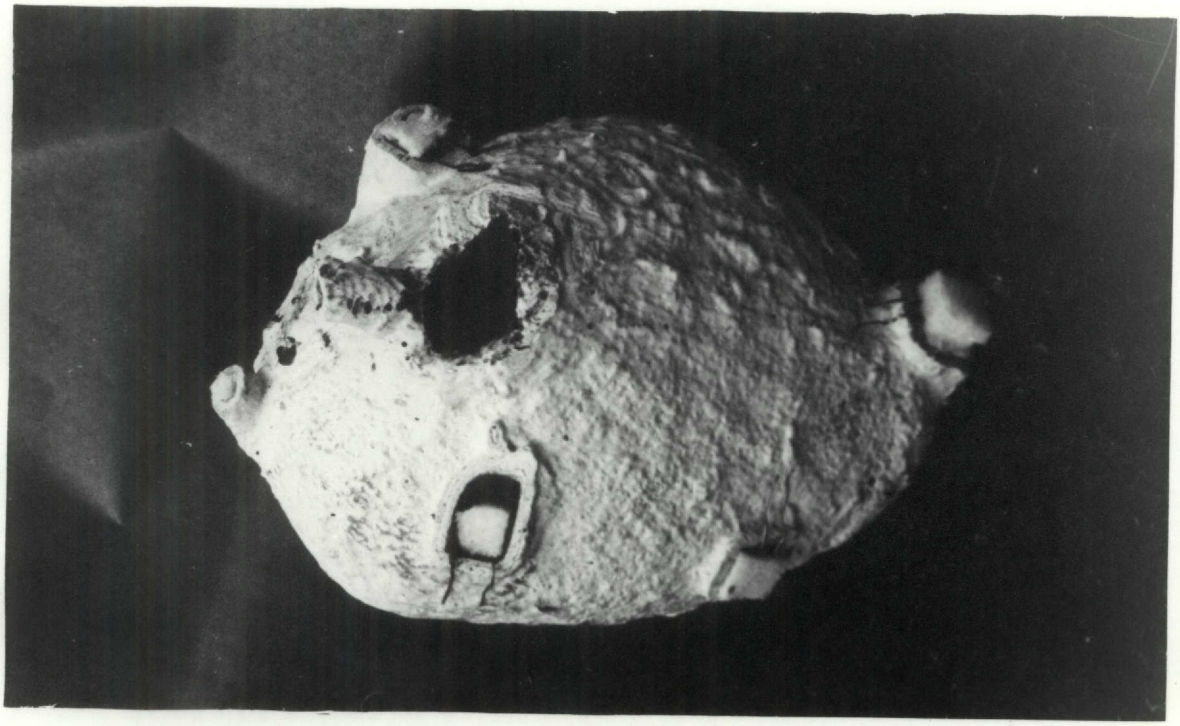


Fig. 61--Slush patterning mold five

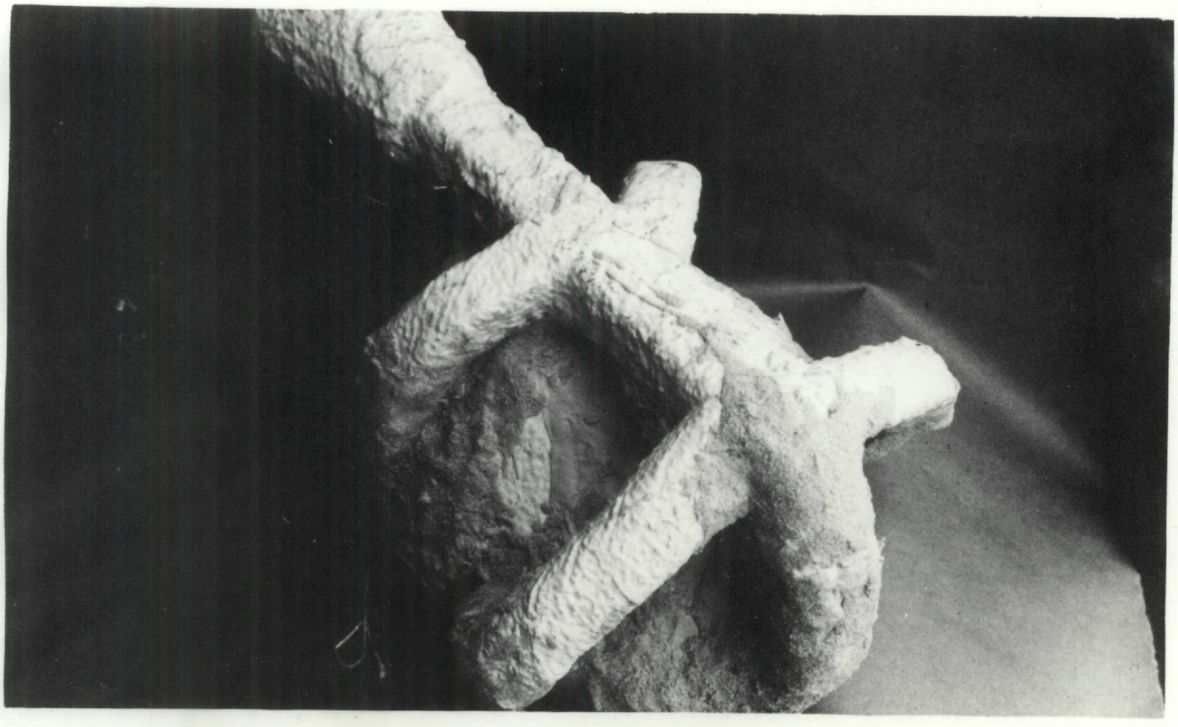


Fig. 62--Molded pattern five

Findings for pattern five.--The casting was medium dark in color, but there was no buildup of carbon. The metal at casting was about 1300 degrees Fahrenheit, apparently causing the dark surface appearance of the metal. The cast did not seem to lack detail of the original pattern as illustrated in Figure 63, p. 131.

The flexibility of the expanded polyethylene 9.0 p.c.f. proved to be an asset in constructing this smoothly organic pattern. The material was bent easily into the desired shape for the pattern. The polyethylene film presented no problem while being stretched over the pattern. The film was held with masking tape. It was not found necessary to cover entirely the folds created by gathering the film on the underside of the pattern; however, the operation was difficult to perform as the warm wax tended to heat the film and to create a looseness which would not have been easily controlled except for the tape. The tape was also used to hold the gathered film around the end of the pattern. Pattern making materials and finishing materials were judged acceptable within the scope of the problem of the study.

Pattern Six

Another pattern, similar to pattern five, was selected in order to re-test the result of burning out a similar volume, utilizing a different family of expanded plastic. The flexible quality of expanded polyethylene was used in

Fig. 63--Cast of pattern five

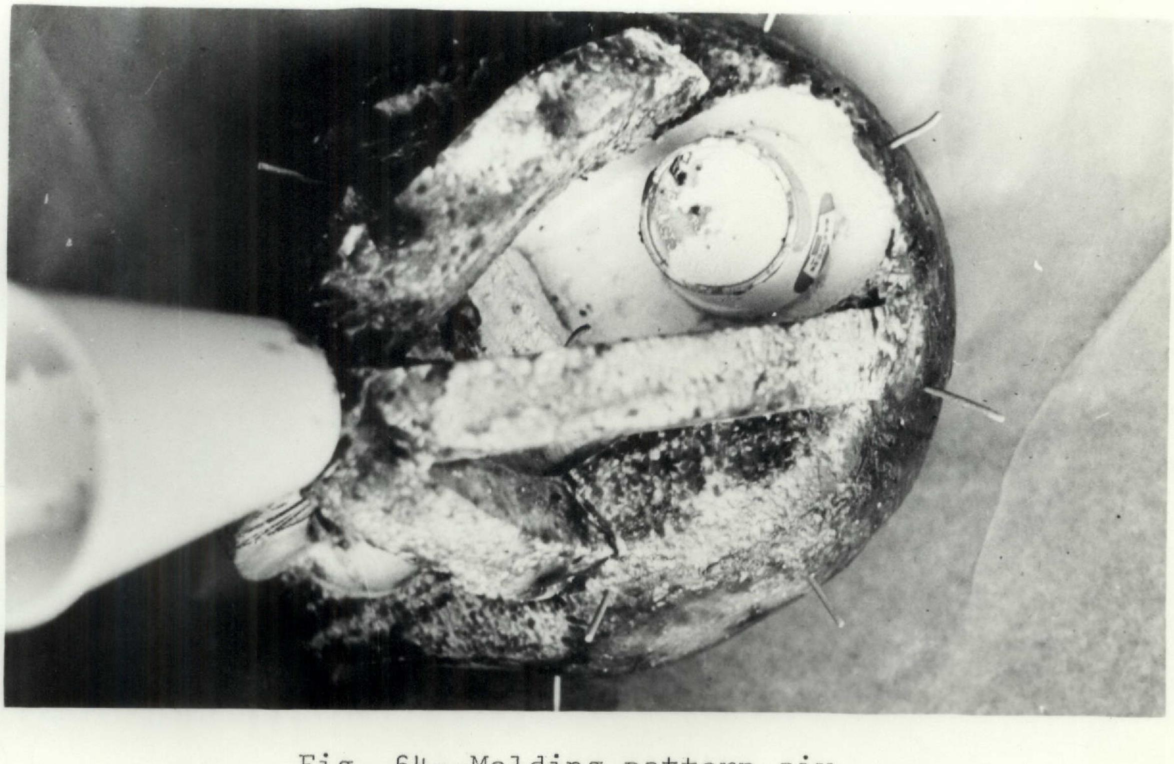


Fig. 64--Molding pattern six

combination with expanded polystyrene to produce a large, voluminous, and organic shape in order to meet the criteria for the study.

Construction of pattern six.--This pattern was constructed of an expanded polystyrene 1.0 p.c.f. core inside a sheath of expanded polyethylene 9.0 p.c.f. The pattern dimensions were 10 x 12 x 7 inches, or approximately 840 cubic inches. The flexible character of the expanded polyethylene allowed it to be shaped by pulling and gluing it around the core of expanded polystyrene, contributing to soft, organic contours in the pattern.

Finishing pattern six.--The pattern was finished with a one-quarter-inch layer of microcrystalline wax on the top surface in order to test the smoothness which might be produced by such material compared to the polyethylene film used on pattern five, described above. The inside back was filled with Thiem (c.) styro fill 42.1 in order to note the manipulative quality of the material as a filler and to compare it to wax as used on pattern five.

Molding pattern six.--The bottom side of the pattern was furnished with a mini-cell expanded polystyrene cup glued to the surface which was to serve as a hole for slush molding the core upon completion of burning out the pattern (see Figure 64, p. 131 above). Molding was done in the prescribed manner.

Burning out pattern six.--The pattern was burned out using the procedure established for the study, above. See Figure 93, p. 207, for the burn out chart.

At the end of one hour, during the first phase of burn out and when the temperature had reached 400 degrees Fahrenheit, a piece of expanded plastic with wax droppings fell from the drain hole in the floor of the furnace. The burning piece of expanded plastic was about the size of a collapsed tennis ball and appeared to be the pattern greatly reduced in size.

After burn out, the mold was observed to have a fine crack across the top side which was repaired with Fiberglas (c.) cloth and ceramic shell slurry. For an illustration of these incidents, see Figure 65, p. 134, and Figure 66, p. 134.

In order to slush-pattern the mold, a hole was cut by using a hacksaw blade to saw through the molded surface around the cup placed on the underside of the pattern. The slush patterning process is illustrated in Figure 67, p. 135. It was also necessary to remove the gating system and fill the gate cavities with expanded polystyrene in order to facilitate a complete casting; otherwise, the gates would have left voids in the final casting. The core was slush molded and the gating system replaced using Fiberglas (c.) laminated in ceramic shell slurry. Subsequently, the wax pattern was

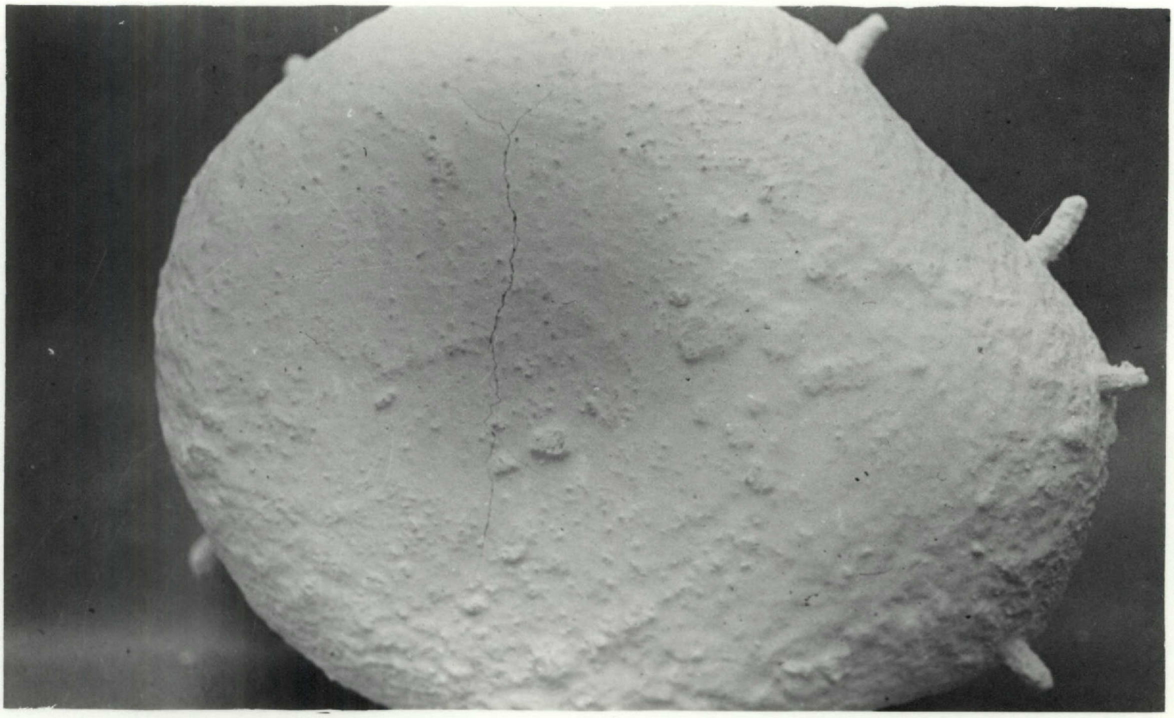


Fig. 65--Cracked mold of pattern six

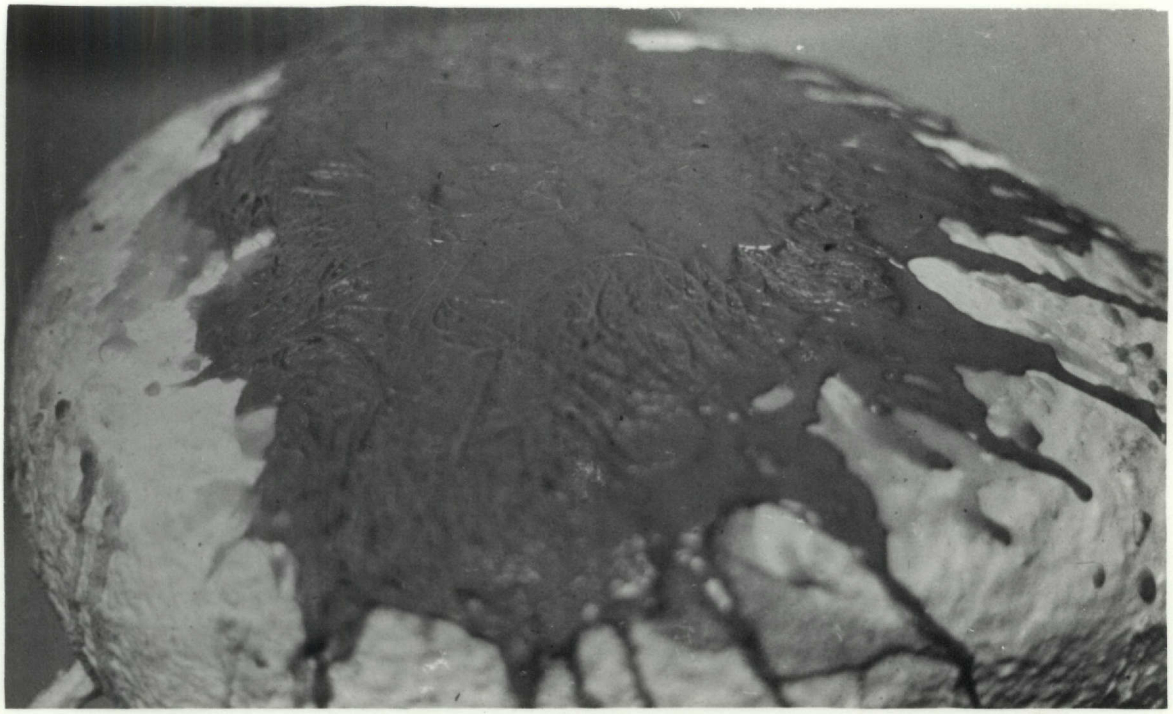


Fig. 66--Repair of mold six

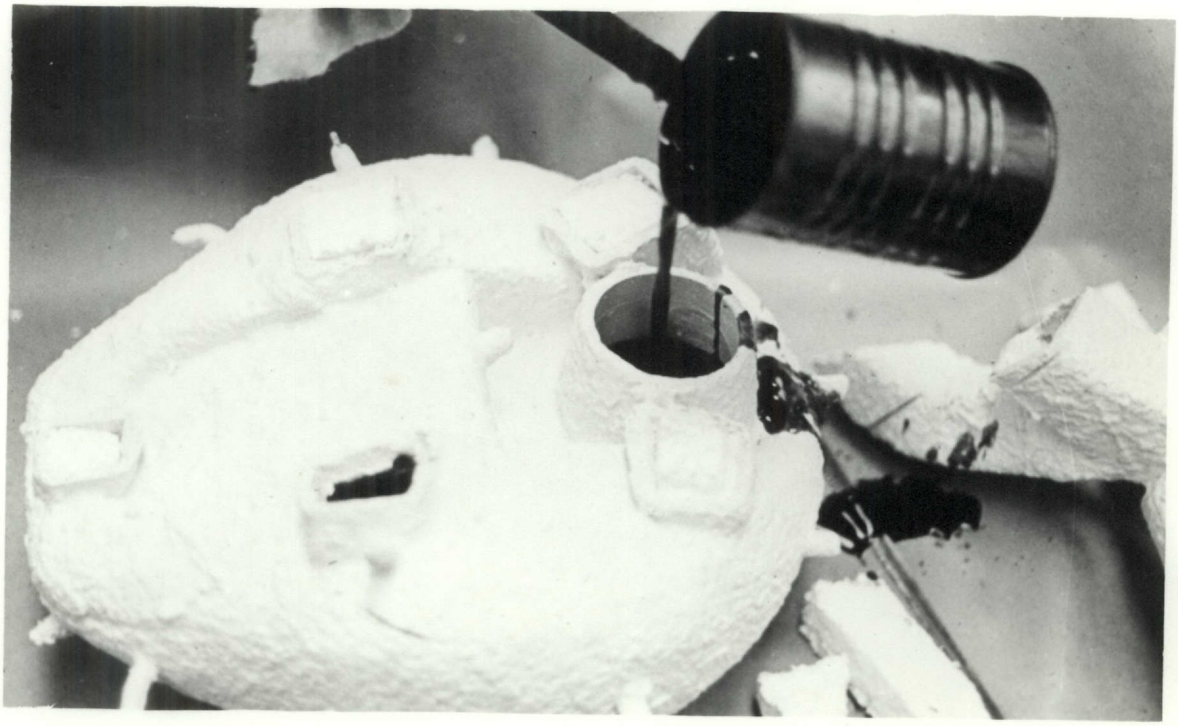


Fig. 67--Slush patterning mold six

Fig. 68--Cast of pattern six

burned out using the normal procedure for shock burn out described for pattern five, above.

Casting pattern six.--The mold was pre-heated and cast in aluminum following the procedures previously described. The mold was then placed in a partial bed of sand for casting. During casting, however, an area of one of the gates sprung a leak which was stopped by tamping sand around the pattern near the leak.

Findings for pattern six.--The wax was easily applied and smoothed with the knife apparently because it was thick. The knife was warmed intermittently on a hot plate to carry out the procedure. Thiem (c.) styro fill 42.1 also applied easier in areas when it was building to one-quarter-inch thicknesses. Cracking of the top surface of the mold during burn out appeared to be the result of raising the heat too slowly during burn out, resulting in expansion of the thickly applied wax finish which was approximately one-quarter-inch thick. Such evidence pointed toward the need to limit the thicknesses of wax buildup when using techniques described in this study. Expanded polyethylene 9.0 p.c.f. and expanded polystyrene 1.0 p.c.f. were accepted as pattern-making materials.

