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PROCESSING OF MAGNESIUM COMPOSITES WITH SILICON CARBIDE: AN OVERVIEW

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Abstract

The burgeoning need for light weight material with appropriate mechanical properties for structural applications ranging from small hinges to aviation structures has invoked significant developments in magnesium metal matrix composites. While several reinforcements are available, Silicon Carbide is widely used due to its sustainability of properties at high temperatures. Reinforcing magnesium with SiC entails an enhancement in mechanical properties but Magnesium being ductile and flammable inhibits the manufacturability. Therefore, the process to be employed must be severely scrutinized in order to fetch the desired results. This paper intends to outline the various possibilities to manufacture such a metal matrix composite and also cite the advantages and disadvantages of the particular process. Also the effects of using such processes and its outcome have been enunciated.

Key words- Magnesium Composite processing, Silicon Carbide, Casting, Powder Metallurgy, Melt Stir Technique, Pressure less Infiltration

I. INTRODUCTION

Magnesium the silvery white metal with a density of 1738 kg/m^3 at 20^{o}C which is as much as two thirds of that of aluminum. Its slender weight and adept to form mechanically resistant alloys have certainly brought it the lime light in aviation industry where in weight is of colossal concern. Being the eighth most abundant element and filling up to almost 2% of the earth's crust magnesium exists as a hexagonal close packed crystalline structure, it also possesses the tendency to coalesce with most nonmetals and acids. Being malleable and mechanically weak it does lack nominal strength to be directly used as a structural member. Due to which magnesium is generally alloyed or reinforced with other metals or elements in order to attain the desirable properties. The magnesium aluminum system of alloys up to 10% is widely put to use in industry. Magnesium alloys cannot sustain their mechanical properties at high temperatures which was a paramount requirement for industrial applications. This was achieved by reinforcing magnesium with silicon carbide which is known for retaining its properties at higher temperatures and also being abrasive it adds hardness to magnesium making it suitable for structural applications. Several other reinforcements are available in the market which includes Aluminum oxide (Al_2O_3), Tungsten Carbide (TiC) etc. Magnesium metal matrix composites in general consists of a minimum of two phases, one of the phase being the metal matrix while the other being the reinforcement. In order to process a composite wherein the reinforcement does not infuse with the metal or to prevent agglomeration, an essential step has to be taken in order to attain a homogenous distribution of the particles. In case the MMC is subjected to temperature changes it in turn leads to change in thermal stresses at the interference of the matrix and the reinforcement which leads to higher dislocation density owing to higher internal stresses. Also another crucial factor to be taken into account is its property of being flammable and its ability to oxidize which impede its processing and lead to various manufacturing defects which in turn provide poor mechanical properties to the synthesized material. Magnesium having its melting point at 650^{o}C wherein the melting point reduces to 1650kg/m^3 and also there is an expansion in volume which is accounted to about 4.2%. Yet another important aspect is that magnesium should be additionally supplied with sufficient amount of cover gases so as to reduce the oxidation. Magnesium composites find a diverse use in the industry with its utility being explored since World War II where Boeing used it for several of its structural applications but the International Air Transport Association (IATA) limited its usage to non structural applications due to high corrosion and fire hazards. Nowadays, MMCs are used in several automotive, aerospace and defense applications, but its comprehensive usage is yet to be explored.

