International Journal for Ignited Minds (IJIMIINDS)

Microstructure and Hardness Studies of Magnesium-Aluminum Alloy and Fused Silica Particulate Composite

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ABSTRACT

The present investigation is aimed at studying the effect of dispersoid content and effect of chill on microstructure and mechanical properties of Magnesium (Mg) reinforced with aluminum alloy (LM-13) hybrid metal matrix composites with Silica (Sio2). The size of the Silica (Sio2) particles varies from 50 to 80 µm. volumetric heat capacity (VHC), and its effect on the microstructure evolution was examined by using copper chill. Stir casting process was used to produce chill cast magnesium-aluminum alloy-silica particulate composites in moulds containing copper chill to accelerate the solidification. The fabricated composites were tested for their hardness and ultimate tensile strength properties according to ASTM standards. The effect of chill and reinforcement characteristics was presented and compared with the hybrid composite without chill material. Microstructural studies of the chill cast composite developed indicate that there is uniform distribution of the reinforcement in the matrix alloy with significant grain refinement and retention of residual porosity. Mechanical properties reveal that the presence of silica particulates has improved significantly the ultimate tensile strength and hardness as compared against the matrix alloy. The results confirm the positive relationship between mechanical behavior and the dispersiod content. The copper chill cast composite with 84.03wt% Mg, 8.4wt% Lm-13 and 7.56wt% Si02 was found to increase mechanical properties..

Keywords *- Aluminum alloy (Lm-13), Magnesium (Mg), Chill Casting, Silica (Si02), Stir Casting, Hardness, Microstructure.*

1. INTRODUCTION

High performance materials are of great interest for modern material applications due to the possibility to develop innovative materials with specific properties. Ongoing from this potential, the hybrid metal matrix composites (HMMCs) meet the desired concepts of the design engineer, because they represent custom-made materials [1]. In HMMCs, two or more components are mixed in same or different ratios; the minor one that is stronger and more rigid than the matrix, in which it is embedded, improves the strength of the mixture. The objective of having two or more reinforcements is to take advantage of the superior properties of both materials without compromising on the weakness of either [2]. Higher temperature materials, higher strength-to-weight ratio materials, highly corrosion-resistant materials have attracted a great deal of attention from scientists and engineers all over the world. Aluminum Composite materials have been considered the "material of choice" in some applications of the automotive and aircraft industries by delivering high-quality surface finish, styling details, and processing options. Cooling conditions during solidification strongly influence the evolution of finer grain structure in the composites [3]. VHC of various chill materials does significantly affect the strength, fracture toughness and microstructure of the hybrid composites [4, 5]. Microshrinkage or dispersed porosity in the composite can be minimized by judicious location of chills. An improvement in the tribological properties of Aluminum HMMCs has been successfully attained by introducing ceramic particles, such as SiC, B4C, Al2O3 and TiC [6,7] using different routes, such as stir-casting, squeeze casting, in-situ and powder metallurgy [8,9]. By adding the ceramic reinforcement problem of machinability occurs. To improve machinability, the graphite is added to matrix materials which reduce mechanical (hardness) properties. Joel Hemanth [10] investigated the effect of reinforcement and chilling on strength, hardness and wear behavior of aluminum based metal matrix hybrid cast composites reinforced with kaolinite (Al2SiO5) and carbon (C) particulates. It is discovered that chilled HMMCs with Al2SiO5-9%/C-3% dispersoid content proved to be the best in enhancing the mechanical and wear properties. Joel Hemanth [11] described production and mechanical properties of chilled aluminum-quartz composite that can cast using metallic and nonmetallic chill blocks. The composite developed is shown to provide significant weight savings and improved mechanical properties. Leela B N et al. [12] studied microstructure and microhardness of chill cast Al-B4C composites. The use of end chills during casting not only favours directional solidification but also accelerates solidification. S Soleymani et al. [13] investigated the effect of SiC and MoS2 particles on microstructural and tribological properties of Al5083 based surface hybrid composite produced by friction stir processing. P. Ravindran et al. [14] have studied the influence of 5wt% SiC and Xwt% graphite (X = 5 and 10) on microstructure and mechanical properties of Al 2024 hybrid composite produced using powder metallurgy technique. Prashant Sharma [15] have reported on the influence of SiC particulate and Eglass fiber reinforcements on fabrication and mechanical testing of Aluminum 6061 hybrid composite. N. Radhika et al. [16] fabricated hybrid composite of aluminum alloy reinforced with alumina and graphite by stir casting process. Investigation showed an increasing trend in hardness and impact strength values with increase in weight fraction of alumina. With the increasing demand for high performance composites, in the present investigation carbon is added which acts as solid lubricant improves tribological properties. But presence of carbon reduces mechanical properties, hence Silica the reinforcement which is one of the hardest naturally available ceramic material.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Aluminum Alloy Lm 13:

The broad use of aluminum alloys is dictated by a very desirable combination of properties, combined with the ease with which they may be produced in a great variety of forms. The chemical composition of matrix material is shown in table 1.