The cast was smooth and matte-like in texture; however, it was dark and slightly pitted as a result of a too hot (about 1200 degrees Fahrenheit) pour of metal into the mold (see Figure 68, p. 135).

Pattern Seven

The combination of three examples of expanded polystyrene were used for this pattern. This combination was selected to meet the criteria for characteristics of long, slim, and attenuated shapes, flat and rectangular.

Construction of pattern seven.--The pattern consisted of a 9 x 9 x 3/8 inch square plate of expanded polystyrene 2.3 p.c.f. appended to the end of a twenty-four inch curving handle-like section. The handle was made of expanded polystyrene 1.0 p.c.f. A facing piece of one-eighth inch thick mini-cell expanded polystyrene was glued to fit the square shape. A hacksaw blade was used to make the shapes.

Finishing pattern seven.--The face of the square was finished with a coat of epoxy resin. The surface was held level and coated with the fast-setting epoxy. The remainder of the pattern was finished with paper-mâché (see Figure 69, p. 138). Epoxy was used in order to test its capability of producing a slick, smooth surface. The paper-mâché was used in order to test its capability for coating a long and slim surface to produce a soft, smooth surface.

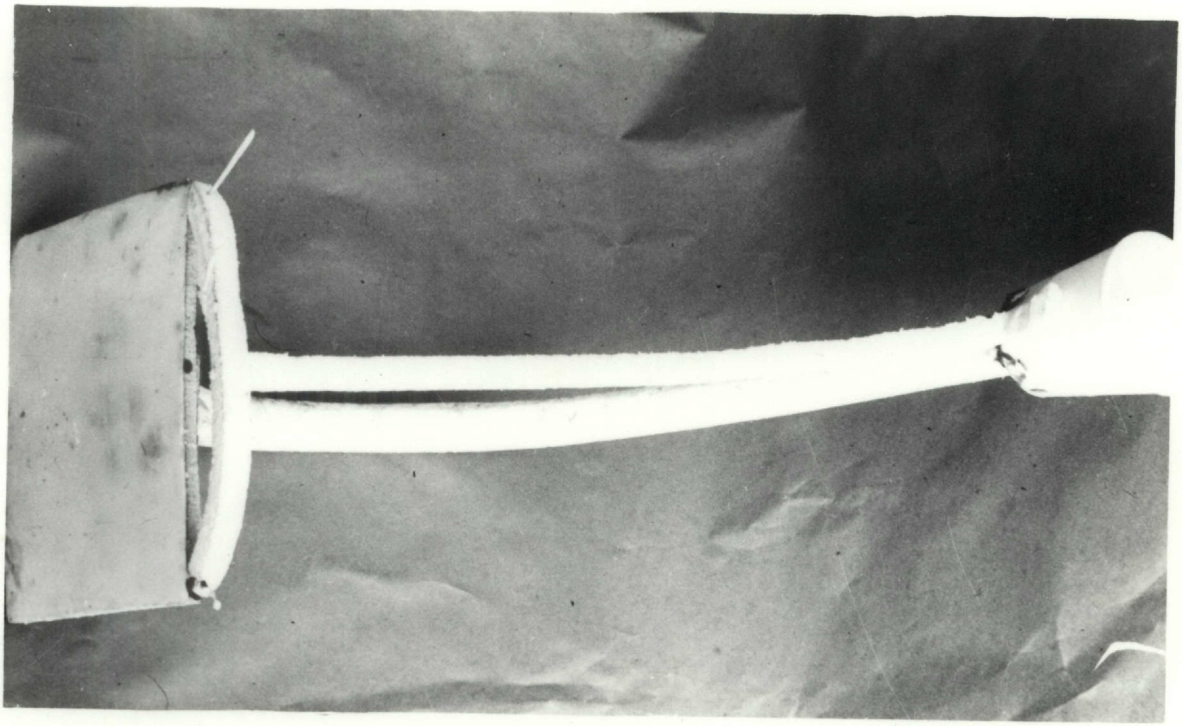


Fig. 69--Finished pattern seven

Fig. 70--Molding of pattern seven

Molding pattern seven.--Vents were constructed from the top of the square to the pouring cup. Expanded polystyrene 1.0 p.c.f. was used for the vent. This gave the pattern more stability during investment since the molding material added considerable weight to the square end shape. The ceramic shell molding material over the vent construction also acted as a strengthening agent after the second and succeeding coatings. Figure 69, p. 138, illustrates the use of the venting system.

In the process of pushing the molded pattern into the slurry during the second dip-coating, the handle-like shape bent slightly as the vent system broke. It was repaired by dipping a strand of Fiberglas (c.) cloth in ceramic shell slurry and wrapping it around the vent and adjacent area of the pattern. See Figure 70, p. 138.

Burning out pattern seven.--The pattern was burned out with a slight variation in the schedule as recorded on Figure 93, p. 208. After burn out, approximately one teaspoon full of black and grey colored ashes fell out. Additional loose ashes were removed by simultaneously applying pressurized air, at approximately forty pounds per square inch, and vacuuming from the pouring cup. The black ashes were thin and brittle. The grey ash was of a sandy consistency. See Figure 71, p. 140.

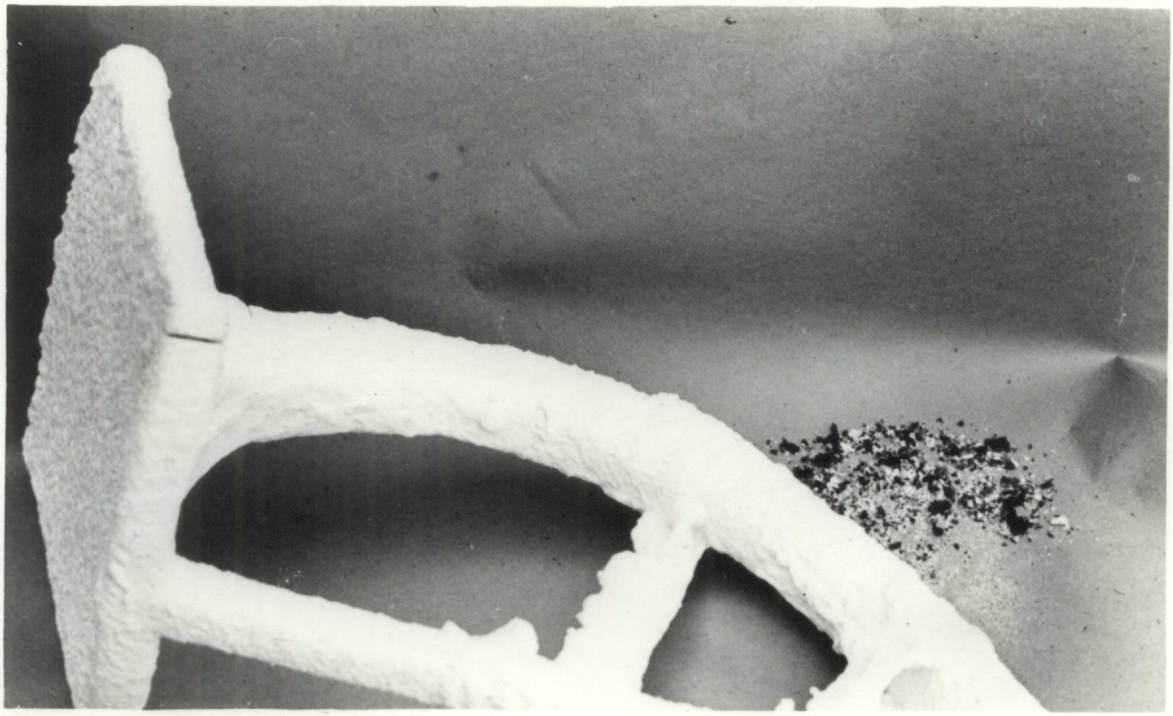


Fig. 71--Mold of pattern seven

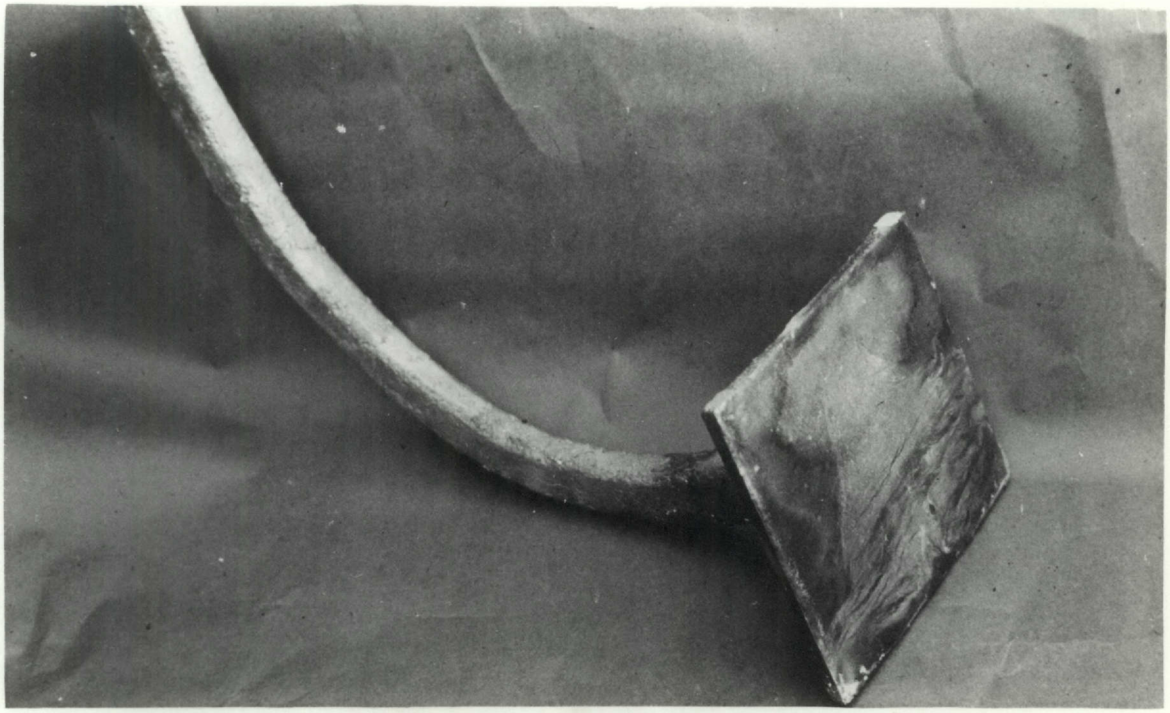


Fig. 72--Cast of pattern seven

Casting pattern seven.--The mold was pre-heated according to the procedures established for the study and then placed in a deep box and lightly packed with sand in order to stabilize it during casting. The cast is illustrated in Figure 72, p. 140.

Findings for pattern seven.--The paper-mâché and epoxy resin were easily applied. The epoxy resin was applied by establishing a perimeter edge and then spreading the epoxy in the center with a knife. The resin was self-leveling. Long, thin shapes of low density polystyrene are not strong enough to resist the pressure of being pushed into the ceramic shell slurry without special care; however, Fiberglas (c.) cloth is reinforcing material which quickly mends any fractures created in the molding process.

After burn out, the black and grey colored ashes remaining in the mold were evacuated with air pressure and vacuuming. The black ashes appeared to be from the paper-mâché used to finish the pattern while the derivative of the fine-grain ashes could not be determined unless they were from the epoxy which was used to finish the flat surface of the pattern. There were no problems in removing the ashes. The casts were clean, bright, and smooth where finished with epoxy. Acquiring such a surface would require application to flat surfaces only. In addition, using the material in order to finish other configurations proved impractical because epoxy is not viscuous until catalyzation begins.

All materials, including the expanded polystyrene 1.0 p.c.f. and 2.3 p.c.f. and mini-cell expanded polystyrene as well as the finishing materials of paper-mâché and epoxy resin were judged acceptable within the scope of the problem on this study.

Pattern Eight

Pattern eight was selected because it combined the use of seven pieces of expanded plastic, including lamination, and further testing for configuration of long, slim, and attenuated shapes, flat and rectangular.

Constructing pattern eight.--The pattern consisted of a twenty-inch long armature with attenuated arms one and one-half inches square, attached to the rectangular base which measured 9 x 11 x ½ inches. The top of the rectangular piece was laminated with a sheet of one-eighth inch mini-cell expanded polystyrene. The armature-like attenuated pieces were made of expanded polystyrene 1.0 p.c.f.; the rectangular base of 3.3 p.c.f. expanded polystyrene. Each was cut with a bandsaw and hacksaw blade. Sections were glued together utilizing match sticks to strengthen the joint.

Finishing pattern eight.--The base was left with the unfinished mini-cell, expanded polystyrene surface. Other surfaces were finished with flour and glue paste (see Figure 73, p. 144).

Molding pattern eight.--Figure 74, p. 145, illustrates the structure of vents which were attached to the pattern. During the molding procedures, the vents were difficult to keep attached or unbroken. The leverage of various lengths of plastic straws against relatively small attachment areas caused breakage or disconnection as slurry and stucco were applied.

Burning out pattern eight.--The pattern was burned out in the manner described above in order to meet the needs of the study. No ash or carbon was apparent. See Figure 93, p. 209.

Casting pattern eight.--After pre-heating, the mold was given extra stability by loosely packing sand around the mold in order to provide adequate control during casting of the pressure of the molten metal against the long, slim, and attenuated mold. The mold was cast in aluminum. Figure 75, p. 146, shows the cast immediately before the mold began to crack loose. Figure 76, p. 146, illustrates the bright, clean cast.

Findings for pattern eight.--The cast was clean and carbon free. The expanded polystyrene 1.0 and 3.3 p.c.f. and mini-cell expanded polystyrene were accepted for pattern-making

