SAND CASTING

Molding processes where a sand aggregate is used to make the mold produce by far the largest quantity of castings. Whatever the metal poured into sand molds, the product may be called a *sand casting.* One of the reasons for the preference of sand molding and casting is the application to very different sized parts and its low cost. Sand mold casting methods can be divided into different groups depending on the type of mold used, such as green sand molding, dried sand mold casting, sjin dried sand mold casting, core mold casting, shell mold casting, gas hardened silicate method known as CO_2, air set molds formed by a mixture of sand, organic binders and catalysts and cured by air polymerization of liquid resins.

Green-sand Molding

Among the sand-casting processes, molding is most often done with green sand. Green molding sand may be defined as a plastic mixture of sand grains, clay, water, and other materials which can be used for molding and casting processes. The sand is called “green” because of the moisture present and is thus distinguished from dry sand. The basic steps in green-sand molding are as follows:

1. Preparation of the pattern. Most green-sand molding is done with match plate or cope and drag patterns. Loose patterns are used when relatively

few castings of a type are to be made. In simple hand molding the loose pattern is placed on a mold board and surrounded with a suitable-sized flask, as illustrated in Fig. 3.1.

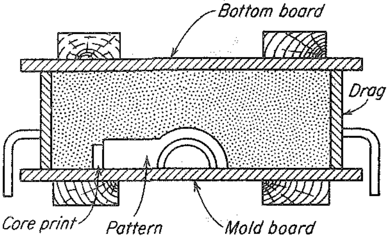


***Fig.* 3.1 Drag half of mold made by hand. Drag is ready to be rolled over in preparation for making the cope.**

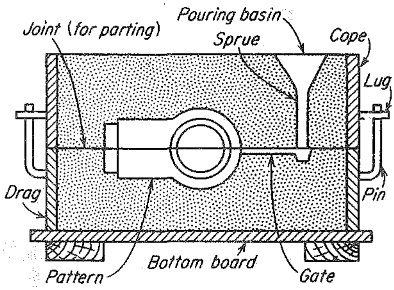


***Fig.* 3.2 Cope mold rammed up. The pattern shown in Figs. 3.1 and 3.2 is shown also in Fig. 1.1.**

2. *Making the mold.* Molding requires the ramming of sand around the pattern. As the sand is packed, it develops strength and becomes rigid within the flask. Ramming may be done by hand, as in the simple setup illustrated in Fig. 3.1. Both cope and drag are molded in the same way, but the cope must provide for the sprue. The gating-system parts of the mold cavity are simply channels for the entry of the molten metal, and can be molded as illustrated in Fig. 3.2. Because of their importance, gating systems are considered in Chap. 9.
3. *Core setting.* With cope and drag halves of the mold made and the pattern withdrawn, cores are set into the mold cavity to form the internal surfaces of the casting. Core setting by hand is illustrated in Fig. 3.3, showing also a mold made by a squeeze-molding machine, a match-plate pattern with attached gating, and an irregular parting surface.
4. *Closing and weighting.* With cores set, the cope and drag are closed. The cope must usually be weighted down or clamped to the drag to prevent it from floating when the metal is poured.

Because of the nature of green-sand molding and molding sands, the process has certain advantages and limitations. Advantages are:

1. Great flexibility as a production process. Mechanical equipment can be utilized for performing molding and its allied operations. Furthermore, green sand can be reused many times by reconditioning it with water, clay, and other materials. The molding process can be rapid and repetitive.
2. Usually, the most direct route from pattern to mold ready for pouring is by green-sand molding.

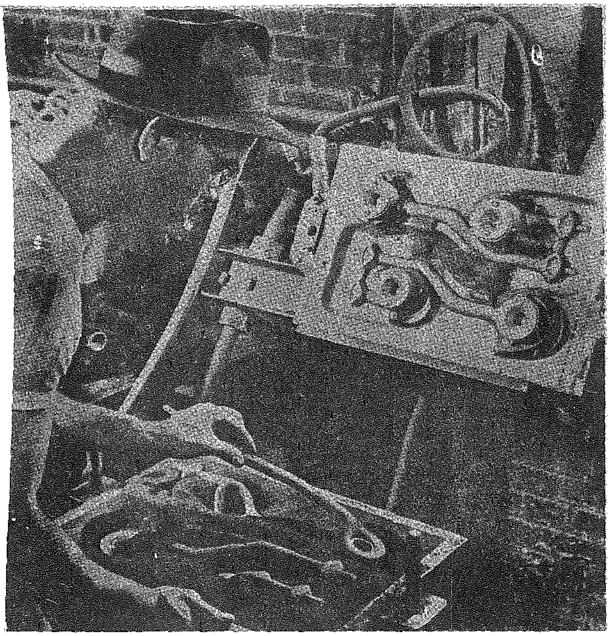


Fig. **3.3 Setting cores in cavity of mold for making domestic gas-range burner castings.** *(Courtesy of Aluminum Co. of America.)*

3. Economy: green-sand molding is ordinarily the least costly method of molding.

Limitations in the use of green-sand molding are:

1. Some casting designs require the use of other casting processes. Thin, long projections of green sand in a mold cavity are washed away by the molten metal or may not even be moldable. Cooling fins on air-cooled-engine cylinder blocks and head, such as those shown in Fig. 3.9, are an example. Greater strength is then required of the mold.
2. Certain metals and some castings develop defects if poured into molds containing moisture.
3. More intricate castings can be made by some other casting processes.
4. The dimensional accuracy and surface finish of green-sand castings may not be adequate. A dimensional variation of $\pm\frac{1}{64}$ in. on small castings and $\pm\frac{1}{16}$ to $\pm\frac{3}{32}$ in. on larger ones may be encountered. However, this

variation on many castings may be much less than that cited if adequate control is exercised.

5. Large castings require greater mold strength and resistance to erosion than are available in green sands.

Dry-sand Molds

Dry-sand molds are actually made with molding sand in the green condition. The sand mixture is modified somewhat to favor good strength and other properties after the mold is dried. Dry-sand molding may be done the same way as green-sand molding on smaller sizes of castings. Usually, the mold-cavity surface is coated or sprayed with a mixture (Chap. 5) which, upon drying, imparts greater hardness or refractoriness to the mold. The entire mold is then dried in an oven at 300 to 650 F or by circulating heated air through the mold. The time-consuming drying operation is one inherent disadvantage of the dry-sand mold.

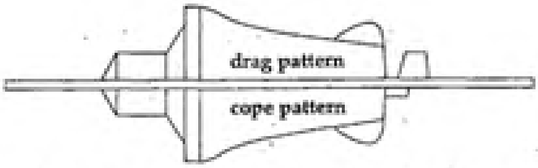
Skin-dried Molds

The effect of a dry-sand mold may be partially obtained by drying the mold surface to some depth, ¼ to 1 in. Skin drying may be performed by torches, a bank of radiant-heating lamps, or electrical heating elements directed at the mold surface. Skin-dried molds must be poured shortly after drying, so that moisture from the undried sand will not penetrate the dried skin.

