CHAPTER XIV

Aluminum Foundry Practice

Foundry molding methods used in casting aluminum are the same as those used in casting other metals. Each casting method has its limitations and the foundry selects the one which works best for it.

Methods of Molding

Quite a number of molding processes are used in the production of aluminum and aluminum alloy castings. The three most popular processes used are: 1) sand casting (green, baked, CO$_2$-sodium silicate, shell, others), 2) permanent mold casting, and 3) pressure die casting. Other methods in limited use are plaster casting, centrifugal casting, ceramic investment or precision casting, and slush casting.

Table 11 rates the various methods of producing aluminum castings. It is designed to serve as a guide in the selection of the molding method best suited for the specifications of the casting. Choosing the correct molding method is as important as creating the casting design and developing an alloy for the casting.

A knowledge of the limitations and advantages of the various molding methods is an essential prerequisite to making a choice. Once the molding method is selected, the design of the casting may require some minor changes. Different design limitations are sometimes imposed by each molding method.

Casting Quantity Affects Choice of Molding Method

The quantity of castings and dimensional accuracy required are important factors in selecting a molding method. Since pattern equipment used for sand casting is much less expensive than dies used for permanent molds or pressure die castings, sand castings are preferred, especially where fewer quantities of castings are ordered. As larger quantities are considered, the point where it becomes economical to consider the use of dies for permanent molds or pressure die castings depends upon the size and complexity of the castings, the metallurgy required, machining specifications, dimensional accuracy, and other factors.

Die casting is primarily a mass production process which is used to produce special small castings such as musical instruments, instrument cases and parts, small motor and pump parts, toys, novelties, hinges, automotive trim, jewelry, etc. However, aluminum has lost much of this market to zinc and zinc alloys since these metals are die cast by pressure methods and to lesser degrees by gravity procedures.

Centrifugal casting molds may be made from a variety of materials including steel, cast iron, ductile iron, sand and graphite. Various mold coatings are applied to the spun molds such as a mixture of graphite and sodium silicate suspended in water and then sprayed.

Most aluminum casting alloys suitable for use with other molding processes can be used for centrifugal casting. The alloys should be poured at about 1000° F. (538° C.) lower than the pouring temperature of static castings. Alloys having short solidification ranges are preferable to those having wider freezing ranges when casting by the centrifugal method. Castings of fairly simple design, such as pipe, wheels, gears and items with circular shapes, etc., may be centrifugally cast.
The molding method least affected by casting size is sand molding, with permanent mold casting next. Die casting has very limited size restrictions. The cost of the dies and die casting machines rises steeply with increased casting size and weight, e.g., it is economically difficult to cast motor blocks in dies.

**Flexibility of sand casting methods** is often the most important factor in the selection of sand molds. By employing this method, changes can be made quickly in the design of a casting. New parts are produced faster with this method than with permanent molds or die casting methods. Even when establishing a new casting part, the developmental work in sand molds is usually done without considering other molding methods, such as permanent molding or die casting.

**Sand casting** has further advantages that are often overlooked. For example, allowances must be made for machining the castings. Why must castings be cast as closely as the pattern? If close casting tolerances that would not require machining can be achieved, then it is well to do so. However, if machining cannot be totally eliminated, then it is best to leave some metal stock on the castings. Aluminum castings under 12” in size require about 1/16” of excess metal on the casting surfaces, so that the castings can be machined in a lathe or a milling machine at lower costs. These castings require 3/32” of extra stock in the bore areas. Medium sized aluminum castings require 1/8” extra metal on the surface, and 3/16” in the bore areas for a savings in tooling costs. Castings over 25” in size require 5/32” of extra metal on their surfaces with 3/16” oversize metal in bores. Machine tooling costs are increased if less metal stock is added during casting, as they are ruined by the adhering oxides, sand and eutectic slags present on the casting surface.

### Sand Castings

Most aluminum alloy foundries are small, and so conventional casting methods are used. More aluminum is cast in green sand than by any other molding method. It is claimed that approximately 98% of all castings are made in sand molds. Green sand is the oldest, most familiar and best technically known molding method. Many aluminum alloy foundries change sand formulations as rapidly as they change alloys of the base metal. Simple design changes are permitted with green sand molding because it is quite flexible. A typical aluminum foundry using green sand molding usually has small production runs with many pattern changes. Green sand allows the foundryman quick molding changes for the least cost.

