MELTING AND CASTING OF NON-FERROUS METALS AND ALLOYS

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WHAT IS CASTING ?

In general sense, a casting is produced when molten metal is poured into a mould and left to cool and solidify. The other name given to a casting is 'Founding'. In casting process, metal/alloy component parts of desired shapes are produced by pouring the molten metal/alloy into a prepared mould (of that shape) and then allowing the molten metal/alloy to cool and solidify. This solidified piece of metal/alloy is known as a casting.

STEPS INVOLVED IN METAL/ALLOY CASTING

The steps involved in the casting process are (i) making a pattern of wood, metal or plastic. The necessary sand mixtures and mold and core making are prepared according to the type of casting to be done. With the help of patterns the mold is prepared along with necessary cores. Mold is a container (of sand or metal etc.) having the cavity of the shape to be cast. A core is a body (of sand etc.) which is employed to produce a cavity in the casting. (ii) Melting of the metal/alloy to be cast. (iii) Pouring of liquid metal into the mould. (iv) Removal of solidified metal from the mould followed by fettling (cleaning and finishing). (v) Inspection and defect analysis, if any.

Interaction of the mold with molten metal

Castings are often subjected to gas porosity, both closed and open. Gas cavities are voids in the cast material, and the surface of which is clean, smooth, and nonoxidised, or shows small colored oxide spots. Gases in metal castings can be present as compounds and solutions. The gases dissolved in metal impairs its plasticity, tend to form blow holes and pinholes. Metals and alloys both in liquid and solid states dissolve in considerable amount of gases. A melt can absorb gases from the moist, rusty or oil coated scrap charged into the melting furnace, from the air supplied to the furnace for fuel burning, from the moisture contained in the fuel, ore, and fluxes, and also the result of the prolonged contact of the melt with the furnace atmosphere whose gases can dissolve in the molten metal/alloy. The solubility of the gas in metals obey the following equation:

$$S = K \sqrt{(p_1 - p_2)}$$

where, S = is the amount of gas dissolved in the alloy, p_1 & p_2 = partial pressures of the gas in the surrounding atmosphere and the melt, respectively. The solubility of the gas (hydrogen) in melt and in the solid, for an example, is shown in Fig. 1. Therefore, before pouring it is required to remove gasses from the liquid metal and this is done by the process which is known as degassing (discussed in the later section).

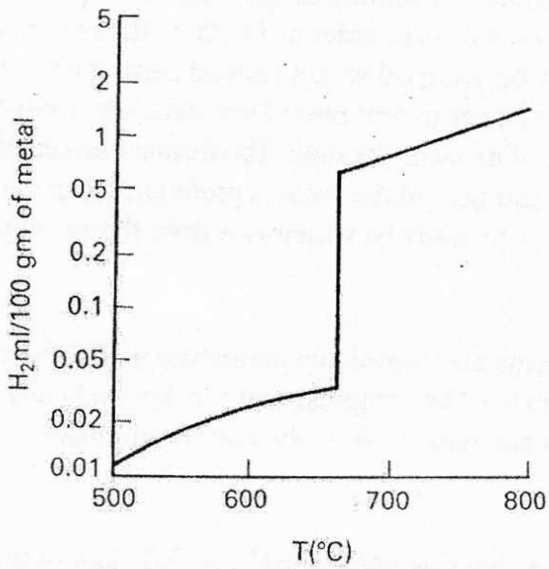

Fig. 1 : Effect of temperature on the solubility of hydrogen in melt.

DIFFERENT CASTING PROCESSES

Sand casting:

The molten metals are poured in a mould made of sand with necessary ingredients. In sand casting process the cooling rate is very slow that leads to a dendritic microstructure for nonferrous alloys. The gating system for an Al-alloy castings must fill the following demands: ensure quiet filling of the mould without impacts and whirling and thus, exclude the entrapment of air and erosion of mould walls; entrap non-metallic inclusions found in the liquid alloy; promote the escape of gases and air formed as a results of decomposition of core sand binders; and effect progressive solidification of the casting. The schematic gating system is shown in Fig. 2.

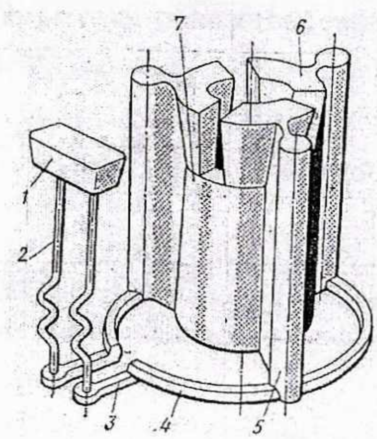

Fig. 2 : Top gating system with slit gates and wavy sprues; (1) pouring basin, (2) wavy sprue, (3) runner (cross gate), (4) ring gate, (5) slit gate, (6) flowoff, (7) casting.