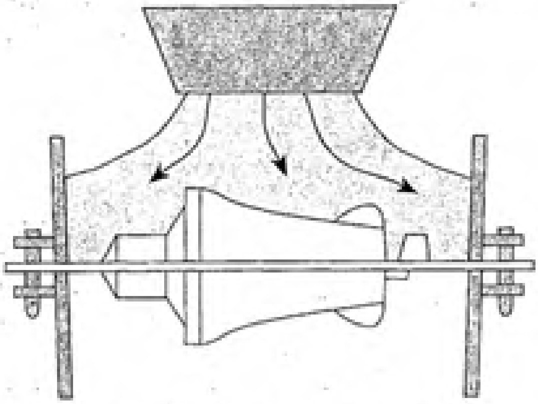
Floor and Pit Molding

The production of large intricate castings weighing from 1 to over 100 tons is, of course, one of the special advantages of the casting processes. An example is given in Fig. 3.4. Consider how difficult it would be to make large intricate shapes in some other way. The surface finish and dimensional accuracy of these large castings in ferrous alloys are not as good as in smaller ones, dimensional tolerances of $\pm\frac{1}{4}$ in. being acceptable unless special experience permits closer control. The problems of mold construction, handling, coring, gating, pouring, and cleaning of large castings require much engineering effort and control.

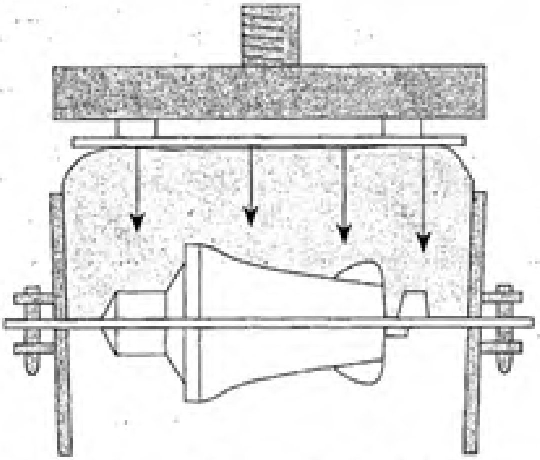
When the molds are medium to large in size, considerable heavy equipment, floor space, and time must be allocated to the molding operation. Floor molding is done on the floor of bays of the foundry set aside for these heavy molding jobs. A molding floor is shown in Fig. 3.5. The size of work handled is revealed by comparison with the men in the figure. A completed floor mold, dried, with dry-sand core in place and ready for closing, is shown in Fig. 3.6.



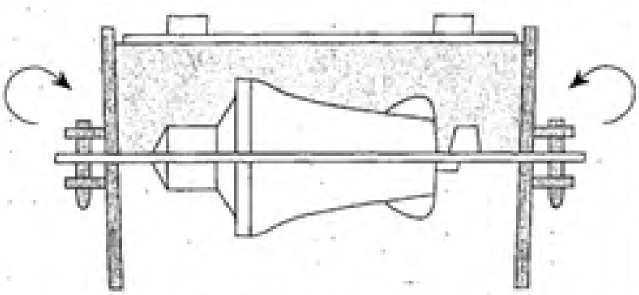
1. In this example, a cope pattern and a drag pattern are mounted onto a plate to form a matchplate.



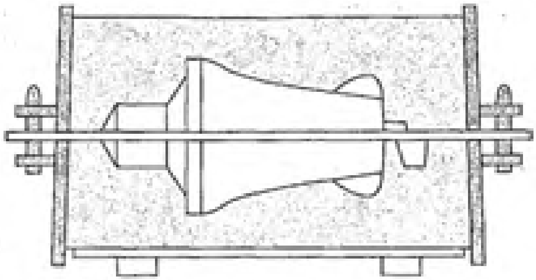
2. A flask is placed around the matchplate, and prepared sand is dumped or blown in on top of it.



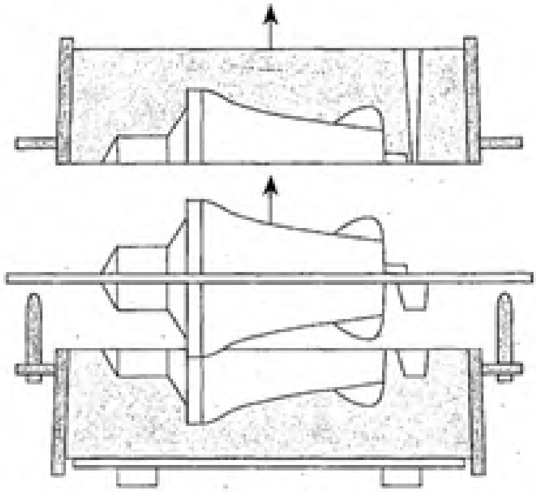
3. A squeeze board is placed over the sand, and the sand is compacted around the pattern.



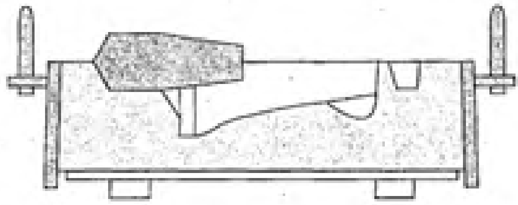
4. After compaction, the flask is turned over.



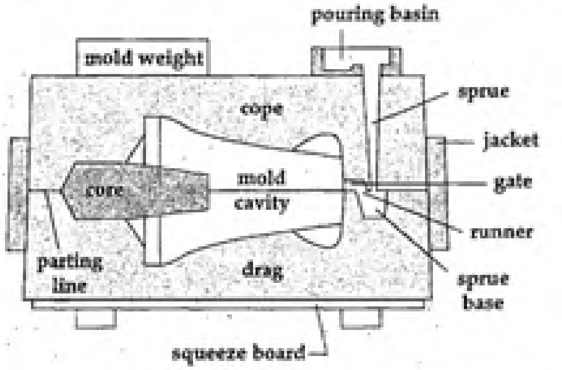
5. After rollover, steps 2 and 3 are repeated for the cope half of the mold.



6. A sprue is cut into the cope. The cope then is lifted carefully off the drag, and the matchplate is withdrawn from the mold.



7. Cores (if any) are placed in core prints in the drag half of the mold.



8. The cope is placed on top of the drag, and the flask is replaced with a mold jacket. Weights are placed on the assembled mold, and a pouring basin is added. The mold is ready for pouring.

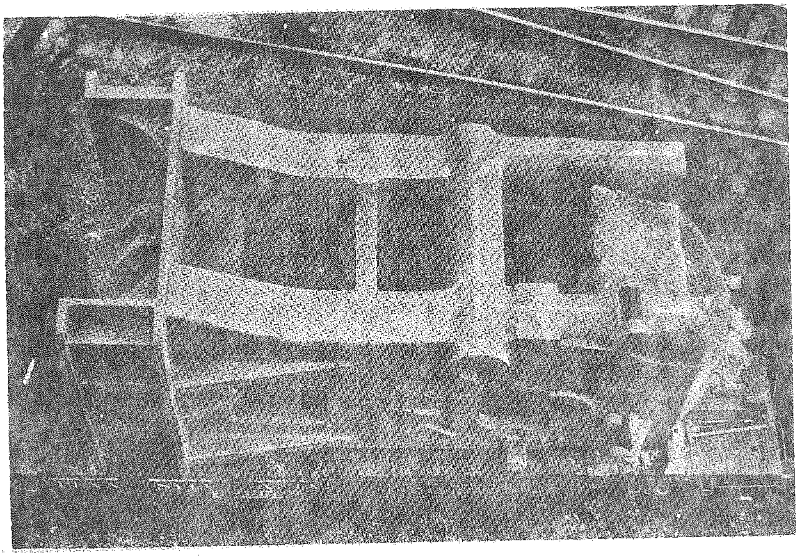


Fig. 3.4 Large intricate casting. Note size relation to railroad flat car. (*Courtesy of Continental Foundry and Machine Co.*)