There are few high production aluminum foundries in operation. Many small aluminum foundries are in existence because of the low, initial cost of establishing a green sand molding unit. There are more squeezer type and small jobbing foundries casting aluminum than any other type of metal.

### Aluminum Casting Alloys

A large number of aluminum casting alloys have been developed. However, the majority of aluminum castings are produced from only a few proven and standard metal compositions. Two of the aluminum-base alloys most widely used are described below. Other alloys of aluminum with higher mechanical properties are available. As a rule, these special alloys of aluminum depend upon the heat treatment or fluxing treatment to develop their superior properties. Special alloys and modifications are generally covered by patents.

**Aluminum-Copper Alloys:** The aluminum alloy containing 7.0% to 8.5% copper, 0.8% to 1.2% iron, and 1.0% to 1.5% silicon is a composition which is generally used for specific castings. The addition of copper to aluminum produces an increase in the strength and hardness of the alloy. When the copper addition exceeds 8.5%, the metal becomes too brittle for many uses. The iron content strengthens the alloy immediately after it solidifies, thereby, generally preventing the occurrence of casting cracks. Iron, however, easily contaminates aluminum and the percentage added to the alloy is constantly under surveillance. Silicon promotes fluidity of this alloy, thus making the alloy easier to cast.

**Aluminum-Silicon Alloys:** An alloy which contains from 4.5% to 6.0% silicon, a maximum of 0.4% copper and a maximum of 0.8% iron is used extensively for sand casting.

The aluminum-silicon alloys remain fluid at relatively low temperatures, but have low shrinkage upon solidification. This combination of properties favors the use of the aluminum-silicon alloys for most casting purposes. Aluminum-silicon alloys are among the most corrosion resistant of all the aluminum alloys. Higher silicon alloys of aluminum are cast chiefly in die and permanent molds.

### General Foundry Practice

Aluminum casting alloys have low strength at temperatures just after solidification. If free contraction of the metal is not permitted,
casting cracks may be produced. Therefore, sand molds are made relatively soft by conventional molding practices. The sand cores must collapse at low temperatures in order to obtain sound castings by not causing the metal to hot tear or crack during solidification.

The low specific gravity of aluminum alloys makes extra venting necessary so that the gases in the metal and mold can be removed rapidly from the mold cavity. The use of a molding sand having a small grain size is required to produce smooth surfaces on these castings. The properties of the molding sands for aluminum alloys depend upon the type of castings to be made. For small castings, a green compression strength of 5 to 8 psi, and a permeability of less than 30 are ordinarily satisfactory, providing the mold hardness is approximately 70. For larger castings, a green compression strength of 7 to 10 psi, and a permeability of from 40 to 80 at a mold hardness of 75-80 are usually necessary. (Chart 15) The refractory property of sands used for aluminum alloy casting varies as the castings become larger and melting conditions more complex. Silica is the sand most generally accepted; olivine is used for certain casting properties; and, more recently, greater amounts of Hevi-Sand (chromite) are being used. The advantage in using Hevi-Sand is its chilling effect; most metal chills can be eliminated with the proper use of Hevi-Sand mixtures.

The base core sand is most important. As the cores break down into the molding sand, the molding sand system is governed by the type and amount of the core sand dilution passing into the system.

A typical aluminum green sand mixture used to cast primarily light to medium castings is as follows:

**MATERIALS**

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica or Bank Sand, AFS Gr. Fn. No. 90-180</td>
<td>95.0</td>
</tr>
<tr>
<td>Panther Creek Bentonite</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Temper Water

3.0 - 3.5

Mulling is important. It distributes the bentonite and forces the temper water into the bentonite bond. To gain moldability and workability, ample mulling time must be allowed on capable mulling equipment. With vertical wheel millers, an all new sand mixture should be milled 2 minutes dry, then 5 minutes wet for best results. Mull 120 seconds with horizontal wheel millers to prevent friable molding sand mixtures. The sequence of the temper water addition may differ from one foundry to another.