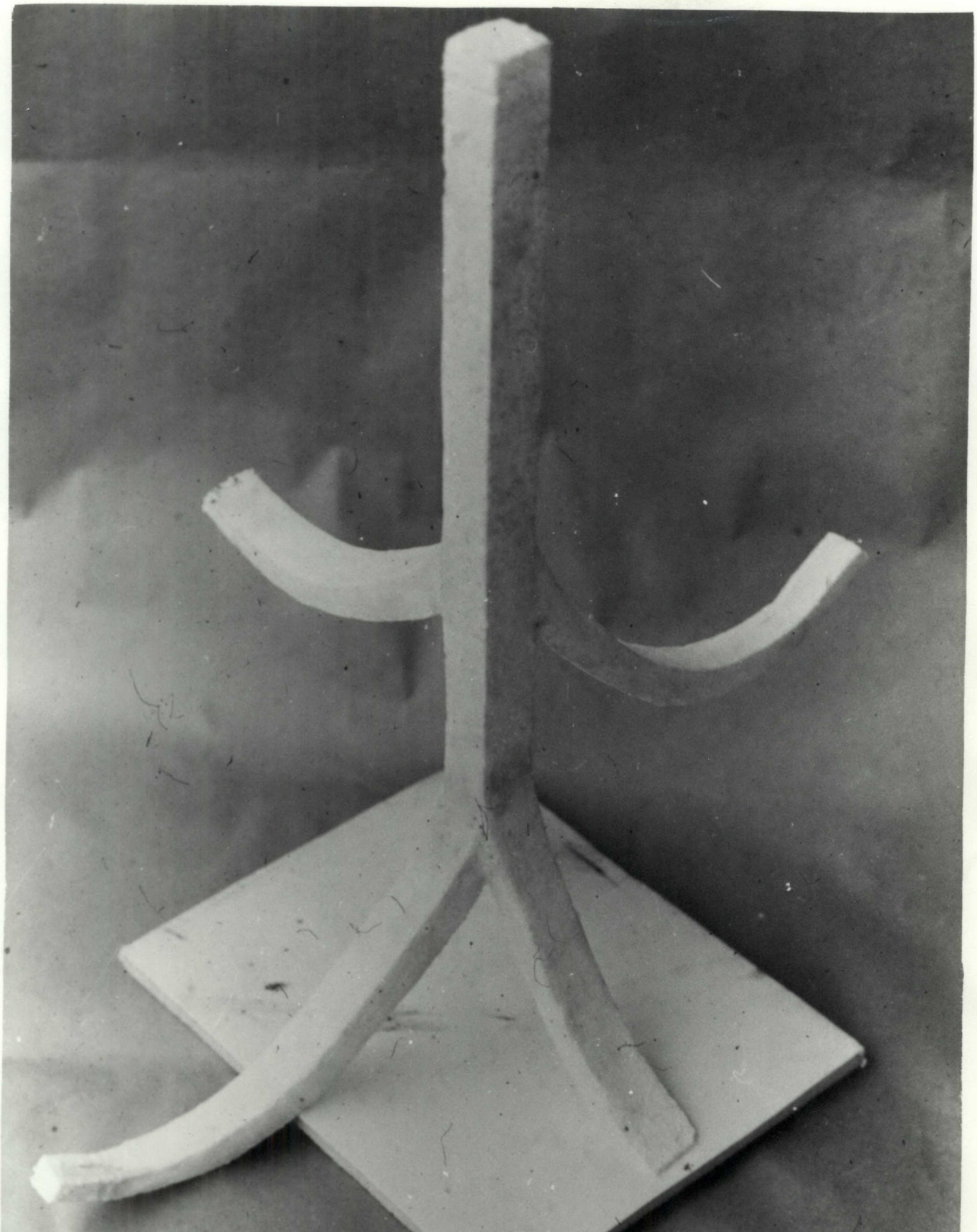


Fig. 73--Finished pattern eight

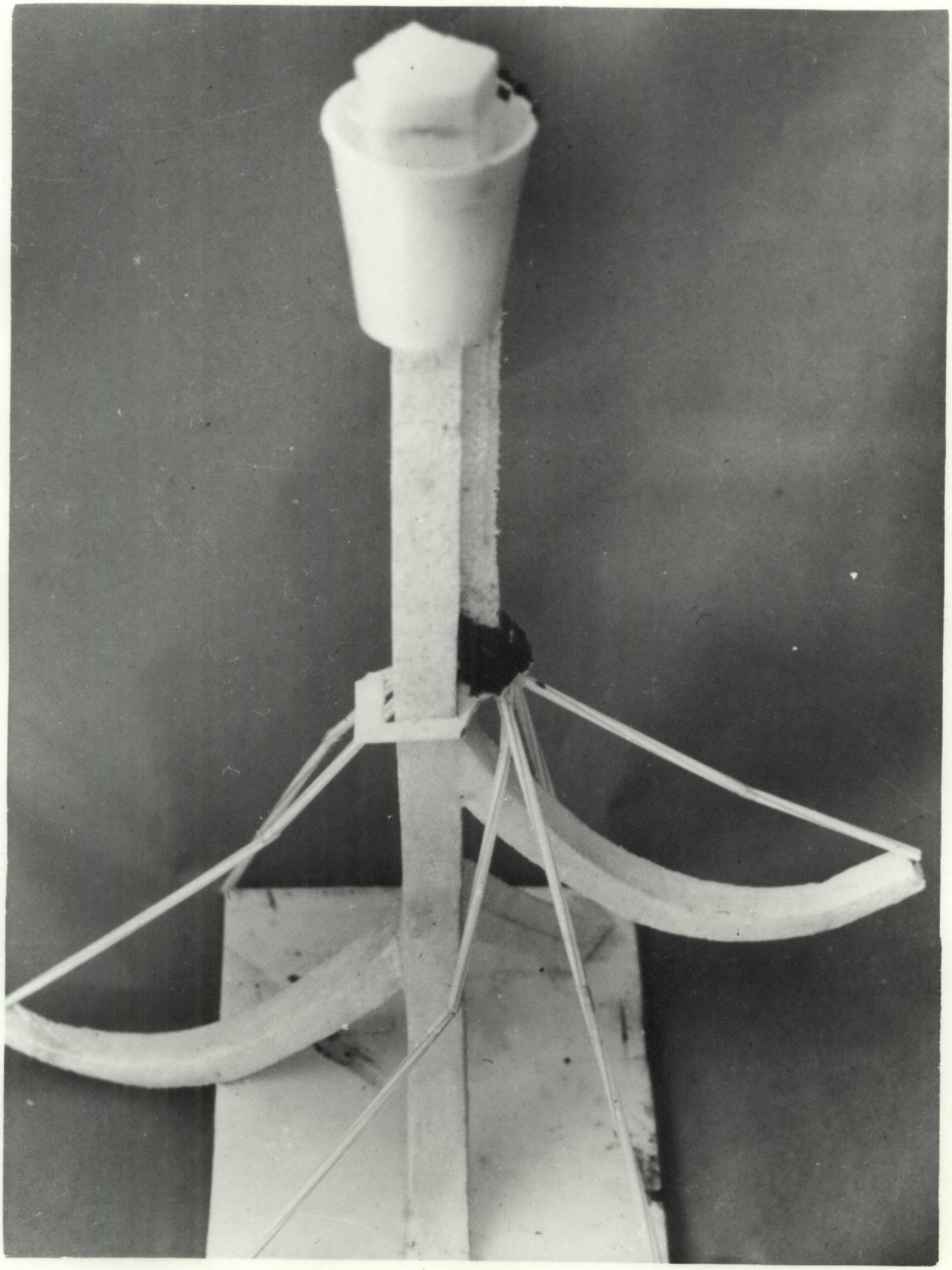


Fig. 74--Gating system for pattern eight

Fig. 75--Cast mold of pattern eight

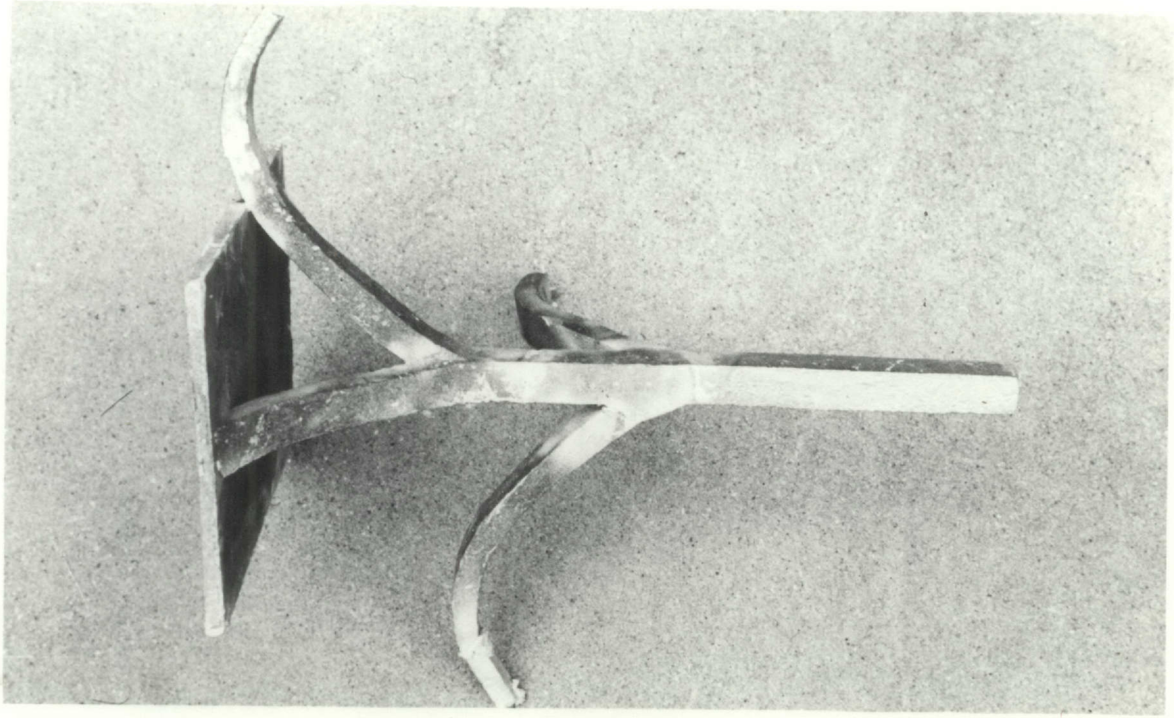


Fig. 76--Cast of pattern eight

materials within the scope of this study, as were the pattern finishing materials of flour and glue paste. Flour and glue paste was again found to be easily applied in two steps: (1) that of heaping areas onto the pattern and (2) that of smoothing the material with a wet knife. The surface differences created by the mini-cell polystyrene and flour and glue paste were apparent. The former material resulted in a matte-finish; flour and glue paste, which shrank on the pattern when dried, resulted in a smoothly, pock-marked surface.

Pattern Nine

Four pieces of expanded plastic employed for packing were used for pattern nine. The pattern was selected in order to meet the criteria for selection of patterns incorporating wide and curved shapes which were varied in thickness.

Construction of pattern nine.--Curved sheets of expanded polystyrene 1.8 p.c.f. one-fourth-inch thick were cut on a band saw and glued to the two vertical side pieces which were about three-eighths of an inch thick. A one-half-inch thick brace of expanded polystyrene 3.3 p.c.f. was added to keep one end of the curved sheet flat. The back side was open (see Figure 77, p. 148).

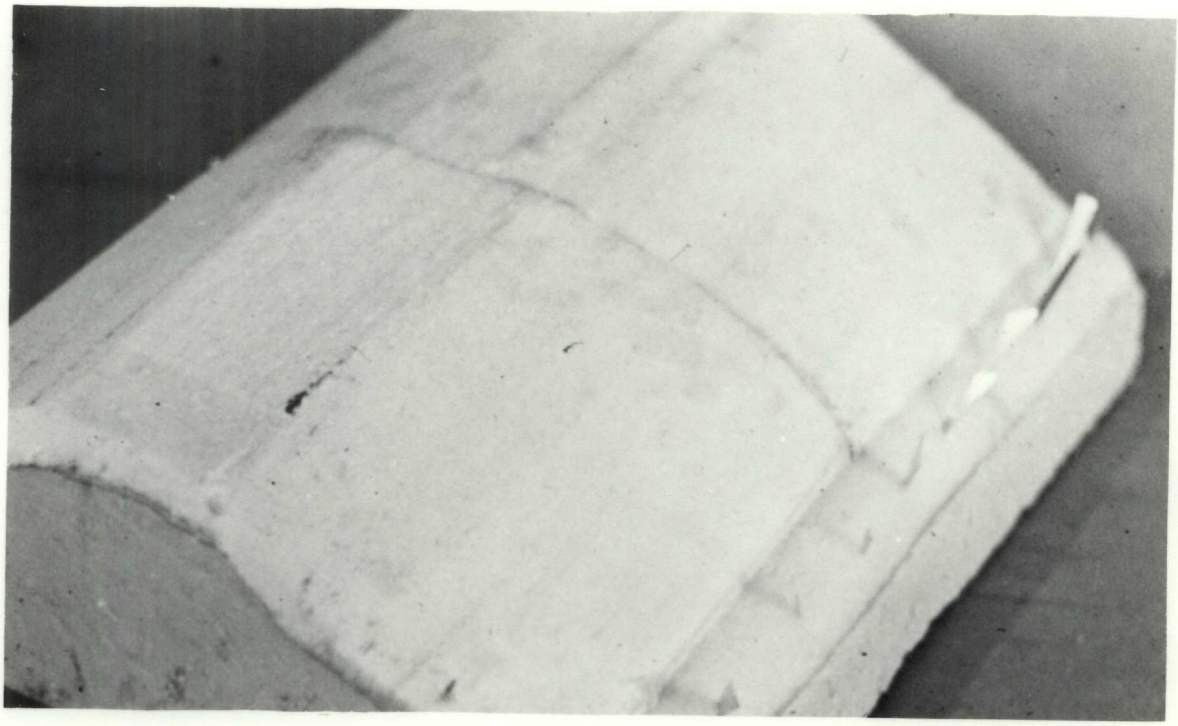


Fig. 77--Constructing pattern nine

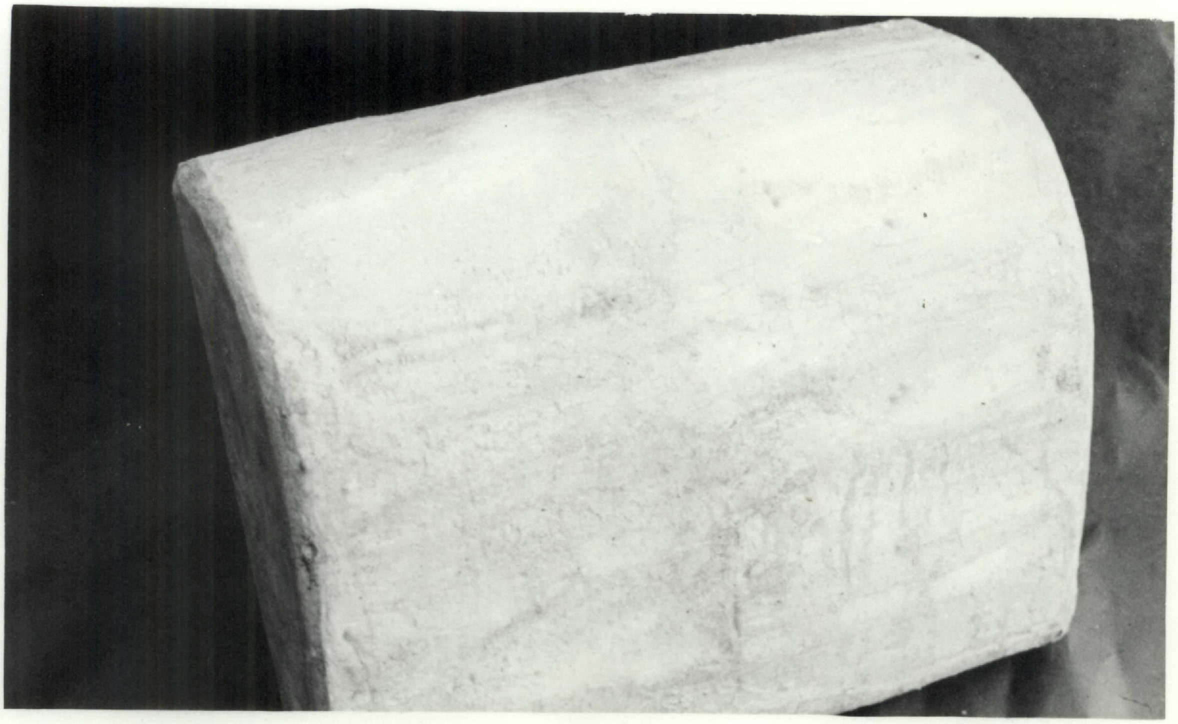


Fig. 78--Finished pattern nine

Finishing pattern nine.--Thiem (c.) styro fill 42.1 was used to fill and finish the surface in order to test the quantity of this material. The pattern is illustrated in Figure 78, p. 148. The sides and back were filled with a light coating of microcrystalline wax because of its ease of application. The Thiem (c.) styro fill 42.1 began to hair check, i.e., minutely crack, as it dried.

Molding pattern nine.--A heavy feeder was placed in the back in order to assist in distributing the charge of metal to the wide flat areas of the pattern during casting (see Figure 79, p. 150).

Burning out pattern nine.--The mold was burned out following the procedures established for this study (see Figure 93, p. 210). When the second phase of burning out temperature reached 550 degrees Fahrenheit, smoke was observed rising from the top of the furnace which indicated excess styrene was being burned.

Casting pattern nine.--The mold was pre-heated and cast with aluminum. The cast is illustrated in Figure 80, p. 150.

Findings for pattern nine.--The surface of the cast was clean with a matte finish. The expanded polystyrene 1.8 and 3.3 p.c.f. used in constructing the pattern and finishing materials of Thiem (c.) styro fill 42.1 and microcrystalline wax were judged acceptable within the limitations of the

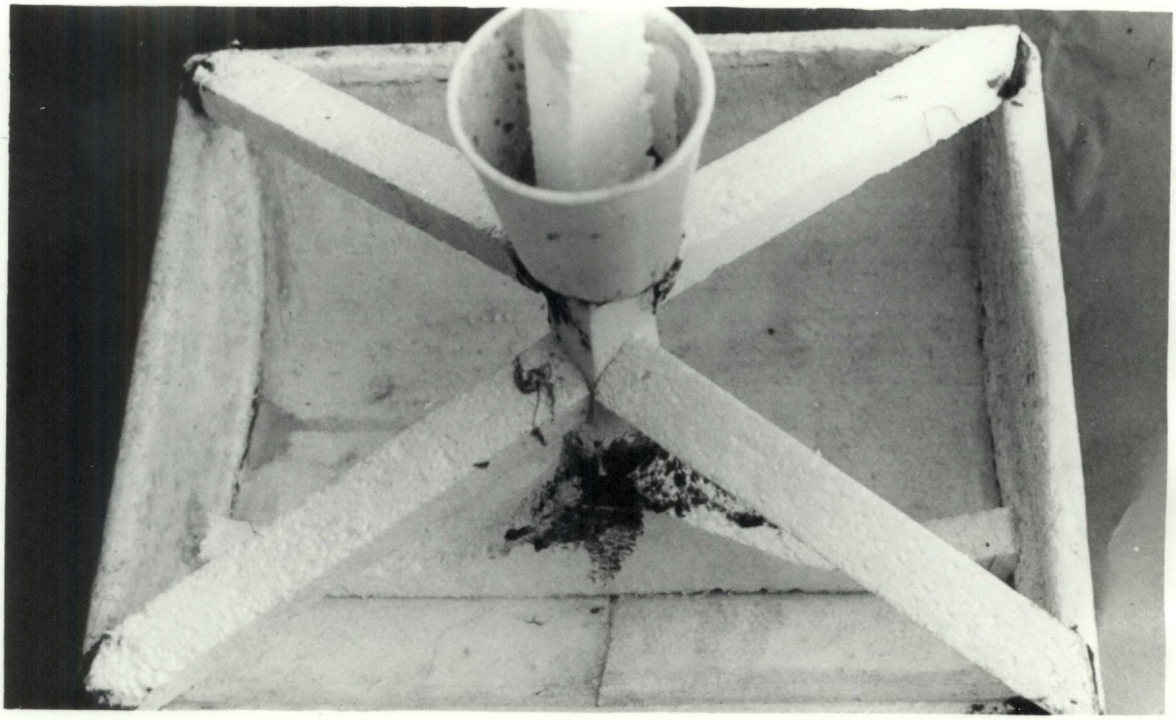


Fig. 79--Gating system of pattern nine

Fig. 80--Cast of pattern nine

problem. The Thiem (c.) styro fill 42.1 produced a raised hair-line network effect, apparently as the result of being applied too heavily, i.e., up to approximately one-fourth-inch thick. The wax was easily applied with a knife; however, no attempt to achieve a smooth surface was made.

Pattern Ten: Trial 1

Pattern ten was tested twice in order to examine more fully the use of burlap as a finishing material. The pattern was constructed of three sections which were glued together in order to form an open-topped bell shape. The pattern required lamination and was selected as representative of wide, curved patterns which were varied in thickness and met the pattern requirements of the study.

Constructing pattern ten: trial 1.--Three curved pieces of expanded polystyrene 1.0 p.c.f. with average dimensions of 13 x 6½ inches were cut with a band saw to make this pattern 14 x 14 x 18 inches. Each piece was approximately three-fourths of an inch thick at the top, gradually coming to a thin edge at the bottom. Two pieces could not be made to curve enough without gluing additional plastic to the center section to permit a deeper, concave back and convex front to be formed by rasping and sanding (see Figure 81, p. 152). The three pieces were glued together after finishing.

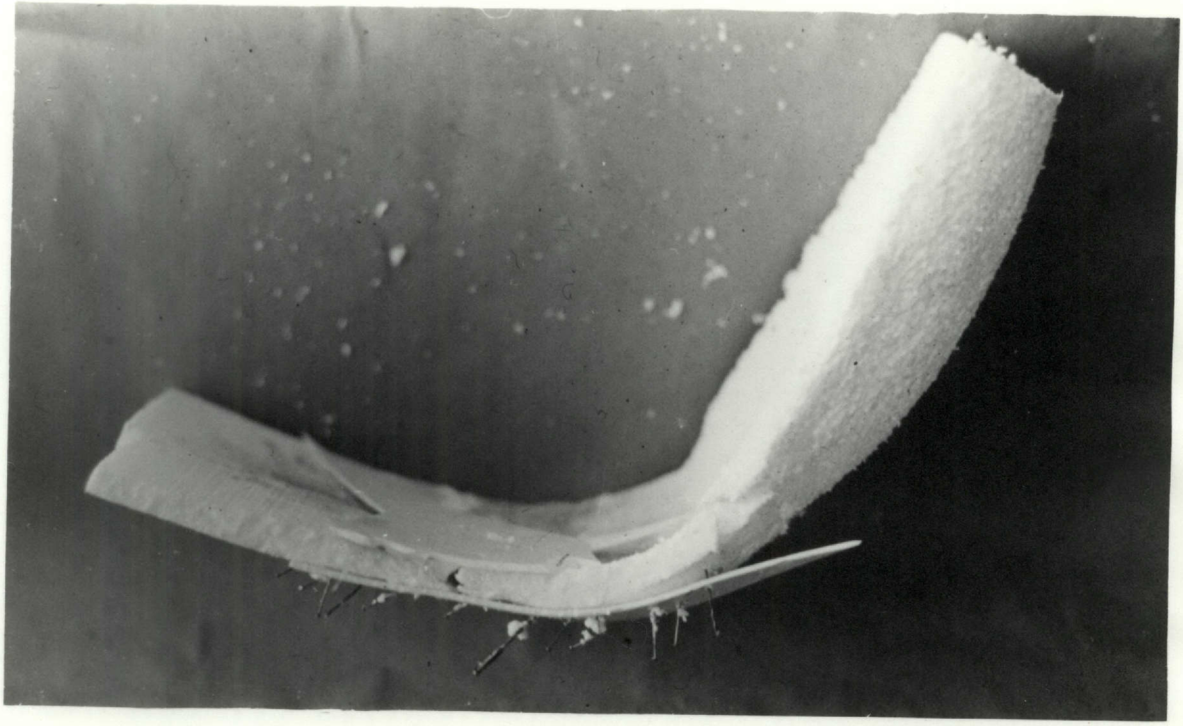


Fig. 81--Constructing pattern ten: trial 1

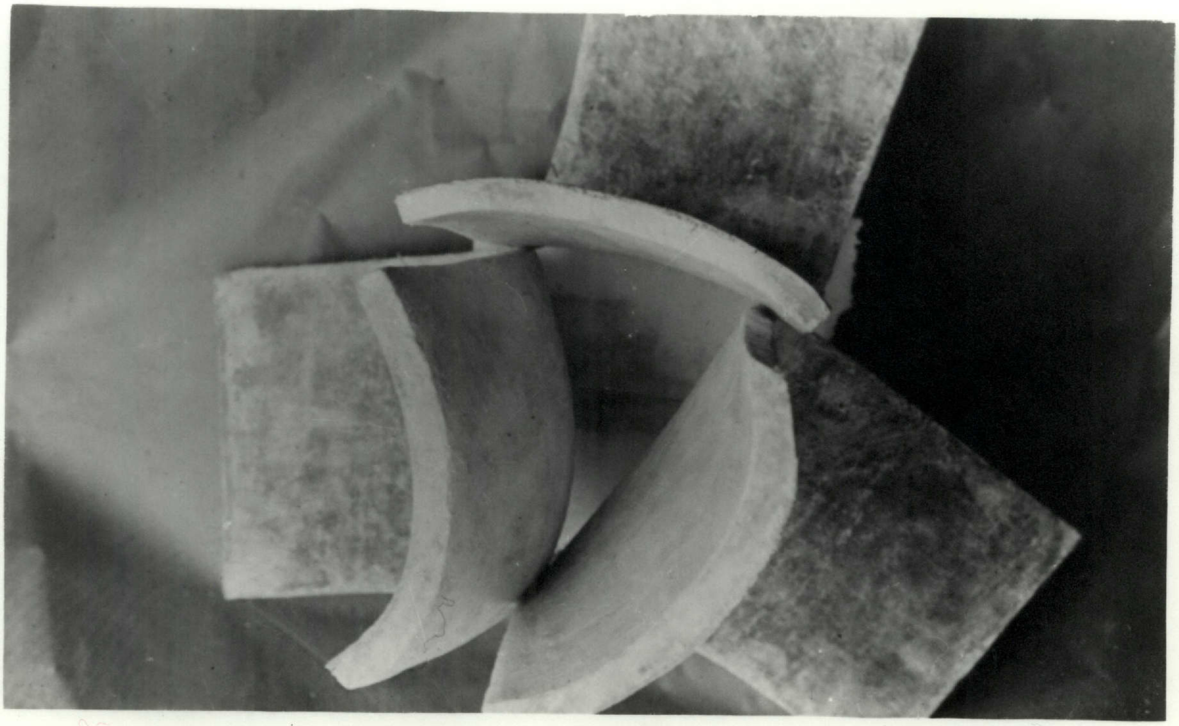


Fig. 82--Finished pattern ten: trial 1

Finishing pattern ten: trial 1.--The bottom outside surface of the three flaring sections was finished with burlap adhered with glue. The inside and top part of the bell shape was finished with Thiem (c.) styro fill 42.1 in order to develop an easy transition from the top smooth surface to the bottom burlap-textured surface. These two finishing materials were used to contrast the different qualities such pattern materials might effect in the casting. The illustration, Figure 82, p. 152, illustrates a top view of the pattern.

Molding pattern ten: trial 1.--The pattern was prepared with polystyrene vents and gating system, except for the risers on the bottom side, in accordance with the procedures described for the study. These curved parts of the gating system were made with cylindrical sections of polyethylene 9.0 p.c.f., as illustrated in Figure 83, p. 154. During this molding process, the material was easily bent and adaptable for risers and furnished a natural flow of the metal.

