

Introduction

The management and staff at *CMH* have been designing and building permanent mold casting machines since 1959 and the resulting machine is one of the highest profit makers in the field today. We have combined our years of experience to bring you the following “Tilt Pour Permanent Mold Casting Guide.”

CMH has continuously strived to improve its products and improve the productivity of our customers. Automated hydraulic, electronic and electric operations of all phases of the casting process, including casting removal and ladeling, have dramatically increased production.

The Process

Aluminum casting alloys are the most versatile of all common foundry alloys and generally have the highest castibility ratings. Aluminum is adaptable to many of the commonly used casting methods and can be readily cast in metal molds mounted on *CMH* casting machines for high volume, cost-effective castings.

In general, aluminum alloys have the following characteristics:

- Good fluidity – important for filling thin sections
- Low melting point – lower melting and casting temperatures relative to those required for many other materials
- Lower density – the lighter weight of aluminum allows for easier handling in the foundry, compared to ferrous alloys
- Fast heat exchange – heat transfer from the molten aluminum to the mold is relatively fast, providing faster castings cycles in metal molds
- Good chemical reproduction – chemical stability is relatively good
- Good as-cast surface finish – surfaces are lustrous and have few blemishes

The tilt pour process using *CMH* tilting devices involves the production of castings by pouring liquid aluminum into permanent molds and tilting the mold, allowing a controlled flow of liquid aluminum to fill the mold cavity by gravity. Basically the process involves the following steps:

- A refractory mold wash is sprayed onto the surfaces of a preheated mold that will be in direct contact with the molten metal alloy
- Cores, if applicable, are inserted, and the mold is closed by the ram cylinder
- The alloy, heated above its melting temperature, is poured into a pouring cup
- The tilting device tilts down allowing the liquid alloy to fill the mold cavity at a controlled rate
- After the alloy has been allowed to solidify, metal cores and other loose mold members are withdrawn, the mold is opened, and the casting is ejected (usually with the casting machine in the tilted up position)
- Steps two and four are repeated until repair of the mold coating is required, at which time step one is repeated
- Usual foundry practices are followed for trimming gates and risers

When permanent mold casting is combined with nonmetallic cores, such as sand cores, the process is referred to as semi permanent mold.

Applications for Permanent Mold Castings

Aluminum permanent mold castings are widely used throughout industry. As the United States government mandates more fuel-efficient cars, the demand for permanent mold castings has steadily increased. Suspension links, intake manifolds, pistons, and other functional parts of internal-combustion engines are typical applications. Other applications include aviation engines, missiles, motor housings, portable tools, nozzles, fan cases, outdoor lighting standards, gear cases, lawn mower chassis, barbeque grills, and kitchen pots and pans.

Advantages and Disadvantages

Because of the various factors that must be considered when choosing a casting process the decision to use tilt pour permanent molding should be based on thorough engineering and production cost studies. Properly engineered well- made tilt pour castings will have the following advantages:

- Dimensional accuracy is superior to sand or shell mold castings, because the mold is rigid and does not allow mold wall movement during solidification. Additionally, dimensional repeatability is improved. The reduction in casting variations allows a reduction in machining allowances, which will lower the down stream cost.
- Ferrous and nonferrous inserts can be accurately cast in place. Typical insert materials can be iron, steel, stainless steel, or copper base alloys. In some cases, threaded inserts can be cast in place, eliminating the need for machining and related costs.
- Because permanent mold castings are *chilled castings*, they are generally sounder than sand castings. Permanent mold castings are generally stronger than sand or die-castings and are less porous than die-castings. Castings produced in the permanent mold process have finer dendritic arm spacing (DAS) and grain structure. The finer structure displays better strength properties than those cast in similar alloys in sand castings. Permanent mold castings have fewer inclusion defects than sand castings. Therefore, the casting designer has the freedom to use thinner sections and lighter weight designs. Permanent mold castings have a higher degree of reliability with regard to pressure applications of fluids and gases.
- The tilt pour process allows the molten metal to flow to the bottom of the mold, forcing the air out the top. As the molten aluminum flows through the runner a static skin of aluminum oxide forms which allows clean metal to enter the mold cavity.
- Automatic pour machines eliminate many of the variables found in hand pouring.
- Generally, permanent mold castings require less finishing than sand castings. Permanent mold castings have a smoother as cast surface finish than sand casting and finishes approaching 100rms can be achieved. In many cases casting buyers can use as cast surfaces without subsequent finishing for cooking utensils, hardware items, automotive parts, and ornamental work.
- Studs, nuts, bushings, pipes and other inserts may be cast as integral parts of the casting. The inserts must be held in positive position in the mold to prevent movement during casting process. The inserts should be scored, knurled, or under cut to provide a locking surface.