**A Semi-Synthetic (Blended) Green Sand Mixture**

Most small foundries, purchasing their first sand preparation equipment, are prepared to change from 100% naturally bonded sand to part natural and part unbonded sand with a bond addition. Since most naturally bonded sand systems are constantly diluted with core sand, the foundry is, and has been, a semi-synthetic operation, whether the foundry recognizes it or not. A regular flow of new bonded sand or bentonite bond to the system is necessary to maintain proper molding properties.
The following formula is a popular semi-synthetic sand mixture:

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>PERCENT BY WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica or Bank Sand, AFS Gr. Fn. No. 90-140</td>
<td>73.0</td>
</tr>
<tr>
<td>Naturally Bonded Sand (8%-12% natural clay as mined)</td>
<td>25.0</td>
</tr>
<tr>
<td>Panther Creek Bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>Temper Water</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Mull and aerate this mixture for best molding results. Control the temper water within ± 0.2%. Do not allow the fines or inert to accumulate. Dilute the system with new sand on a regular schedule. Bentonite additions and regulated mulling procedures control, to a great extent, the increase or reduction of the various strengths in a sand system.

**Sand molding methods** used by other metal foundries need only to be slightly modified for use in producing aluminum castings. The handling, conditioning and preparation of the sand remains the same. However, because aluminum and its alloys have lower melting temperatures, there is less need for sand replacement when compared to the larger replacement quantities required by ferrous foundries. Aluminum alloys do require certain preferred molding practices because of characteristics peculiar to this alloy. When the engineer, designer, and foundryman understand these characteristics, successful production of aluminum castings is assured.

The outstanding characteristic of an aluminum alloy is its light weight, and this significantly influences molding practice. Aluminum's light weight, which is one-third that of cast iron, steel or brass, lowers mold pressures and necessitates lighter ramming of the sand mold. Mold weights are not always required when pouring small or medium molds; in fact, slip flasks and metal bands may not be required in snap flask molds.

**Selection of the Base Sand (Green Sand Molding)**

Perhaps as many different types of sand mixtures are used in the production of aluminum and its alloys as there are aluminum foundries. Nearly any local, fine sand (naturally bonded or unbonded) works well if there is proper sand control. A low priced sand which is easily available at low freight rates should always be given first consideration.

Naturally bonded sands are sometimes preferred in the aluminum foundry because of their handling ease. Many types and varieties may be used because aluminum alloys cast more easily than other higher melting metals and their alloys.

A fine grained, naturally bonded sand with an AFS Clay Content of 8% to 20% may be selected, providing a smooth casting surface can be obtained. Also, a naturally bonded sand may be used if little or no mechanical equipment is available in the foundry. The moisture content of naturally bonded sands must be closely controlled or else the low permeability of these finer sands can result in casting blows, pinholes and gas porosity when the molds are rammed incorrectly. Correct temper water for molding varies between 5% to 7% by weight for most naturally bonded molding sands.

The melting temperature of molten aluminum and its alloys rarely exceeds 1400°F (760°C), so the molding sand does not take much punishment at this lower pouring temperature. The durability of the molding sand is generally good. Weak strength in the molding sand occurs when the system is diluted by the core sand.

Although local sands are acceptable for molding, many aluminum foundries use synthetic (compounded) sands which perform better than naturally bonded sands under controlled supervision.

Sand grain distribution is not as important in aluminum foundries, as it is in steel, iron or malleable foundries. Aluminum alloys containing both copper and silicon demand additional attention; molding sand must be under control. Better sand technology has been developed for the casting of aluminum alloys containing magnesium, as these molding mixtures require inhibitors to protect both the metal and the mold from mold-metal reactions.

**Selection of Additives**

The foundry sand additives used with synthetic sand mixtures in aluminum molding mixtures are added in 0.25% to 2% increments and guarantee nonferrous casting quality.

