Expanded Polystyrene (EPS) Molding

- The concept of molten metal vaporizing a foamed polystyrene pattern was first patented in 1958. In its original form, patterns were fabricated from expandable polystyrene insulation board and surrounded with bonded sand after which the metal was poured. With certain improvements, this process is still in use today and is suited for large one-of-a-kind castings such as dies for stamping of large automotive sections and large dimension, heavy-sectioned castings used by machine tool builders. Expanded polysty-rene is suitable for use with both ferrous and nonferrous metals.

- The basic patent for the "cavity-less process" (patent #2,830,343)* was issued to inventor H. E. Shroyer who assigned U.S. Patent rights to Full Mold Process Incorporated. Actually the patent was not based on the production of castings, but on its first use — that of art castings. One of the first foamed polystyrene castings was the bronze statue "Pegasus" by A. Duca, sculptor and metallurgist at the Massachusetts Institute of Technol-ogy. Since the original patent, several process improvement patents have been issued.
- One of the earliest of these was U.S. Patent 3,157,924 awarded to T. R. Smith whose development provided for the use of un-bonded sand as the medium for surrounding a polystyrene pattern prior to pouring. In this evaporative casting process, *a pattern refers to the ex-pandable polystyrene or foamed polystyrene part that is vaporized by the molten metal. A pattern is required for each casting. Figure 64 shows a foamed pattern and the casting produced from the use of this pattern.

- The evaporative casting process is an economical method for producing complex, close-tolerance castings using an expandable polystyrene pattern and unbonded sand. Expandable polystyrene is a thermoplastic material that can be molded into a variety of complex rigid shapes. Common uses for expandable polystyrene include insulation board, hot drink cups, novelty items, packaging materials as well as patterns for the foundry in-dustry. The expertise for molding complex, thin-walled patterns with rela-tively smooth surfaces and at the low densities required for the casting pro-cess has also been achieved. With these developments, the evaporative casting process has now made it feasible to produce high volume production castings.

- The evaporative casting process involves attaching expandable polystyrene patterns to an expandable polystyrene gating system and then applying a refractory coating to the total assembly. After the coating has been dried, the foam pattern assembly is positioned on several inches of loose dry sand in a vented flask and additional sand is then added while continuing to vi-brate the flask until the pattern assembly is completely embedded in sand. A suitable downsprue is located above the gating system and sand is again added until it is level to the top of the sprue. Molten metal is poured into the sprue, vaporizing the foam polystyrene and perfectly reproducing the pattern. Gases formed from the vaporized pattern permeate through the coating on the pattern, the sand and finally through the flask vents.

- The term expandable polystyrene applies to discrete particles of thermo-plastic polystyrene which contains 5-8% of a volatile liquid expanding agent. The capacity to expand to a broad range of densities, excellent thermoinsulating efficiency, impact and shock absorbency and the ability to be molded into simple and complex rigid shapes makes expandable polysty-rene unique among thermoplastic materials.

- Production of expandable polystyrene begins with crude oil and natural gas. Benzene, a derivative of crude oil, and ethylene, which is derived from natural gas, are combined to form ethylbenzene. By chemical removal of hydrogen, ethylbenzene is converted to styrene. Styrene is a clear water like liquid composed of 92% carbon by weight and 8% hydrogen by weight. This material is highly reactive and possesses the ability to combine with itself to form a long-chain polymeric material named polystyrene. Conversion of styrene to polystyrene is accomplished through a reaction known as suspension polymerization.

- Styrene — and a large volume of water and soap to suspend the styrene in the water —'is added to a steam-jacketed agitated vessel. The entire mix-ture is then heated with proper agitation through a prescribed thermal pro-gram. At this point, the conversion of styrene into a highly useful thermal plastic polymer, polystyrene, is complete. However, to produce an *ex-pandable* polystyrene requires one additional step. An expanding agent, such as normal pentane, is added to the vessel and is absorbed into the po-lymer through continued agitation and heat. When the reaction is com-plete, the pentane bearing beads are subjected to a postreactor processing and are separated into product types according to bead size. The molding process for expandable polystyrene actually follows five steps:

- Pre-expansion
- Stabilization
- Molding
- Inspection
- Aging

- Expandable polystyrene beads are supplied in an unexpanded form with a bulk density of 40 ln/ft\ Since the blowing agent in the bead will disperse over a period of time, the usual shelf life for unexpanded beads is two months. Beads are first pre-expanded to the density required for the partic-ular application. Pre-expansion is accomplished by either steam, vacuum or hot air depending on bead size and ultimate density required. In the case of pattern molding for the evaporative casting process, a small bead prod-uct, pre-expanded to a density ranging between 1.0 and 1.5 lb/ft' is re-quired to produce the highest quality casting.

