“Do's and “Don’t’s in Aluminium Foundry Operations

Is metal-casting an ‘Art’? or a ‘Science’?

Many thermodynamic factors, physical metallurgy principles and foundry techniques are involved in converting the metallic raw material(s) into castings.

A Luminium and aluminium alloys

A Luminium is the 20th century metal. T was considered very costly till end of 18 century. After the Hal-Herold electric extraction process became commercial in 1911, the metal is widely used now.

A Luminium alloys have excellent properties like:

- Good electrical & thermal conductivity
- Low density
- Superior corrosion resistance
- Easy fabrication and superior recycling nature
- High strength development by alloying

A Luminium alloy castings are used widely for making components for automobiles, aeroplanes, electrical equipment and household appliances. Corrosion resistance is superior due to self-healing nature of aluminium oxide. Exposing the metals to ambient condition promotes formation of $\text{Al}_2\text{O}_3$ layer, which has higher volume than the volume of aluminium from which it is formed.

Special feature of any cast-alloy group is the possibility of forming new alloys in the group. Cast aluminium alloys are used with or without precipitation hardening treatment, the only strengthening heat treatment applicable to these alloys. Heat treatable cast alloys are difficult to weld while it is easier to weld non-heat treatable alloys. LM 0, LM 2, LM 4, LM 5, LM 6, LM 12, LM 13, LM 24 and LM 26 are the major cast alloys used for various applications. These are British grades, but are also popular in India. Al-Si (6061), Al-Cu (2024), Al-Zn (7075) are some precipitation hardenable alloys. Mechanical properties of cast aluminium alloys in heat treated
condition are comparable to cast iron or steel, and are preferred when “strength : weight” ratio is considered.

Production processes

Moulding

Aluminium alloys have relatively lower melting point (660°C or lower). Fine grain sand can be used for moulding. Permeability should be at least 25-30 to allow gases generated in the mould (during solidification of the poured metal) to escape. Mould should not be rammed very hard. Fine-grain sand with moderately rammed mould will improve plasticity of the mould. Solidified hot aluminium alloys are lower in strength, hence if free contraction is restricted by the mould, the casting may develop cracks.

Skin drying or complete drying of the mould is important in Al-Mg alloy casting where Mg tends to react with water vapour at mould walls, causing pinholes or subsurface porosity. If the metal is poured immediately after mould closing, skin drying is enough. For delayed pouring, complete mould drying is necessary, otherwise moisture from the interior of the mould would diffuse into the dried skin of the mould, causing defects in the castings.

Metal moulds, with hexachloroethane or hexchlorobenzene based coatings, and sand moulds with boric acid will give good results.

Gating system

Non-pressurised gating (having area of Ingate(s) > area of Runner(s) > area of Sprue) should be used to permit rapid filling of the mould with negligible turbulence, as turbulence leads to air aspiration which may prevent mould filling by forming oxide layers. Gates cut in the reverse direction, step gates or slot gates are preferable for smooth mould filling.

A aluminium alloys have higher coefficient of thermal expansion. During melting metal expands further (expansion in aluminium is more than that in steel iron cast iron). Hence during solidification, the alloy contracts heavily, resulting in shrinkage. Higher shrinkage necessitates the use of large size risers.

Entrapped air, slag/dross inclusions are more common in aluminium alloy castings. Entrapped air is found beneath the cope surface. Hence the runner should have effective extension. Streamlining of molten metal flow is beneficial (Reynolds number < 3500/4000).

Viscosity is the resistance to flow of any fluid at given condition. As the temperature increases, viscosity drops.

Furnace atmosphere

During melting aluminium tends to get readily oxidized at elevated temperature. Loss of some alloying elements (for instance Mg) also takes place. Hence furnace atmosphere should be slightly reducing, and maximum temperature should be controlled.

Moisture:

Dissociation of moisture during melting produces oxygen and hydrogen, which in turn, increases hydrogen pick-up by the molten metal, resulting in higher pinhole porosity, a common defect in Aluminium castings. Hence controlling moisture is important. Alloying elements and flux must be preheated well to eliminate chances of moisture pick-up. For Mg addition into the melt, we should use inverted perforated cup to prevent Mg burning on the slag.