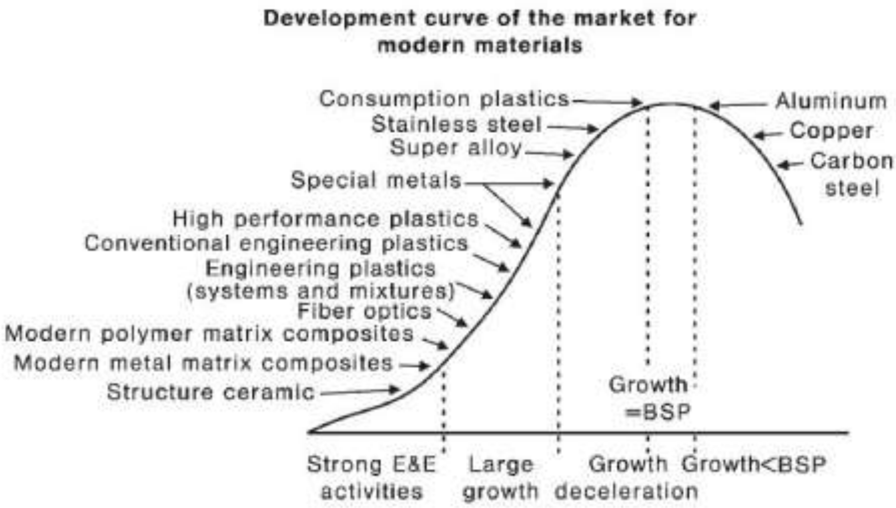

Figure 1 Development curve of Modern Materials [1]

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II. CASTING

Magnesium is seldom used in its pure form; it has to be alloyed with other metals to influence its properties. Casting is a much preferred process because it allows uniform distribution of constituents and interphase formation between magnesium and alloying elements. For structural applications, like frames and heavy equipments like propeller blades etc. excellent directional properties can be achieved. Some of the casting processes are described below which can be used for the manufacturing of magnesium MMCs with silicon carbide.

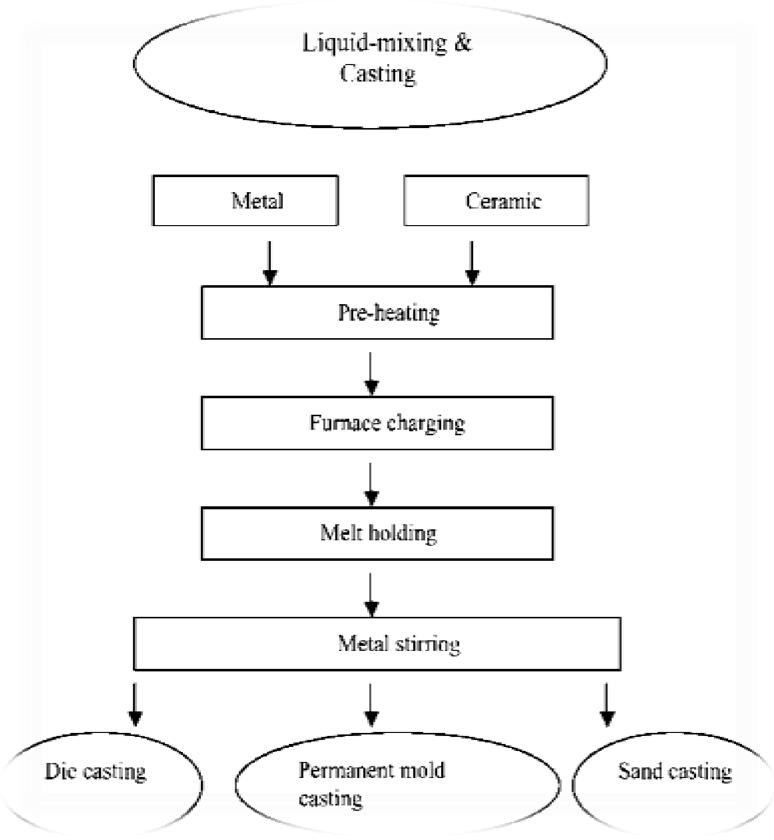

Figure 2 Casting Process [2]

A. Gravity Casting

Gravity casting, which includes permanent mould casting and sand casting, is probably the oldest forms of casting. [3]A. Luo suggested that gravity casting of magnesium MMCs is largely dependent upon its solidification parameters to avoid excessive interfacial interactions and increase wettability. The main drawback of gravity casting is that it does not employ cover gases which leads to oxidation of molten magnesium. Also, lack of pressure on the melt mix leads to localised damages such as particle cracking, matrix cracking. Presence of large amount of SiC reduces the tensile strength thus leading to low ductility of magnesium MMCs.