**Southern bentonite** (Panther Creek) is the favorite bond additive for aluminum sand mixtures. Some western bentonite (Volelay) is used to enhance deformation and toughness in the sand mixture, which promotes easier molding and better lifting of the green sand mold from the pattern. Of course, even new, naturally bonded sand is added in some instances because its clay content gives and maintains green compression strength. Many naturally bonded sands used in casting aluminum have only limited green compression strength, so regardless of how much is added to the system only the original green strength of the naturally bonded sand can be reached. Where synthetic (compounded or formulated) sand mixtures are used, a bentonite should be added as the clay bond.

**Wood flour** (Five Star) or **grain cellulose** (Cellflo) are added to aluminum molding mixtures in 0.25% to 2% increments to guarantee against buckles or other similar expansion difficulties which generally occur on flat casting surfaces. Wood flour and cellulose also allow good collapsibility of the molds and cores.

**Carbon additives** are not widely used by the aluminum foundry.
If carbon additions become excessive, there is a tendency towards pitting, blackheads, black streaks, craters, and other improper aluminum casting surface defects. Carbons are used to improve certain molding properties, and additions are maintained within 0.5% to 2%. The peel of the molding sand from the castings is improved where cellulose is added to the sand mixture.

**Tempering**

Tempering molding sands in the aluminum foundry is most important. Molding sand must be tempered until it "feels right" to the molders. The added temper water must be controlled within close limits to guarantee a continual production of good aluminum castings. Sprinkling cans, hoses and other "personal" application tools are unsound methods of judging the correct temper water additions. **Temper water must be metered to obtain proper control.** A continuous increase in clay and water content is not always the answer to foundry problems.

Tempering of synthetic (formulated) sand mixtures is easier because less water is required. However, these sand mixtures are very sensitive to temper water changes. Better tempering control of synthetic sand mixtures is achieved in foundries having mechanized sand equipment. (Chart 16)

**Mulling**

As in all foundries, aluminum and aluminum alloy foundries must have properly operating mollers to do an effective job. Proper mulling builds sand properties needed to produce good molds and which, in turn, give greater assurance of good castings. Mollers help distribute and equalize the temper water in sand mixtures, creating deformation and toughness, and developing workable sands with green compression strength. Mulling improves sand properties which allow the molders or machines to produce higher quality molds. Proper mulling ensures against certain foundry scrap, particularly less burn-in or burn-on due to a poor distribution of temper water in the molding sands.

**Aerating Molding Sand**

A molder may hand shovel or hand riddle the molding sand to aerate it. However, the best method of aeration is to place the molding sand through a mechanical unit to ascertain that the sand has been properly conditioned. Good sand preparation is very important and does lend towards improved economics. Sand systems with spotty wet or dry areas should be aerated to achieve better blending and uniformity, thereby producing better molds.

**Temper Water Problems**

In spite of the wide use of conventional molding sands, their properties leave much to be desired. Many problems arise from an inability to control moisture content in these sands. Slight variations in moisture content can cause radical changes in the molding sand’s green compression strength, dry strength, hot strength, permeability and flowability. If these changes are not corrected, both surface and interior defects may occur in the castings. The moisture content of molding sands can vary appreciably during storing, molding or pouring as a result of evaporation losses. Little can be done to prevent the evaporation of temper water because of its relatively low boiling temperature (212°F [100°C]).

Conventional molding sands must be permeable; that is, they must allow gases to escape freely. A large volume of water vapor and gas is evolved when molten metal contacts the molding or core sand. Permeability is a direct function of the amount of pore space which, in turn, is related to the sand particle size and density of the rammed mass. The amount of pore space required limits the degree of fineness that a base sand should be when used in pouring certain types of castings.
Waterless Binders - Oil Bonded Molding Sand

For centuries, foundrymen have been aware that the use and abuse of water in green molding sand is the cause of most casting scrap. Even with the best moisture control, castings of certain design may be scrapped because of steam formation during the pouring of castings. The formation of excessive steam during casting also necessitates the use of molding sands which are relatively coarser than normally required.