- To expand a small bead product at densities below 1.5 lbs per cubic foot, a vacuum pre-expander is required. After pre-expansion, the beads are allowed to stabilize for at least one hour before molding. This is accomplished by storing the beads in a fine mesh bag to allow free access of air. After pre-expansion, the re-maining blowing agent will continue to disperse. This limits the shelf life of the expanded beads to approximately 24 hours.

- Molding presses specifically designed for expandable polystyrene are sup-plied by several companies. The foam pattern molds are made of cast aluminum and machined to finished dimensions. Since polystyrene is not abrasive, tooling wear is minimal. Several hundred thousand patterns can be made before the mold requires maintenance.
- One-half to one degree draft is sufficient. Mold cavity and core walls contain small holes or core-box vents through which steam can enter the mold cavity. Expanded beads are blown into the mold, completely filling the cavity. Steam heats the ex-panded beads, causing them to further expand filling void areas between the spherical beads and fusing them together. Mold and pattern are then water-cooled after which the polystyrene pattern is ejected. (Fig. 65)

- Freshly molded patterns contain 6-8% by weight internal moisture. Over-night aging at ambient conditions will usually dry the patterns to moisture level that does not interfere with casting. Oven aging at 140F (60C) will ac-celerate the drying process. Molded foam polystyrene patterns shrink with age. Patterns will shrink a maximum of about 0.100 inches/foot over a peri-od of 30 days. The planned lag time between pattern molding and casting must be considered when designing a pattern mold.
- Foundries molding their own polystyrene patterns will usually plan to cast within a few days. On the other hand, a foundry purchasing foam patterns from an outside source will usually allow for the maximum shrinkage indicated above.

- Metal shrinkage in the evaporative casting process is generally the same as the liquid metal shrinkage in conventionally bonded sand molding and must be considered along with pattern shrinkage when designing the aluminum mold. Close inspection of the molded polystyrene pattern is critical. A de-fect in the pattern, such as an underfilled section or other cavity in the sur-face will become part of the casting. Therefore, it is far less expensive to scrap a foam pattern than it is to scrap the casting.