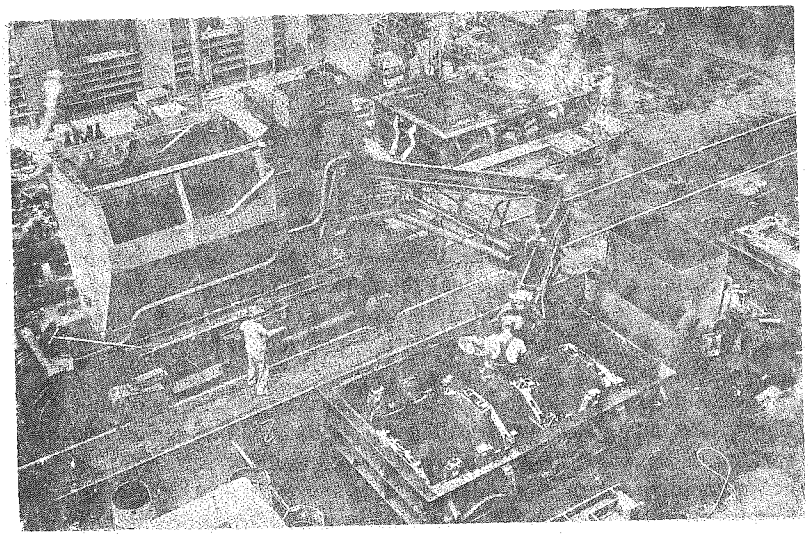


Fig. 3.5 General view of foundry floor for making large mold by ramming with a motive slinger. (*Courtesy of Beardsley-Piper Division, Pettibone Mulliken Corp.*)

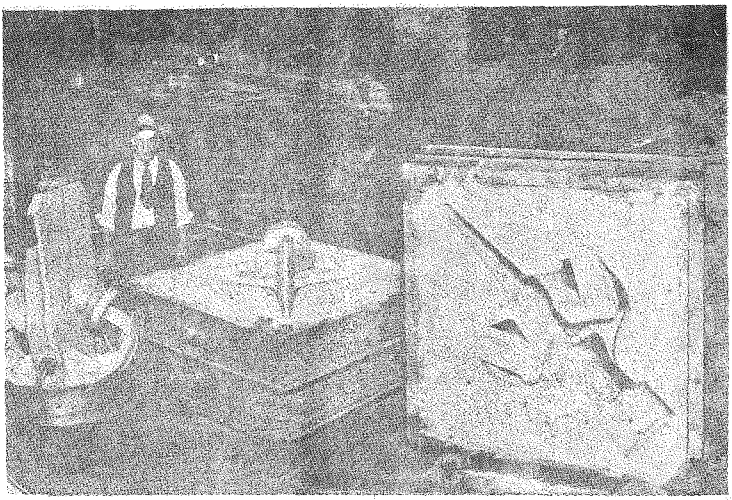


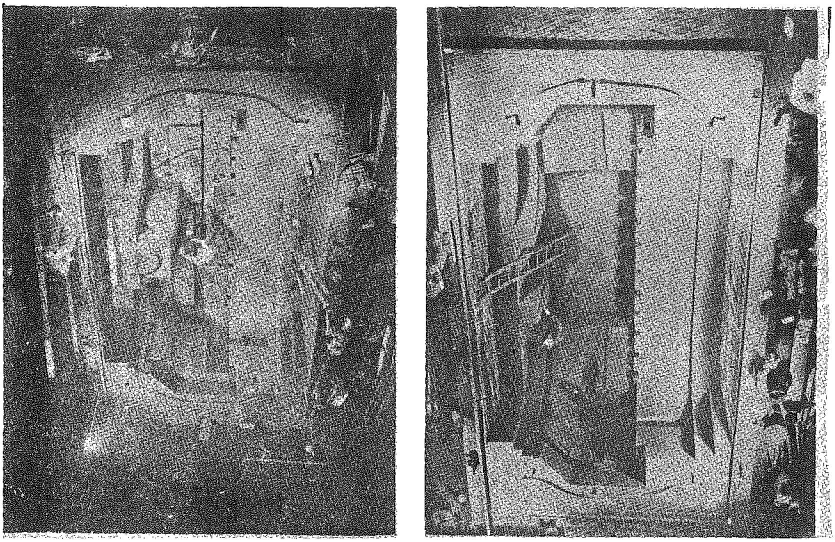
Fig. 3.6 Dry-sand floor mold ready for closing. (*Courtesy of Steel Founders' Society of America.*)

When the pattern being molded is too large to be handled in flasks, the molding is done in pits. Molding pits are concrete-lined box-shaped holes in the molding floor. The pattern is lowered into the pit, and molding sand is tucked and rammed under the pattern and up the side walls to the parting surface. The cope of the pit mold is finished off with cores or with sand rammed in a cope flask. An example of a pit mold partially completed is shown in Fig. 3.7. Such large molds are always dried.

When a large mold for a gray-iron casting can be constructed in multiple-piece flasks or by bricking up a large portion of the mold, loam is used as the molding material. Loam is a moist, plastic molding sand containing about 50 per cent sand grains and 50 per cent clay. It is troweled onto a brickwork surface and brought to the pattern dimensions by using skeleton patterns, sweeps, or templates as the molding progresses. A loam mold under construction is shown in Fig. 3.8. Loam molds must be thoroughly dried.

Cement-bonded Sand Molds

Cement-bonded molding sand is a mixture of sand, 8 to 12 per cent high-early-strength hydraulic cement, and 4 to 6 per cent water. This sand develops great hardness and strength by the setting action of portland cement. Molding may be performed by the methods discussed



(a) (b)

Fig. 3.7 Pit mold for large steam-turbine exhaust end under construction. (a) Pit mold with pattern withdrawn. (b) Same mold having been dried and in process of being fitted with cores. (*Courtesy of Allis-Chalmers Co.*)

above and others specially suited to the cement. The sand must be allowed to set or harden before the pattern can be withdrawn. Then the mold is allowed to cure, or continue setting, for up to 72 hr before the mold can be closed or assembled for pouring. When the mold is poured, heat causes the water of crystallization of the cement to be driven off, and thus steam must be allowed to pass off through the sand by means of its porosity and suitably distributed vent holes. Cement-bonded sand molds can be constructed with considerable accuracy, often more than that obtainable in other processes for making large molds. Consequently, more accurate castings may be obtained.[17]

Core Sand or Core Molds

Sometimes molds are made entirely of an assemblage of cores. In place of patterns, core boxes are used for making all parts of the mold. The cores are fitted together to make the mold, being located by alignment bosses and holes. They usually are poured without a flask surrounding the mold.