To avoid the disadvantages of a molding sand containing water, many water-free molding sands have been tried in foundries over the years. Some water-free sands of the past contained only oil as the bonding agent; clay was omitted because it is damaged by oil additions. Oil is believed to be superior to water, because it boils at a higher temperature than water and evolves less gas. Oil bonded mixtures require less daily sand control due to lower evaporation losses of the oil as compared to water. Oil tempered sands chill the molten metal less which is considered good in many cases. In spite of these advantages, early oil-sand systems were always found to be impractical because of their low green, dry and hot strengths.

To obtain the required strength in the absence of water, a bonding agent effective in oil was needed. Neo-Bond was developed. Neo-Bond is a dry powder that contains a mixture of heavy metal oxides, fats, hydrous-aluminum silicates, and chemicals.

Neo-Bond molding mixtures consist of new, washed silica sand (AFS Gr. Fn. No. 130-150), 3% to 5% by weight Neo-Bond, 2% to 10% by weight Klean Surf iron oxide, and 1.25% to 1.85% high viscosity coastal oil. A catalyst is used at times, but alcohol and catalysts are not required in Neo-Bond mixtures. Exceptionally good results are achieved when aluminum, copper-base alloys, and light weight gray iron castings are cast in this sand mixture. Other metals successfully cast with Neo-Bond are brass, bronze, nickel and stainless steel. Better casting surfaces are produced with this molding sand mixture than with more expensive molding mixtures. Neo-Bond mixtures must be mull 10 to 15 minutes in a vertical wheel muller prior to mulling for best results. Mulling produces a green compression strength of 12 to 15 psi.

Oil bonded mixtures should be rammed hard, about 80 to 85 mold hardness. Many nonferrous foundrymen make the mistake of attempting to make smooth castings with very "soft" molds. Although it is true that it is easier to make a relatively smooth mold with weak, naturally bonded molding sands, when using a high strength bond such as Neo-Bond, it is necessary to ram the molds harder. The closer the sand grains are rammed to each other, usually the smoother the casting. To achieve this, many foundrymen have needlessly spent thousands of dollars on special machinery. The foundries' existing molding equipment can do an adequate job of ramming Neo-Bond waterless binder mixtures.

Less than 1% Neo-Bond is required to rebind a Neo-Bond mixture after use, and 0.10% or less emulsion or coastal oil will bring the waterless mixture to temper (1.25% to 1.85%), the preferred choice of the foundry.

Melting - Pouring - Gating Problems

The advantage of light weight is partially offset by the fact that the molten aluminum's low density makes the elimination of metal oxides, metal gases, and mold cavity gases increasingly difficult. Heavier metals can force mold gases from the mold, thereby easily riddling themselves of oxides in the gating system. With aluminum alloys, it is necessary that the melt be delivered to the mold with a minimum amount of oxides. This can only be done by thorough fluxing in the ladle, preferably with chlorine gas. In addition, enough permeability of the mold and core is needed to allow the escape of air, water vapor, and other mold gases. Correct mold permeability can be achieved through lighter mold squeezing and ramming. Permeability varies with the mold hardness, as well as with the fineness of the base sand. Some foundries add permanent vents to the pattern to guarantee venting of the mold cavity.

Hot shortness of some aluminum alloys may cause "hot cracking." Certain alloys have low mechanical strength at temperatures just below their solidification point. These castings may crack or hot tear if the alloys are cast in a mold which resists contraction of the metal as it solidifies. Hot shortness varies with the casting alloy used. Therefore, the baked and hot compression strengths of the molds and cores must be controlled at a low temperature level. Selecting the correct binders and maintaining a correct percentage of addition are factors that can help prevent scrap caused by "hot cracking."

The aluminum-silicon alloys show considerably less hot shortness than aluminum-copper alloys. An aluminum alloy which shows hot cracking tendencies must have better sand control than other alloys. Usually, the control of temper water and bond additions plus mulling procedures of the sand mixture corrects this metal problem.

Personnel

Personnel employed by an aluminum foundry are generally hired from local sources. Management is aware of their abilities and faults, and supervisors dictate policy at an operational level. Most aluminum foundries are successful for this basic reason. These foundries produce good castings because management appears more often on the molding floor to direct and supervise each operation. It is top management's interest that breeds success in aluminum foundries.