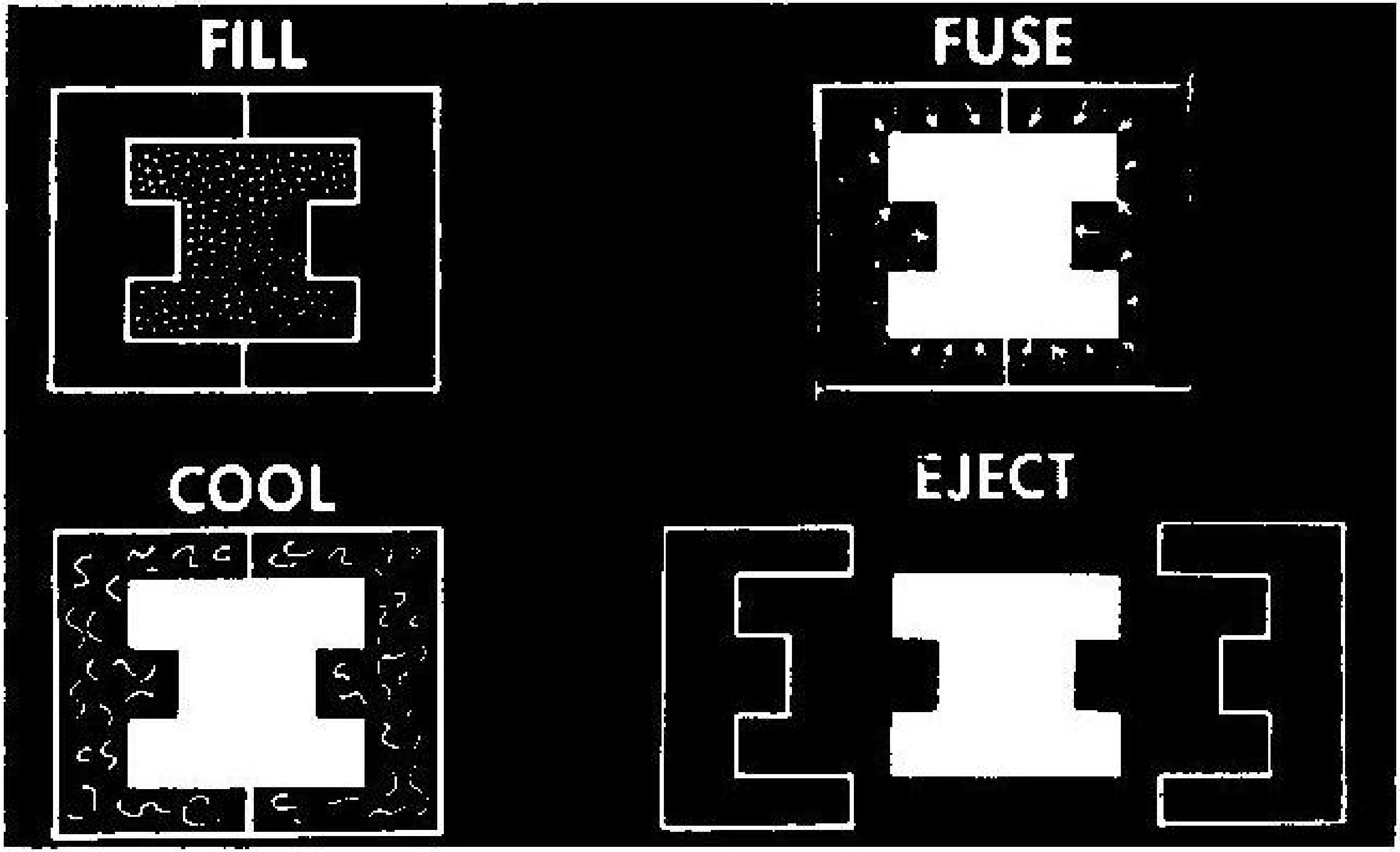

Fig. 65—Steps in molding expandable polystyrene.

- *Density and Bead Size* — Experience with the evaporative casting process has shown that patterns molded at a low density using a small bead ex-pandable polystyrene product will produce the highest quality castings. A low density pattern is required to minimize the amount of gas evolved dur-ing vaporization of the pattern since the gas must permeate through the coating, sand and vent itself to the atmosphere. If the gas forms faster than it can vent, a defective casting will result. Gas formation is a function of pattern density and metal pouring temperature. If pattern density is in-creased," more gas will be formed at a constant pouring temperature.

- Like-wise, if pattern density is held constant and pouring temperature is in-creased, more gas will be evolved since the polystyrene molecule will break down into more basic molecules at the higher temperature. As a result, steel castings generally require a lower density pattern than gray, malleable or ductile iron. Ferrous castings generally require a lower density than cop-per alloys, which in turn require a lower density than when casting alumi-num. The ratio of surface area to volume should also be considered.

- All of the gas that is formed must pass through the coating on the surface of the pattern. Patterns with wall thicknesses between 1/8 inch and 1/4 inch can usually be poured in iron at densities between 1.4 and 1.5 Ib/ft^3. Thicker patterns will require densities of 1.25 pounds per cubic foot or lower. As a general rule, the required pattern density will range between 1.0 and 1.5 lb/ ft^3 depending upon the part geometry and the metal being poured.

- Regarding bead size, a small bead is required to obtain a relatively smooth surface on molded patterns. In addition, the small bead will also enable fill-ing of the thin-wall section (e.g. 1/4 inch and less).
- Gating — Proper gating is critical and is usually a trial-and-error approach by the foundry until experience is gained with the evaporative casting pro-cess. The trial gating system is cut from low density foam board and glued to the pattern or multipattern assembly. Once the proper gating has been determined for a particular application, it is usually molded sometimes even as an integral part of the pattern.

- Venting is a major problem due to the enormous quantity of decomposi-tion products which are the direct result of the vaporization of the polysty-rene. Venting is best accomplished simply by using the combination of an "open" sand and adequate vents placed at strategic pre-planned exit points in the total molding concept. Inadequate venting will contribute-materially to gross casting defects.

- Gluing — Multicomponent polystyrene patterns along with gating systems can be assembled with any contact cement provided the solvent is not an aromatic hydrocarbon. Rubber cement maybe satisfactory for the initial casting evaluations, and other proprietary cements for polystyrenes may be obtained in model or hobby shops. Other contacts may be made with ma-jor adhesive manufacturers.

- Coating — Pattern assembly, with the gating system attached is coated, us-ually by dipping with a permeable refractory coating which has been spec-ially formulated for expandable polystyrene and then air or oven dried at 140F (60C or less). The coating prevents sand collapse during pouring. The portion of the gating system where the downsprue will be attached is *not* coated. The refractory coating is important since it actually is part of the mold. The contact line between the coating and the pattern is the actual mold wall surface. (Fig. 66)

- Sand — A coarse (e.g. 25-30 AFS GFN) rounded or angular sand is gener-ally used. This type of sand is recommended for its maximum permeability so that the gases evolved during pouring and the vaporization of the poly-styrene can freely exit from the mold cavity.

- Flasks — Mating cope and drag flasks are not required for unbonded sand castings. Instead, a flask can be any container that is rigid enough to with-stand vibration and the weight of the sand. The flask must be vented with slots in the side walls to allow rapid escape of the gases formed by vaporiza-tion of the pattern. A fine meshed screen should line the inside walls of the flask in order to prevent sand loss through the vents.