2.1.2 Magnesium:

Magnesium, among commercial metals, is the lightest metal of which demand is gradually increasing. It is the key material to realize weight reduction for the enhancement of energy efficiency, becoming an important resource for the future growth of automobile which needs the light weight, thermal resistance and high strength of magnesium, is expected to grow steadily. The specific gravity of magnesium is 1.74 which is mere 25 % of steel and 70 % of aluminum and is lightest among metals having many superior characteristics such as high specific strength, and shock absorption. Table 2 shows the chemical composition of magnesium.

2.1.3 Silica:

Synthetic amorphous silica (SAS) is used in a wide range of applications such as reinforcing fillers in rubber and tires, free-flow or anti-caking agents in powder materials. Table 3 shows the chemical composition of silica.

2.1.4 Chill Materials:

Table 4 shows the thermo-physical properties of chill materials.

2.2 Chill Casting Procedure

The present investigation aims at producing cast aluminum alloy-magnesium-silica particulate composites in moulds containing copper, steel, and silicon carbide end chills by dispersing silica particles in molten aluminum alloy and magnesium above the liquidus temperature. Commercially available aluminum alloy (LM13) and magnesium (Mg) material are used and is melted in a resistance furnace at around 9500C; Silca (Sio2) particulates were added at end of process. A stir casting process is used to fabricate hybrid composites reinforced with various weight fractions of silica particulates. Properties of silica are Density = 2.196 kg/m3, Hardness = 7.0 Mohs. Fig.1 shows a sectional view of the stir casting arrangement. Combination of dispersoid varies from 1.63 to 4.91wt% in steps of 1.63wt% of silica particulates. Reinforcements were introduced evenly into the molten metal alloy by means of feeding attachments. The size silica particulates dispersed is between 30 and 80 µm. Meanwhile, the molten HMMCs was well agitated by means of a mechanical mixing which was carried out for about 15 min at an average mixing speed of 760 rpm. The melt was next poured into a sand mold with a chill attached to it at one end. Different molds are prepared with different chill materials like copper, steel, and silicon carbide. The same type of mold was used to sand-cast a specimen in which case no chill was used. The chills were of 150 mm long, 35 mm high and 25 mm thick in dimension. The moulds produced plate-shaped ingots of dimensions 150 X 120 X 25mm. Moulds were prepared using silica sand with 5% bentonite as binder and 5% moisture according to American Foundrymen Society (AFS) standards, and were dried in an air furnace.

Elements	Zn	Mg	Si	Fe	Mn	Ni	Al
% by wt	0.5	1.4	12.0	1.0	0.5	1.5	Balance

Table 1: Chemical Composition of Matrix Material (LM 13).

Elements	Al	Zn	Mn	Si	Fe	Ca	Cu	Ni
% by wt	2.5	0.6	0.2	0.1	0.005	0.04	0.5	0.05

Table 2: Chemical composition of magnesium (Mg).

Elements	Si	O_2
% by wt	0.46	0.53

Table 3: Chemical Composition of Silica (Sio2).

Types of chill material	Density kg/m^3	Thermal conductivity W/mK	Specific heat J/kgK
Copper	8.80	380	151
Steel	7.61	52	55
Silicon carbide	3.21	120	750

Table 4: Thermo Physical Properties of Chill Materials

Fig 2 shows the arrangement of mold used for casting specimens. Specimens for all the tests were selected only at the chill end of the casting and all the specimens were heat-treated by aging before testing. Properties such as hardness, tensile strength of the developed hybrid composites were tested as per ASTM standards.