There are limitations to the size of castings produced in the permanent mold process. Most castings weight less than twenty pounds, however castings as large as 350 pounds have been poured. The casting design may be so complex that it is not practical in permanent mold processes.

Mold Design

In permanent mold casting, solidification occurs much more rapidly than in sand casting. However tilt pouring allows better filling of the mold with minimum turbulence and controlled thermal gradients to establish directional solidification towards a riser. The rigidity of a permanent mold necessitates some differences in the application of these principles. It is essential that the entire casting and its gating system be removed with a simple parting from the mold. Removal must be possible without excessive mechanical force on the casting or

without excessive abrasion of the mold coating. A *CMH* front ejector will ensure that the casting draws straight and pulls with the movable mold half.

Heavy sections are generally placed on the parting line to permit feeding. Sprues, runners, gates and risers are also placed on the parting line so they can be stripped with the casting. The casting and gating system must be arranged to promote directional solidification starting in the remote areas and progressing towards the riser. Due to the wide variation in cross sectional area of commercial castings it may be necessary to use highly conductive chills, air cool, water cool or take advantage of varying the mold wall thickness in order to promote directional solidification. Adequate gravity head should be provided to ensure filling of all parts of the cavity.

Ample flat area should be allowed to seal against metal leakage at the parting line. Two inches at the bottom and one and one half inches at the sides is normally enough to seal molds up to thirty inches square. Caution must be used when designing molds not to make them too rigid. The parting line is the hottest portion of a mold, and each face of the mold/platen assembly will run progressively cooler (see fig. 1). Different heating of the mold will cause the mold to open at the parting line. In order to prevent mold warping at the parting line, over all mold thickness should be held to a minimum and stiffening ribs should not be used.

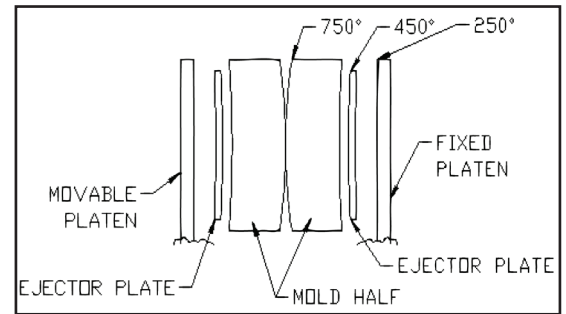


Figure 1

Mold design can dramatically affect casting quality as well. When designing a mold, the following factors must be considered.

- Venting
- Gating and risering
- Chills

Venting – All the air in the mold must escape as the mold is filling. Natural outlets, such as the parting line, and clearances around ejector pins, usually provide adequate venting. A properly designed gating system in the tilt pour process can reduce the venting necessity. The molten metal can be taken to the bottom of the mold, there by forcing the air out the top as the mold is tilted. In some cases, supplemental venting must be added.

Commonly used venting methods include:

1. Slot or “scratch” vents usually .005 to .010 inches deep, cut along the parting line leading to the outside of the mold
2. Very small holes drilled through the mold in areas where they will not affect the casting surface or the ability to strip the casting
3. Plug vents, which are holes that are drilled in the mold and filled with a slotted plug

Gating/risering – As the mold is tilted, molten aluminum enters the permanent mold and loses heat rapidly compared to sand molds. The rapid cooling also necessitates rapid filling. In general, the gating/risering system in the tilt pour process should accomplish the following:

- Fill the mold cavity in a tranquil manner reducing turbulence and the formation of dross
- Feed the casting during liquid contraction
- Provide fast solidification to increase production by reducing cycle time
- Promote progressive solidification to the riser
- Minimize further down stream processing (decrease finishing time for gate removal)

Figure two illustrates three types of tilt pour gating. The multi ingate system has lower finishing cost, but can cause turbulence and dross defects. If high quality levels are required, the continuous ingate might be desirable. This system could be used with a top riser and/or shrink bobs as necessary. Direct gating can be used very effectively in tilt pouring because the automatic tilting of the mold eliminates human variability in the pour rate. Additionally, as the liquid aluminum enters the mold it flows through a static skin of aluminum oxide. The oxide acts as a barrier allowing only clean metal to enter the mold cavity.

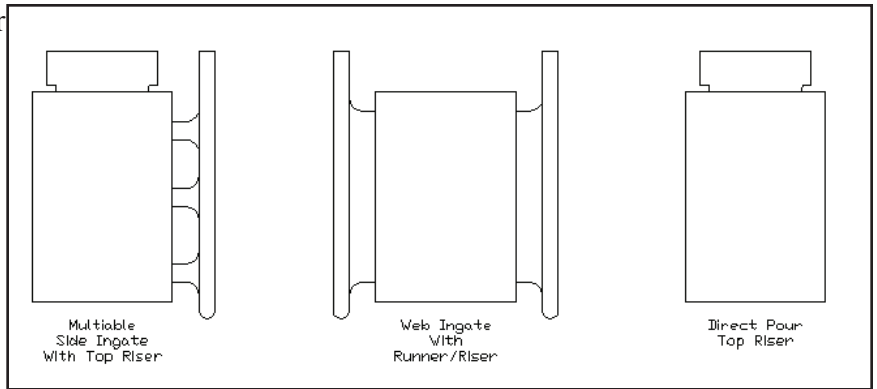


Figure 2

The use of a side riser permits more control over distribution of the metal into the casting cavity through the gates. With castings of irregular cross section, it may be desirable to vary the rate of fill to sections of greater or less mass. The **CMH** programmable tilt option was designed to allow the caster to vary the tilt rate, therefore the mold fill rate, as necessary. In such cases multi ingates may be placed at various levels to allow metal to flow at the most desirable rate. For large castings, the gating system might be placed on both sides. In applications when a runner/riser is being used, a runner extension should be used to prevent the backwashing of dross contaminated first metal of the pour.

The actual dimensions of the mold and gating system will depend on the weight and dimensions of the casting to be produced. Figure four is given as a guideline. All the dimensions are based on the thickness of the casting which is referred to as "T". In permanent mold casting riser sizing is critical. The riser must be large enough to eliminate shrinkage defects. In some cases an over size riser can superheat the mold and actually cause a shrinkage defect in the casting. Furthermore, a riser in which metal freezes too slowly may delay the opening of the mold until excessive contraction stresses have developed in the casting. An oversize riser will increase cycle time and reduce production

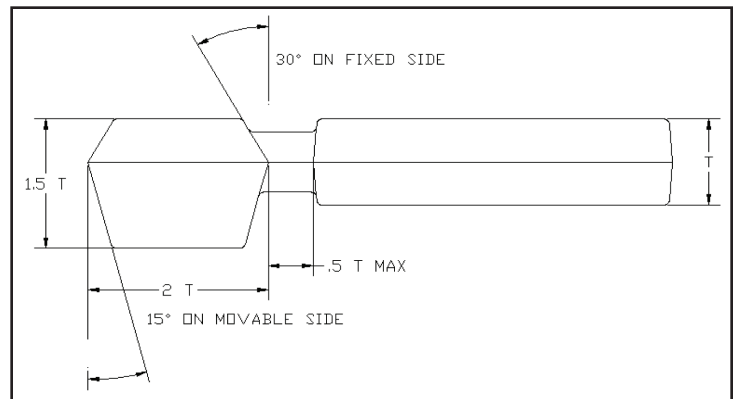


Figure 3

Chills – In absence of other variables, the thin sections (sections of low modulus) will naturally solidify before the heavy sections (sections of higher modulus). When the shape permits, it is preferred to place the casting in the mold so that solidification starts in the thinner sections and progresses to the heavier sections. Due to the wide variation in castings, this is not always possible and a *hot spot* will form. Some relief may be obtained by adding ribs to a boss to introduce more feed metal into the heavy section. Ribbing is not always effective or the casting may not be modifiable. In such cases, it is prudent to cool the heavy section of the mold so that the casting will solidify quickly.