- Casting Procedure — Several inches of sand are first placed in the bottom of the flask to form a base for the pattern. The coated pattern assembly is then positioned on the sand base and sand is added while vibrating the flask until the sand reaches a level point with the gating system. A suitable downsprue should be located above the gating system and additional sand is added until it is level with the top of the downsprue. Care should be taken to prevent any sand grains from dropping into the downsprue. Pour-ing procedures and methods are the same as in bonded sand casting.

- The pouring rate is determined by the rate at which the pattern vaporizes. A constant head of metal must be maintained. As soon as the castings have solidified they are ready for shakeout. The usual method is to empty the flask onto a steel grating. The sand will fall through the grating to be col-lected and returned to a storage bin by a conveyor system. The sand is ready for reuse as soon as it has cooled to approximately 14')F (60C) or less. If the sand is not properly cooled, the heat can cause the next patt ;rn around which it is to be used to distort. Castings may then be processed in keeping with the usual procedures. (Fig. 67)

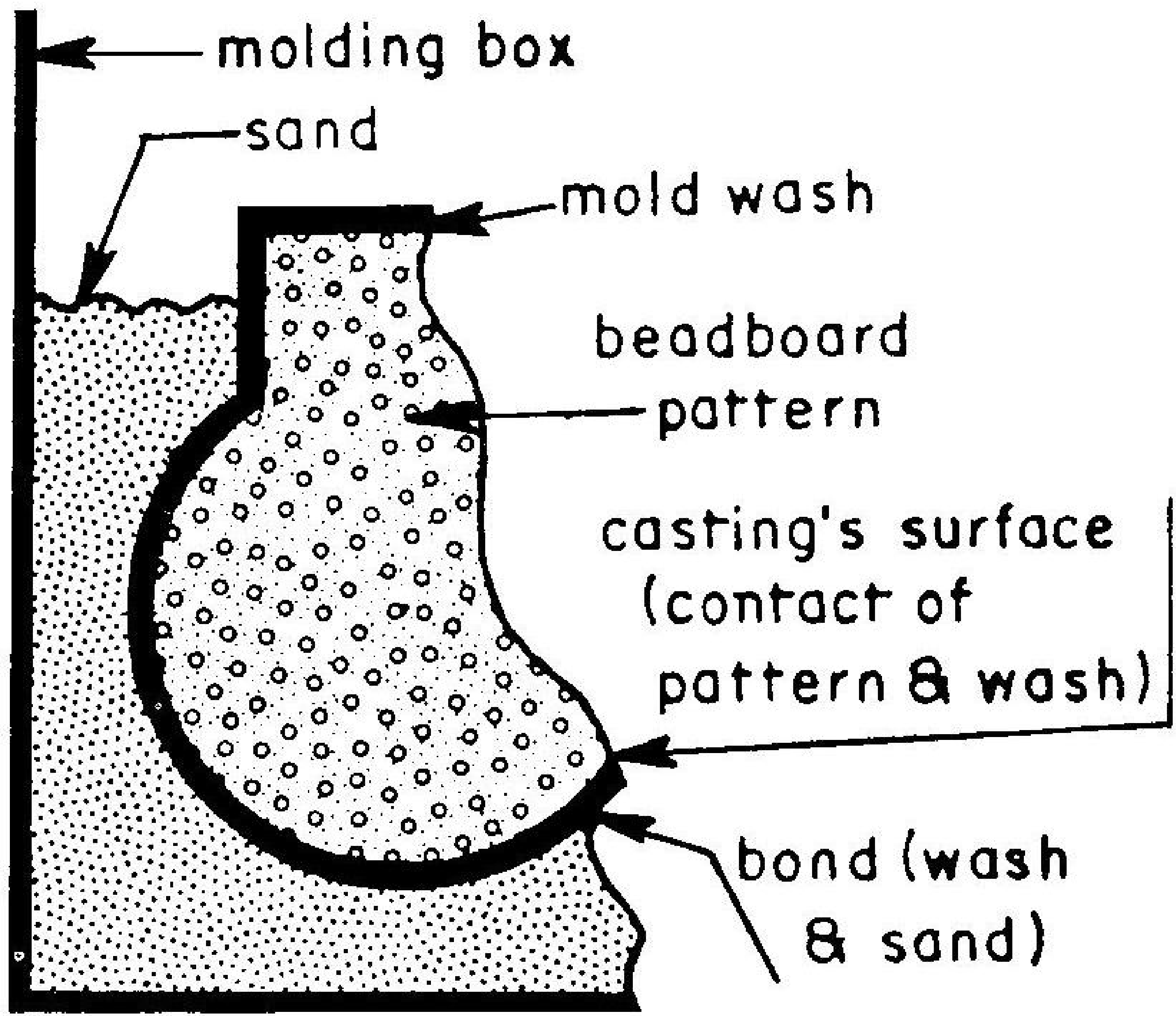

Fig. 66—A schematic diagram illustrating the application of a refractory coating as a sealing mechanism as well as its function as part of the mold.