Permanent -mold castings:

Permanent molds are made of dense, fine grained, heat resistant cast iron, steel meehanite and sometimes of bronze anodized aluminium, graphite or other suitable refractories. A permanent mold is made in two halves in order to facilitate the removal of casting from the mold. A permanent mold may be designed with a vertical parting line or with a conventional sand molds. The mold walls of a permanent mold have thickness from 15mm-50mm. Cores of permanent molds are made of metal or dry sand. The former one can be used when they can be easily extracted from the castings and the latter is preferred when the cavity to be cored is such that the metal core cannot possibly be withdrawn from the castings.

Pressure Die Casting:

In pressure die casting molten metal is forced into permanent mold (die) cavity under pressure. The pressure is generally obtained by compressed air or hydraulically. The pressure varies from 70- 5000 kg/cm^2 and is maintained while the casting solidifies.

Centrifugal Casting:

The principle of centrifugal casting was established by A.G. Eckhardt in 1809. The interesting features of centrifugal casting are the introduction of the liquid metal into the rotating mold. Centrifugal force plays a major role in shaping and feeding of the casting. Centrifugal force produced owing to mold rotation is large compared to hydraulic forces. This force is used to distribute liquid metal over the outer surface of the mold through hollow cylinders.

ADVANTAGES OF METAL/ALLOY CASTINGS

- Casting provides the greatest freedom of design in terms of shape, size and product quantity.
- Casting imparts uniform directional properties and better vibration damping capacity of the cast parts.
- The shapes that are difficult and uneconomic to obtain can be obtained by casting process.
- Casting can be done in one piece and therefore the need of metal joining can be avoided.
- Heavy and bulky parts (like those of power plants and mill housings) which are otherwise difficult to fabricate can be cast easily.

The melting and casting of Al- alloys are discussed below.

Aluminium alloy castings:

Aluminium alloy castings have attained pre-eminent positions due to combination of unique properties like strength to weight ratio, good thermal and electrical conductivity and resistance to fatigue and corrosion.

Casting properties of Aluminium alloys

The properties depend on the chemical composition. The various alloys with their characteristics and the effect of alloying elements are given below:

Al-Cu system

Higher strength/ hardness.
Response to thermal treatment.
Higher tendencies for hot treatment.
Decrease castability.

Al-Si-Mg system

Improved castability.
Better resistance to hot working.
Mg in this system increases hardness/strength on heat treatment.
Mg_2Si hardening phase- useful solubility limit up to 0.7% Mg.

Al-Si

Outstanding castability.
Prone for gas porosity.
High silicon alloys for wear resistance.

Al-Mg system

Binary alloys-high resistance and ductility.
Good corrosion resistance.
Tendency for hot tearing is high.

MELTING OF ALUMINIUM ALLOYS

Aluminium alloys easily oxidise on melting, dissolve gases and harmful admixtures. A strong oxide film that forms on the bath surface after melting prevents the metal against further oxidation. In melting of aluminium alloys it is highly important to make the right choice of the charge materials and the melting unit.

Melting units for Aluminium alloys

The furnaces used for melting aluminium alloys could be either oil-fired or gas-fired or electrical resistance or medium frequency induction furnaces. Generally silicon carbide or graphite

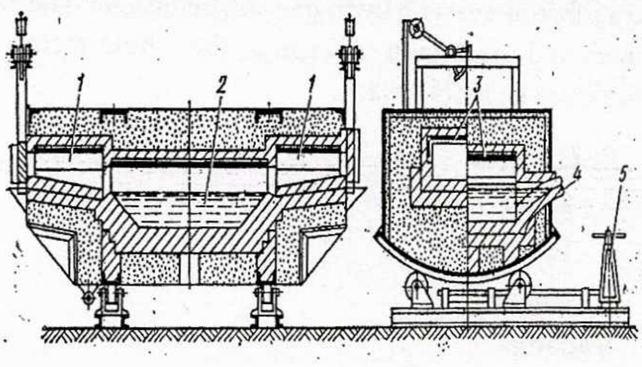

Fig. 3 : Schematic diagram of resistance furnace for melting of Al-alloys; (1) Charge chamber, (2) metal receiver, (3) heaters, (4) tap hole, (5) drive of the furnace tilting mechanism.

crucibles are used. For melting aluminium alloys, crucible furnaces are lined inside or given a refractory coat which is then burned at 500 to 600°C for 3 hrs to 5 hrs. Fig. 3 shows the schematic of resistance furnace for melting of Al-alloys.

Fluxing

Aluminium alloys oxidise readily in both solid and molten state and this increases with temperature and hence, the melting temperature shall be maintained as minimum as possible, preferably around 710°C. The oxides are removed by good fluxing technique, which will de-wet the oxide/melting interface and enable reduction of those non-metallic oxides. The types of fluxes used are as follows:

– Cover flux (Coverall: KC_1/NaC_1);	- Minimises surface oxidation
– Cleaning flux (Chloride salt + Fluoride)	- Wetting oxides
– Drossing Flux:	- Separation of Al_2O_3 dross layer from the molten metal
	Reacts exothermically.
	- Double fluorides & compounds which melt as eutectic.