Charging

Charge selection is important. Clean aluminium alloy ingots and foundry returns are preferred. Turnings, borings or any metal cuttings should be avoided as lubricants from such scrap will spoil the melt or cause explosion. Foundries may use pre-alloyed ingots purchased from quality ingots manufacturers or prepare the alloy at home (using hardner alloys). While alloying at home, charging sequence must be based on the free energy calculations such that utilizing heat evolved by reaction between two elements is used for increasing the heat content of newly added another element. By this practice energy can be preserved and elemental loss is also minimized.

If we use charcoal cover, aluminium may get locked into the charcoal pieces. Skimming off the charcoal would then result in larger
loss of the metal. Moreover it may remain ineffective for protecting the melt, because aluminium would come up through it and react with air. Zinc chloride / Ammonium Chloride is useful for cleaning. It separates the metal from the dross by changing the interfacial energy.

Low melting point elements like Zn, Mg can be added in elemental form, preferably with phosphorizer to deoxidize and capture hydrogen gas \((2P + 3H_2 = 2PH_3)\), whereas other elements must be bought in the form of hardner alloys. To produce Aluminium-Nickel hardner alloy, Aluminium is melted first, then Ni shots are taken in small crucible and slowly agitated into the melt. Excessive quantity of shots at a time would produce a pasty mass. For Al-Cu system, Cu should be melted first, then Al ingots to be added.

**Melting crucible**

Graphite, SiC crucibles or Cast Iron pots (coated with a thin layer of refractory powder with sodium silicate mixed with water as a binder) are used for melting. Fuel economy is good with Cast Iron pots, but efficient lining is needed to avoid excessive contamination of the melt with Fe. Reworking of coating at regular interval and prior drying is a must, as loose oxide pieces or moisture may affect the melt.

**Temperature control**

Temperature control is essential in aluminium alloy melting. If the dross formed by adding flux is allowed to come in contact with air, at temperature above \(950^\circ C\), a strong crystalline aggregate of corundum is formed. Its specific gravity of 3.9 gm/cc is higher than that of Al, hence it settle down, exposing new melt surface to further oxidation losses and hydrogen pick-up. Presence of Alkali (Na, Ca, Sr, Li) of rare earth elements like Ce or Be reduces oxidation tendency even at higher temperature (if sufficient content in the melt). This is because high temperature leads to loss of these elements. Na offers one detrimental effect to the melt. It encourages hydrogen pick-up from furnace gases. Temperature control by regular check up with pyrometer in advisable in case of coke fired crucible furnaces. A sorption of hydrogen is promoted as its solubility with less resistance for diffusion.

Fluxing at low temperature is desirable to form oxide layer. A once corundum (crystalline aggregate) is formed at high temperature, it would be very difficult to decompose it and recover base elements.

Proper degassing will eliminate the chances for occurrence of defects due to gaseous elements. In melting Aluminium alloys \(C_2Cl_6\) (Hexachloroethane) tablets were preferred over chlorine gas. A present use of SF6 (Sulfur hexafluoride) with carrier gas has become popular. It is better than earlier practice as it does not cause damage to environment. \(C_2Cl_6\) not only degasses the melt, but also refines the grains (heterogeneous nucleation). Gas flushing is more effective than salt addition for degassing since chloride salts need time to decompose, liberate Chlorine and then remove hydrogen. It may introduce gas rather than removing it, if it is not properly dried.

**Directional solidification**

Directional solidification is the desirable phenomenon in any casting as it tends to improve the yield. By layman’s point view, it is a case where useful cast portion solidifies first, followed by the riser/feeder. By technical understanding it is the solidification process proceeding with and assisted by temperature gradient pattern from cast portion towards the riser. Chills and exothermic or insulating sleeves are useful in achieving directional solidification.
Among the three types of heat transfer mechanisms (viz. conduction, convection, radiation), conduction is dominant in mould filling and solidification - both in die-casting and sand casting. Metals with low melting point should have good fluidity during pouring since temperature gradient between the mould walls and the surrounding atmosphere would be less, i.e. Heat Transfer rate, \( Q = \frac{-KA \ dt}{dx} \) is less, where

- \( K \) : Thermal conductivity of the mould material,
- \( A \) : Area of heat transfer,
- \( dt/dx \) : Temperature gradient over the distance in the mould wall.

But this does not happen in aluminium alloy casting. The reasons are:

(a) The oxide layer does not fuse, but acts as a barrier in mould filling.

(b) Composition/Dendrites: Molten metal gets entrapped in between the primary, secondary and tertiary dendrites formed during solidification. Very severe in case of long freezing range (mushy nature) alloys, resulting in microshrinkage and interdendritic segregation.