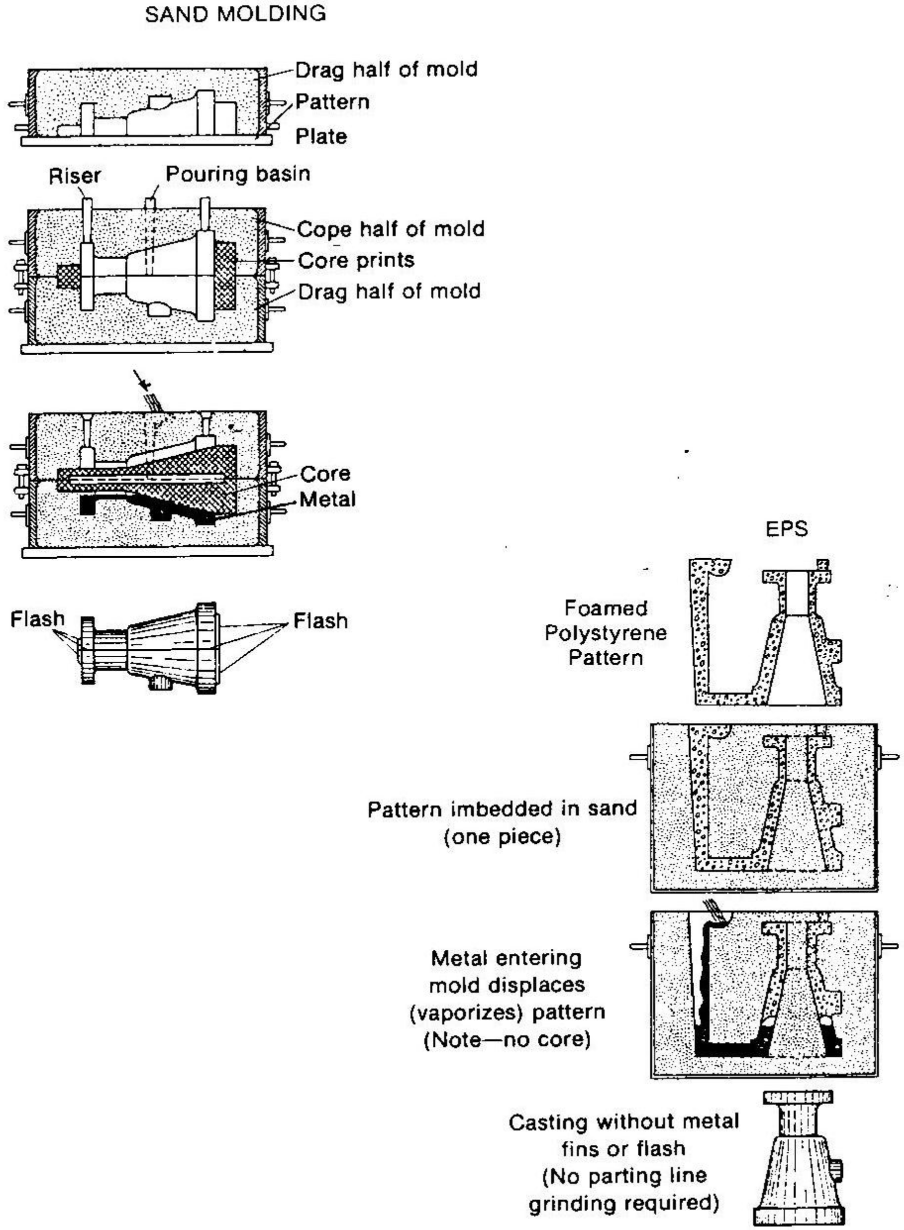

Fig. 67—A schematic comparing the sand molding process and the expanded polystyrene (EPS) molding process.

Using the Polystyrene Casting Process for Making Patterns

- The polystyrene or expandable pattern process has been in use for a number of years and is still being used almost exclusively for castings such as automotive dies. A typical procedure for the casting of an automotive die would consist of the following steps: standard polystyrene board shapes are used to fabricate the patterns. The foam board is available in blocks or sheets in sizes from 4 feet wide to 18 inches long and with thickness vari-ations from 1 inch to 18 inches making it adaptable to all design require-ments. Its ease of handling is best illustrated by comparing one cubic foot of polystyrene at approximately 1-1/2 lbs. to 1 cubic foot of mahogany at 50 lbs. (Fig. 68)

- The woodworking tools found in modern pattern shops can be used for all cutting and shaping processes. Patterns are cut out of board stock with a band saw or hot wire.