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B. Stir Casting

Stir casting is a process where the melt is stirred mechanically to enable uniform mixing of alloying elements. In case of composites it is highly preferred because most reinforcement exhibit poor wettability in the melt and most of the SiC is found to be accumulated where the melt was solidified at last. Stirring helps in thoroughly mixing the reinforcements while keeping the already mixed particles suspended. A wide range of reinforcements re not directly soluble in the magnesium melt including silicon carbide.

[4] J. Hashim et al. suggested employing vortex spinning with addition of silicon carbide particles at the side. [4]He also suggested that the impeller design, surface properties of the reinforcement, stirring speed and holding temperature are the most essential parameters to obtain a wide range of mechanical properties. The stirrer speed also has an effect on the melt; high speeds tend to agglomerate SiC particles at the boundary and slower speeds leads to coagulation of SiC particles inhibiting uniform mix.

[5]W. Zhou and Z. M. Xu employed a novel idea of two- step mixing where the molten metal is brought to its liquidus temperature and maintained between its liquidus and solidus states. The preheated reinforcement is now added to the semi- solid melt and heated again. This mixing process leads to uniform grain distribution and multiple nucleation sites for uniform solidification.

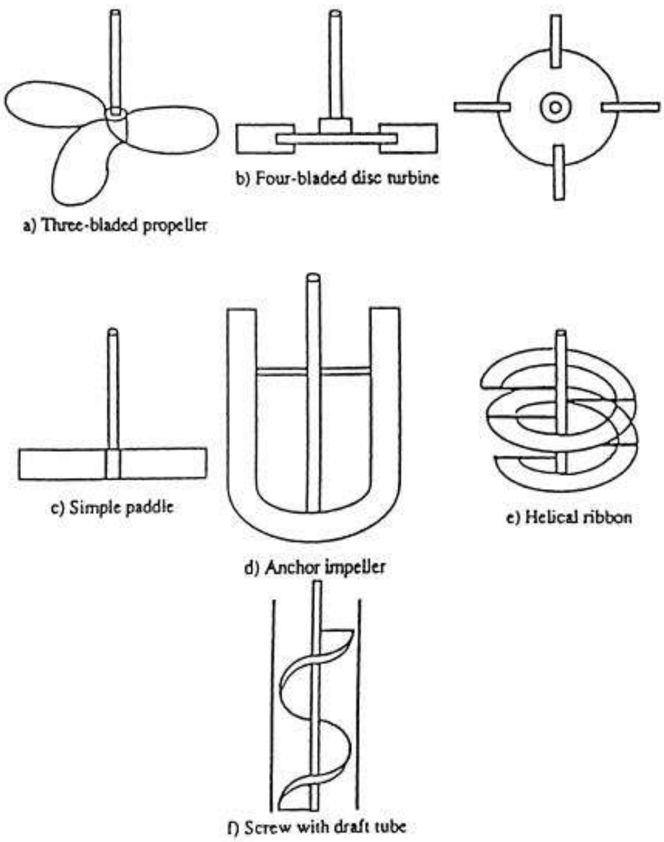

Figure 3 Stirrer Paddle Designs [6]

C. Squeeze Casting

Squeeze casting is a process where the molten metal is poured into the die and pressure is applied on the melt while solidifying. Squeeze casting is sometimes also referred to as pressure crystallization, liquid metal forging and extrusion casting as the process combines the casting and forging processes. [7] H. Hu described the process parameters for squeeze casting which are based for the manufacture of magnesium MMCs; he suggested that variation in applied pressure directly influences the solidification time because the solidus and liquidus lines are shifted as well as the eutectic composition of the alloying elements.

Another major issue with magnesium casting is that the melt should be kept free from atmospheric gases thus; the furnace should be purged with cover gases (SF_6 or argon). Also, magnesium casting utilizes non- conventional gating system where the melt has no contact with atmosphere. Due to this accurate metering of melt is crucial as the excess metal cannot be accommodated elsewhere. The tooling temperature is also very important for maintaining the solidification time. The tooling temperature must be kept between 200°C and 300°C for magnesium MMCs. The time delay between pouring and pressurization must be kept minimal. For Mg-SiC system it should be less than 1 minute as the pressurization should be mainly in the liquid state. The increase in pressure increases the melting temperature (7.58°C for AZ91 and 8.7°C for AZ31) and decreases the solidification time. Thus, while performing squeeze casting the pressure should be kept well above 150 MPa, pouring time should be minimized for an equi- axed structure formation.

