A REVIEW OF RHEOCASTING TECHNIQUE ON AL/MG ALLOYS

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Abstract- The problem of casting Aluminium or Magnesium alloys is a big deal for researchers since molten alloys while casting causes the occurrence of various defects. The defects arise when grain particles are settling down during normal solidification by irregular arrangement and leading to dendrite forming structure along with solidification shrinkage and hot tearing. In 1970, it is found that semi solid metal casting can sort out the above mentioned defects which utilize the thixotropic behavior of the Aluminium and Magnesium alloys. In this paper, an attempt has been made to review the properties of the Aluminium and Magnesium alloys, the SSR technique and DCRC process for the aluminium and magnesium alloys.

Keywords- Al/Mg Alloy, SSM, Thixotropy, SSR™, Direct Chill Rheocasting.

I. INTRODUCTION

Casting is one of the manufacturing processes, aging about 6000 years, in which molten material is poured into a hollow cavity called mold which is similar to desired shape, and then material is allowed to solidify. After solidification, required part is ejected out of the cavity. Depending upon type of mold, casting process is further divided as sand casting, permanent die casting, investment casting, lost foam casting, high pressure die casting, centrifugal casting, continuous casting, and glass casting. Casting is semi- finished process and manufactured components needs machining for its end use.

Semi Solid Metal (SSM) Casting is a new technology in casting which combines the advantage of both, forging and casting. The components produced from this technique require very less machining (nearly $1/3^{rd}$) in comparison to other processes. The technique was first invented by Flemings et al. The technique is used for non-ferrous metals, like aluminium, copper, magnesium etc. Few SSM processes are rheocasting, thixomolding, SIMA and thixocasting. The method generally involves the melting of metal followed by cooling to a state of liquid-solid state. It is then kept in a die for the final casting. The advantage of this technique is that it prevents the further tearing of the casting, which is common in aluminium casting by eliminating the cavities formed during solidification caused by volume contraction, wrong feeding system or gas development.

Various advantages of using this technique are ability to produce complex and porous less shape with excellent mechanical performance and tight tolerances. This technique can also be used to produce thin walls castings. Lower pressures and temperatures are required to die cast semi-solid metal in the die material. Often graphite or softer stainless steels may be used. Even non-ferrous dies can be used for one time shots. Because of this the process can be applied to rapid prototyping needs and mass production. This also allows for the casting of high melting point metals, such as tool steel, if a higher temperature die material is used. Other advantages include: easily automated, consistent, production rates are equal to or better than die casting rates, no air entrapment, low shrinkage rates, and a uniform microstructure.

In the article, a brief review of work done on rheocasting is presented in a concise manner. Rheocasting is an emerging technology that is applied to obtain casting of metals and alloys in semi-solid state. The semi-solid state is achieved all because of metal that exhibits in two phase's i.e. primary and secondary phase. The liquefied secondary phase act as a lubricant for the conformation process of the material during solidification. To assist this, stirring or use of grain refining method is used. Stirring techniques include electrical or mechanical methods, depending upon the size of ingots. For larger ingots (>80mm), mechanical stirring is effective and electrical stirring is not practical because of the limitation of the depth of the magnetic field produced. Experimental setup of mechanical and electrical stirring process was proposed by Flemings and Ichikawa.

The major purpose of the Rheocasting is to homogenize the microstructure as the whole part of an alloy ingot by the fragmentation of the dendritic crystals with the rotation of the stirrer immersed in the molten alloy. It eliminates the crack initiation points like interdendritic shrinkage pore, inclusions, secondary dendritic arm spacing. The speed of the stirring plays a major role to fulfill the purpose. However, the high speed stirring is not possible as cause of the fear of the formation of air spaces, but in case of the controlled high speed stirring process, there are better results.

II. ALUMINIUM/MAGNESIUM ALLOYS

Rheocasting technology is mainly used on aluminum and magnesium alloys. Various properties of aluminum and magnesium are same.

2.1 ALUMINIUM ALLOYS:

Aluminium is known for its light weight, malleability, and ductility, and conductance, resistance to corrosion, low density, non-magnetic nature and machinability. It is also the third most abundant metal on the Earth. In the recent 100 years, it has become a vital metal for the aerospace industry because of its light weight & its alloys are widely used in automobiles, packing sector and decorative industries.