Burning out pattern ten: trial 1.--The pattern was processed in the prescribed manner, with the exception that there was an attempt to blow the mold out after burn out with about forty pounds of pressure per square inch of air in order to eliminate loose ashes. There was approximately one tablespoon of ashes evacuated from the mold. Figure 93, p. 211,

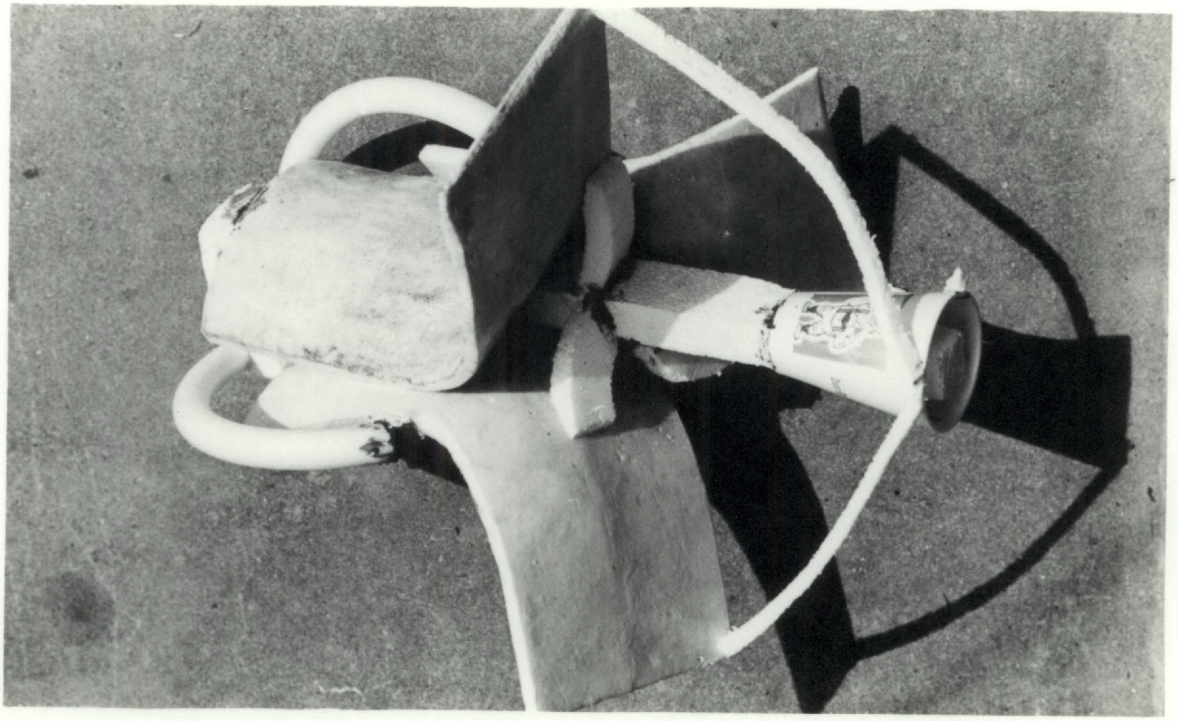


Fig. 83--Gating system for pattern ten: trial 1

Fig. 84--Detail of cast ten: trial 1

indicates a slightly irregular burn out. The irregularity was not considered significant.

Casting pattern ten: trial 1.--The mold was pre-heated and cast in aluminum as required for the study.

Findings for pattern ten: trial 1.--Burlap was easily glued to the expanded polystyrene surface. Thiem (c.) styro fill 42.1 was easily applied to the burlap and plastic surfaces. The pattern was smoothed at the top by using sandpaper.

The casting revealed, however, that there were several areas of the pattern where the burlap had slightly charred and remained attached to the mold surface as shown in Figure 84, p. 154. In these areas, the metal was occluded and/or the surface poorly textured; i.e., not textured as was the pattern. Figure 85, p. 156, illustrates the cast before removal of the gating system. The surfaces which were burned out revealed an apparent contrast in texture. The pattern construction material of polystyrene 1.0 p.c.f. and finishing material, Thiem (c.) styro fill 42.1 were judged acceptable within the scope of the problem.

Pattern Ten: Trial 2

A re-trial of pattern ten was suggested by the poor burn-out results of pattern ten: trial 1. The pattern selected was also wide, curved, and varied in thickness. This

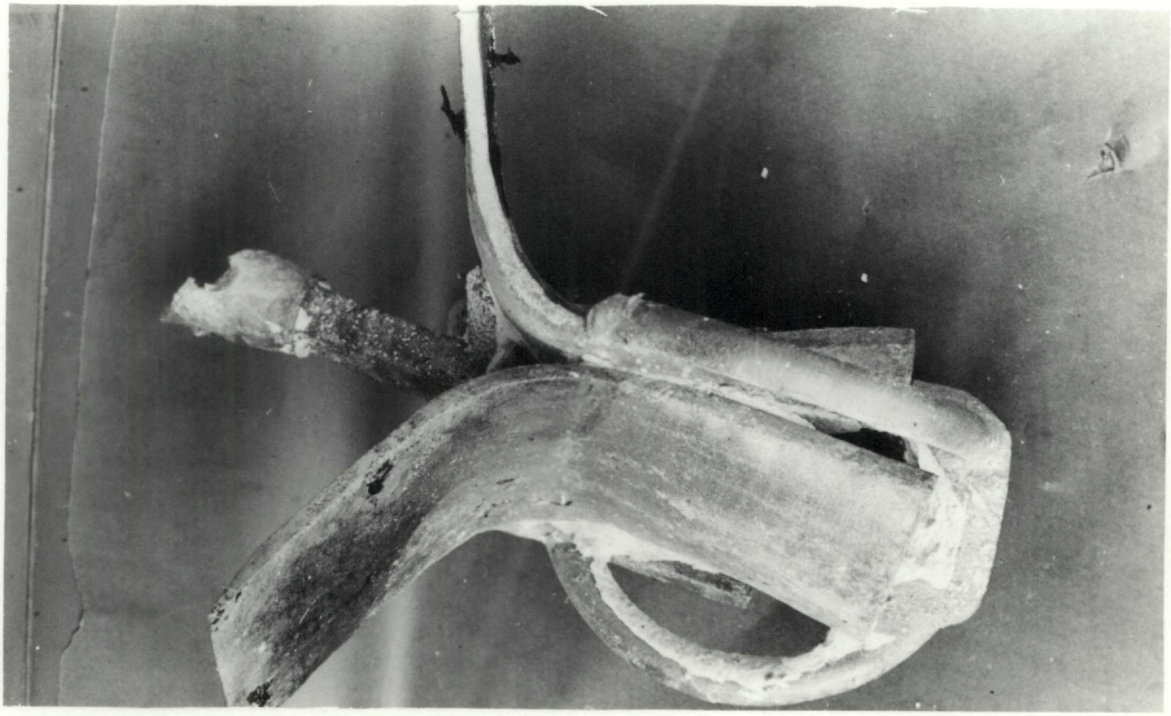


Fig. 85--Cast of pattern ten: trial 1

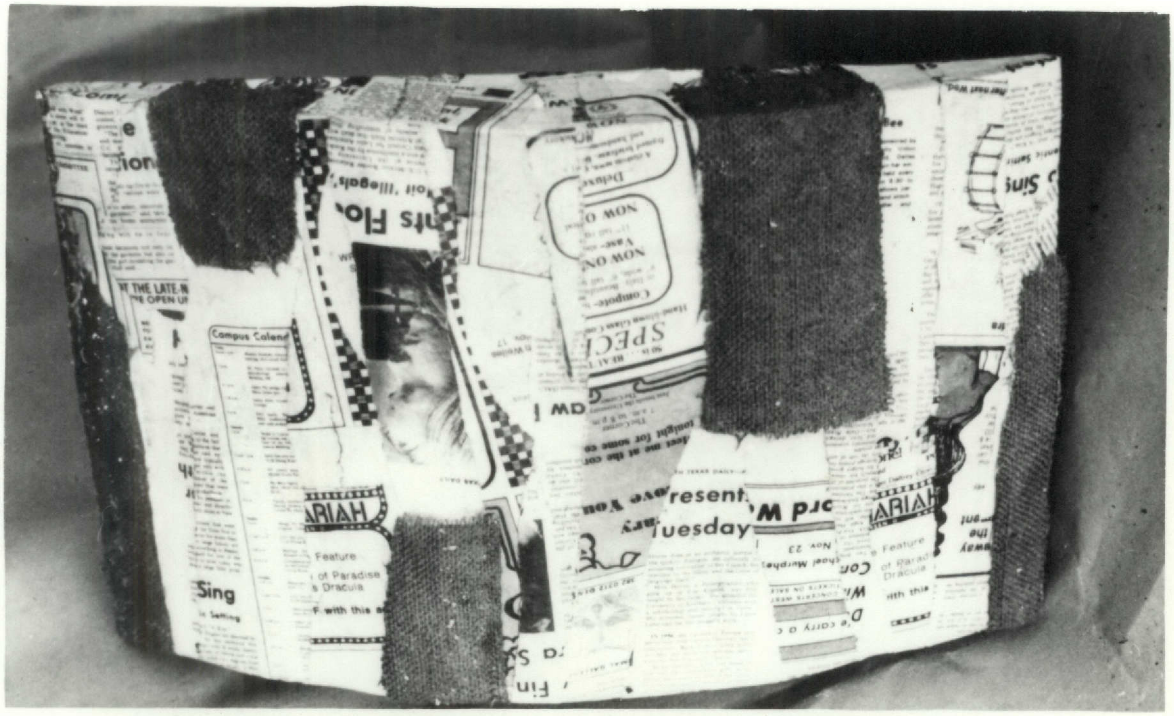


Fig. 86--Finished pattern ten: trial 2

pattern also consisted of three sections glued together. Both criteria met the requirements of the study.

Constructing pattern ten: trial 2.--Three pieces of expanded polystyrene 1.0 p.c.f. were cut on a band saw, one-fourth-inch thick for the curved top and one-half-inch thick at the sides. A one-inch wide feeder was built into the pattern in order to facilitate casting the thin, wide surface. The dimensions were 12 x 19 x 3½ inches.

Finishing pattern ten: trial 2.--The top surface of the pattern was finished with strips of paper-mâché and varying sizes of rectangular shaped burlap, glued at intervals shown in Figure 86, p. 156. Elmer's (c.) glue was used to adhere the burlap pieces. The small pieces of the burlap and paper-mâché were used in order to vary the surface while meeting the criteria for the study.

Molding pattern ten: trial 2.--The pattern was furnished with the gating system affixed to the back (see Figure 87, p. 158). Burlap surfaces were given heavy washes of vinyl floor wax to prevent the ceramic shell slurry from embedding itself in the weave of the cloth.

Burning out pattern ten: trial 2.--Figure 88, p. 158, shows the pattern being blown out with forty pounds per square inch of air pressure while simultaneously being vacuumed. About one teaspoon full of grey and black ashes

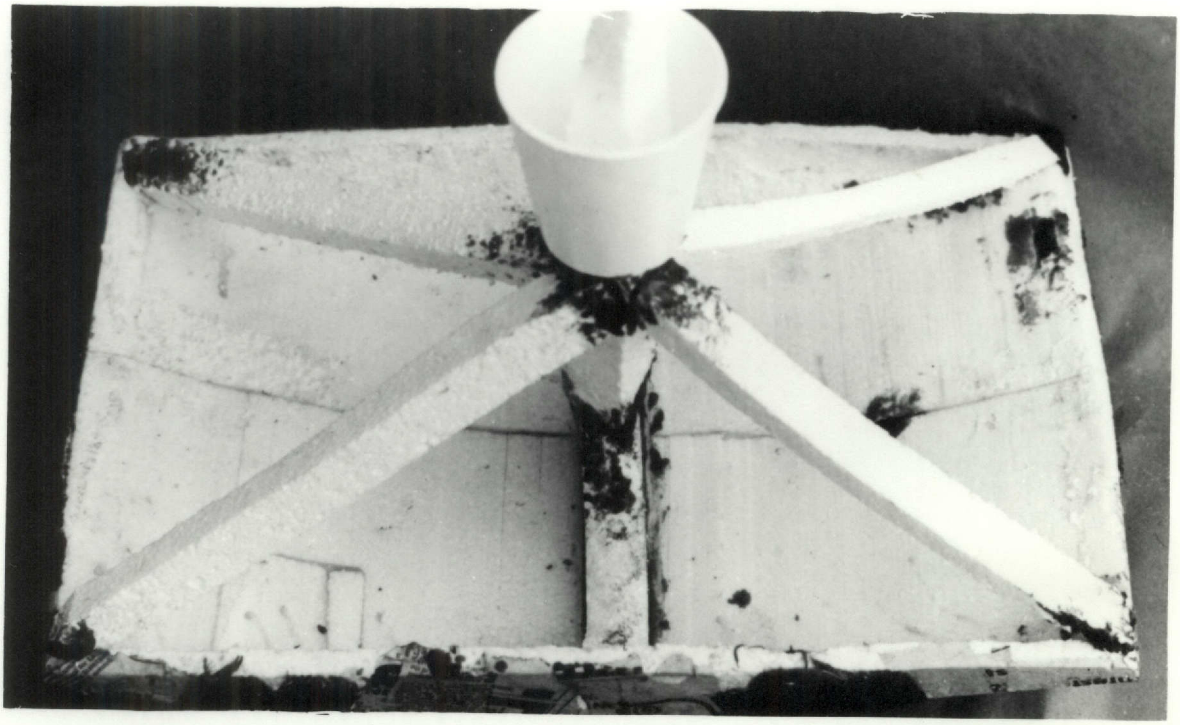


Fig. 87--Gating system of pattern ten: trial 2

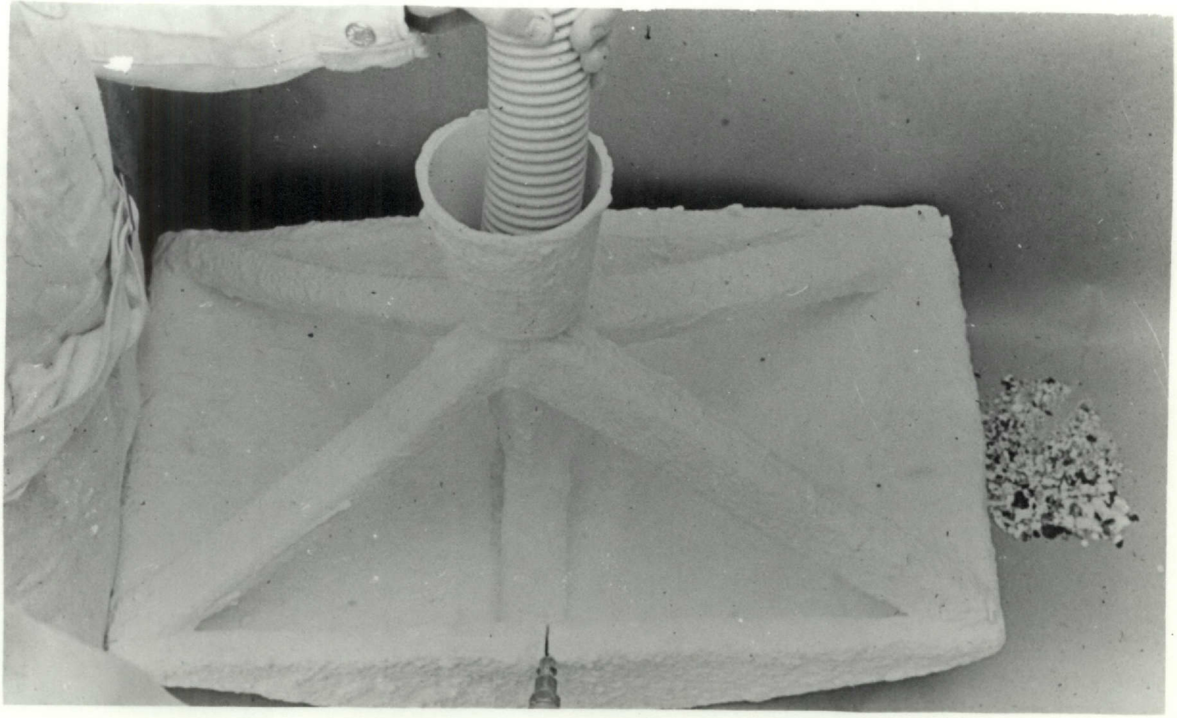


Fig. 88--Burned out pattern ten: trial 2

shaken from the mold are shown on the right side of the illustration. See Figure 93, p. 212.

Casting pattern ten: trial 2.--The mold was pre-heated and cast in aluminum. Figure 89, p. 160, shows the cast mold immediately after casting. The cast appeared as illustrated by Figure 90, p. 160. Figure 91, p. 161, illustrates the cast.

Findings for pattern ten: trial 2.--Both burlap and paper-mâché were easily applied. The burlap was sealed with a heavy coating of vinyl floor wax. There was evidence of about one teaspoon full of black ash after burn out which was vacuumed and evacuated by air pressure of about forty pounds per square inch.

The surface differences were apparent in the contrast of the flat smooth areas against the rough burlap textured areas; however, there were small occlusions in the casting in the areas of the burlap texture as illustrated in Figure 92, Detail of cast ten: trial 2, p. 161. Apparently the floor wax had failed to seal small areas of the burlap surface and permitted the ceramic shell slurry to impregnate the burlap material thus making those areas mold surfaces instead of pattern surfaces and leaving the irregular impressions in the cast.

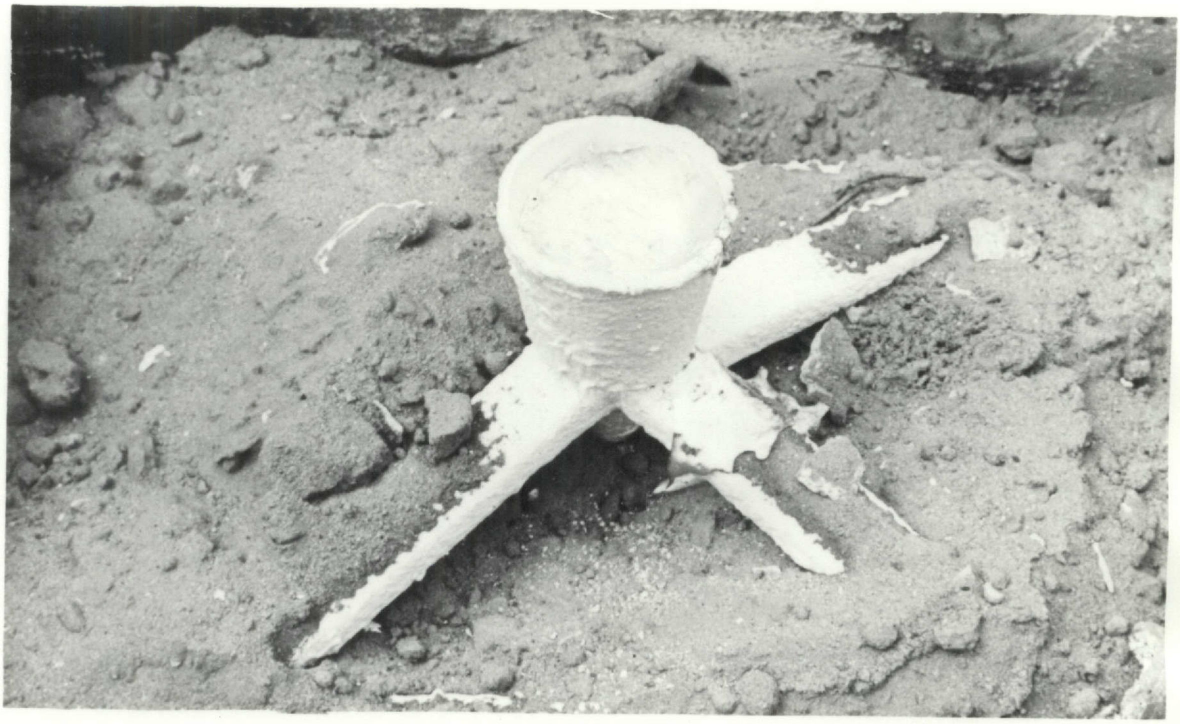


Fig. 89--Casting mold ten: trial 2

Fig. 90--Cast of pattern ten: trial 2, emerging from mold

Fig. 91--Cast of pattern ten: trial 2

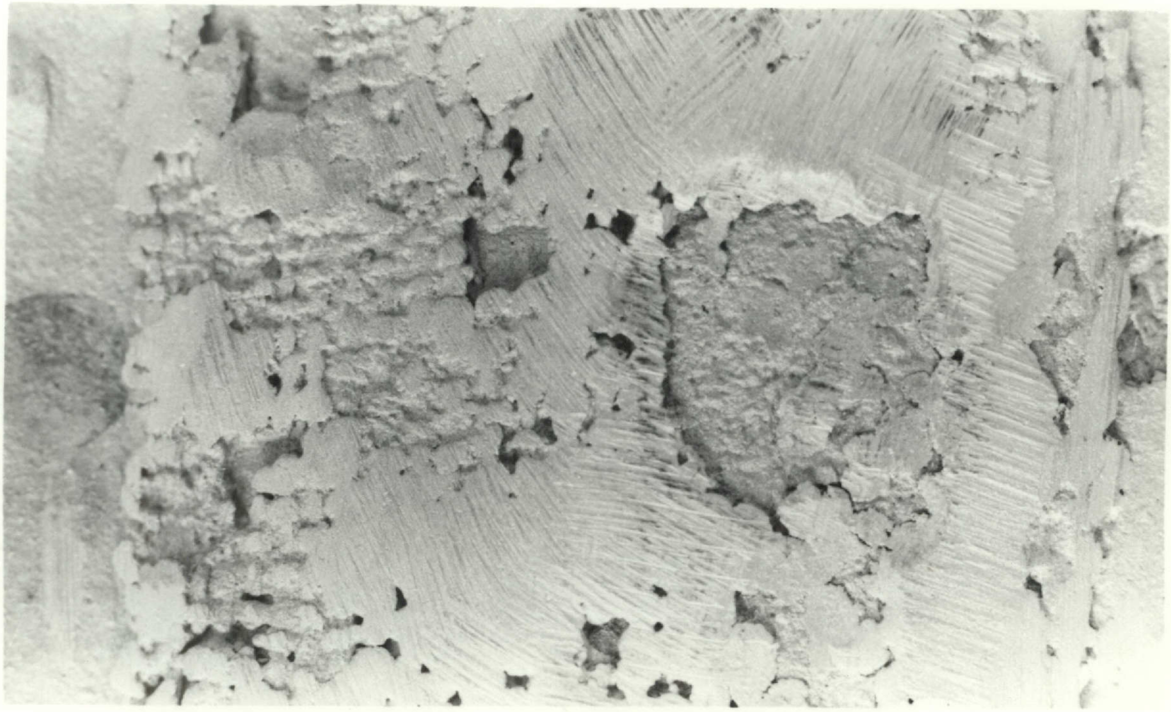


Fig. 92--Detail of cast ten: trial 2

The expanded polystyrene 1.0 p.c.f. and paper-mâché were accepted within the scope of the study. Burlap was not judged acceptable as used in the study.