Core sands usually consist of mixtures of sand grains and organic binders which develop great strength after baking at 250 to 650 F. Their strength after baking makes it possible to cast metal around thin sand

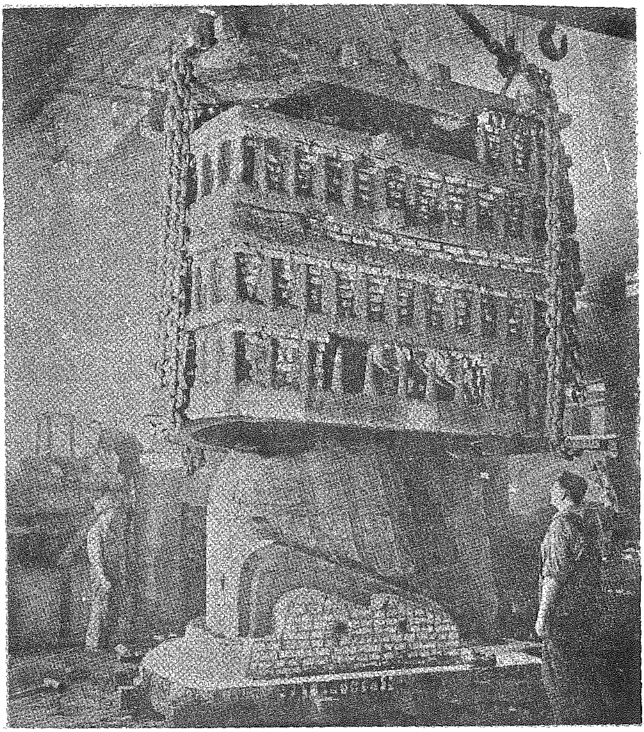


Fig. 3.8 **Loam mold under construction.** *(Courtesy of Allis-Chalmers Manufacturing Company.)*

projections without having them break or erode because of the hot-metal action. The baking operation and the core-sand binders plus difficulties in reusing the sand makes the process more costly. This cost is usually justified, however, in the intricate castings made by this process. Figure 3.9 illustrates intricate castings made in core-sand molds.

Core-sand molds are also sometimes made with dry molding sands or cement-bonded sands, where the great strength and heat resistance of a dry-sand mixture are required, as in large castings.

A process in which the molds do not require baking is known as the air-set process. A mixture of sand, liquid organic binders, and catalysts hardens with time by polymerization of the liquid resins. Molding is mainly done by pouring the free-flowing sand mixture around the pattern. Vibration or ramming is sometimes used to obtain a denser mold. In about 20 min or more, the mixture hardens, and the core box or pattern may be removed. The pieces are then ready for core assembly.

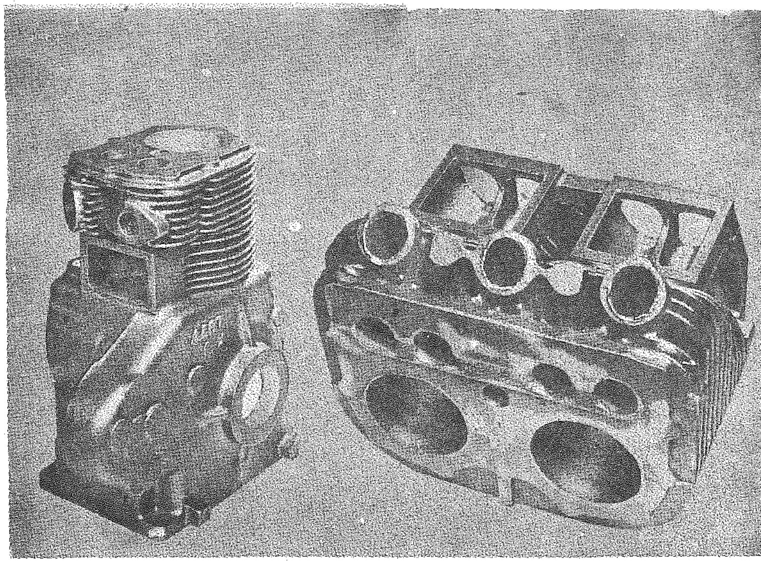


Fig. 3.9 **Gray-iron air-cooled cylinder-block castings made in core-sand molds. (*Courtesy of Brillion Iron Works, Brillion, Wis.*)**

CO_2 *Process*

The CO_2 molding process, also called the sodium silicate process, invol a mixture of sand and 1.5 to 6 per cent liquid silicate. The sand mixtu is first packed around the pattern or into the core box. A harden mold is produced by passing CO_2 gas through the sand mixture. T mold is then assembled from the hardened pieces.[1]

Chapter 8

Shell Moulding

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Shell moulding, known originally as the Croning or 'C' process, is a process whereby a suitable refractory medium, usually sand, is coated with a resin system that is, initially, thermoplastic. This coated medium is allowed to take-up the required form around a suitable heated pattern thus causing the resin to convert to a thermosetting condition such that, upon removal, it retains its shape without a distortion. This shape subsequently forms the basis for the shell mould and it normally constitutes one half of a complete mould.

There are obviously a considerable number of detail refinements that need to be added to the basic technique to produce a shell suitable for a particular casting. Shells may be required to be thick enough to be self-supporting when cast or may be supported by some backing medium. They may be produced by a simple dumping action or a sophisticated blowing technique between two formed plates. The range of equipment and production techniques is widely variable to suit differing casting requirements.

The process was originally conceived in Germany during the Second World War and it is probably more widely used there than in any country outside the USA. In Europe the process is still known by its original name, the Croning process, so called after its originator. Shell moulding became known in the UK and the USA in about 1945 as a result of an Intelligence survey. Its initial claim to importance was due to the relatively simple equipment required to produce a castable mould. In its basic form this is still true, but development for specific purposes has led to the use of increasingly sophisticated and expensive equipment both for the production and casting of the shell moulds.

As in the original process, the moulds are made from a mixture of resin and a 'filler'. This latter material is normally a silicon sand but zircon, olivine and chromite sands may also be used. The choice of material is largely an economic one but the need for specific properties in the sand, such as rapid cooling and high refractoriness, may lead to the adoption of one of the more exotic materials. As the prime cost of these materials is in the region of 5–7 times that of silicon sand, the advantages need to be considerable; however it is normal to reclaim the base sand after casting to minimise these cost disadvantages.

SAND REQUIREMENTS

To produce a satisfactory shell mould the sand to be used should exhibit the following properties, if the maximum economies in resin usage and the advantages of the process are to be realised.

1. The sand should be free of any extraneous material. With silicon sand this means clay or peat which are commonly found in association with the sand deposits. As the strength of the shell depends upon the relatively strong resin bond created between the sand grains, any material that interferes with this bond will require extra resin to counteract its effect if the strength of the shell is not to suffer. Sands, therefore, to be considered for shell moulding should be clay-free or be capable of separation, by relatively cheap means, from any extraneous material present.

2. As the process requires that the sand shall be free running in order to achieve maximum packing density at the pattern surface, it follows that the grains of the material need to be rounded. This requirement, when allied to the previous one, considerably narrows the range of sands available. In the UK this source is limited to two major deposits with several other small ones.

3. So that maximum density may be achieved, a range of particle sizes are needed within the sand. Theoretically three particle sizes in the ratio 50:25:1 give the ultimate in packing density if correctly distributed. As this occurs extremely rarely in nature, the sand to be used should have as close a sieve grading as practicable so as to achieve both maximum shell density and maximum shell strength for a particular resin content.

4. The sand fineness should be such as to give the required degree of surface finish to the casting being produced. When considering this it must be borne in mind that although a fine sand will give a good finish it will also require more resin to produce a shell of a particular strength. It is interesting to note that the maximum strength per unit of resin added is achieved with a reasonably fine grade of sand and that as sand gradings become coarser or finer the amount of resin required increases.

5. As well as being free from physically intermixed impurities, the sand should be free from chemically banded impurities. This is to ensure that the sand will withstand the casting temperature without fusion of low melting point tertiary or binary minerals that may be formed between impurities and the basic sand.