– Refining Flux: Refines impurity elements like Mg, Na, Ca, Li, K, (Nucleant 2: TiB_2 and Nucleant 200: Carbon); Cl_2 Compound reacts with these elements to form insoluble Chlorides.

Degassing

Aluminium alloys have great affinity for hydrogen, and requires effective degassing to control the hydrogen within the acceptable level to avoid porosity in castings. The acceptable level of hydrogen is 0.12- 0.20 cc per 100gms. The different techniques are used for degassing the aluminium alloys and the best-proven method is rotary degassing. The rotary degassing helps in elimination of hydrogen and non-metallic inclusions by gas bubble injection of natural gas (Argon). Hydrogen dissolved in liquid metal diffuses inside the bubble by superficial forces and bubble moves to the surface along with hydrogen and inclusions. The effectiveness depends on extremely fine bubbles and dispersion and gas in the whole metal. The comparison of different degassing techniques is as follows:

– Technique	Bubble size
– Rotary	2 - 5 mm
– Porous plug	3 - 10 mm
– Lancing	20 - 30 mm
– Tablets	Variable

To reduce the hydrogen pick-up, refractories, crucibles, tools and oily scrap should be thoroughly pre heated to remove water. Burner flames should be slightly oxidising to avoid excess hydrogen in the products of combustion. The melt temperature should be kept as low as possible since more hydrogen is dissolved at high temperatures. If the metal cools reatively slowly, as in a sand mold, the ejected gas can build up into small bubbles, which are trapped in the pasty metal. These are then uncovered by any subsequent machining or polishing operation and show a "pinhole" porosity defect in the finished surface. The mechanical strength and the pressure tightness can also be seriously affected. Where the rate of solidification is more rapid as in gravity and low pressure die- casting, the emerging bubbles are usually small and well dispersed. They, therefore, affect the mechanical properties less, and indeed have a beneficial effect in offsetting possible shrinkage unsoundness that may otherwise cause the casting to be scrapped. For high integrity gravity and low-pressure castings, it may still be necessary to apply a full degassing process.

Earlier, it has not been usual to degas metal for pressure die-casting since die-castings usually contain gas porosity arising from air entrapped in the casting during metal injection. The additional porosity from hydrogen in the melt was not considered serious, particularly since the metal holding temperature for pressure die-casting is usually low, reducing the amount of hydrogen pick-up. Recently, with the improvement in die-casting technology, more die-casters are using degassed metal.

Refinement

Grain refinement of aluminium alloys is essential to obtain better mechanical properties which will depend on the control of the impurity levels, control of solidification rate and through effective grain refiners. The most effective grain refiner is TiBAl consisting of 5% Ti and 1% Boron. The tensile properties of the alloy increase with the decrease in grain size. The optimum grain size achievable is 50 -100 microns. Addition of Ti grain refiner is preferred at molten alloy temperature of 750°C, as at lower temperatures the dissolution is slower.

Modification

Some of the Aluminium alloys containing silicon require modification to refine the grain size i.e. the acicular or needle shaped particles to globular particles. The hypereutectic alloy (Si<10%) and eutectic alloy (Si 10 - 13%) alloys are modified with either Sodium, Strontium, Calcium or Antimony, whereas the hypereutectic alloy (Silicon 13 to 25%) are modified with metallic phosphorous or phosphorous copper alloy. The structural refinement through modification is time dependent. The refinement will be better with faster solidification like any metal molds. The characteristics of various modifications are as follows: -

- **Na** - Commonly used; most volatile and causes agitation; has fading effect; reduces fluidity.
- **Sr** - Lasts much longer; less volatile; does not affect fluidity; but compatible with Na. The action is cumulative. Too much high Sr content can cause H_2 pick-up especially in thick sections.
- **Sb** - Acts as a permanent modifier; but has counter effect in the presence of Na & Sr. not suitable for heavier sections; causes health hazard.

APPLICATION OF ALUMINIUM ALLOYS

The Aluminium alloy castings are widely used in various sectors like aerospace, automobiles, electrical, electronic, and general engineering. Some of the important sector wise applications are given below:

Automotive : Truck and trailer castings cylinder head; Rocker arm connecting rod; Pistons; Cylinder heads; Pumps; Cylinder blocks; Air compressors; Car frames.

Aerospace : Structural parts; housing; Impellers; Gear box; Under Carriage Components; Engine castings; Compression castings; Generator housing; Hardwares; Gas turbine end components; Pump parts, Fittings, Nuclear Energy Installation and Transmission Housings; Fittings, Brackets requiring Moderate Strength & Shock resistance.

General Engineering : Turbine and super charger Impellers; Vacuum cleaners; Floor Polishers; Freeon Compressors; Pumps; Pulleys; Cover; Plates; Instrument cases; Torque converter elements.

Electrical : Rotor castings; Motor housing; Motor body; Heat sink; Support structures.