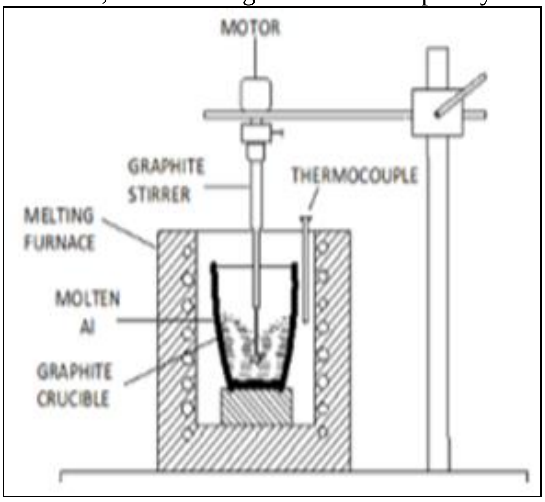


Fig 1: Stir Casting Setup

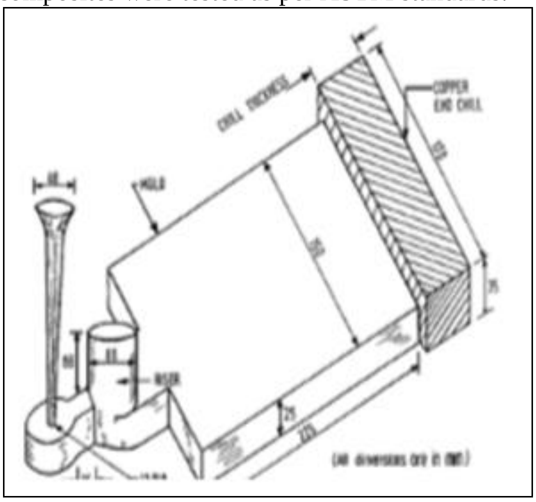
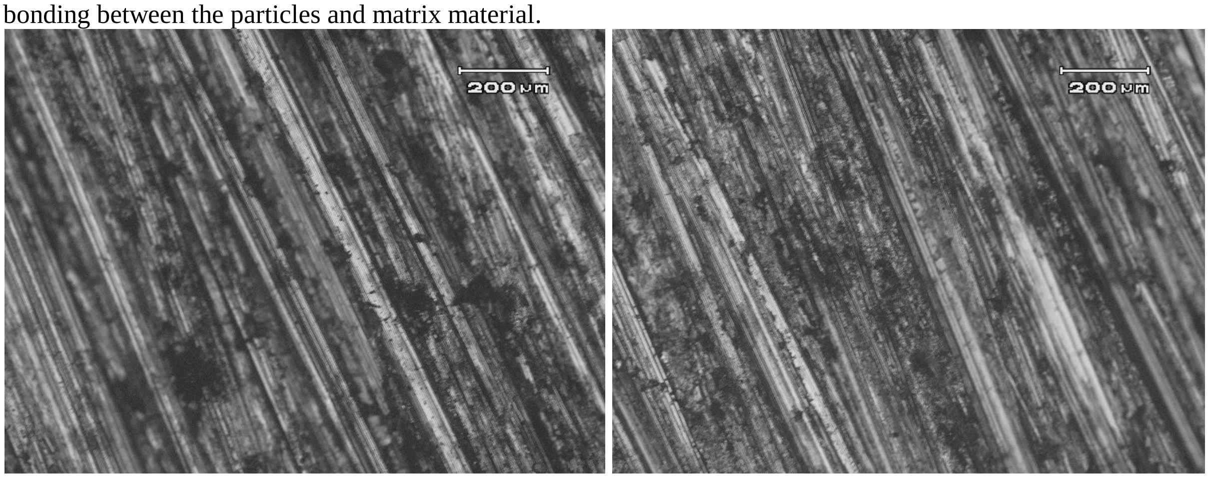


Fig 2: Mold For Casting Specimen

3. RESULTS AND DISCUSSIONS

3.1 Microscopic Examination

The mechanical properties of composite materials are strongly dependent on micro structural parameters of the system. The evolution of microstructure depends largely on the cooling rate during phase change. Though the microstructure evolution depends on many process parameters, the final structure is decided by the cooling conditions during solidification [17]. The present investigation aims at producing cast magnesium-aluminum alloy -silica particulate composites in moulds containing copper end chill by dispersing silica particles in molten aluminum alloy and magnesium above the liquidus temperature. The dispersoid added is 7.56wt%. Cast composites with 7.56wt% silica exhibits highest values for tensile strength and hardness. Figure 3 shows the optical micrographs of magnesium composites reinforced with 8.4wt% Lm-13 and 7.56wt% silica with copper chill materials. The volumetric heat capacity (VHC) of the copper chill block not only favors directional solidification but also accelerates solidification. Faster cooling rates give rise to finer structures and improved mechanical properties [18]. Optical micrographs of hybrid composites show clearly the uniform distribution of magnesium and silica in the matrix, and no void and discontinuities were observed. There is a good interfacial bonding between the particles and matrix material.



(a) Copper Chill (5X) (b) Copper Chill (10X)

Fig 3: Microstructure Plot of Copper chill with 5X and 10X.