As previously mentioned, for the majority of purposes silicon-based sand is the most economical and is adequate for the purpose. In certain areas of the world it may be feasible to replace silicon with one of the other minerals due to the local supply being relatively cheap, but in the UK it is necessary for particular properties not exhibited by siliceous base materials to be required, before other sands are considered. An example of this is in the casting of grey iron air-cooled cylinder blocks for motor cycles. The higher heat abstraction rate of zircon sands has led to their use in this field as it is claimed that denser, stronger castings are produced than when silicon sand is used. To offset the extremely high cost of the raw material, it is necessary to reclaim all of the base sand after the casting cycle so that it may be recoated. To ensure that the material is not contaminated, it is important that no other type of base sand is used within the plant, *ie* cores as well as moulds must be made from the same sand.

RESINS

Having established the particular type and grade of sand that is to be used, the next consideration is the bonding agent required to hold the sand grains together. This is normally a resin that must have several important properties if a suitably coated sand is to result.

When the shell sand is introduced to the heated pattern the binder should fuse so that the sand assumes the shape of the pattern and forms as dense a shell as possible by grain-to-grain contact. At this stage the resin is acting in a thermoplastic manner, *ie* the shell is in a plastic condition and would distort if any attempt was made to remove it from the pattern. It is, therefore, obvious that the resin must undergo a further change, *ie* become thermosetting, before the shell may be removed in the form of a rigid mould. This second property of the resin is normally imparted by an addition that reacts with the resin at the pattern temperature to convert it to a thermosetting condition, thus creating a time-temperature dependent resin system.

Currently, the resins in general use are of the phenol-formaldehyde type with the base resin containing insufficient formaldehyde to make it thermosetting. This extra quantity is supplied as a result of the breakdown at temperature of an additive to the resin, hexamine being the only practical one. After the sand has been invested onto the pattern the resin retains its rather viscous thermoplastic condition but gradually hardens as the hexamine breaks down and releases formaldehyde. As previously indicated this reaction is time–temperature dependent. As the temperature is increased, the time for the reaction to be completed is decreased. Unfortunately, this is only applicable between certain temperature limits. Below these limits, the reaction is too slow to be of practical use, and above these limits, the resin undergoes other changes that create undesirable sand properties.

When sands having this type of resin system are used to make certain types of castings, particularly low and medium carbon steels, the release of nitrogen as the resin breaks down causes pin hole defects in the castings. In an attempt to overcome this defect, resin research has been directed toward the creation of nitrogen-free resin systems. As a spin-off from this research, a lower nitrogen resin with a reduced hexamine addition has been developed and this has proved extremely useful for the production of large shell moulds with minimum distortion when they are removed from the patterns. As a direct result of this, the production of automobile crankshafts in shell moulds has been rendered much easier. With earlier resin systems the problems of maintaining a shell area of some 6 ft^2 (0.5 m^2) flat were considerable; little or no difficulty is now experienced with this problem. The original concept of nitrogen-free resins has also largely been achieved, but only at the expense of other properties of the resin. This limits the use of these types of resins to, typically, such uses as the production of low carbon steel castings, where the avoidance of pin-hole defects is more important than the loss of other qualities of the sand.

In the majority of resin sands a third component, in addition to the resin and hexamine, is present. This is a release agent that may be a natural or artificial wax. The term 'release agent' only indicates a portion of its purpose, it also acts as a lubricant to the sand grains when the sand is initially placed in the pattern. This enables higher packing densities, and hence better casting finish, to be achieved due to better flowability. As a result of this higher packing density, the quantities of resin required to produce a given strength of shell are also reduced. The residues that remain in contact with the pattern after curing assist the removal of the shell from the pattern.

COATED SAND PRODUCTION

The sand mixtures used in the shell process have been of two distinct types. Originally the moulds were made from a sand to which was added a dry resin that was merely stirred-in to provide a physical mixture of the two components. This was an extremely inefficient way of using the resin, as the quantity required to produce a given strength of shell was relatively high. Accordingly, the technique of coating individual grains of sand with resin has totally superseded the original method. This 'precoated' sand looks very like a new raw sand in that the resin envelope is thin enough to be transparent and almost colourless. On occasions, however, a dye may be added to the resin so that sands having differing resin contents may be distinguished. The resin envelope is quite hard and the sand retains its free running properties until it comes into contact with the heated pattern whereupon the resin softens temporarily with adjacent envelopes fusing together forming the chain bond that subsequently hardens.

Several precoating techniques have been used, each of which is a considerable improvement on the dry mixing method mentioned earlier. There is, however, a wide variation of efficiency within these techniques.

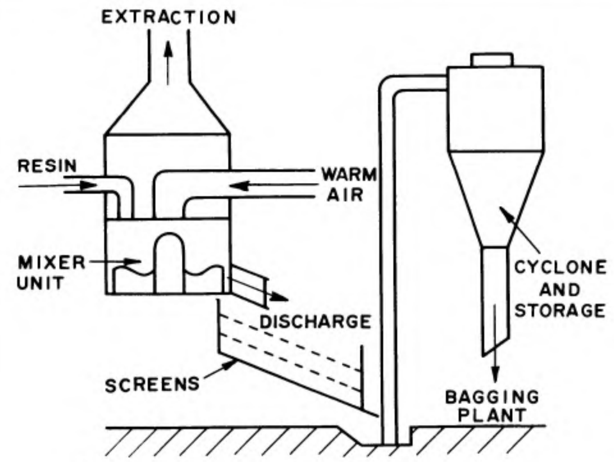

Fig. 1. Layout of a typical warm coating system.

Possibly the most obvious method of coating is to dissolve the resin in some suitable solvent so that it may be mixed with the sand in a fluid state. This solvent is then removed or allowed to evaporate, usually the latter. Unfortunately, whilst this technique is suitable for use in conventional core mixing equipment, the type of solvents that have to be used, namely volatile, usually inflammable, liquids, renders the process rather dangerous. The amounts of resin required are still relatively high.

A second method uses a viscous liquid, usually a phenolic resin, to mix with, and coat, the sand. The primary resin is then added to the mixer in the form of a fine powder which is absorbed into the phenolic resin coating. This is an improvement on the previous method, but still the amounts of resin required are greater than with the two most commonly used processes. These two processes produce by far the largest proportion of shell moulding sands currently manufactured. Both use a sand temperature somewhat above ambient, and are known as the warm and hot processes respectively.

The warm process (Fig. 1), as its name implies, uses the lower temperature of the two, this being of the order of 40–70°C depending on the particular plant and resin employed. In the process, hexamine, a release agent and the warm sand are milled together in a modified core mixer. The modification consists of a means of blowing warm air through the sand whilst it is being mixed. The resin added is solvent based and is added as a rather viscous liquid and the mixture is milled together. The solvent is then driven-off by the warm air passing through the mill and the sand aggravates. This may be seen externally by the marked increase in electrical power required to drive the mill during this period. As milling proceeds the lumps of sand break down and the coated sand is finally discharged through a screen to remove any remaining lumps and put into bags or containers for storage until required for use.