There are several materials which are used with aluminium to enhance its metallic properties. Some important materials are silicon, iron, copper, manganese, magnesium, zinc, nickel and titanium. Pure aluminium is cant be used because of its low strength and stress bearing capability. Al alloys have also some desired features which are not a part of aluminium. Table 1 shows benefits of using various alloys of aluminum instead of using it alone.

Table 1: Benefits of various alloys of aluminum in comparison to pure aluminum

Alloys	Induced features
Al+Si	Improves casting properties
Al+Fe	At a content of 0.4% and above, reduces the tendency to stickiness in pressure die casting
Al+Cu	Increases strength
Al+Mn	Partially offsets iron's negative effect on ductility when iron content is >0.15%, segregate in combination with fe and chromium
Al+Mg	Improves corrosion resistance
Al+Zn	Increases strength
Al+Ni	Increases high temperature strength
Al+Ti	Increases strength

Despite of the possibility of the manufacturing of different alloys of the Al, still, the care must be taken in account to maintain the percentage. Otherwise, it may create undesirable effects.

2.2 MAGNESIUM ALLOYS

Magnesium is lightest of all metal elements. Magnesium is usually use in alloy with aluminium, which are called as the sister metals. Remarkable feature of the Magnesium is that it is much lighter than the Aluminium and also, the 8^{th} most abundant metal on Earth. The general metals which are mixed with it are aluminium, zinc, magnesium, silicon, manganese, copper and rare earth metals. Magnesium alloys have the hexagonal lattice structure. The alloys are typically used as cast alloys, but recent works have shown that wrought alloys can also be applicable. Due to its perfect strength to weight ratio, it is a crucial element for the aerospace industry. The modern high speed vehicles are also using the alloys. Even, to provide strength in light weight, it is now a day essential alloys material for camera, phones and several others electronic accessories. The use of aluminium alloys is greatest for portable electronic devices because the material has several advantages, they are light but being metallic they radiate heat better than plastic; they maintain metallic texture but are non-magnetic ; they can block electromagnetic waves and minimize the influence of noise. Because of damping properties, they are readily used for steering wheels in cars.

Magnesium alloys also have the capacity to damper and absorb vibrations and electromagnetic waves. The problems with the Magnesium alloy are the low strength, less toughness, poor corrosion resistance, and easily flammable nature with oxygen. This restricts the use of the alloys and make manufacturer choose aluminium alloys above it. The problem with the casting of magnesium alloys is same as that of aluminium.

Several works have been done yet in order to increase the material capabilities of Mg alloys. Prof. Yoshihito Kawamura et.al succeeded in developing the high strength and fast solidifying alloy Mg97Zn1Y2 using powder metallurgy.

It can be produced by casting also. Some more outstanding works done to increase the dependency over the alloy are improvement in Heat Resistance, by Shigeharu Kamado et al, improvement in the mechanical properties by ECAP method by Segal et al, 1981 and micronization of crystal grains by precipitation by Katsuyoshi Kondoh.

III. SSR™ TECHNOLOGY FOR AL CASTING

This is a very new technology developed in 2000, at MIT which is found to be very successful in creating non-dendritic material for aluminium alloys. The researchers are trying to get it commercialized by experimenting with different aluminium alloys. During research, it is mainly applied over the 356 Al alloy.

The advantages listed are: (a). Possibility of production of high quality, heat treatable, complex parts with minimal entrapped air or shrinkage porosity because of planar front filling of the metal at relatively high injection velocity when compared with high integrity casting process. (b). Reduction in die dwell time because of reduced metal heat. (c). Increased die life because of reduced thermal shock and fatigue due to decrease casting temperature which is a matter of greater significance.

Table 2: Chemical Composition of 356 Al alloy used for SSR™ casting

ELEMENT	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr
WEIGHT	6.96	0.10	0.01	0.65	0.32	0.01	0.06	0.0139

Earlier, the stirring process was done with the onset of the liquidus phase, but it did not provide much advantages. Then, emphasis was led on the copious nucleation and dendrite fragmentation when the solidification starts. Low temperature cooling is a way to do the latter. A number of semi-solid processes, most notably using the cold chamber of a die casting machine or an external cup to initiate cooling, are based on low temperature cooling.