- If duplicate sections of segments are needed multiple pieces of polystyrene board may be stacked and cut to the full capacity of the saw. Shaping can be done with a router, spindle sander or sharp knife. Although standard shrink allowances are used in pattern construction, draft considerations on patterns is eliminated so that con-struction is simplified. Board sections are joined together by commercial glues or adhesives made expressly for use with the polystyrene foam, as well as wire brads in order to reinforce the cemented bond.

- Usually sharp inside corners are broken with fillets. These fillets are an aid to casting soundness and generally will be accomplished by using a wax fillet mate-rial. Beeswax is the material used and paraffin waxes are not recom-mended. Pattern job numbers for identification, etc. are stamped into zinc tapes which are then fastened to the pattern.

- The pattern is weighed to estimate the casting weight. One pound of poly-strene requires approximately 350 to 370 pounds of metal. The weight of the wax, glue, etc. must be estimated. If the polystyrene pattern as it is re-ceived from an outside source or the company pattern shop has any open joints, these must be taped in order to prevent these openings (cracks) from appearing in the casting. A gummed masking tape or plastic type tape may be used. When the final pattern is complete, a thick coating of refrac-tory wash is necessary in order to obtain a satisfactory casting surface.

- The special refractory coatings for use with polystyrene patterns have been developed by coating manufacturers, and the instructions for application should be followed closely. Usually, a first coat is applied, and after it has been dried, a second coat is applied, generally with a high pressure hydrau-lic airless type spraygun where very little over-spray is encountered. Many of the successful polystyrene casting producers use as many as three coats of the refractory coating, making sure that there is a specific time interval allowed for complete and thorough drying of each of the coats.
- A coating thickness of 1/32 to 1/16 inch minimum is necessary for heavy sections (6 to 10 inches cross section). Refractory coating runs and brush marks on the wash coat are not important since the surface adjacent to the polystyrene actually forms the final metal finish.