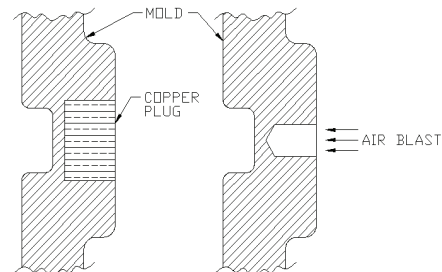


Figure 4

Localized chilling can be obtained by installing copper inserts (fig. 4). Extending them outside the mold and cutting cooling fins into the chill can increase their effects. Air chills are holes drilled into the mold and a blast of air is blown into to the relief. Moderate control of solidifications can be accomplished by varying the thickness of the mold coating.

Mold Materials

Mold materials for permanent castings are usually chosen on the basis of the number of castings to be produced and the cost of mold materials plus machining. Regardless of the mold material selected, all materials must include the following properties:

- The mold material must have adequate machinability. Machining the cavity is often the most significant cost factor. Tool wear, breakage, speed and feed rates all influence mold cost. Gray iron die blocks can usually be machined for less cost than tool steels.
- The mold must have good dimensional stability, high temperature strength, and thermal shock and fatigue resistance. The mold should not warp or change uncontrollably in size during the cycle. The mold must be able to withstand prolonged and repeated thermal cycling without softening, cracking or oxidizing.
- The mold material must be wear resistant to reduce dimensional changes caused by sand blasting, hand cleaning, liquid metal erosion, abrasion from moving mold components and abrasion from casting removal.
- Molds must display good thermal conductivity properties. Thermal conductivity is the rate heat flows through a unit area of material under a given temperature gradient. Higher thermal conductivities reduce cycle time and produces finer cast aluminum structure by cooling the casting faster.

Good quality hot work tool steel is preferred for most medium to high production permanent mold applications. As noted above, the steel should have the following properties.

- Low thermal expansion coefficient
- High yield strength
- High temper resistance
- Good resistance to erosion
- High thermal conductivity

The thermal expansion coefficient should be low in order to maintain low thermal stresses. A high thermal conductivity reduces the thermal gradients and thereby the thermal stresses. High hot yield strength is beneficial in resisting heat checking. Although the mold may begin with high hot yield strength, it may soften during use due to constant exposure to heat from the casting metal. As the mold material softens, the risk of heat checking damage increases. The softening associated with temper resistance is clearly accelerated by mechanical load. The mold is exposed to both high temperature and mechanical load.

In permanent mold casting of aluminum, certain factors are critical to mold life and the need for mold maintenance and repair. Some of the factors are:

- Heat checking
- Erosion
- Gross cracking
- Plastic deformation

Heat checking is a thermo-mechanical fatigue process caused by thermal cycling, which creates cyclic stresses and strains in the cavity surface. Typical damage is the gradual growth of a network of fine cracks. Heat checking is considered as the normal mold life-limiting factor. As noted above, high hot strength, as well as a

high tempering resistance are important mechanical properties of the mold material to obtain resistance to heat cracking. Additionally, toughness and ductility have shown to produce beneficial effects. Among physical properties of the mold material, low thermal expansion and high thermal conductivity are fundamental for heat cracking resistance.

Erosion is a complex phenomenon, which includes both chemical and mechanical wear processes. It is a very common failure mechanism in permanent mold casting. It occurs first in the exposed parts of the mold, such as gate areas, and special maintenance is required to prevent erosion. Besides good chemical resistance to the molten casting metal, high hot strength in the mold material is necessary for corrosion resistance.