CHAPTER V

ANALYSIS OF THE DATA

Results of the ten main tests presented in Chapter IV are shown in Table V, p. 164. Variables of particular relevance in this study, as indicated in the first column of Table V, were those of configuration, materials and their densities best indicated by p.c.f. Variables which were judged of secondary importance were those of construction, including number of pieces required to make up a pattern, finishing, and special preparations such as coring and venting. The third order of variables in consideration of effects upon the overall study were those of molding and burn out. The latter two were, in fact, not so much variables as techniques which may fluctuate in the normal course of practice of the established procedure for each. The molding techniques were done by hand; variations in thicknesses which may have occurred due to the slurry mixtures, viscosity and humidity, were not measured. Each pattern was given five coats of ceramic shell slurry and four coats of silica stucco under normal sculpture studio conditions. The first coat of slurry was stuccoed with fine-grain silica, the second through fourth coats of slurry were stuccoed with medium-grain silica, and the fifth coat of

TABLE V

COMPARISON OF MATERIALS, TECHNIQUES, AND FINDINGS

Variable	Pattern Number										
	1	2	3	4	5	6	7	8	9	10: 1	10: 2
Configuration	d	d	c	c	a	a	b	b	e	e	e
Materials and p.c.f.	g 1.0	g 1.0	g 1.0 1.3	g 1.0 h	f9, g 1.0	f9, g 1.0	gl, 2.3 h	gl, 3.3	g 1.8 3.3	g 1.0	g 1.0
Construction and Pieces	j 2	j 1	j 3	j,k 3	j 3	j 2	j,k 3	i,j 7	i,j 4	i,j k,3	i,j 3
Finishings	o,q	o,t	r,s	l,s	p,t	s,t	n,r	l,o	s,t	m,s	m,r
Preparations and Vents	0	2	0	1	u 1	u 0	2	5	0	3	0
Molding	v	v	v	v	w	w	v	v	v	v	v
Burn Out	v	v	v	v	v	v	v	v	v	v	v
Casting	y	y	y	y	y	y	y	y	y	x,z	z

Configuration Variables

[a] large, voluminous, and organic

[b] long, slim and attenuated, flat and rectangular

[c] organic, varied in thickness

[d] small, irregular

[e] wide, curved, and varied thickness

Materials

[f] expanded polyethyle

[g] expanded polystyrene

[h] mini-cell, expanded polystyrene

Construction and Number of Pieces

[i] band saw

[j] hack saw blade

[k] laminated

Finishing Materials

[l] unfinished

[m] burlap

[n] epoxy resin

[o] flour and glue

[p] polyethylene film

[q] polyester resin

[r] paper mâché

[s] Thiem (c.) styro fill 42.1

[t] microcrystalline wax

Preparations and Number of Vents

[u] core pins used

Molding

[v] average conditions

[w] cored after initial burn out

Burn Out

[v] average conditions

Casting

[x] ashes present

[y] bright or clean

[z] Occlusions

slurry was not stuccoed. As indicated by the table, there were no pronounced fluctuations in molding procedures or results nor in the burn-out schedule established for the study. The burn-out temperatures and times were recorded on burn-out charts, Figure 93, p. 202. The patterned molds were vaporized by placing them in a furnace and gradually raising the temperature of 500 degrees Fahrenheit over a period of one and one-half hours. Subsequently the temperature was raised to 800 degrees Fahrenheit in thirty minutes and 1000 degrees Fahrenheit in fifteen minutes before sintering the molds at 1200 degrees for thirty minutes. The last item on the table, cast, was itself a test of the complete study. Any variations from brightness or cleanness in casts reflected problems in the ability to mold the expanded plastics and/or finish with materials tested, or it indicated the inability to burn out these materials leaving a clean mold necessary for clean castings.

Configuration and material for patterns were judged to be of particular importance to this study because of the apparent increase of burn-out failure existing in the pilot study when pattern sizes were increased. The ten patterns tested using the vaporization/burn out method were perhaps not exhaustive of configurations possible in sculpture, but they were extremely varied in overall size, thickness, volume, and length, within the range of three to twenty-four inches, which is probably within the range of the average pattern size cast in ceramic shell. The materials used to construct the patterns for the study were also quite varied but were kept within the limits of expanded polyethylene and polystyrene of medium and low density, respectively. The pilot study had indicated expanded polyurethane and polyvinyl chloride with nitrile rubber samples used in that test would not be consistently successful when the vaporization/burn-out technique with the scheduled temperatures and times established for this study was employed.

Results indicated that small and irregular patterns such as one and two made of low density (1.0 p.c.f.) expanded polystyrene were successfully burned out and cast, producing bright and clean castings. Pattern one was easily made from two pieces of expanded polystyrene shaped by a hacksaw blade and glued together. Flour and glue paste, among the most difficult finishing materials to apply, burned out well, contributing to the clean and bright cast. Polyester resin was used only once in this study. Its effects on the pattern produced a clear textured variation of the plastic's surface when broken apart. The pattern was not vented.

The four forms of pattern set two were also easily shaped each from one piece using the hack saw blade. Again, flour and glue paste were used to produce a pocked surface which contrasted with the slick wax surface. The latter material is easy to apply but difficult to smooth using a knife. Two of the patterns were vented; two were not.

Vents were considered more important for casting into corner pockets than for burn out.

Patterns three and four, both organic shapes, varied in thickness, were also made from expanded polystyrene of low density. Both castings were clean and bright, indicating pattern and finishing materials burned out successfully. Densities of 1.0 and 1.3 were used to make three shapes cut with a hack saw blade and glued together to make pattern three. The finishing material of paper-mâché and Thiem (c.) styro fill 42.1 were easily applied. It was necessary to vacuum the paper-mâché ashes from the mold before casting. No vents were used. Pattern four was also made of three pieces of expanded plastic glued together, including 1.0 p.c.f. and mini-cell expanded polystyrene. The mini-cell material was laminated to the hack saw shaped pieces. Thiem (c.) styro fill 42.1 was easily applied with a palette knife. The mini-cell material was left unfinished. The pattern received one vent which assisted in filling the mold when casting.

Large, voluminous, and organic shapes were used for patterns five and six. These patterns, although not identical, were made in similar confirmations from a piece of expanded polyethylene of medium density (9 p.c.f.) and a second piece of low density expanded polystyrene of 1.0 p.c.f. shaped with a hack saw blade. The only use of polyethylene film for finishing was tested on pattern five. It had unique qualities of slickness but is limited perhaps by its flatness and the problem of disguising the edges of the material when draped over organic shapes. Both patterns were also partially coated with microcrystalline wax. Pattern five was vented, and pattern six was not. When burned out, pattern six cracked across the top, apparently resulting from a too thick (approximately 1/4 inch) application of wax finish. After burn out, both patterns were slush-patterned with wax, cored with ceramic shell and burned out by the shock burn-out method. Cast five was slightly dark but clean and carbon free. Cast six was clean and matte in texture.

Numbers seven and eight were long, slim, and attenuated, flat and rectangular patterns. Both produced excellent castings as shown on Table V. Pattern seven was made of three pieces of expanded polystyrene shaped with a hack saw blade consisting of pieces of 1.0 and 2.3 p.c.f. with mini-cell expanded polystyrene laminated to the face surface. The pattern received the only application of epoxy resin used in the study; it was easily applied to the flat face surface. The remaining surface was finished with paper-mâché. It was necessary to vacuum the paper-mâché ash from the mold before casting while the remainder of the pattern was finished with flour and glue paste. Five vents were used which also strengthened the pattern while molding and assisted in casting triangular pocket areas.

Wide, curved, and varied thicknesses characterize the configurations of patterns nine and ten, trials 1 and 2. All were made with low density expanded polystyrene, shaped by band saw and hack saw blade. Pattern nine was from three pieces of 1.8 and one piece of 3.3 p.c.f. material, glued together. It was finished with Thiem (c.) styro fill 42.1 wax. The wax surface crazed from relatively thick application when drying. The cast was clean. Pattern ten, trials 1 and 2, although different in confirmation were made from three pieces of 1.0 p.c.f. expanded polystyrene. Trial 1 was constructed by laminating small sections of the material to larger sawed shapes. Both patterns were finished with burlap, and in addition trial 1 was also finished with Thiem (c.) styro fill 42.1 and trial 2 with paper-mâché. Trial 1 was vented in three places; trial 2 was not vented. As the table shows, the cast of trial 1 revealed occlusions in the cast and ashes from burlap material. The mold for trial 2 was vacuumed, but the cast was blemished by occlusions, apparently resulting from undermining of the finish material by the ceramic shell slurry while investing.

Generally, the table indicates the vaporization/burn-out procedure is a workable process using the molding techniques established for this study in making sculptural forms from expanded plastics finished with readily available commercial products and household items. Specifically, expanded polyethylene of medium density and expanded polystyrene of low density was judged acceptable pattern-making materials. Expanded polystyrene is more rigid than expanded polyethylene and therefore more useful since it does not need an armature to function as a pattern. Both materials are easily tooled and finished; however, expanded polyethylene's lack of rigidity is perhaps its greatest asset. It can be molded around expanded polystyrene, bent and curved in a unique fashion which could facilitate making soft, organic or flowing surface contours not as easily achieved by the more rigid material. The mini-cell variety of expanded polystyrene used in this study facilitated acquiring flatened surfaces which required less finish than either of the other two materials. The matte quality produced satisfactory matte metal surfaces. There appeared to be no problem with the size or volumes of patterns made from these two expanded plastics; however, the piece of expanded plastic which dropped out of the mold in the process of burning out pattern six indicates the large volume of pattern material had not vaporized at the end of one hour and when the temperature had reached 400 degrees Fahrenheit. Perhaps with increase of pattern size or volume, problems in burn out will develop. Other investigators will perhaps be able to determine if larger sizes and volumes present problems. They may also be able to find other expanded plastics which will add to the versatility of the two expanded plastics investigated as pattern-making material in this study.

The finishing materials used in this study were also judged acceptable, except for burlap cloth. Burlap cloth was not completely consumed in the mold for pattern ten, trial 1. Noticeable occlusions resulted in pattern ten, trial 2, apparently from the penetration around and through the cloth's weave by the ceramic shell molding material. As Table V, p. 164 shows, casts for patterns one through nine were clean or bright. Such appearance may depend upon proper casting procedure but is more directly the result of burn out of the pattern finishing materials. Epoxy resin and polyethylene film produced the optimum smoothness of surface. Both require special circumstances for application as previously discussed. Paper-mâché, microcrystalline wax, and Thiem (c.) styro fill 42.1 were the easiest applied. All produced comparably smooth but not shiny surfaces; paper-mâché and Thiem (c.) styro fill 42.1 were sanded and waxed; the wax was smoothed with a knife. Flour and glue paste requires somewhat more effort to apply and shrinks while drying, but does produce a uniquely pocked surface when used over expanded polystyrene. Polyester resin, when carefully applied to expanded polystyrene, also produces a unique, eroded, surface, simplifying the texture of the expanded polystyrene.

The pilot study, Chapter III, established the possibility of successfully using medium density expanded polyethylene and low density polystyrene in the vaporization/burn-out method discussed above. It also established the possibility of successfully using the burn out of seven of the eight finishing materials used in the study. As shown by Table V, p. 164, the study generally confirmed the preliminary findings reported in the pilot study.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of the present research project was to investigate the feasibility of using expanded plastics as sculptural patterns for burn out in ceramic shell molds. Such a procedure would provide sculptors with an alternative to the rather cumbersome and not always accurate and refined present methods available. Although most industrial applications of the procedures and techniques examined in this study are outside the limitations of this study, there is room, however, for speculation regarding the application of the newly developed technique for casting. Industry has a history of unlimited variations of the use of expanded polystyrene molded in green sand which were doubtlessly unforeseen by the artist Shroyer, who invented the full mold process.

The information gleaned in the systematic investigation conducted in this study is reflected in Chapters I through V. The introductory chapter briefly summarized the historical incidents leading up to the study, including the industrial developments of expanded plastics and ceramic shell refractory. The problem of this study was formulated on the basis of the background information: the feasibility of using two families of expanded plastics for making sculptural patterns molded in ceramic shell refractory which were to be burned out. Questions to be answered centered around the problem of which expanded plastics would be suitable for making patterns and what finishing materials would be suitable for finishing patterns molded in ceramic shell and burn out leaving clean or bright castings. The study was limited to an investigation of the feasibility of using expanded polyethylene and expanded polystyrene as sculptural patterns invested in ceramic shell molds and for submitting both pattern and mold to a burn-out technique. In addition, the patterns were to be finished with two of eight different materials and molds were to be cast in aluminum to test their strength after burn out. The significance of the study lay in finding an alternative process to those available then for using expanded plastics as pattern material to be burned out in ceramic shell molds. The process was also seen as significant because it offered more efficiency, better production of details, and less distortion of attenuated forms while molding than the full mold sand casting method using similar patterns.

In Chapter II, related and pertinent literature concerning techniques and materials employed in metal casting with reference to the industrial development and use as well as artistic use of technologies in expanded plastics and ceramic shell refractory were reviewed. Attention was given to characteristics of materials and experimental processes related to the use of expanded plastics as patterns, molding, and depatternization procedures and techniques. The chapter concluded with a review of the only previously reported use of expanded plastics used as patterns and burned out in ceramic shell molds.

Preparatory to the trial of the identified expanded plastics used as patterns, the general procedures and methodology for the pilot tests and main study are outlined. The pilot tests were conducted to determine what expanded plastics may be best for making patterns for burn out, what finishing materials may produce acceptable changes in surfaces of expanded plastic patterns, and what temperature ranges may be appropriate for burn out of these patterns and finishing materials. Four tests were conducted. Pilot test I was a shock burn-out test of small patterns (2 x 4 x ½ inches) made from expanded polyethylene, polystyrene and polyvinyl chloride with nitrile rubber. Results indicated that expanded polyethylene and polystyrene, including the finishing materials of microcrystalline wax, flour and glue paste, paper-mâché, epoxy, and Thiem (c.) styro fill 42.1, would burn out acceptably. However, expanded polyurethane and polyvinyl chloride with nitrile rubber, including finishing materials: acrylic paint, gesso, Fiberglas (c.), and Bondo (c.) were unacceptable for such burn-out procedure.

They either cracked the mold or left excessive ashes and residue.

Pilot test II found that in a test of patterns of expanded polyethylene and polystyrene of 100 cubic inch volumetric-organic shapes, the results were inconclusive. Molded in ceramic shell and subjected to the shock burn-out method, the densest example of expanded polystyrene of 3.3 p.c.f. as well as the 1.8 p.c.f. example broke the molds. It appeared that vents might contribute to burn-out of the denser examples of expanded polystyrene. Pilot study test III revealed, however, that six patterns made from 1.8 and 3.3 p.c.f. expanded polystyrene broke or cracked their molds in three separate burn outs using five, ten, and fifteen vents, respectively. Finally test IV of the pilot study achieved preliminary results using patterns of expanded polyethylene and polystyrene, sixty-four cubic inches in volume. Such patterns and the following finishing materials burned out satisfactorily using the vaporization/burn-out method introduced in this study: microcrystalline wax, flour and glue paste, paper-mâché, epoxy resin, Thiem (c.) styro fill 42.1, and polyester resin. Expanded polyurethane and polyvinyl chloride with nitrile rubber left excessive ash and cracked molds. The vaporization/burn-out method consisted of slowly raising the heat until the expanded plastics were vaporized and then proceeding directly into burn out and sintering the molds as used throughout the remainder of the study. The pilot study indicated that a slow rise in heat using a muffled furnace could possibly provide a solution to the problem. Inherent in such a solution was the vaporization in the process of burning out of the two families of expanded plastics used as patterns which was introduced in this study.

Chapter IV presented the main study; it discussed the criteria for selecting pattern shapes and sizes as well as the construction of patterns of different densities and pieces. Also included are the procedural techniques for development, molding and burning out patterns, including casting of molds to be tested. The criteria for selection of patterns which were developed in the study included diversity in structural manipulation in order to examine the capability for combining, fabricating, and tooling the expanded plastics used in the study. These diversities included patterns constructed of one or more than one piece, including different families and different densities of expanded plastics, combined into one pattern, and patterns constructed from laminated expanded plastics. Criteria for finishing the patterns were established to attain different textures using two of the finishing materials on each of the ten patterns. Patterns were selected to test the following criteria which illustrated a variety of shapes representative of the configurations typically found in sculptural patterns as well as reflective of the size distribution of patterns usually cast in ceramic shell: small, irregular shapes; organic patterns, varied in thickness; long, slim, and attenuated shapes, flat and rectangular; large, voluminous, and organic shapes; and wide curved patterns, varied in thickness. For the purpose of the study dimensions of less than ten inches were considered small; lengths over twenty inches were considered long; volumes over 500 cubic inches were considered voluminous; and shapes over six inches across were considered wide. The method of burning out, entailing vaporization by slowly increasing the heat from atmospheric temperatures and proceeding directly into burn out and sintering of the molds at 1200 degrees Fahrenheit, was maintained throughout the study.

Three methods of documentation were used in the study: critical incidents observed in the study were noted and used as the basis for this report; color slides were made during the study in order to record pictorially the procedures and techniques used. These photographs were reproduced in black and white and used to illustrate the processes which were reported and as support for analysis of data; the burning out of each pattern was recorded in order to analyze burn-out schedules established for the study. This second section of the chapter consists of descriptions and evaluations of the development and examination of patterns, molds, and casts which were developed in the study. Findings from molding, burn out and casting in aluminum revealed that patterns constructed with low density expanded polystyrene and medium density expanded polyethylene were acceptable. Seven of the eight finishing materials used to coat the patterns were also acceptable. One, namely, burlap combined with the molding material or did not burn out completely.

Conclusions

The data derived from the ten main pattern tests, analyzed in Chapter V, were the result of a series of questions which directed the entire study. As the major findings of this study will show, all of those questions were answered.

In regard to the question of what physical characteristics make up expanded polyethylene and expanded polystyrene suitable for use by the artist: the two families of expanded plastics possess common characteristics of lightness, ease of tooling, sanding, and joining and strength, which are physical characteristics found appropriate to use by artists, as proven in the construction of patterns one through ten.

Sculptural form can be quickly realized by use of simple tools. Other methods of pattern construction employ tedious operations which encumber the spontaneity often cherished by or indicative of the working habits of many artists. Large wax, clay, and plaster constructed patterns require strengthening by armatures and other materials. These structural problems do not apply to expanded plastics because of their inherent rigidity. Moisture, humidity, or temperature control required for working wtih other pattern-making materials is also not a requirement when using expanded plastics.

Concerning the question of which members of the two families of expanded plastics are suitable for forming patterns, construction of patterns one through ten proved the suitability of medium density expanded polyethylene and low density expanded polystyrene.