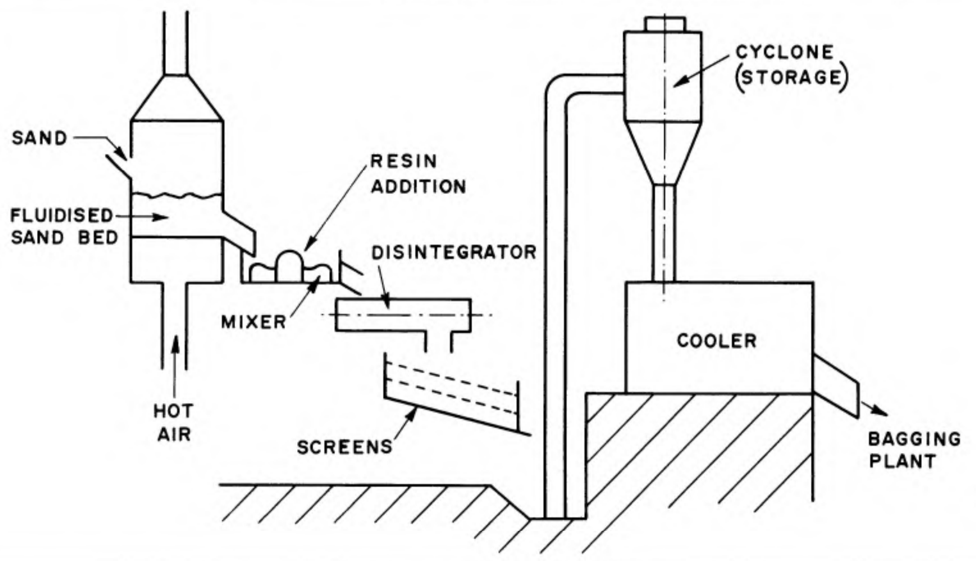

Fig. 2. Typical plant layout for the hot coating system.

Hot coating (Fig. 2) is generally used for high production, continuously rated, plants such as those used by manufacturers specialising in the supply of this type of sand. Sand temperatures of 125–130°C are used, the heating being carried out in fluidised bed systems heated by gas or oil. As the hot sand passes into the mixer, the resin is added as flakes of solid resin. At the working temperature the resin melts and coats the sand grains. The hexamine addition is then made as an aqueous solution. The subsequent evaporation of the water and the effect of adding the cold liquid causes the resin to harden again. As with the warm process, it causes the sand to agglomerate and this has to be broken down before final cooling, followed by grading and storage. Both of the final processes produce a suitable coated sand at minimum resin cost. They obviously both suffer the disadvantage of requirements for specialised plant and so are normally only suitable for relatively high production outputs.

PATTERNS AND PATTERN PLATES

Patterns for the production of shell moulds are normally made from a close grained cast iron. The cost of such equipment is necessarily high and this is one of the drawbacks of the shell process for other than quantity production. Aluminium or other cheaper materials may be used to produce patterns for shorter runs but these are not too successful. Although aluminium is in itself more expensive than cast iron, its easier manipulation renders the patterns cheaper overall. Mixtures of materials should generally be avoided due to differences in expansion rates, although brass or bronze may be used to repair or modify cast iron patterns. Patterns made entirely from these latter materials have been employed, but physical properties and cost are the main reasons for their limited use. The quality of the pattern making needs to be extremely high as the shell process is capable of reproducing extremely fine detail. Any gaps or joints will be reproduced on the shell and the casting, the defect rapidly increasing in size as wear takes place.

Patterns, which in this context include pattern plates and running systems, should exhibit certain properties if they are to be successfully used for shell mould making. Ideally, they should be stable at all temperatures neither expanding nor contracting. Unfortunately, this property is not an economic practical proposition, as all common pattern materials exhibit varying thermal expansion which has to be taken into account when patterns are made. Patterns should be as uniform in cross section as is possible to avoid areas of local temperature loss and consequent poor sand curing or pattern distortion. They should be of either a high thermal conductivity material, so that heat may be rapidly transferred from the heating medium to the pattern face, or, alternatively, be of sufficient thickness to act as a heat reservoir during the investment and curing cycle. In areas where there is a local heat deficiency due to casting design, it may be necessary to insert a higher conductivity material in such a position as to rectify this. The surface finish of the pattern should be of a sufficiently high standard so as to reap the maximum benefits from the process, but not to the extent of a highly polished surface as this creates difficulties of 'dragging' when the shell is removed from the pattern causing shell distortion or breakage. A finish equivalent to 30 μin (0.75 μm) is quoted as acceptable.

In order that the shell may be removed from the pattern, the pattern plate assembly is provided with an ejection system usually in the form of headed pins. These are distributed across the surface of the pattern plate so that they may lift the shell clear of the pattern when pressure is applied to them. These pins have a shaped head designed to ensure that sand does not become entrapped beneath them during the shell making and so that the pressure they apply is distributed over as much area as possible to prevent puncturing of the shell. This head is set onto a plain or threaded parallel shank that passes through a clearance hole in the pattern plate. The pins may be unattached to the ejector plate which is used to apply pressure to them during ejection, or they may be screwed into the plate. With the former type of pin, it is usual to use a spring retainer for patterns for use

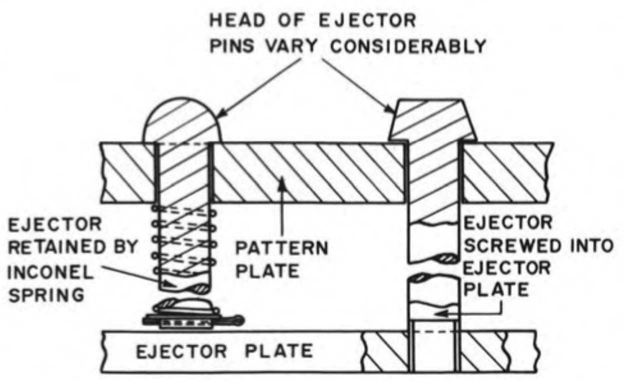

Fig. 3. Common shell mould ejection arrangements.

on a 'roll-over dump machine', to prevent the pins from falling out of the pattern plates (see Fig. 3). When the shell is to be ejected the pattern plate is restrained, and pressure applied to the ejector pins via the ejector plate. Pressure must be applied to each of the pins simultaneously and in a direction perpendicular to the axis of the pattern plate, in order that the pattern tapers are utilised and the shell leaves the pattern without distortion or breakage.

In order to locate the two halves of a shell together after manufacture, two or more dowels must be provided in the pattern plate, the counterparts of which reproduce in the shell mould. Although it is more usual to make male and female in the appropriate portions of the shell, two female may be used, the location being made by a metal pin applied at assembly. So that the two halves mate together exactly, the location method has to satisfy two conditions. Both longitudinal and latitudinal location must be catered for and the locations should have sufficient difference in height as to promote a clearance between them on closing and assuring good joint contact.

Where possible, to minimise the pattern costs, the patterns are assembled onto the pattern plate about the centre line of the plate in such a way that each half of the plate is complementary to the other half. This enables a complete mould to be produced from two half shells taken from one pattern plate

Release agents

To facilitate the removal of the shell from the pattern, in common with all moulding processes, some degree of taper should be provided. Taper is less on this type of pattern equipment than with conventional moulding, half a degree being common. In order to maintain pattern and subsequent casting at this low degree of taper, it is usual to employ release agents. As previously mentioned, traces of the lubricant remaining in the sand act as a release agent but the further addition of a separate agent to the pattern is normal. These release agents are based on silicone compounds and take the form of greases, aqueous sprays or aerosols.

The quantity of release agent used varies considerably, however, there is a strong tendency to use far more than necessary with the intention of improving the release. Unfortunately, release is not improved by such over-use of agent. With any silicone-based spray there is a build up of unused silicone in recesses and corners that will eventually have to be removed by wire brushing or chemical cleaning. This build up is normally very slow, occurring over several thousand shell moulds, but this length of time will obviously be markedly reduced if excessive spraying is carried out. For this and reasons of economy, it is good policy to use an absolute minimum of spray when producing shells, particularly if large quantities are to be produced from one pattern.