Gross Cracking is the catastrophic cracking of the die, due to mechanical or thermal overloading. This phenomenon can occur suddenly, completely destroying the mold. In practice, gross cracking is rare, but because of its abrupt and devastating consequences, it must be avoided.

Plastic deformation, or indentations in the cavity, is a matter of insufficient hot strength in the mold in relation to actual mechanical strain. Hot strength and tempering resistance in the die material are of crucial importance in avoiding plastic deformation.

The demands on the mold material used in permanent mold casting are heat and thermal fatigue cracks are the most common cause of mold failure. Thermal fatigue cracks are caused by a combination of thermal cyclic stress and plastic strain on the surface. The plastic strain starts the crack and tensile stresses propagate the crack growth. The following factors influence thermal fatigue:

- Preheating temperature
- Surface temperature
- Holding time at peak temperature
- Cooling rate

The preheating temperature should be a minimum of 300°F (150°C). At this temperature the fracture toughness is almost twice as high as room temperature. At surface temperatures of 1100°F (600°C), the stresses are moderate for normal tool steel, but at higher temperatures the risk of heat checking is significant. Longer holding time implies an increased risk of over tempering a mold. This will result in a reduction of the mechanical strength and accordingly a lower resistance to mechanical and thermal loading. More rapid cooling results in greater stresses and will lead to premature cracking.

During casting the metal enters the mold as a liquid. Under certain conditions it can lead to a reaction between the molten metal and the mold steel and can dissolve the steel. This phenomenon is known as erosion or corrosion of the mold. Factors that influence erosion are:

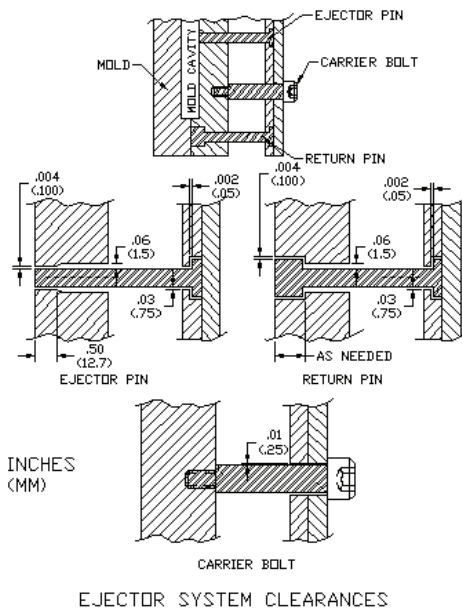
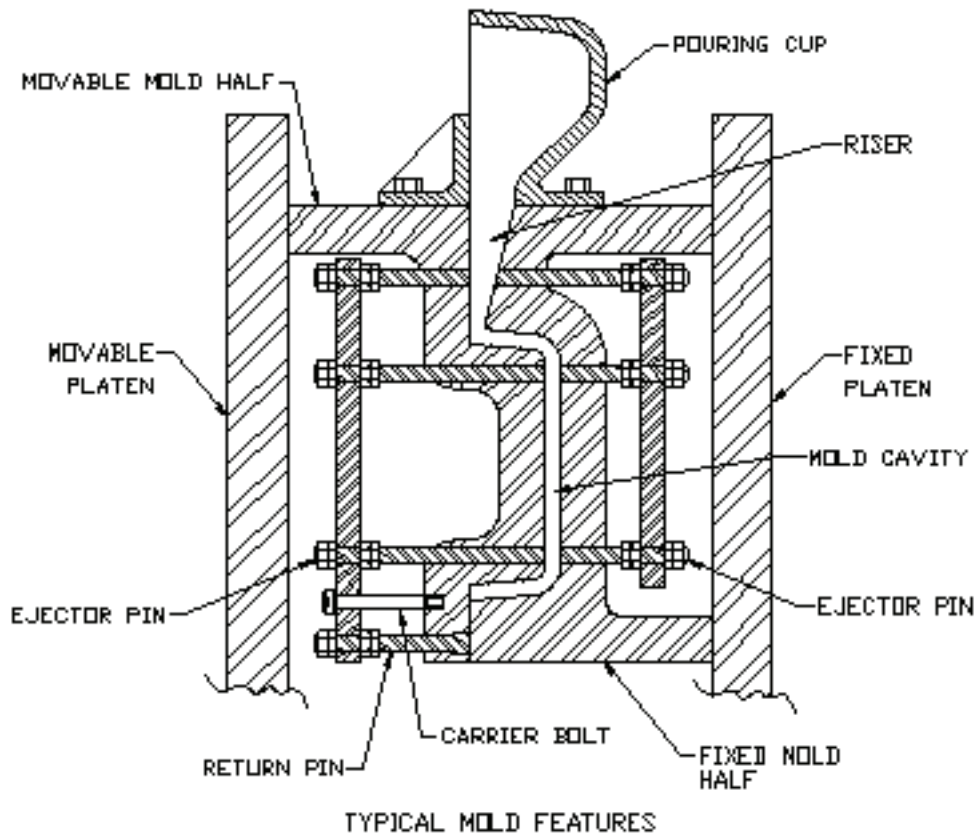
- Temperature of the casting metal
- Composition of the casting metal
- Design of the mold
- Heat treatment of the mold
- Surface treatment of the mold