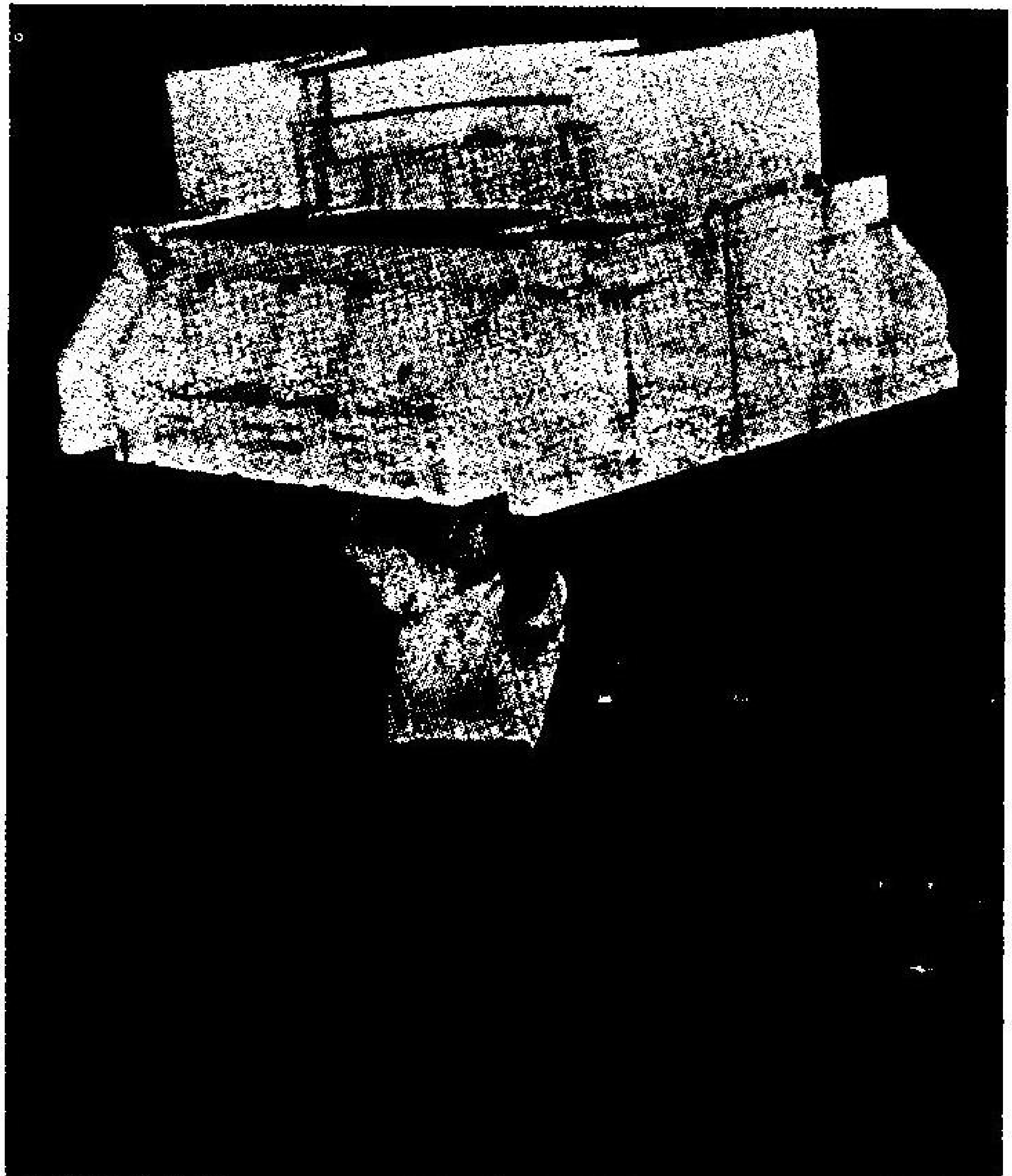

Fig. 68—This foamed polystyrene pattern weighs 45 pounds. It will be used to produce an 8-ton gray iron casting.

- Because polystyrene patterns are structurally flexible, the cope plate must be flat and true to prevent bent castings. Usually it is necessary to level with a dry sand bed, plywood sheets or sheets of polystyrene. The cope boards must be dry in order for the molding sand to harden properly as it is rammed in about the polystyrene pattern.

- The gate areas for the gating of the metal to the polystyrene pattern are figured at about twice that used for wood molded patterns. In the pouring of polystyrene, as it vaporizes, there is a slight back pressure which is generated when the metal vaporizes the polystyrene. Bottom gating into all of the lowest points appears to do the best job of producing cleaner cope surfaces, which has been a general problem with polystyrene patterns.

- Gates can be bridged from one part of a casting to another simply with a strip of 1 x 2 inch polystyrene. Runners are constructed of 2 x 4 inch pieces of polystyrene which are laid on the cope board and the down gates are attached with nails or glue. A refractory wash coating on the gating system is not necessary.

- The sand mixture usually used is of the air-hardening chemically bonded sands and consists of a base washed and dried silica sand of approximately AFS GFN 55. The air-hardening sand is applied to the pattern and the gates to a depth of 2 inches minimum. Any of the air-hardened chemically bonded sand mixtures may be used for the molding, ramming and venting in of the polystyrene pattern.

- Problem areas, where burn-in might occur can be faced with either zircon or chromite sand. It is essential that the sand be compacted against the pattern by hand packing or tapping. This will prevent excessive burn-in and metal penetration into the void areas. In deep pockets and side openings, it is important to use reenforcing rods.

- In supporting a deep horizontal pocket, tablets should be hung through the polystyrene from the cope surfaces. If the chemically bonded air-hardening sand is to be used only as a facing, then after the facing sand has hardened, the mold may be finished-rammed with regular backup sand. This procedure, as well as variations, is totally dependent upon the individual facility's processing system.

- After the mold has been rammed, the bottom board is bolted or fastened and the drag rolled over. This must be done carefully to prevent cracking of the facing sand which can result in runouts. The molding board is removed and loose sand removed from the cope surfaces. An interesting aspect of this casting process is that very few risers are required on castings containing ribs and pockets. For heavy chunky castings, conventionally sized side risers are required. It is best to use polystyrene blind-type risers in order to prevent the need for removing the cope after ramming.

- Blind risers help prevent excessive flames and heat by excluding air from the vaporization process of the polystyrene as the metal is poured. Risers are placed in the required locations and cores or ceramic tile are placed on the runner to form the downsprue. Downsprues are arranged for pouring with one or two ladles depending on the equipment available as well as the size of the casting. Each riser and the ends of the runner are vented with a number 10 wire to help remove some of the gas pressure which is generated

- during the pouring. A safety core or plug can also be planned to be placed in the cope to be used in case the gating system fails at the beginning of pouring or this core may be removed at the end of the pouring to make cer-tain that the mold cavity is full of metal. One-half inch vent rods may also be used in risers in order to provide a "flow-off" indication.

- The cope is sanded in a manner similar to the drag. Rod and "gaggers" can be used if the flush bar spacing exceeds 12 inches. Normally, an 8 to 10 inch cope is completely filled with the air-hardening chemically bonded sand. The cope flask is clamped in the conventional manner to the drag flask and a pouring box may then be set. In all cases where air-hardened chemically bonded sands are used, it is essential to insure enough time for the chemi-cally bonded sands to thoroughly cure.

- The extensive development of the polystyrene patterns indicates that the measurable savings are in pattern construction costs and machining advan-tage. The polystyrene material is priced less than wood, easily fabricated and is easier to work with than when working with wood.
- Since the polystyrene pattern is lost for each casting made and must be re-. newed for the production of another one, the economics of the process are, therefore, influenced to a great extent by the quantity of castings required. Estimates indicate that for small batches, the average cost for handmade polystyrene foam patterns is between 20 and 25% of the production cost of corresponding wooden patterns including core boxes.