The differences found in these two families of expanded plastics also make them compatible materials for use in constructing sculptural patterns. Expanded polystyrene is more brittle, making it easier to sand, than expanded polyethylene; however, it is also susceptible to bending, an asset in combining several pieces when specific dimensionality is not required. Expanded polyethylene is not brittle; in fact it tears rather than breaking. Its ability to bend, be compressed, and wrapped around more rigid pattern material is an asset which artists may be able to utilize to advantage in contouring patterns, especially volumetric ones as were patterns five and six.

The mini-cell variety of expanded polystyrene, of one-eighth-inch thicknesses or less, was useful for lamination, but its value as a finishing material should not be overlooked. It offers a flat, smooth, and coarse, matte surface unique in the finishing materials discussed in this study.

With reference to the question of which member of the two families of expanded plastics would burn out in ceramic shell molds, leaving clean, carbon- and ash-free molds, low density polystyrene, including mini-cell expanded polystyrene and medium density expanded polyethylene burned out in an acceptable manner in ceramic shell molds using the vaporization/burn-out procedures discussed in this study, as proven by burning out patterns one through ten. These expanded plastics apparently left clean, carbon-,and ash-free molds, as proven by burning out the patterns used in this study.

Low temperatures apparently assisted in vaporization of expanded plastic patterns beginning at about 175 degrees Fahrenheit. Combustion of any remaining gases and materials apparently occurred at about 425 degrees Fahrenheit. All residue was apparently eliminated by continuing to raise the temperature of the furnace to 1000 degrees Fahrenheit as proven in the vaporization/burn-out procedures conducted for patterns one through ten. Such capability permits the sculptor quicker access to his end product than previous methods. Using the vaporization/burn-out method, he eliminates the added step of solvenizing the pattern, then burning out. Vaporization/burn out generally offers one process to replace these two. The advantages of using expanded plastic as patterns over their use as armatures for wax build up is also readily apparent. In addition, solvenizing the back-up or armature of expanded plastic, then slush patterning the mold, and subsequent burning out can be accomplished in one step utilizing the vaporization/burn-out procedure.

As far as the question of what influence size, configuration, and volume would have on the burn-out process of the ceramic shell molds, all patterns made from the two members of families of expanded plastics used in the study burned out successfully. The size, configuration, and volume of patterns used in the study did not appear to have any influence upon success of the burning out procedures introduced in the study. Experience with rectangular-shaped wax patterns often results in cracking along the angular edges or edges of thin shapes. There has been considerable attention paid to patching remedies for the situation. Expanded plastics do not appear to crack patterns at such points. Again one can readily see the short-cut vaporization/burn out of patterns in ceramic shell molds effects as well as the relief from apprehension for successful, i.e. crack- or break-free burn outs.

As to whether eight finishing materials used on the patterns to vary the surface texture of the cast pieces would undergo burn out and produce clean, carbon- and ash-free molds, microcrystalline wax, flour and glue paste, epoxy resin, Thiem (c.) styro fill 42.1, polyester resin, polyethylene film, and paper-mâché all burned out successfully.

From the experience of using these finishing materials, it was further concluded that they offer a versatility not readily afforded by use of other pattern-making methods. One would have difficulty applying these materials to clay or wax and perhaps less difficulty in using them on plaster. However, the loss of detail incurred in transferring these textures to a mold from plaster or clay patterns would add to the inherent drawback of using such an indirect method of pattern-making for ceramic shell molds. These five materials add to the versatility of making patterns from expanded plastics. They add to the ease of manipulating the expanded plastic surface; they may also add to the expediency of realization of sculptural form. One may manipulate the surface of other pattern materials in other ways--such possibility also exists for manipulating expanded plastic surfaces, e.g. burning and sanding, but the conclusion being adumbrated here is that the simple application of these materials to the easily constructed pattern material may be more direct, fresh, or spontaneous in addition to concise, detailed, or controlled. Achieving alternative surface effects when using other pattern materials often result in arbitrary appearance or excessive machining.

Although microcrystalline wax is difficult to smooth out on the expanded plastic surface, it does offer the positive qualities of adhering readily and being quick to apply. Flour and glue paste shrinks upon drying. Such results has the effect of leaving a slightly pocked surface when filling expanded plastic surfaces. The appearance of such surfaces offers an alternative which may be a desirable variation in textural surface on metal sculpture. Although epoxy resin is not easily applied to concave or convex surfaces, it does offer the results of a smooth surface effect upon cast metal. It appears to be most appropriate for application to flat surfaces of expanded plastics. The material is self-leveling and the qualities of level and smooth surfaces are often required for sculptural surfaces.

Thiem (c.) styro fill 42.1 tends to crack when applied in over one-eighth inch thicknesses to expanded plastic surfaces. It is easily applied. The resulting texture is similar to wax; however, such surfaces can be smoothed with sandpaper, leaving a matte finish.

Polyester resin acts similar to epoxy resin; however, it solvenizes expanded polystyrene. When applied in thin coatings, it leaves a radically eroded surface similar to burning the plastic. The resultant expanded polystyrene surface is not a finish in the usual sense of the word; however, polyester resin does coat expanded polyethylene leaving a smooth, flat finish on leveled surfaces, due to its self-leveling characteristics.

Plastic films of polyethylene probably have limited use by themselves because of the cut edges or gathers which result from fitting or adhering the film to expanded plastics.

The film can be used with wax or other materials to obscure undesirable edges or folds.

Paper-mâché appeared to leave at least some ashes; however, the small amount and fragility of the ashes made them easy to evacuate from molds. The evacuation was considered a minor problem when compared to the versatility and utility the material offered for finishing expanded plastic patterns. The material is easily applied in strips or small pieces. It can be smoothed by sanding and produces a matte surface.

Burlap cloth fibers appeared to separate and to absorb the ceramic shell slurry and resulted in molding occlusions into the pattern surfaces. The separations appeared to be attributed to be a breakdown in the sealer used, i.e., vinyl floor wax, on the material before molding. The floor wax apparently dissolved upon contact with the water-based ceramic shell slurry, permitting the absorption or penetration into the fiber and weave of the cloth. Burlap cloth was not accepted as finishing material within the scope of the study.

The major findings of this study answer the original questions posed. Although none of the burn-out techniques which had previously been tried on expanded plastics used as patterns in ceramic shell molds had been totally successful, it was believed such a technique could be developed. The pilot study provided the necessary information regarding expanded plastics which were suitable for the artist's use and which would burn out consistently. The key to solving the problem was also discovered during the pilot study. While expanded plastics produced too great a concentration of gaseous matter inside the ceramic shell when the shock burn-out method was used for depatternization, a slow temperature rise from room temperature to the desired firing and sintering temperature would vaporize the expanded plastic, leaving the ceramic mold intact. The main study corroborated that information and tested its limitations further. While the successful casting of all the molds produced in the main study proved that the newly developed method was a successful one, the fact that none of the molded patterns failed to depatternize properly leads one to wonder what the limitations of pattern size and shape really are.

Information on refinement, variation, and investigation of techniques which motivated and supported the present study were gleaned primarily from industrial sources; such information was invaluable to this study. The free exchange of information provided by industrial periodicals and the technical progress such exchanges can propogate is an invaluable asset for industry. With the exception of the National Sculpture Center Proceedings, published semi-annually by the National Sculpture Center, Lawrence, Kansas, lack of information was apparent in art-oriented publications.

One may compare industry's ready dissemenation of new ideas to the relative silence from the artist's studio; one may compare it to the cherished information secreted in the sculpture department of a university or art school. Pondering such attitudes of secrecy on the part of artists, one wonders about the latent interest in metal casting of sculpture which is growing into widespread open interest; one also wonders what artists might contribute to the body of technical information which they are free to take for their own use.

The need for more art-oriented technical information in sculpture became apparent during a survey of the literature, materials, and techniques research for this study. Techniques-oriented books in sculpture were found generally inadequate and lacking in comprehensive information. Many journals exist for the critical evaluation of aesthetic considerations in sculpture. Many sculptors are hampered, however, by the period of time acquisition of technological and technical skills required before they can proceed to express their own ideas in some discipline. Furthermore, due to lack of technical information on the part of the artist, sculptural projects are sometimes executed in one particular process which may have been better done in another. Only one periodical, Leonardo, International Journal of the Contemporary Artist, published by the Pergamon Press, Ltd., Oxford, England, exists for publishing manuscripts dealing with new materials, science and technology of possible use to artists. In its nine years of publication, there have been no articles on metal casting, ceramic shell, or expanded plastics. A continuous flow and ready resource of technical information such as that promised by Leonardo could result in more vigorous activity. Perhaps the scope of the needed periodical could be limited to certain technologies. Some artists would be moved creatively by the introduction of a process while others would be able to find the answer to their present technical problem in the kind of articles suggested here.

The information referred to above would also facilitate more alternatives for education of the sculptor. Students must rely on the teacher's introduction of a limited range of techniques due to the teacher's own sometimes limited experience or background knowledge. Periodicals which up-date and elaborate upon materials and techniques referred to in classrooms and sculpture materials and techniques books would offer an advantage to the teaching and experi-mentations necessary to the vitality of sculpturing in general and metal casting in particular.

It appears that one partial explanation for the lengthy delay in development of experimental casting in the United States is the reluctance of artists to accept industrial invention and perhaps a climate of feeling which considered indirect techniques such as metal casting less valid than working with the most direct processes. Indirectly, metal was also expensive.

These considerations still exist; however, there are characteristics unique to metal casting which still merit its use. Casting offers strength, freedom of forms, thin supports, space probing masses, and many possible surface characteristics. Molten metal also appeals to numbers of artists who prefer working with cast metal.

Another partial reason for the delay in development of a thoroughly vigorous sculptural metal casting tradition in recent years may stem from the involved technological processes of the medium. Metal casting requires perhaps no more skill or intracacies of manipulation than other processes. It does, however, usually require more roundabout steps. For this reason it is called an indirect method of producing sculpture. Indirectness, in recent years, has been discarded for directness and immediacy in many facets of our culture. Indirectness in sculpture requires, as an example, in the case of producing a sculpture from clay or plaster: modeling; then molding in plaster; making the wax model from the plaster mold; repairing, cleaning and finishing the wax model; investing in refractory material; burning out; and finally casting. The processes introduced in this study seem to make casting metal sculpture more direct. The process requires only modeling in expanded plastics; finishing; investing; burning out; and casting. All sculptural problems may not be efficiently solved in only these five steps, but compared to seven for the first example above, the possibility of a simplified, more direct method of casting, now exists. The possibilities for more finishes and perhaps easier application of sculptural finishes have also been introduced in this study. Another advantage is in finishing of the cast. Using the finishing materials introduced in this study should result in less finishing of casts. These expediencies do not make the process of producing metal sculpture direct but do provide means for quicker realization of sculptural ideas.

Admittedly, these kinds of considerations have not emphasized sculpture as art. They may seem to adumbrate only the technological needs of sculpture. It is true that aesthetic considerations are not within the scope of this paper. This is not to say they are not considerations. In fact, the point being made here is that if artists or student artists were free of the labors of extensive research; of trial and error, of continuous re-discovery of what has already been found, of diluted and, therefore, inadequate information, they would have more freedom or ease of acquiring the facility to express their ideas and feelings.

This study was attempted because of a dissatisfaction with the encumberances of solid investment molding, of inaccuracy and finishing problems in the full mold process, and an appreciation for the potential of ceramic shell molding, first experienced by the investigator at North Texas State University in 1973. In addition, there was a certain naive conviction that expanded plastics would burn-out in ceramic shell using the shock burn out method. The potential alternative of using expanded plastic instead of the irradic pattern material microcrystalline wax and a conviction that an alternative method could be found led to a deepening respect for research and its products.

Recommendations for Further Study

The following statements are recommendations for further study and investigation in development of expanded plastics used as patterns for burn out in ceramic shell molds:

1. That other densities of the expanded plastic identified in this study be tested;

2. That other families of expanded plastics be examined as pattern materials, e.g., cellulose acetate, epoxies, phenol formaldehyde, silicones, urea formaldehyde, and vinyls;

3. That an examination be conducted of the limitations of size of expanded plastic patterns which can be molded in ceramic shell and burned out using the vaporization/burn-out procedures developed in this study;

4. That other varied kinds of finishing materials be experimented with, including different weights and qualities of burlap, and different methods of sealing and weave of the cloth materials, e.g., hair spray and shellac;

5. That other methods of burning out be examined, including shorter burning out periods;

6. That other types of furnaces and ovens be investigated, including electric ovens, core ovens, and perhaps small, electrically heated rooms for large molds which may possibly be used to cast other materials than metal.

7. That study be conducted of the feasibility of publication of a periodical, with emphasis upon metal casting technology, use of expanded plastics as patterns, molding processes, and aesthetics in sculptural media as a ready resource for artists.

APPENDIX A

GLOSSARY

Alumina.--Aluminum oxide, occuring naturally as corundum or as a very hard crystalline substance; prepared as a white, tasteless, amorphous powder;

Autoclave.--A closed vessel for conducting chemical reactions under high pressure and temperature;

Blind feeder.--A reservoir of molten metal which is not open to the atmosphere at the top of a mold. See also feeder;

Block mold.--A refractory investment material surrounded pattern or cavity contained in a flask. In addition see also solid investment and sand molding;

Bondo (c.).--A commercial automobile filler with epoxy base;

Burn out.--The heating of a mold in order to drive out water and volatile materials;

(c.).--A copyrighted product;

Carbon dioxide process.--A process of hardening molds or cores in which carbon dioxide gas is blown through sand which has been tempered with sodium silicate;

Cast (noun).--An object produced from pouring metal into a mold;

Casting (verb).--The act of pouring molten metal into a mold;

Casting, sand.--An object produced in a mold made of green sand, dried sand, or a core sand;

Cellulose nitrate.--A nitric acid ester of cellulose manufactured by the action of a mixture of sulfuric acid and nitric acid or cellulose, e.g. purified cotton linters;

Ceramic shell.--Silica in a liquid binder which is used with a dry refractory stucco to form a thin contour mold around a pattern;

Ceramic mold.--A precision mold used to cast metals;

Choked runner system.--A restriction placed in the runner system to help maintain a full sprue;

Celloidal.--A finely divided material less than 0.5 micron (0.00002 inches) in size;

Core.--Part of a complex mold that molds undercut parts;

Core pin.--A metal rod or wire used to stabilize the position of a core inside a mold cavity;

Ductile.--The ability of a material to be drawn into a thinner cross section;

Ester.--The reaction product of an alcohol and an acid;

Ethyl silicate (tetraethyl silicate).--A strong light-brownish bonding agent (industrial grade), for sand and refractories which deposits silica upon drying from a water solution;

Expanded plastic.--A cellular plastic whose structure is produced by gases generated from the chemical interaction of its constituents; also called foamed plastic;

Expanded polyethylene.--Produced by expansion of low density polyethylene in the extrusion process by use of a blowing agent, yielding a uniform closed cell foam;

Expanded polystyrene.--Produced by heating beads of polystyrene containing a blowing agent, which vaporizes to form distinctive cells within softening polystyrene. Sintering causes an interconnected cellular structure;

Expanded polyurethane.--Formed by reaction of an isocyanate and a polyol in presence of catalysts, blowing agents and surfacants. Foaming takes place during polymerization when added water reacts with the isocyanate, which forms carbon dioxide--the blowing agent;

Feeder.--A reservoir of molten metal to compensate for the contraction of metal as it solidifies;

Finish.--Surface condition, quality or appearance;

Foaming agents.--Chemical blowing agents, or foaming agents, are inorganic or organic materials that decompose under the influence of heat to yield at least one gaseous decomposition product;

Gate.--That portion of the runner in a mold where molten metal enters the cast or mold cavity;

Gating system.--The complete assembly of sprues, runners, gates and individual casting cavities in the mold;

Green sand.--A naturally-bonded sand or a compounded molding sand mixture which has been tempered with water;

Hydrolysis.--A chemical reaction of a substance with water;

Injection molding.--A molding procedure whereby a heat-softened plastic material is forced from a cylinder into a relatively cool cavity which gives the article the desired shape;

Investment.--A flowable mixture of a graded refractory filler, a binder and a liquid vehicle which when poured around the pattern conforms to its shape and sets hard to form the mold;

Lost wax process (cire perdue).--A casting process in which a wax pattern is invested and melted or burned out of the mold cavity;

Macromolecule.--Large molecules built up from small repeating monomer units;

Mesh.--The coarseness or fineness of particles, as measured by a metal screen through which they pass;

Monomer.--A single molecule, or substance consisting of single molecules which can react to form a polymer;

Nitrile rubber.--An emulsion copolymer of acrylonitrile and butadiene;

Pattern.--A master or mother shape, i.e., a model;

p.c.f.--An abbreviation for pounds per cubic foot;

Phenolic (resin).--A synthetic resin produced by the condensation of phenol with formaldehyde in base;

Pitch.--Residue from the distillation of tar and petroleum;

Polymerization.--A chemical reaction in which the molecular weight of the molecule formed is a multiple of that of the original substance;

Polyvinyl acetate.--A thermoplastic material composed of polymers of vinyl acetate in the form of a colorless solid; used extensively in adhesives;

Polyvinyl chloride.--A thermoplastic polymer synthesized from vinyl chloride, a colorless solid without resistance to water, alcohol, and concentrated acids and alkalis;

Pouring basin.--The enlarged mouth of the sprue into which the molten metal is first poured, i.e., a cup;

Pyrometer.--The pyrometer used in this study was a portable pyrometer, type T-2, made by Paragon Industries, Dallas;

Ramming up.--The process of packing sand into a mold with a rod or hammer;

Refractory.--A material which resists the action of heat;

Resin.--A synthetic substance with significant binding qualities of high molecular weight, with no definite melting point;

Sand casting.--An object produced in a mold made of green sand, dried sand, or core sand;

Shell molding.--A process for forming a mold from resin-bonded sand mixtures brought into contact with pre-heated metal patterns;

Sintering.--The bonding of adjacent surfaces of particles of a mass by heating;

Slit.--The passage in a mold designed to exhaust gases incurred during burn out of pattern;

Slurry.--A watery mud-like substance. The ceramic shell slurry used in this study, Nalcast (c.), was made by Nalco Chemical Company and is composed of Nalcong Colloidal Silica 1130 (c.) and fine grain sand, GP-1, produced by Glasrock Products, Incorporated. Nalcong Colloidal Silica 1130 (c.) consists of 70 per cent water and 30 per cent silica. The grain size of GP-1 sand is described thusly: 8 per cent of the sand will not go through a 50 mesh sieve; 89 per cent will not go through a 140 mesh sieve; and 3 per cent will go through a 200 mesh sieve (see stucco, below);

Sol.--A colloidal solution in which the system is apparently liquid;

Solid investment.--Investment (refractory) material surrounding pattern cavity contained in a flask, i.e., a block mold;

Sprue (downgate).--The channel connecting the pouring basin to the runner and mold cavity;

Stucco.--A process of sprinkling a wet, dip-coating of ceramic shell slurry with fine or medium grain sand: The fine grain sized sand stucco used in this study, G1, which is produced by Glasrock Products, Incorporated, is described thusly: 100 per cent of the sand will go through a 200 mesh sieve; 25 per cent will go through a 325 mesh sieve; the medium grain sized sand stucco used in this study, G2, produced by Glasrock Products, Incorporated, is described thusly: 100 per cent of the sand will go through a 100 mesh sieve and 45 per cent will go through a 325 mesh sieve (see slurry, above);

Thiem (c.) styro fill 42.1.--A product of Thiem Corporation, used as filler for expanded plastics patterns;

Trichlorethylene.--A colorless, liquid used as a solvent;

Urea formaldehyde resin.--A thermosetting product of condensation from urea or thio-urea and formaldehyde, used as a sand binder;

Vent.--A small opening or passage in a mold or core to facilitate escape of gases when the mold is poured;

Venting.--The process of perforation with a vent wire of the sand over and around a mold cavity to assist in escape of the gases;

Zircon sand.--A refractory sand of unusual fineness, low thermal expansion and high thermal conductivity; consists principally of zirconium silicate.