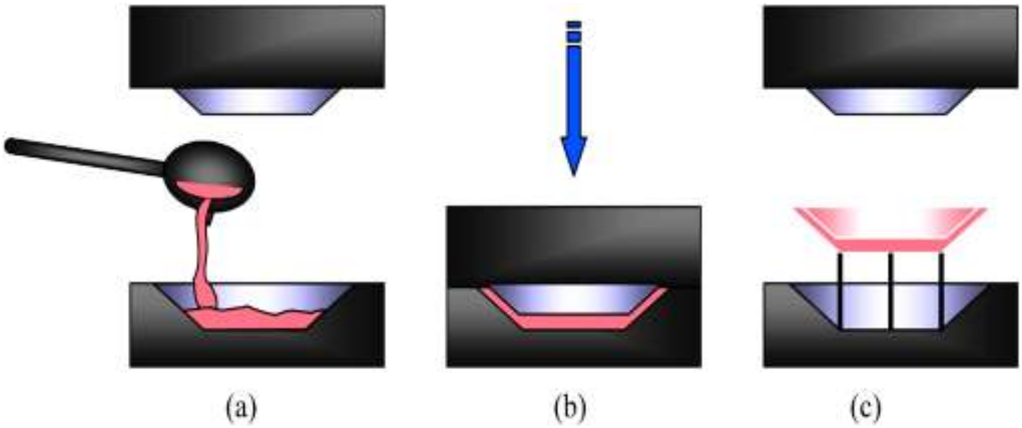

Figure 4 Schematic illustrating direct squeeze casting process operations: (a) melt into die cavity; (b) close tooling, solidify melt under pressure; and (c) eject casting [8]

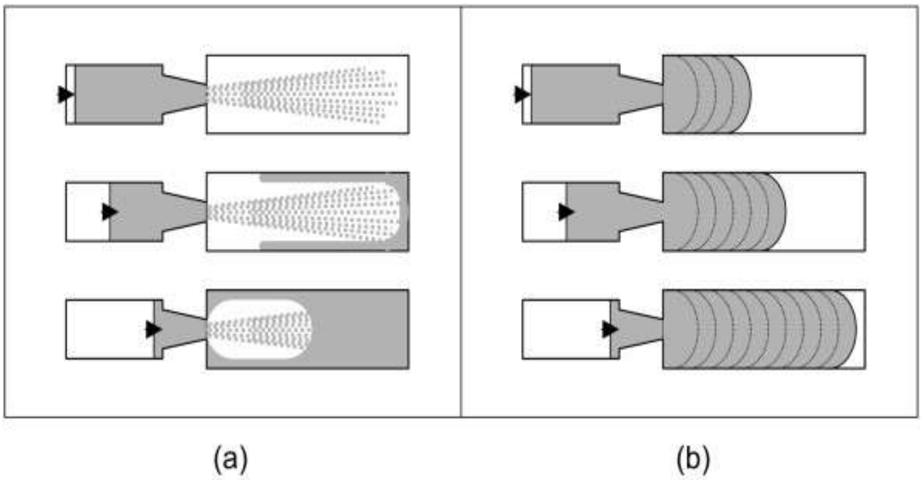

Figure 5 Schematic illustrating metal flow in (a) conventional die casting; and (b) indirect squeeze casting process [8]

III. POWDER METALLURGY

[9] B.W. Chua while discussing the influence of Sic particles on an Mg based composite have used the technique of powder metallurgy in order to reinforce 10 vol% SiC particles with Mg9Al0.7Zn0.1fMn in the form of powder. The SEM micrographs indicated homogenous distribution of the SiC with a very negligible agglomeration which is very suitable for a MMC. While the tensile tests summarized a decline in Elastic Modulus, Ultimate Tensile Strength and Elongation the predicted fracture toughness showed a considerable increment which explains the reduction in malleable property of the alloy.