- This means that small batches of up to five castings can be pr6duced economically by the polystyrene process. Patterns for large quantities must be produced in au-tomatic polystyrene molding machines. Since this would be a significant cost factor, it is generally necessary to have orders for 5,000 and up to 20,000 castings in order to make quantity production a really economical proposition.

- Castings weighing from 100 to 200,000 pounds have been produced in a variety of grades of steel. The only metallurgical limitation experienced to date concerns steels with low carbon contents. Vaporization of the polysty-rene foam pattern results in a carbon-rich atmosphere which may create a slight carbon pickup of approximately 0.03%. This carbon pickup is con-sidered negligible for alloy steels having a carbon content in excess of 0.1%. The process is not recommended for steel castings with very low car-bon contents.

- The mere handling of ligntweight polystyrene material in the pattern shops is far easier than handling wood. Polystyrene foam is worked with metal cutting tools, but the power requirement is far less. Smooth casting sur-faces are obtained by selecting high speed tools for cutting the pattern and by applying suitable refractory coatings which are specially formulated for use with polystyrene patterns.

- Advantages of the evaporative casting process, as compared to the conven-tional bonded-sand casting techniques, are numerous. Undoubtedly the most important advantage is that no cores are required. Other immediate advantages of the process:

- Castings can be made to closer tolerances as walls as thin as 0.120   inches have been cast.
- *   No binders or other additives are required for the sand which is reusa-ble.
- Flasks for containing the mold assembly are inexpensive.
- Shakeout of the castings in unbonded sand is simplified-not requiring the heavy shakeout machinery.
- The need for skilled labor is greatly reduced.
- Casting cleaning is minimized since there are no parting lines or core fins.

Polystyrene Advantages

- Advantages of the evaporative casting process, when compared to conven-tional bonded-sand techniques, other than the prime advantages of no cores, reusable sand, no binders or additives and inexpensive flasks, indi-cate a cost analysis production savings of 20-25% on reasonably simple cored items, and as much as 45-50% on complex castings. The benefits of the evaporative casting process can be better appreciated if viewed in terms of actual savings as analyzed by studying the following major cost centers.

- Reduced *operating costs* are chiefly the result of two factors. First, since the sand is reusable and cores are eliminated, sand consumption is greatly reduced along.with elimination of binders and other additives. Secondly, skilled labor requirements are considerably reduced. Skilled sand molders are replaced by semi-skilled laborer, who merely position a foam pattern assembly and pour sand around it into a vibrating flask. There is no need for the skilled patternmaker, coremaker and coresetter. In addition, labor savings may be obtained in the areas of maintenance and cleaning room personnel since less complex equipment is required and grinding e.g. core fins, parting line flash are eliminated.

- There is a great savings in equipment and equipment costs. Equipment costs for **an** evaporative casting **plant** including in-house production of **foam-pattern molding equipment** has **been** estimated **at** 1/2 **the** cost of the conventional green sand foundry. If polystyrene patterns are purchased from an outside source, equipment savings can be even greater and ac-counting costs much more accurate.

- More specifically, core machines, core dryers, sand molding machines and sand mullers are eliminated. Sand han-dling and shakeout equipment is simplified and much less equipment is needed for the abrasive cleaning as well as grinding of the castings for ship-ment.

- Building costs are also materially reduced because of the lack of need for heavy equipment foundations. Core molds, metal patterns and mating cope and drag flasks are also eliminated. In their place are the sim-ple flasks and foam-pattern tooling which can last indefinitely, because of the lack of actual sand abrasion where metal patterns are involved in nor-mal production. In addition, the use of polystyrene as a pattern material may also make it possible that storage of seldom used patterns may be eliminated.

- Since castings are consistently poured at closer tolerances with less grinding finishing stock, the dimensional variability usually associated with core setting, etc. is eliminated. This overall casting quality achieve-ment reflects savings from amount of metal poured to casting processing costs.

Polystyrene- Disadvantages

- Pattern coating process is time-consuming, and pattern handling requires great care.
- Greater molding skill is required to compact the air-hardened chemically bonded sands without pattern damage and to properly place vents.
- Pouring is more hazardous.
- There is less room for mistakes in the process. (A scrapped casting means replacement not only of the mold but the pattern as well.)

- The continued and future use of polystyrene patterns in the metalcasting industry is bright. Its versatility has been fully recognized and has been used to advantage is solving many problems. Further developments can be anticipated as time goes on. Improvements in polystyrene board stock will in turn improve casting finishes. Economical reproduction of large patterns in quantity is already a reality.

- Mass production of small patterns has be-come an accepted practice and continued future developments as well as experience with the use of this material wiil open new areas for its use in actual casting where intricate cored passages are part of the casting design as well as for the continued use of polystyrene for patterns.