APPENDIX B

Pattern One

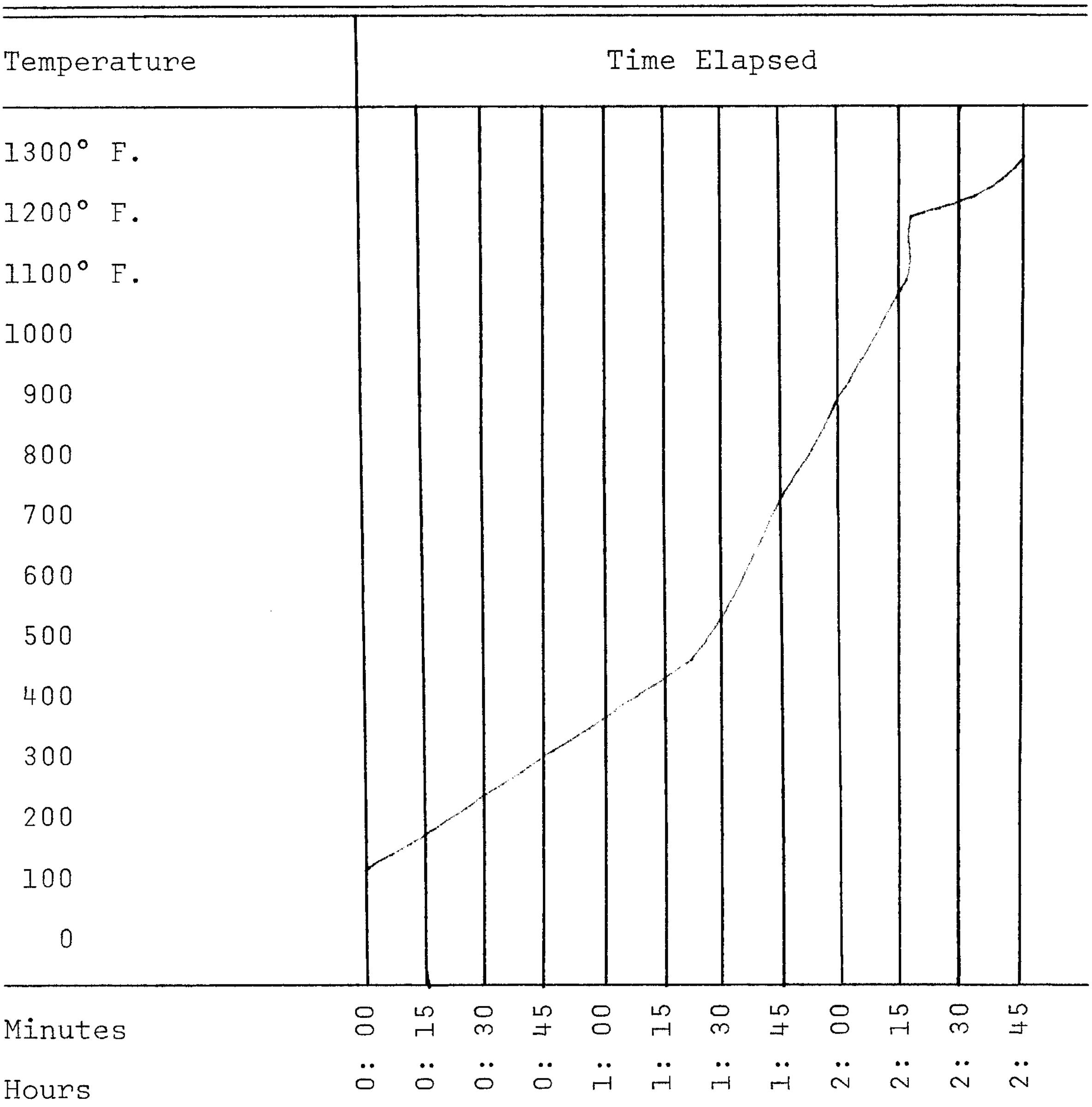


Fig. 93--Burn-out schedules

Pattern Two

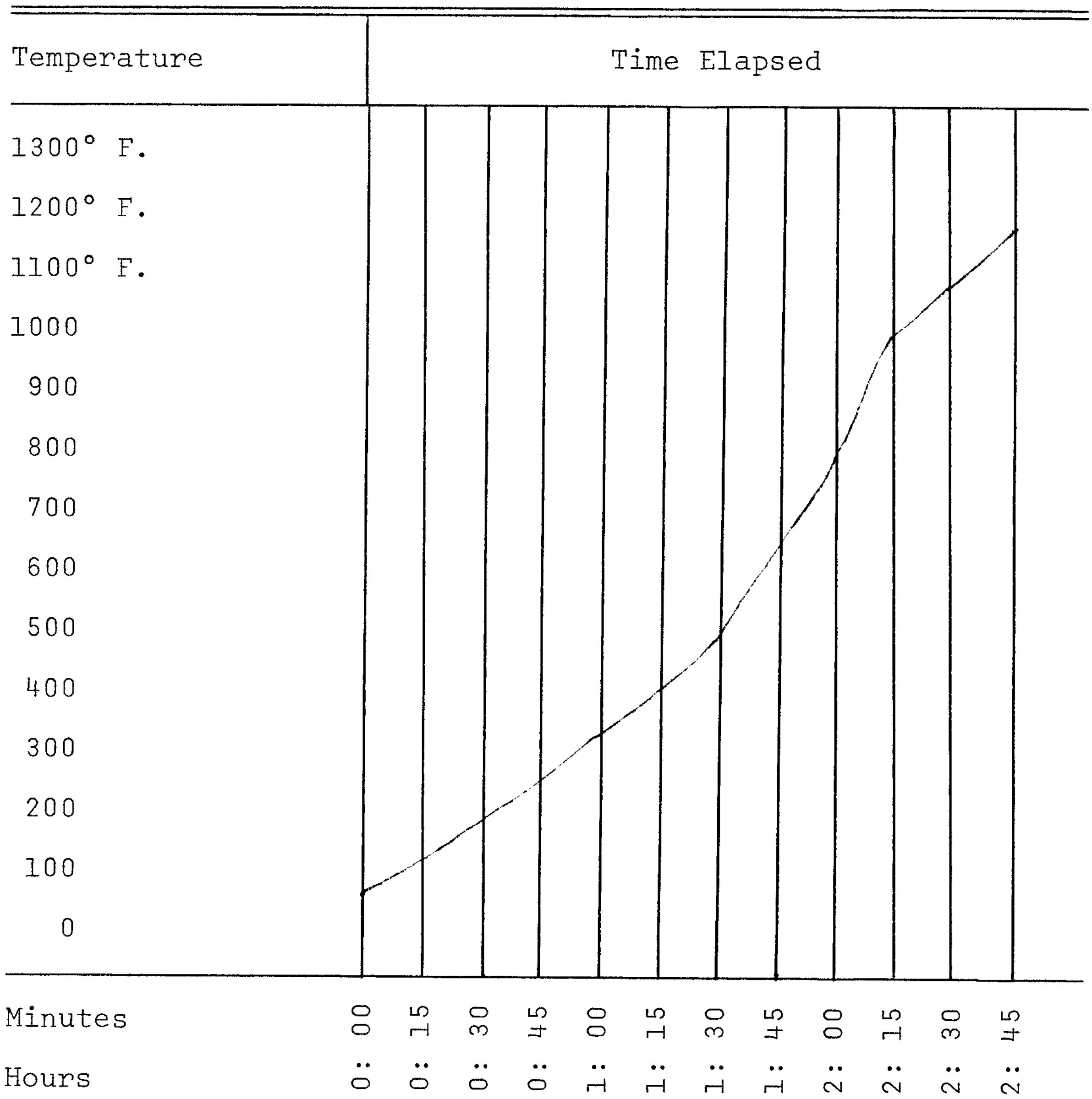


Fig. 93--Burn out schedules--*Continued*

Pattern Three

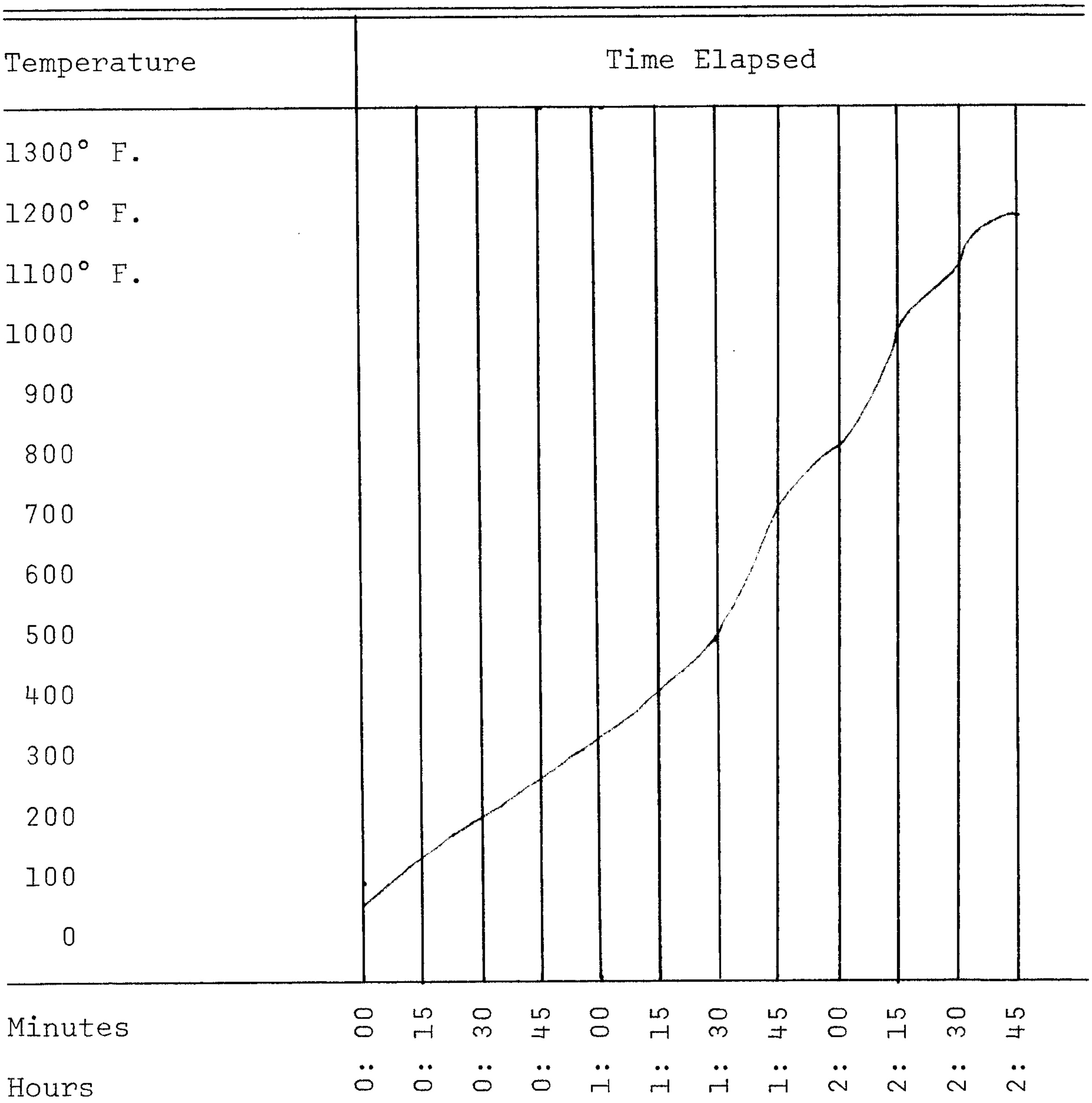


Fig. 93--Burn-out schedules--<u>Continued</u>

Pattern Four

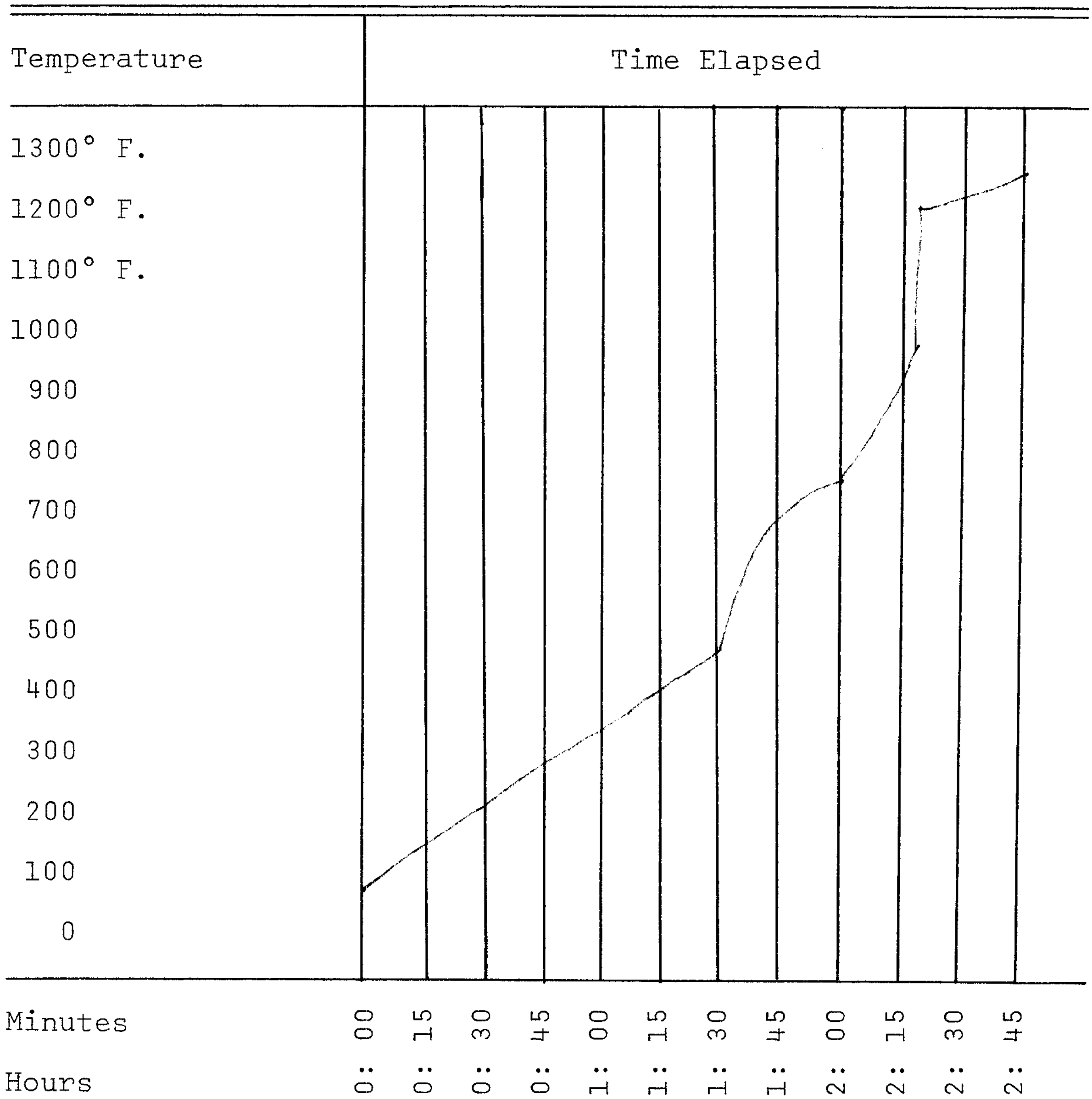


Fig. 93--Burn-out schedules--*Continued*

Pattern Five

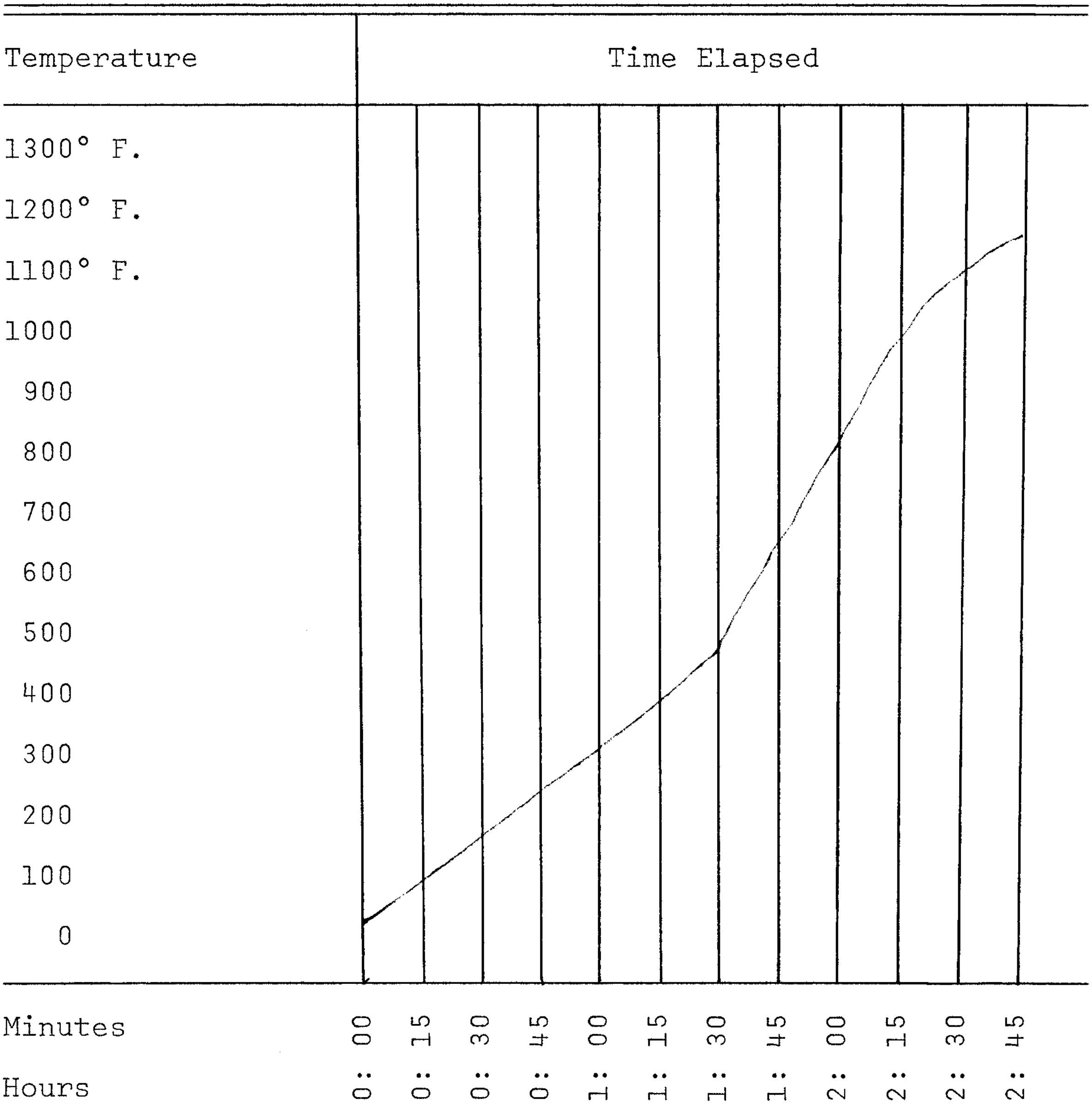


Fig. 93--Burn-out schedules--Continued

Pattern Six

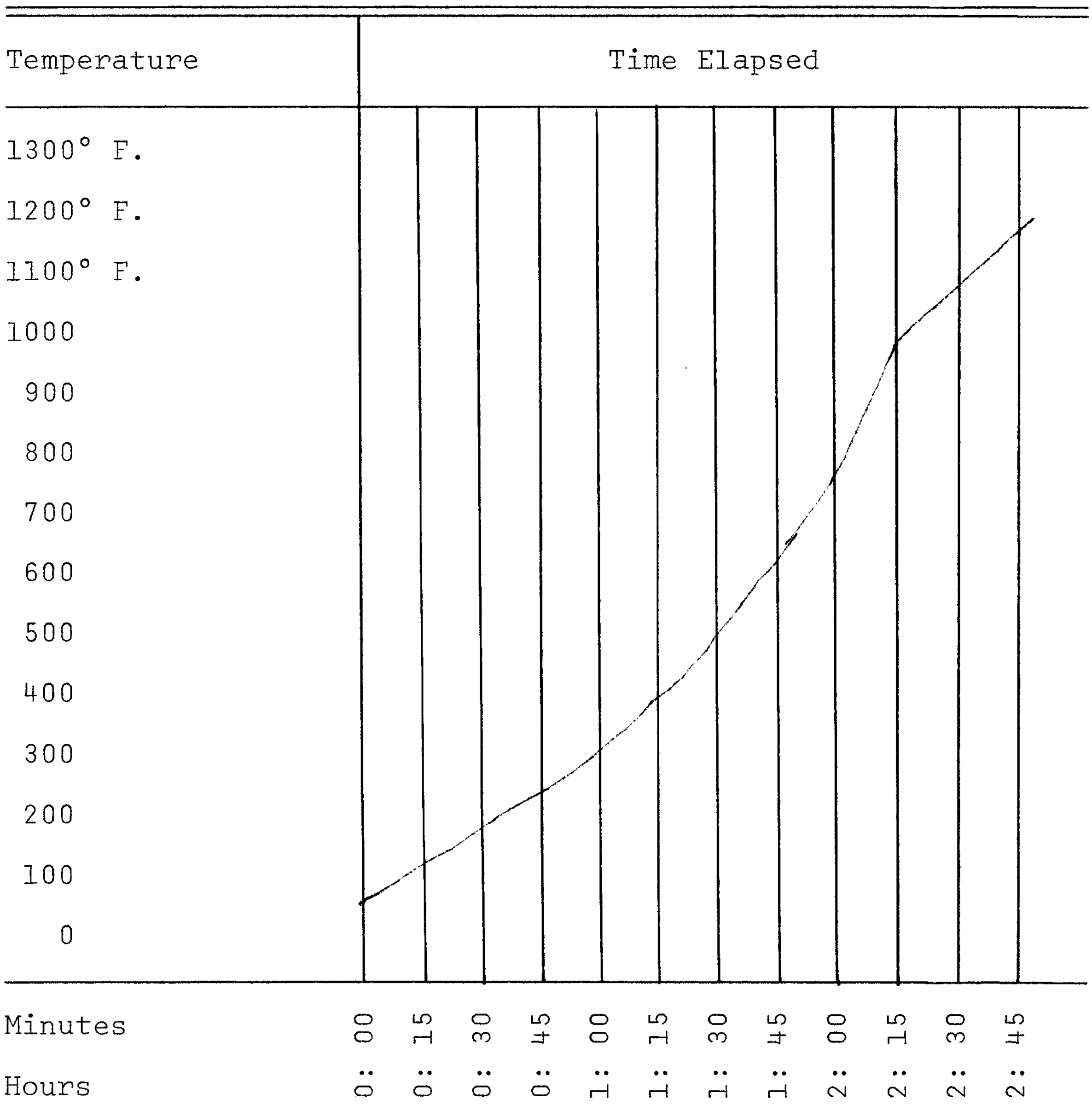


Fig. 93--Burn-out schedules--Continued