Casting alloys have critical temperatures above which erosion attack increase. In most aluminum alloys, the critical temperature is 1330°F (720°C). Pure aluminum attacks the mold material at a greater rate than commercial alloys. Gating and mold design is critical in preventing erosion. A thin directed jet of molten metal from a gate can cause hot spots and erosion problems. Care should be taken to avoid designs where jetting gates are near a core or cavity wall. If metallic contact between the mold and the molten metal can be avoided, the risk of mold erosion can be reduced. It is imperative that molds be properly coated with a refractory coating at all times. Mold coating touch up must be performed during the workday to ensure that the risk of erosion is

minimized. In extreme cases molds can be nitrided to give extra protection.

Other types of mold materials include:

- Cast iron
- Ceramics
- Graphite
- Tungsten (normally a core material)
- Beryllium copper (normally a chill material)



Mold Coating

Permanent mold coating is one of the operational parameters of the casting process that is often overlooked or misunderstood. Permanent mold coatings are necessary for three basic reasons.

- Coatings provide a protective barrier between the mold and the casting to prevent mold erosion and wear.
- Coatings provide some degree of control over the solidification rate and direction.
- Coatings provide a barrier between the mold and the casting so that the casting will release from the mold.

With proper use, a permanent mold coating can be used to control the thermal gradients such that directional solidification can be achieved. This allows a pathway for feed metal to flow into the solidifying structure and compensate for normal metal shrinkage during solidification. This is particularly important in castings with thin sections changing to thick sections. The thin areas must remain open to ensure that shrinkage will not occur in the adjacent thick section.

In some casting designs there might be two or more characteristics working against one another. For example, a design might have a thin walled section in need of additional insulation to prolong solidification yet is also in an area that is difficult to release from the mold. In this case a compromise must be reached. By their very nature release coatings are not insulative and insulative coatings will not aid in the release of tight or difficult geometries. In such cases a choice must be made as to which of the two operational characteristics is most important. One choice may be to use a combination coating that will allow for some insulation and some release. Another option is to use an insulating coating as a base coat and a release top coat.

Insulation coatings can vary greatly in insulating qualities as well as the surface finish the coating will impart to the casing. The insulating qualities of a coating are a function of the type of refractory filler that is used and their thermal conductivity and heat capacity. Also contributing to a coating's insulative capabilities, as well as surface finish, is the amount of binder and the dilution rate. Typically binders are a sodium silicate. Typical refractory materials found in mold coatings include:

- Vermiculite
- Bentonite
- Talc
- Titanium dioxide
- Alumina
- Olivine
- Graphite

Release and chill coatings both contain materials that act as heat conductors to allow for more rapid solidification while protecting the mold against wear. Release coatings typically contain graphite as the lubricant, which is non-wetting by aluminum.