3.2 Ultimate Tensile Strength (UTS)

To study the tensile behavior of the hybrid composites, specimens were prepared and tested as per ASTM E8M standard. Figure 4 shows the plot of UTS v/s dispersoid content of the HMMCs near the chill end for composites cast using chill of 25 mm thickness. It is evident from this plot that for a copper chill, the UTS of the composite increases as silica content is increased up to 6.3 % by weight, beyond which it drops again. It is evident from these results that the HMMCs with the highest UTS is the one 7.56wt% cast composite with a copper chill, followed by those cast without chill in that order. This is because the copper chill has the highest volumetric heat capacity and hence extracts heat most quickly from the HMMC during casting, followed by no-chill. The results confirm the positive relationship between UTS and the dispersiod content. There is therefore no advantage in reinforcing the Al matrix with silica contents above 6.3wt% as far as UTS is concerned. The tensile strength of .The tensile strength of 7.56wt% cast composite with a copper chill is 60.49N/mm2 and young’s modulus=10kN/mm2. If in case porosity is present, the solidified microstructure reduces the mechanical properties of cast hybrid composites as the plastic deformation is initiated from the voids formed. The large difference in co-efficient of thermal expansion (CTE) mismatch between the aluminum and hybrid reinforcements could actually induces the enormous amount of dislocations in the hybrid composites. These induced dislocations act as a barrier for the dislocations movement. Hence the strength of the hybrid composites are increased significantly even for the addition of very low weight percentage of the reinforcements..

3.3 Hardness Studies

Hardness tests were performed on the cast samples with a Brinell hardness testing machine. A precision ball indenter is impressed on material at a load of 250 kilograms for 10 sec. The results of micro hardness test (HV) conducted on chilled MMCs samples revealed an increasing trend in matrix hardness with an increase in reinforcement content. Results of hardness measurements also revealed that copper chill has an effect on hardness of the composite.

This significant increase in the hardness can be attributed primarily due to the presence of harder silica ceramic particulates in the matrix, a higher constraint to the localized deformation during indentation due to their presence and reduced grain size due to chilling [19,20]. In ceramic reinforced composite, there is generally a big difference between the mechanical properties of the dispersoid and those of the matrix. These results in incoherence and a high density of dislocations near the interface between the dispersoid and the matrix. Hardness of 7.56wt% silica cast hybrid composite is 67.7.

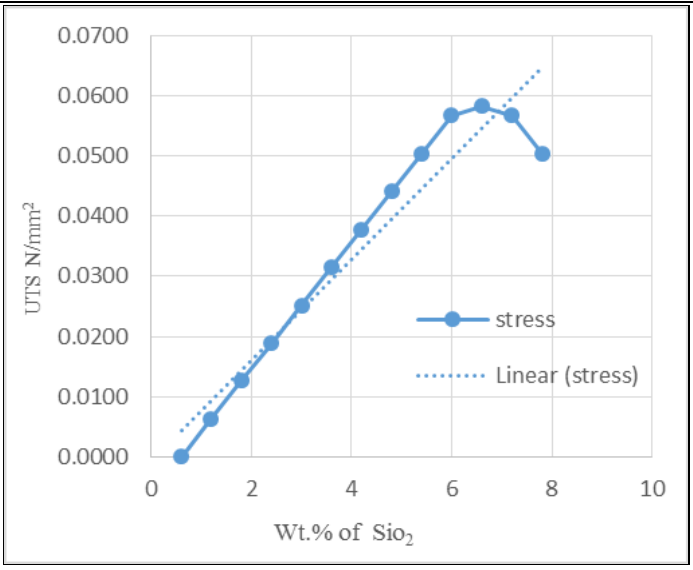


Fig 4: Plot of UTS v/s wt % of Silica.

It is evident from the results that copper chill extracts heat most quickly from the HMMC during casting. Hardness values of the hybrid composites are higher for 8.4wt% Lm-13 and 7.56wt% Si02 which has superior hardness value.

4. CONCLUSION

- Magnesium matrix aluminum alloy-silica reinforced composites were successfully cast by stir casting route using copper end chill materials. From the analysis of the cast specimens the following conclusions can be drawn.
- The chilling effect is optimum in case of copper chill. The chilling effect successively reduces composite without using chills. Volumetric heat capacity (VHC) of the chill is found to increase the amount of heat absorbed.
- Fine grain structure, uniform distribution of dispersoid and good bonding between the matrix and the dispersoid is obtained with the use of copper chill, whereas, the grain size successively increases without use of chill.
- A dispersoid content 8.4wt% aluminum alloy + 7.5wt% silica with copper chill was found to increase the mechanical properties, and therefore, it is considered as the optimum limit.

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