So, faster cooling must be created during cooling to convert concentrated porosity into dispersed, isolated porosity by forming fine grains and to avoid shrinkage. Unfortunately even dispersed porosity becomes undesirable when the pores are interconnected. It results in leakage and loss of pressure tightness, important in valves and pumps. As a remedial measure, sealing of porosity either by shot peening or hammering or impregnation is done.

During melting most metals (except grey iron and bismuth) undergo volumetric expansion, and on cooling (i.e. during solidification) contraction. This may develop internal stresses acting on semi-solid metal. The pulling action by solidified metal on solidifying zone cause cracking. This occurs mostly in mushy nature alloys like Al alloy containing appreciable amount of Cu or Zn (Al-Cu-Zn, Al-Si-Zn), and leads to hot shortness (i.e. high temperature cracking during solidification) in intricate castings. In such cases design modification (i.e. filleting) in the component or providing a padding is preferred.

**Inclusion control & grain refining**

Inclusions (oxides, carbides, graphite flakes or borides introduced by grain refiners) are dangerous in aluminium castings, especially under fatigue load. Crack initiation, propagation and failure are steps involved in fatigue failure which is favoured by surface irregularities or cracks. These inclusions affect surface appearance and also act as nucleating site for cracks. Proper skimming action before pouring, use of tea-spout ladle for pouring, use of strainer core, skim, bob gating or filter usage are followed. Besides the efficiency of filter, increasing the meallostatic height should be considered,

\[ P = \rho gh \]

Where,

- \( \rho \) : density,
- \( g \) : gravity force
- \( h \) : height of molten metal in the sprue.

Grain refining is important and desirable in aluminium alloy castings as it improves mechanical properties of the castings. Chill usage or ladle addition of elements like B, Na, Ti and Cb are useful in refining the grains. Al-Ti (Ti = 3-10 %) or Al-Ti-B (Ti = 3-10%; B= 0.2-1%; Ti/B ratio = 0.1) can be used for grain refining, if other proprietary agents are not used.

For modification of silicon needles in Al-Si alloy, either Na (in the form of mixture of NaCl + NaF or NaCl + NaF + KCl) or Sr (in the form of Al-10% Sr alloy) can be used. Sr seems to be good in maintaining the modification for 3 hours, while Na can maintain it only for 20-30 minutes at the temperature 750-780 °C. Mn or Be can also be added for modification, in which the later performs dual role - as a deoxidizer and a modifier.

**Salvaging**

Welding of aluminium alloy casting should be done before heat treatment as it improves mechanical properties of the castings. Chill usage or ladle addition of elements like B, Na, Ti and Cb are useful in refining the grains. Al-Ti (Ti = 3-10 %) or Al-Ti-B (Ti = 3-10%; B= 0.2-1%; Ti/B ratio = 0.1) can be used for grain refining, if other proprietary agents are not used.
minimize the heat loss from the welding zone. Cleaning action of Al₂O₃ layer formed during welding is performed well by AC or DC (Reverse Polarity). But, again salvaging by welding has associated difficulties like porosity, liquification (solidification) cracking and distortion. Distortion can be overcome by low heat input while cracking is not due to hydrogen as in the case of steel or cast iron but solidification stresses, which means rapid cooling necessary. Welding should be followed by heat treatment.

Concluding remarks

As per the latest forecast, by 2006 Indian aluminium foundry industry could produce 1 lakh tones of aluminium alloy castings. China may produce 17 lakh tones (which is around \( \frac{3}{4} \) th of the total Al casting demand of nearly 25 lakh tonnes in the USA). This indicates a huge potential demand if Indian aluminium foundries (including die-casting units) take appropriate actions.

Foundry activities need not be secretive. Larger size foundries must initiate more R & D and involve the smaller units in getting the work done by agreement. Due to this even smaller units will have direct or indirect role to play, enabling the larger units to tap the full potential of the overseas casting market.

There are many manufacturing processes. Let us attract the designers to choose metal casting process over other processes.

There are thousands of foundries world-wide. Let us attract global casting users to choose Indian foundries in preference to others.

Think at micro level (e.g. grain refining and modification) in technology, and at macri level (e.g. productivity) in management.

References

- Dr. Koch Hubert, “31 Reasons to Use Al casting”, Foundry, Vol XV, No.6, Issue 90.
- Campbell L. Harry, “Metal Casting”, John Wiley & sons Inc.
- www.castingsource.com
- www.key-to-metal.com
- other related websites.