Mold Coating Application

As in any coating application, surface preparation is critical. New molds should be thoroughly cleaned (see Preparation of a New Mold, next section). Molds that have been in service must have all the old coatings completely removed. The type of cleaning media used varies and includes sand, metal shot, grit, glass beads and dry ice (CO₂). The choice depends on availability as well as how difficult the coating is to remove. In most cases it is recommended the dry ice blasting be used for routine cleaning with periodic sand blasting to restore the mold surface finish for mold coating. Over blasting, especially with sand, shot, or grit, can erode mold detail and shorten mold life.

Mold coatings should be sprayed onto the mold surface with an airless spray gun or an aspiration type spray gun. Spraying equipment may be one of many different styles and types of spray guns. Use of a paint gun is not recommended as the heavy materials in the mold coating easily clog the small ports. A siphon type gun that has one straight fluid tube with replaceable fluid tips works well. Some siphon guns are available with interchangeable pots. With extra pots, two or three different types of coating may be kept on hand, mixed and ready. As the need arises for a particular coating, it may be snapped on the spray head and used immediately.

In areas where a high degree of insulation is required, such as gates, runners, risers and pouring cups, brushing the coating on will provide more insulating capability. In addition to the insulating properties of the coating itself, brushing will trap air bubbles, which enhance insulation. Additionally, the rough surface caused by brushing can aid in molten metal flow through the gating system by continuously disrupting the oxide skin as the metal flows.

Thoroughly mix the coating in its original container before diluting or using only a portion of the can weight. This will alleviate any settling problems that can occur during transit and storage. When diluting, soft warm water works best, but cold water is acceptable. In either case, adequate mixing with any equipment such as a Lightning mixer or a bent rod in a hand drill is required. Excessive shear should be avoided.

The mold should be heated to 600°F (315°C). Care must be taken to heat the mold uniformly. Optical pyrometers should be used to determine if the mold is heating evenly. While the mold is hot it should be sprayed lightly with water. This will increase a porous oxide film on the mold, which will provide a good surface for the mold coating to bond to. The water spray also cools the mold to the desired coating application temperature, 350° - 400°F (75° - 200°C). If the molds are too hot, the rapid expanding water vapor front moving away from the mold will cause a phenomenon known as “kick back,” and very little coating will adhere to the mold. Even the coating that does adhere will not be properly bonded. If the mold is too cold the coating might run resulting in an uneven surface.

Depending on the brand of coating, a primer coat may be required. This could be a specifically designed primer or a diluted version of the main coating. The purpose of the primer coat is to create the best possible adherence of the coating to the mold. This occurs because very diluted sodium silicate solutions allow for bonds that are more parallel to the mold face. This structure forms a stronger bond, which is more resistant to wear. In contrast, high sodium silicate solutions create bonds that are perpendicular to the mold face and can be sheared off. Care must be taken not to over dilute the primer coating, as sufficient sodium silicate must be present to generate the bond. Once the primer is applied, the main coating can be applied at higher concentrations. Do not try to cover the mold face with one heavy coating. A gradual build up of the coating is preferred over one heavy coat. The number of coats and the exact coating thickness will vary with the casting design and may vary within the mold itself. A working profile should be developed for where a heavier or thinner application of coating should be applied to aid solidification. After the coating has cured, excess coating should be removed from the parting line and core prints with a wire brush or soft brass scraper.

As noted, most all commercial mold coating materials are bonded by sodium silicate with carious filler materials for their insulative, lubricative or cosmetic qualities. Mold coating is supplied in five-gallon cans or fifty-five gallon drums. The coatings should be stored in their original covered containers with the lids firmly in place when not in use. Mold coating should be stored in a dry place away from excessive heat or cold or drastic temperature change. Ideal storage temperatures range from 50°-75°F (10°-25°C). Under no circumstances should the coating material be allowed to freeze, as subsequent thawing may not restore the coating to its original condition. Refer to the coating manufacturer's instructions for additional storage information.

Preparation of a New Mold

A new mold should be first heated to approximately 600°F (345°C), with the ejector pins retracted, using a gas burner and a gentle flame. The rate of heating should be very slow, taking about six hours for a 24 x 24 mold. A magnetic thermometer, optical pyrometer, or a temple stick should be used to check the temperature periodically.

Make sure all oil and other products of machining are burned off. The mold should be lightly sand blasted with 100 mesh or finer silica or glass beads. Ejector pins should be extended after removing from the heat, but retracted before sandblasting.