Pattern Seven

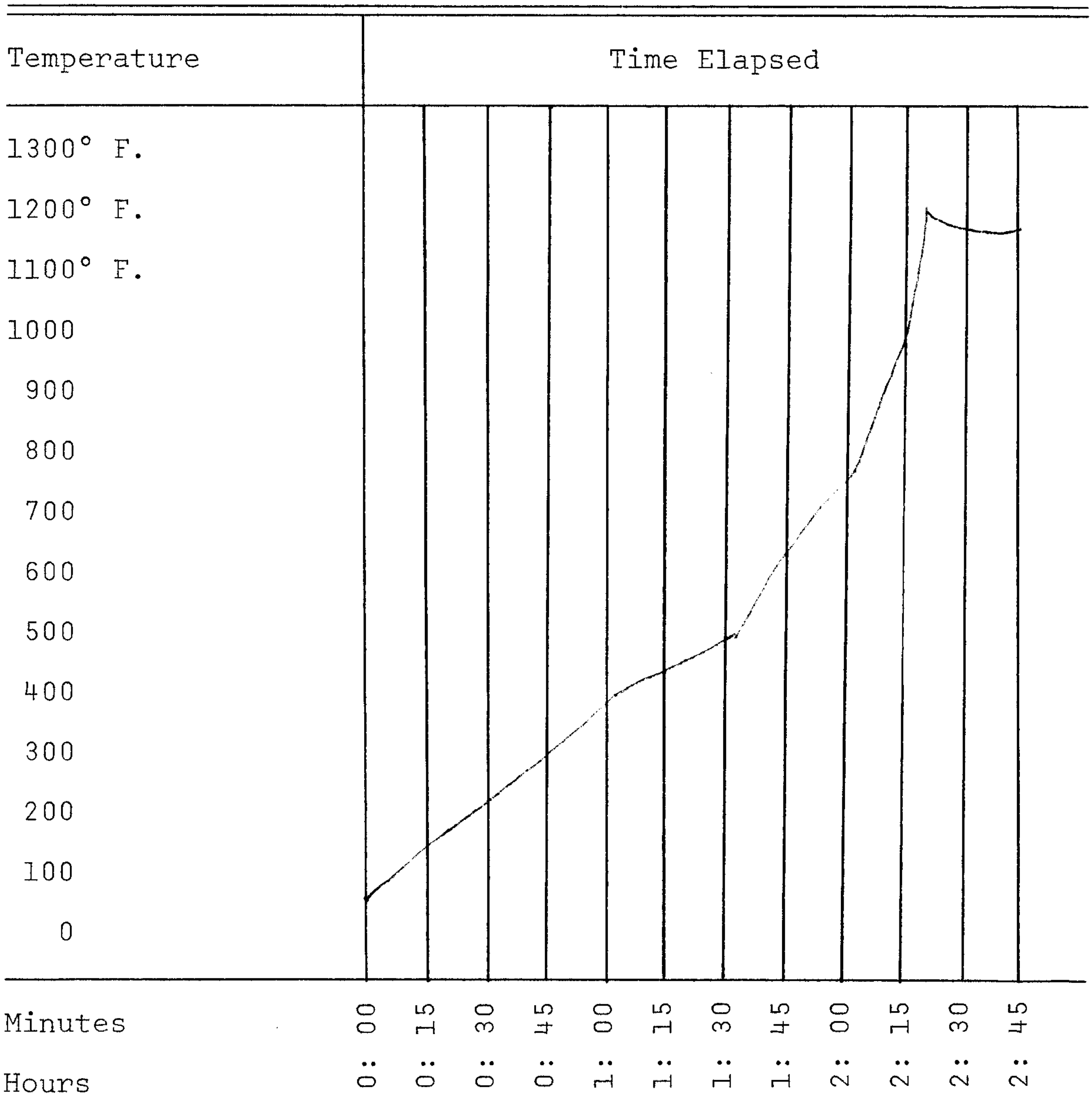


Fig. 93--Burn-out schedules--<u>Continued</u>

Pattern Eight

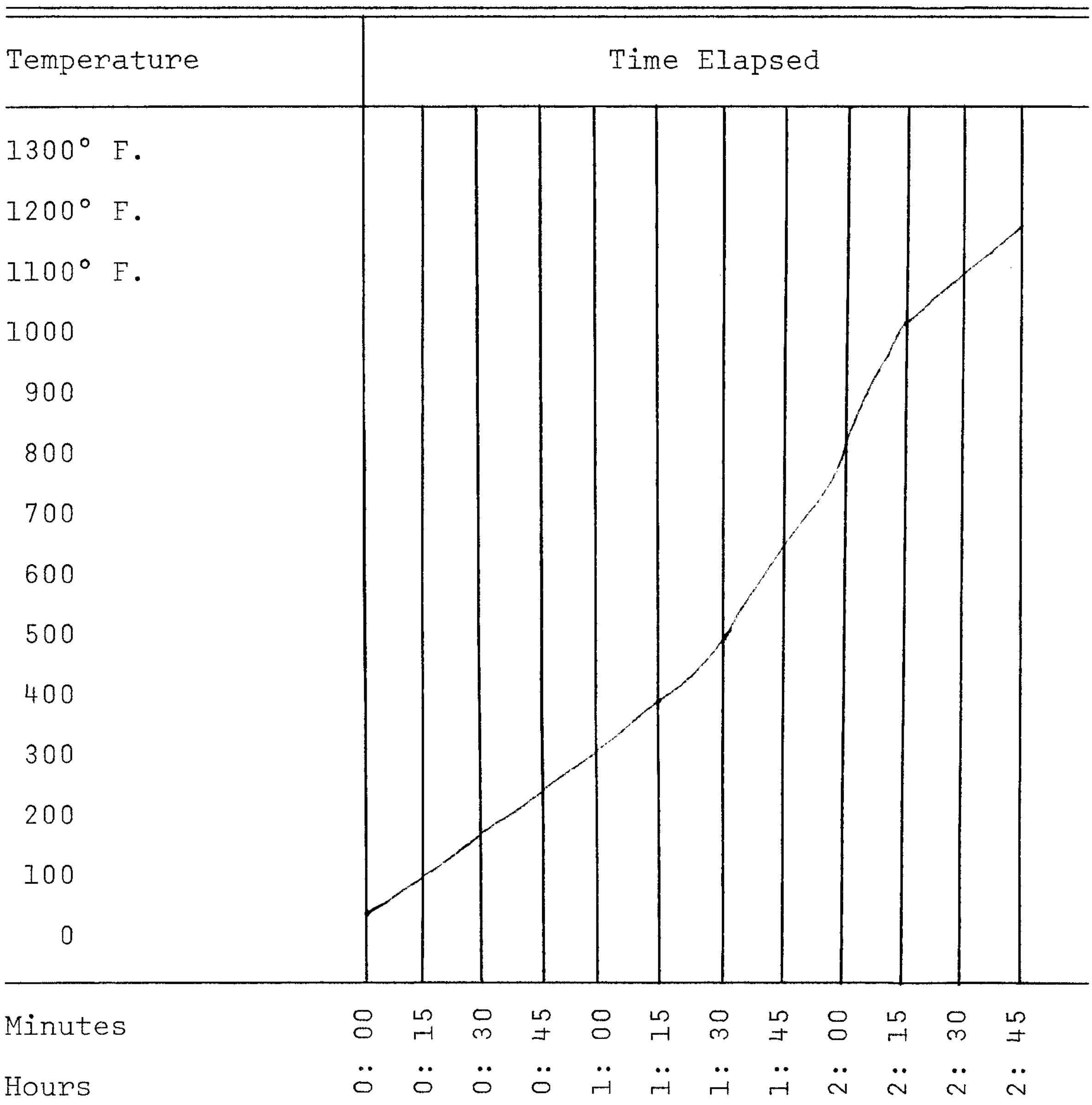


Fig. 93--Burn-out schedules--<u>Continued</u>

Pattern Nine

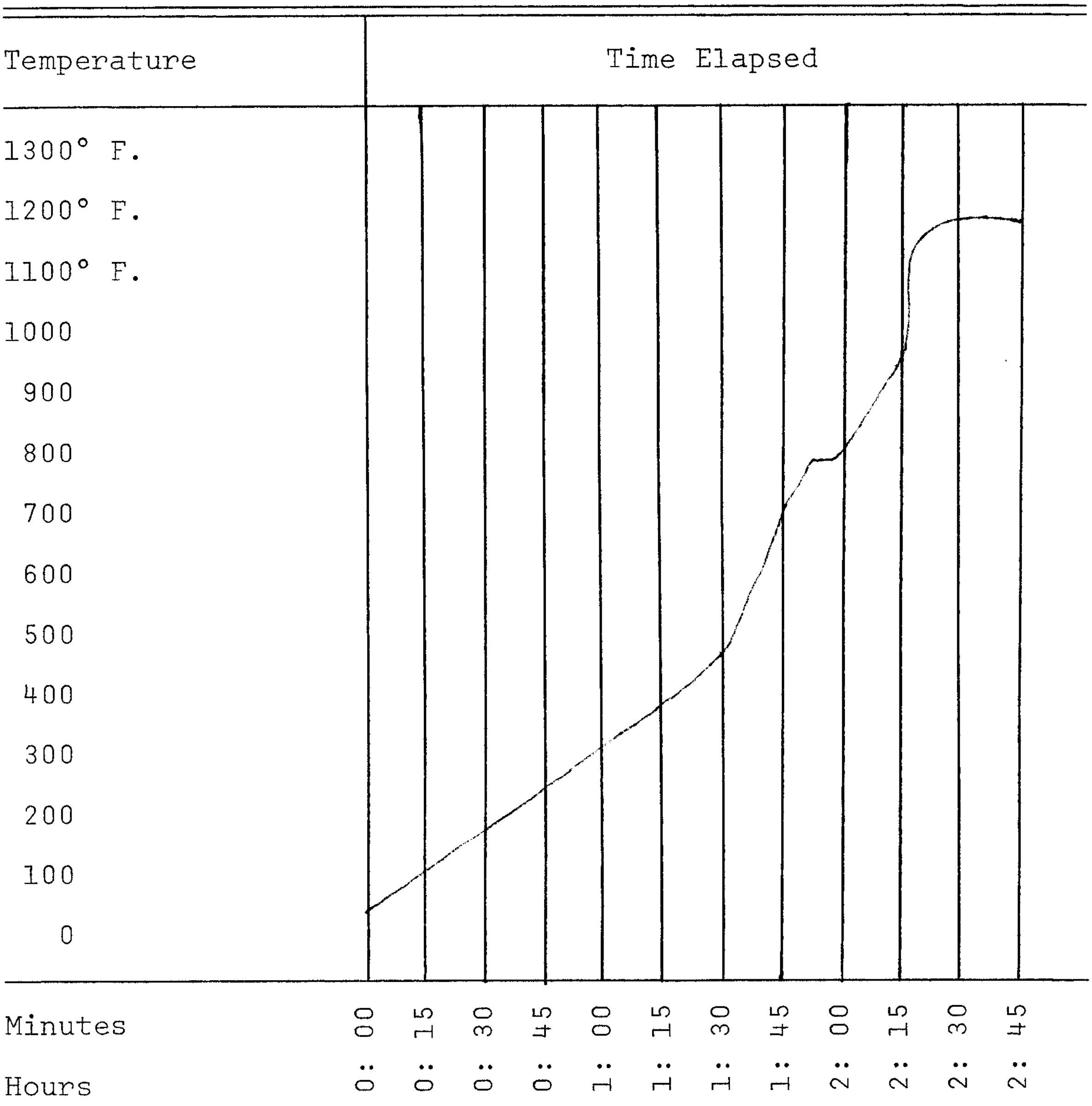


Fig. 93--Burn-out schedules--Continued

Pattern Ten: Trial 1

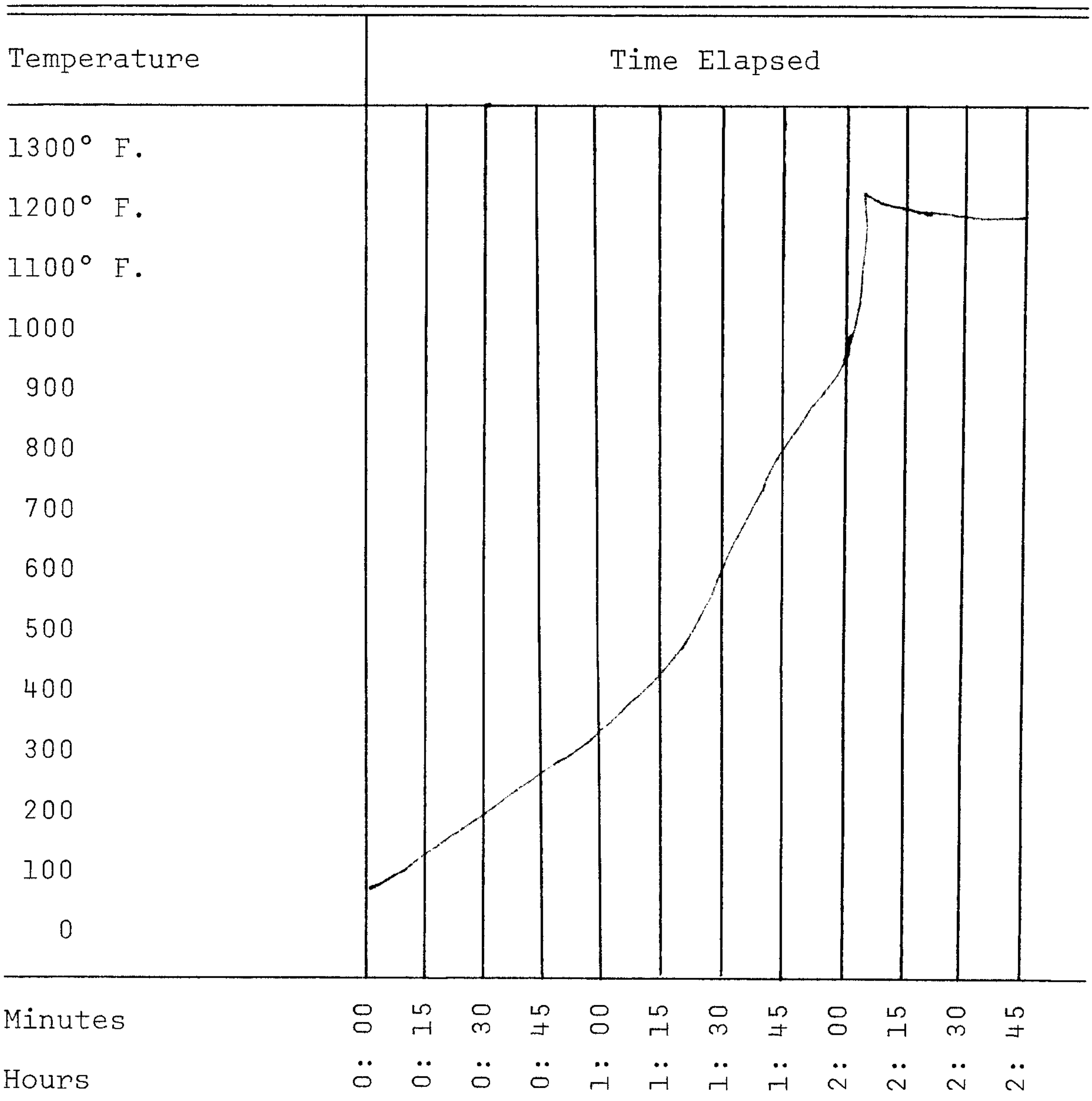


Fig. 93--Burn-out schedules--*Continued*

Pattern Ten: Trial 2

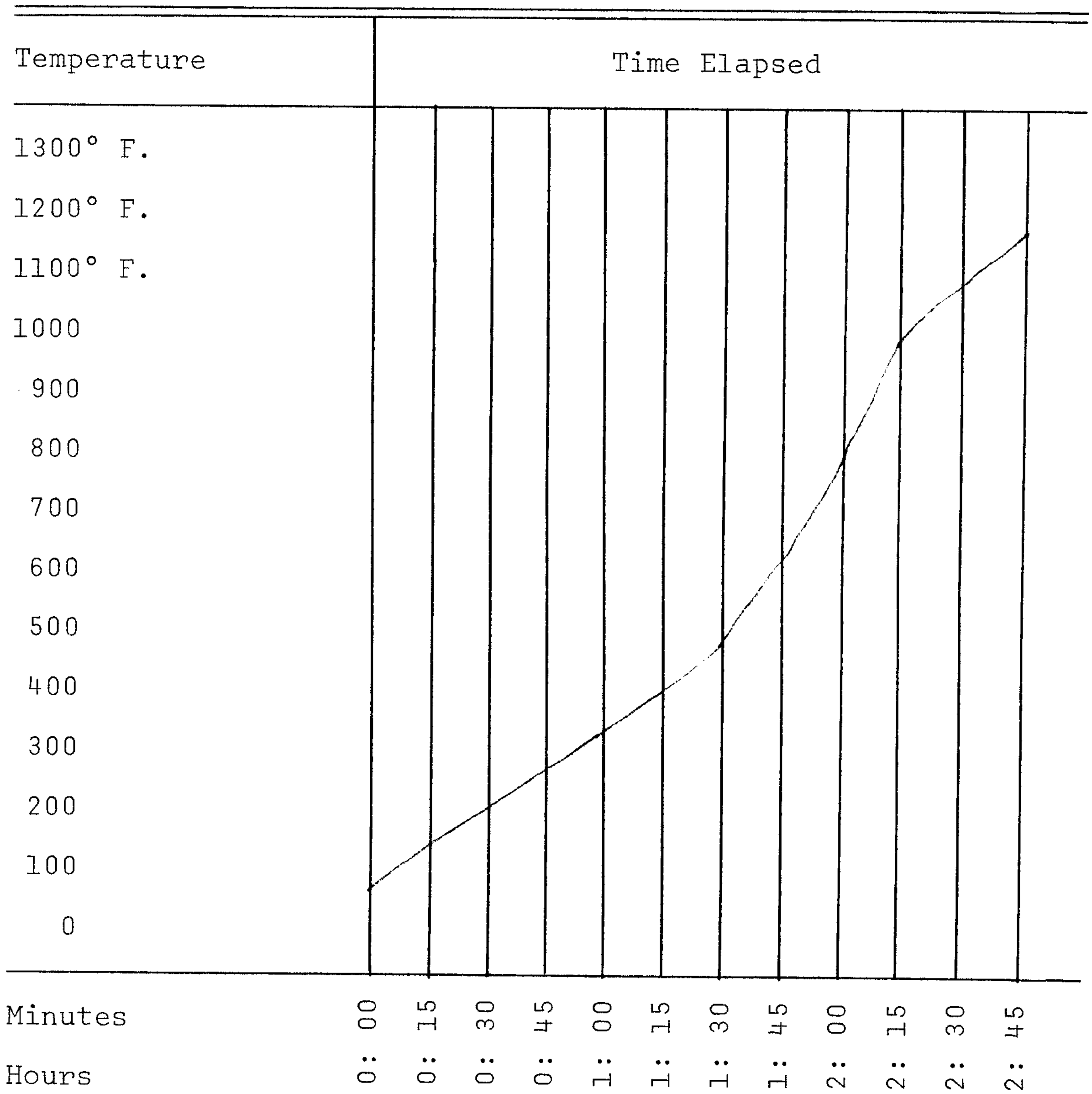


Fig. 93--Burn-out schedules--Continued

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