Pattern heating

It has already been indicated that the process of shell moulding is a thermal one, therefore some form of pattern heating has to be provided. Gas or electric heating may be used, the choice being largely personal, but the trend appears to be in favour of gas heating for several important reasons. When high production rates are required it is extremely difficult to put sufficient heat into a pattern plate using electrical energy alone. Due to the physical size of the heating units required and the complexity of safety precautions, most larger and faster units are using gas heating. For this purpose gas appears to offer a more reliable, safer, faster heat source. When considering the curing portion of the cycle, however, electric radiant heating is equally as good as its gas counterpart. However, the tendency to heat the patterns by gas is carried on into the curing section due largely to a desire to maintain a common type of heating system throughout the machine.

Gas heating applied to the pattern plate is normally in the form of a multi-burner system mounted below the plate and this may or may not move with the pattern plate during the production cycle. Burners are provided so that critical areas of the pattern may be heated more than others, thus ensuring an even shell thickness when the shell is dumped. Control of the gas input to the burners may be automatic through a thermostatic control on the pattern plate or manual depending partially on the complexity of the machine used, although it is possible to adequately control complex systems without any thermostatic control whatsoever.

When heating the curing oven the heating is via radiant heat units to produce an even cure all over the shell surface without the hot spots that would be caused if direct burners were used. In practice, this even cure is extremely difficult to achieve due to inevitable variations in pattern height and configuration.

Electrical heating, when used, takes the form of rod heaters or wire heaters inserted into either the pattern plate or blocks that may be screwed onto the back of the pattern plate. Some form of thermostatic control is also normally fitted. Adequate safeguards against element failure are an obvious requirement here. Radiant heaters for curing ovens follow a similar pattern to those used for gas.

For the production of good quality shell moulds the control of temperature is extremely important. Too high a pattern temperature leads to overcuring and burning of the shell, shells that are too thick, and possible premature breakdown of the resin upon casting. Conversely, too low a temperature may lead to weak uncured shells that break on ejection, thin shells, lengthy production cycle times and the evolution of excessive gases on casting. Almost as severe is the condition of uneven temperature where the shell may distort or possess any combination of the above defects. Initially, therefore, some measure of the temperature may be necessary. This can take the form of a built-in colour indicator in the sand that changes colour when the shell is correctly cured or some external measurements of the pattern plate temperature. This latter may be achieved using pyrometric equipment built into the machine so that the heating cycle is controlled automatically or some more simple method, such as colour temperature systems, where a dye placed onto the pattern changes colour at a particular temperature. With a series of dyes the plate temperature may be ascertained with sufficient accuracy for the production of good shell moulds. On rapid production cycles the normal difficulty is the maintenance of sufficient temperature to produce a satisfactory shell. In an extremely short time a satisfactory balance between pattern temperature and machine cycle can be achieved without necessitating any direct temperature checking. The checking is carried out by virtue of the fact that satisfactory shells are being produced. It is obvious that this applies to a certain set of conditions only.

When the temperature is to be measured, the practical difficulty is where to carry out the measurement. As temperature will vary across the pattern and plate, experience has to determine the critical area to be measured. Unfortunately, the critical areas are often the most inaccessible ones so that some compromise has to be made. A contact pyrometer or colour sensitive crayon appears to offer the most sensitive system.

Typical working temperatures are between 230 and 240°C, the actual levels being determined by the resin and shell manufacturing cycles. Some resins require a lower curing temperature than others, producing brittle shells if cured at too high a temperature. Resins also vary in their investment and curing rates. Some invest slowly and cure quickly, whilst other work in the reverse direction. A typical cycle time used for the production of shells 940 mm × 610 mm at a pattern temperature of about 240°C is 18 seconds investment followed by a similar curing period. In addition, there is a machine operation time of 13–15 seconds between investment and curing, giving a total heat application time of 49–51 seconds per cycle.

MOULD MAKING TECHNIQUES

Having produced a satisfactory pattern mounted in such a way that it may be heated, a method of introducing the sand must be arranged, followed by the removal of the cured shell after manufacture. There are two principal techniques of introducing the sand: either the sand is (1) blown into the gap between the pattern plate and a profiled plate, this produces a shell of controlled thickness with a profiled back; or (2) dumped under the influence of gravity onto the pattern, this technique produces a shell whose thickness is governed by the pattern temperature and it relies on heat transfer through the sand from the pattern face to produce the shell.

Each of the methods has its advantages for particular purposes. If the methods are considered in more detail, the advantages of each become a little more obvious.

Blowing

In effect the shell mould is produced within a corebox by this method. It enables the exact thickness of sand that is required to be obtained in any part of the shell, but the preparation of the pattern and its associated back plate is expensive. Each plate has to be made for the pattern and should any major pattern modification need to be made the profile of the plate would probably also have to be modified. However, the quantity of sand required for any particular shell is usually less and it is claimed that the shells produced by this method are denser than those produced by dumping. There is an additional advantage in that required detail may be incorporated into the rear of the shell, such as 'ribbing up' to enable larger shells to be cast unsupported than is possible with dumped shells. Due also to the fact that the shell is being cured from both sides immediately after blowing, faster production rates should be possible. This does not necessarily follow, however, as the introduction of multi-stage dumping machines rather nullifies this advantage.

Shells of equivalent size to those that are dumped may also be blown but, in the larger sizes particularly, the section thickness may have to be increased to facilitate the transfer of the sand during the blowing sequence. As the shell size increases above a certain size, the technique of blowing the sand from one open edge of the box is no longer practical as the sand begins to invest before reaching the extremities of the box leaving poorly blown areas within the shell. To overcome this problem the sand is introduced through multi-blowing holes fitted into the back of the box. So that the shell may be removed, these holes, and the associated blowing head, are normally water cooled and fitted with some means of returning excess sand to the sand reservoir immediately after the blowing operation to reduce spillage. To help the flow of sand and to prevent air being trapped within the corebox, small slotted vents are placed at the extremities of the blowing operation in a similar way to other core blowing techniques.

A development of this method of shell production is used in Japan for crankshaft production where large quantities of a small number of designs are required. In this, a number of backing plates are used, with a single pattern set up. The sand is blown between the plate and pattern as already discussed but is not removed from the plate. Plate and sand facing are taken away and a fresh backing plate introduced.