While the mold is still above 300°F (150°C), the primer spray may be started. If not, it may be necessary to re-heat the mold with the burner. If re-heating soots the mold, additional sand blasting will be necessary.

Proper original mold priming temperature is 300°-375°F (150°-190°C) for the original primer coat. Additional coats of spray may be put on at higher temperatures. If brushing is used to build up insulative coatings on gates, it should be done at 160°-220°F (70°-105°C). Gates that are brush painted should first be coated with primer.

Touching up a mold while in use goes much the same as preparing a new mold, but some extra rules must be used. Make sure any sheared or stuck on aluminum is removed before adding the touch up coat. If coating area is spalled, cracked, or blistered, be sure to remove it with sand paper, steel wool, or steel brush.

Specific Gravity to Control Solidification

In aluminum permanent mold casting the solidification rates are typically faster than in sand casting, due primarily to the greater thermal conductivity of the metal mold as compared to the sand mold. This faster solidification rate allows for a much finer and more densely compact grain structure. Because of the tighter grain structure, castings can be made with higher levels of dissolved hydrogen, since the faster solidification rate will not allow the gas to come out of solution in such a way as to cause a porosity defect, but rather the micro porosity will remain dispersed. By making a casting with micro dispersed hydrogen gas, the casting has a lower specific gravity. Typical commercial aluminum castings have a specific gravity rating of 2.4 to 2.5 while reduced specific gravity castings can be as low as 1.9. The benefit of this practice is that reducing the specific gravity can eliminate some solidification shrink defects.

Grain Refinement

Aluminum alloys will normally form coarse, equiaxed and columnar grains during solidification. The degree of coarseness or the length of the columnar grains depends on the pouring temperature of the metal, thermal gradients set up within the mold, and the naturally occurring grain nuclei, such as nonmetallics or mold surface features. All common alloying elements added to aluminum decrease grain size. The more soluble the element

is, the greater the decrease in grain size is.

Grain refinement is one of the inoculations made late in the melting operation to alter the structure of cast metal. It is done to produce a finer grain during solidification. Refining grains in aluminum has the following advantages.

- Less hot tearing – Course grain metals are more prone to hot tearing during solidification because they develop more localized strain areas. Smaller grain sizes also tend to prevent hairline contraction cracks in solid solution alloys.
- Less shrinkage porosity – Shrinkage that occurs in risers can form pipes, which can be an indication of grain size. These pipes, which frequently form when pouring coarse grain metal, become shallow cavities when the grains are refined. The reduction in porosity is directly related to the decreases in average pipe size.
- Increased pressure tightness – Porosity is smaller and more evenly distributed in fine-grained castings. This helps make the casting more pressure tight because there are fewer tendencies for shrinkage.
- Improved mechanical properties in heavy sections – Mechanical properties in heavier sections are higher.
- Consistent properties after heat treatment – Because grain refinement results in a finer distribution of the alloying elements throughout the casting, a faster response to and more consistent mechanical properties after heat treatment can be expected.
- Improved feeding characteristics – Grain refinement leads to improved feeding characteristics. Coarse grain intermetallics (alloying elements and impurities) solidify at temperatures higher than the parent metal temperature and can interfere with feeding by nucleating the primary solid solution and bridging across dendrites. When the alloy is grain refined, dendrites are broken down into small grains that are transported easily within the casting, aiding feeding.
- Improved appearance – Because large grains show up as areas of different reflectivity, a fine grain size will improve the appearance of castings.
- Improved machinability – As the grain size is reduced, porosity is distributed on a smaller scale, thereby improving machinability.

A grain refiner, when added to a melt in a small amount, does not substantially change the composition of the base material. The most common and practical means of controlling grain size in permanent mold casting is by the deliberate induction of grain refining elements such as titanium or boron immediately before pouring.

Titanium and boron are highly efficient grain refiners. They form nuclei or seeds of titanium aluminide, titanium diboride or more complex intermetallic compounds throughout the mass of molten metal. These countless seeds of insulating material cause fine grains as the casting solidifies.