Another vital erudition from the XRD depicted chance of embrittlement due to presence of Mg_2Si phase which could adversely influence the mechanical properties of the composite. By using powder metallurgy the metals are not required to be brought into molten form. Another intriguing detail is that the compaction which is carried out does resist the pores which do not deter the properties of the mold. And also in addition to it the sintering which is done following the compaction of green mold adds subsequent strength due to the better bonding between the molecules.

[10] W. Brian James augurs the economy of the powder metallurgy process being lower in comparison to the other processes, also another grave feature being that by avoiding the molten phase of the metal the hazard from the reactivity of magnesium can be subsequently reduced. Another important consideration is that due to compaction the green density of the mold is augmented which produces a pore free mold and also the volume fraction of Sic used can be increased as agglomeration is very scant.

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Although an unprecedented disadvantage which has been acquainted is that due to the excessive shrinking which occurs in the mold leads to an aberrant dimensional accuracy. Yet another leverage being the machining and finishing requirements for a powder metallurgy mold is minimal.

IV. PRESSURELESS INFILTRATION

A unique method to process this magnesium metal composite was investigated by [11] Hiromitsu Kaneda wherein the molten metal are subjected to capillary action. SiO_2 powders referred as infiltration agent powder blended with SiC particles with sizes 1.2, 2, 3, 4 and 8 µm were placed in a alumina crucible in turn this was again placed inside a steel crucible.

The Magnesium ingot which when kept over the SiC-SiO_2 mixture and heated the magnesium was thawed and spontaneously infiltrated through the SiC-SiO_2. This spontaneous infiltration can be attributed to the rise in temperature due to the reaction between magnesium and infiltration powder.

The results obtained by the microstructure analysis enlightened a homogenous distribution of the SiC particles.

V. MELT STIR TECHNIQUE

[12] R.A. Sarvana while analyzing the characterization of pure magnesium reinforced with 30% SiC of 40µm utilized melt stir technique. In this process the magnesium metal was wrapped in an aluminum foil and subjected to resistance heating furnace with a capacity of 5 KW which was carried out in a steel crucible. After the temperature was scrutinized in order to reach 700^{o}C, due to the sealed crucible the amount of oxidation which occurred was minimal and the oxidized layers were further dislodged. Now by using a rotating impeller a whirl was created in the melt and the SiC particles which were preheated are ejected into the whirl. The molten metal was poured in a mold and the billets formed were homogenized up to 500^{o}Cand subjected to hot extrusion in a ratio of 13:1.

The microscopic analysis of this billet indicated a homogenous distribution of the reinforcement and did not include any significant casting defects. Satisfying wetting of the reinforcement in the magnesium suggested absence of any reaction products at the coalescence of the matrix. The macro hardness of the reinforced metal showed an increase of about 15 VHN whereas the micro hardness leaped about 13 VHN in contrast to the unreinforced metal.

The Ultimate tensile strength of the reinforced metal was attributed to be higher and the % elongation was subsequently reduced, this conspicuously broached that the ductility increases at inflated temperatures on the other hand the strength decreases gradually. The SEM fractrograph revealed that the matrix displayed a quasi-brittle fracture which was the reason for SiC particle fracture which was observed. Also an improved wear resistance has been noted for the magnesium composite. The conclusion stated the possibility for successfully achieving the composite by melt stirring process without utilizing any flux or cover gas or rather a protective atmosphere.

VI. CONCLUSIONS

In essence several processing methods being available for manufacturing a Magnesium metal matrix composite, squeeze casting and powder metallurgy seem to be productive in terms of results. Squeeze casting product showing a uniform grain distribution with less pores and solidification time, while the process is arduous and involves higher cost. Whereas on the other hand powder metallurgy possessing high dimensional accuracy and surface finish but complex and intricate shapes seem to be difficult to process.

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