The work at the MIT revealed that the critical factor for creating the non-dendritic, semi-solid slurry is the combination of rapid cooling and convection as the alloy cools through liquidus, with agitation almost unnecessary after formation of very small fraction of solid.

The technology used cooling rods, most preferably Graphite rods, cause of its non-wetting nature with aluminium and high thermal diffusibility. However, it can be also applied with the low fraction solid because it requires the transfer of the metal much quicker as it has low viscosity and can be done through small hole, to the cold chamber. It is successfully tested on alloys 356 and 357. But it kills some advantages like decrease in the overall process time because the heat reduction is not that much and also compensate with the die life.

SSR™ experiment results were quite exciting. A no. of alloys and casting were then rheocast on 800 and 1000 ton die casting machines. The technique was applied over 380, 356, 365 and Magsimal™-59. There was a sharp 25% reduction in the dwell time in all cases. The overall outcome can be explained as: A. The design of the new machine for the SSR™ technique, B. It can be also applied for the low fraction semi solid casting, C. Alloy 356 is successfully casted without porosity and decreased dwell time, D. It is then applied for the other alloys also- 365, 380 and Magnisimal™- 59.

IV. RHEOCASTING OF MAGNESIUM ALLOYS

Magnesium alloy with aluminium show a very good castability, thus the pressure casting is used for it. Magnesium has excellent die filling properties and large, thin walled and complex components can be produced. Low heat capacity, lower latent heat of solidification and less affinity to iron are further advantages of magnesium castings resulting in shorter casting cycles and longer die life time.

As the magnesium alloy has the thixotropic property, work is going on to use the rheocasting of the alloys with maximum advantages. The problem with the HPDC (high pressure die casting) of magnesium is that it gains shrinkages and pores. Even hot tearing occurs in them. To avoid these problems, thixomolding is furthermore detailed to cast the mg alloy, but it has found to be has its own limitations. There is a need of the precursor materials of good quality which is not easily available and it add on the cost. So, NRC (New Rhecasting Process) and DCRC (Direct Chilled Rheocasting Process) techniques are developed.

4.1 DIRECT CHILL RHEOCASTING METHOD

The Brunel University is playing a lead role in the advancements of the casting process of the Magnesium. It has recently developed the new rheocasting process. The new developments include direct chill rheocasting, rheoextrusion process and twin roll casting process, collectively known as rheoforming process.

It is a technique developed by BCAST at Brunel University for production of high quality Mg alloy billets and slabs. The process consists of a high quality semi solid slurry supply system, continuously feeding a conventional direct chill caster, to produce billets. The process was found to be very successful in producing fie and uniform microstructure.

Tools Employed:

Various tools involved in process are as follows:

a. Twin screw slurry maker: it has a pair of coroating, fully intermeshimg and self wiping screws rotating inside a barrel. The screws are designed to produce high shear rate and turbulence.

b. The stirrer: used to prevent agglomeration of the solid particles, clean the inner surface and force the semi solid metal slurry to flow downwards.

c. Standard dc caster.

Process: The alloy was melted at 700 C. The range of the barrel was managed at 629 – 633. AZ31 alloy (refer table 4) was first fed into the twin screw slurry maker and processed at rpm screw rotation n. It is then supplied to the water cooled copper mould for the final solidification, at the speed of 800 rev/sec. The prepared ingot was heated at 350 C and the extrusion is done by 800 ton machine.
The tensile test was done later.

Table 3: % composition of alloy AZ31

Aluminium	Zinc	Manganese	Be	Cu	Fe	Ni	Si
3.411	0.698	0.318	0.0007	0.033	0.004	0.002	0.053

The result was found to be very interesting. The x-ray diffraction was then used to check the texture after extrusion. The average size of the microstructure before extrusion was averagely 50 μm and after extrusion, it was around 3μm. It also revealed that improvements are possible on the conventional Mg alloys.

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