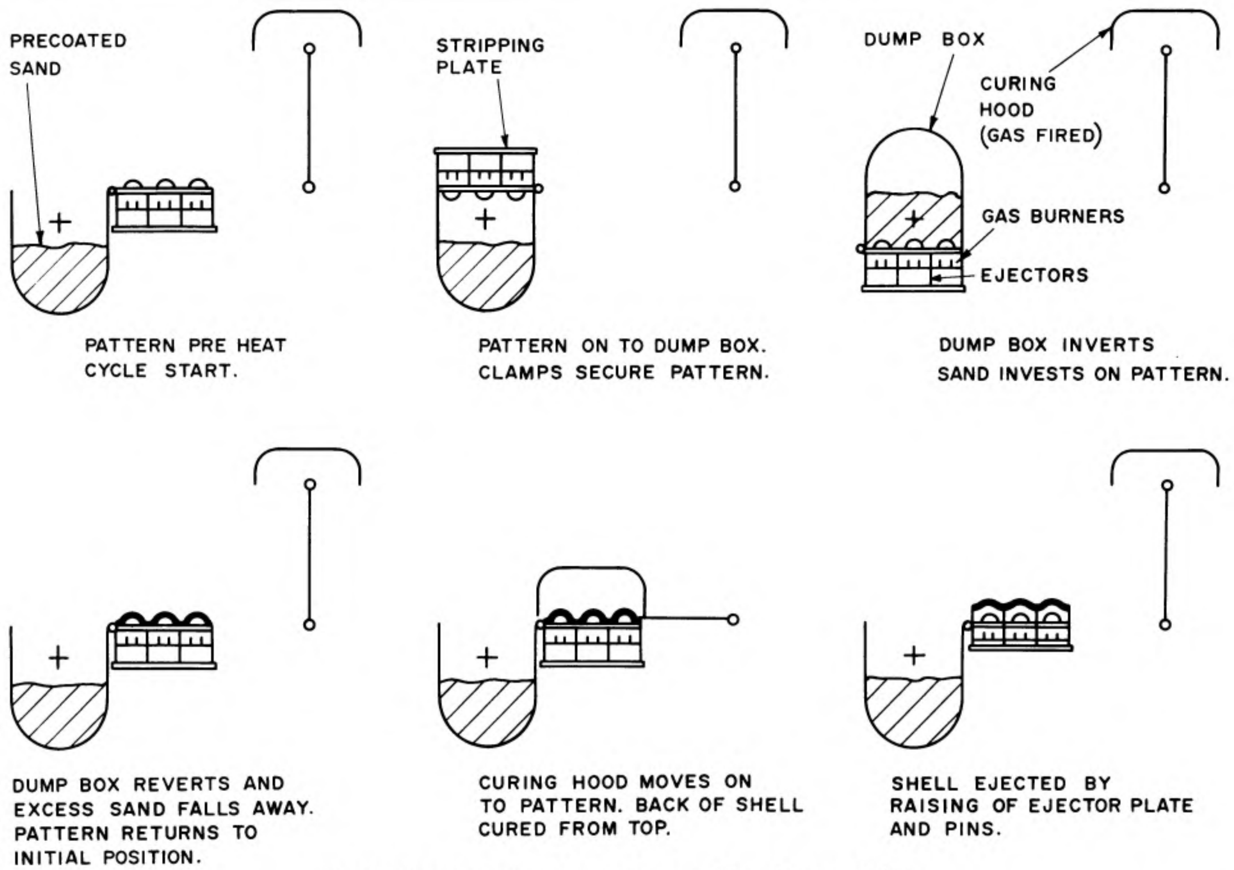

Fig. 4. Stages in the dump action mould making technique.

The backing plate with its sand facing is changed to another of the same type and forms a rigidly backed shell mould. It is claimed that spheroidal graphite iron crankshafts may be cast without any feeder heads being used. The capital cost of such a plant is considerable, however, and one such plant in the USA has now ceased production.

Although blowing of shells has several advantages, the cost of the machinery necessary, particularly in the larger sizes, tends to limit its use.

Dumping

In its basic form this technique is extremely simple and is a method whereby shell moulds may be produced with little or no special equipment. The heated pattern is placed over a sand container and the whole is then inverted. The sand will fall onto the pattern and begin to cure. The dumping action causing the sand to fall and conform to the pattern profile is the most critical of the whole operation as this determines the density of the shell produced. The container and pattern remain inverted for a period of time sufficient for the heat from the pattern to cause the resin coating on the sand to fuse to other sand grains, and for this action to penetrate far enough through the sand to produce the required shell thickness. Then, when the unit is turned the correct way up, the excess sand falls from the pattern leaving behind a layer of sand that ranges from the outside to the pattern surface in its degree of resin fusion. The pattern is now said to have been 'invested'. The pattern with its sand coating may now be removed from the container and introduced into an oven so that heat may be applied to the outside of the shell to cure the resin. At the same time, this curing action is taking place from the pattern face outwards. When these two areas of cure meet the shell may be ejected from the pattern and the pattern cleaned ready for the next cycle (see Fig. 4).

In its most simple form this method is both slow and laborious but it lends itself readily to various degrees of mechanisation, the ultimate being a large automatic multi-station machine. Correspondingly the cost of shell moulding machines of this type varies enormously ranging from a few hundred pounds (sterling) for the simplest to many thousands for the more complex automatic types. Shell sizes of up to 1070 mm × 610 mm are commonly made by this method.

Production rates will also vary enormously but a single station, single pattern, semi-automatic machine may produce shells of some 940 mm × 610 mm at a rate of 40 halves per hour, whilst a multi pattern fully automatic machine will produce shells of a similar size at rates of up to 200 per hour.

ADVANTAGES AND DISADVANTAGES OF SHELL MOULDING

1. Extremely good detail definition is retained by the shell mould. Machine marks left on patterns will accurately reproduce on castings. This detail retention enables automatic transmission components with fine detail channels to be cast. In combination with shell cores, complex valve bodies and assemblies may be cast that would be difficult to produce by other means. Finely finned air cooled cylinder blocks may be cast easily with the shell moulding process. This latter is one use of zircon based sands in shell moulding.

2. Better surface finish is possible than with other types of moulding. When green sand moulding, the fineness of the sand is limited by the necessity of escape of gases created by the casting process. Some permeability of the sand is necessary. Although shell moulds are closer grained than normal green sands, the gases created by casting are able to escape due to the relatively thin layer of sand to be permeated. Even when shot backed, the relatively coarse backing allows the free passage of the gases.

3. Contrary to what might be anticipated, shell moulds have slower cooling rates than an equivalent solid mould. This is due to the highly insulating nature of siliceous sands and also to the 'still' layer of air that surrounds a shell mould. Consequently some metallurgical problems with section-sensitive metals, such as cast iron, may be experienced, necessitating analysis correction. This cooling rate is one reason why zircon based sands are used for the production of air cooled cylinder blocks. A relatively rapid cooling rate is required and zircon sands provide this with their lower insulation characteristic. By thickening the shell or by backing the shell with a material having a high conductivity rate, such as shot, the cooling rate may be increased.

4. Metals with a short freezing range are most suited to shell moulding. This ensures that the relatively weak mould has to withstand the casting stresses for the minimum amount of time. Casting temperature obviously determines the time for which the moulds are subjected to these stresses and it is advisable to cast into shell moulds at as low a temperature as is practical to produce sound clean castings.

5. Knockout properties of shell sands are excellent. Under normal conditions the resin at the mould face is totally destroyed some time after casting. This enables the shell remaining to be easily removed. With higher melting point materials, the breakdown of the sand carries to completion without the assistance of any outside agency. Casting may have a satisfactory finish with only an extremely light cleaning operation.

6. Although there is a limitation in the sectional thickness of a product that is castable in an unbacked shell mould, physical size is not necessarily the controlling factor. More and more cylinder blocks are being cast in shell moulds in European countries, whilst in shot backed moulds poured weights of 90 kg are not uncommon. In this type of system the limitation has been found to be physical size of the plant used rather than the casting to be produced. A pair of crankshafts each weighing 43 kg are currently being produced in a single shell mould.

7. Economics vary considerably with the type of casting to be produced. Certain types of extremely simple castings produced in relatively cheap materials do not require the advantages possible with shell moulding. Hence, for this type of work, shell moulding is uneconomical.

Where extreme accuracies are required or where exotic alloys are involved, the wax or investment process might be more economic. Diecasting of light alloys offers advantages that shell moulding does not. Each process offers some advantages for a particular set of circumstances and shell moulding has to be evaluated in this light, alongside these other processes. Shell moulding uses an extremely high quality metal pattern that is expensive to produce. This is necessary whatever the quantities involved. Other processes will be able to use wooden equipment at a much lower price level. Shell sand is relatively expensive when comparing it with normal green sand mixtures but cheaper than the materials used in investment casting.