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Study of Dispersoid Content and Chill Effect for Improved Mechanical Properties of Aluminum-Garnet-Carbon Hybrid Metal Matrix Composites

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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 aluminum alloy (LM 13) hybrid metal matrix composites reinforced with garnet and fixed 3wt.% carbon. The size of the garnet particles varies from 50 to 80 µm and amount of addition varies from 3 to 12 wt.% in steps of 3 wt%. By using chills of different material with different volumetric heat capacity (VHC), the effect on the microstructure evolution was examined. Stir casting process was used to produce chill cast aluminum alloy-garnet-carbon particulate composites in moulds containing various chills of copper, steel, iron and silicon carbide 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 garnet 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 9wt.% garnet and 3wt.% carbon was found to increase mechanical properties.

Keywords

Aluminum, chill casting, garnet, hardness, microstructure, stir casting.

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, B_4C, Al_2O_3 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 (Al_2SiO_5) and carbon (C) particulates. It is discovered that chilled HMMCs with Al_2SiO_5-9%/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-B_4C 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 MoS_2 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 5 wt.% SiC and X wt.% 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 E-glass 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 increase in the 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 Garnet reinforced 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 Garnet: Garnets are a group of silicate minerals that have been used as gemstones and abrasives. Garnet helps to control the mechanical behavior of the Earth’s crust, mantle, and transition zone because of garnet’s inferred high strength in comparison with the other mineral components. Table 2 shows the chemical composition of garnet.

2.1.3 Chill materials: Table 3 shows the thermo-physical properties of chill materials.

2.2 Chill casting procedure

The present investigation aims at producing cast aluminum alloy-garnet-carbon particulate composites in moulds containing copper, steel, iron and silicon carbide end chills by dispersing garnet-carbon particles in molten aluminum alloy above the liquidus temperature. Commercially available Aluminum alloy LM13 material is used and melted in a resistance furnace at around 750^0C; Garnet and carbon particulates were preheated to 700^0C.

A stir casting process is used to fabricate hybrid composites reinforced with various weight fractions of garnet and carbon particulates. Properties of garnet are Density = 4.19 kg/m^3, Hardness = 7.8 Mohs. Fig.1 shows a sectional view of the stir casting arrangement. Combination of dispersoid varies from 3 to 12 wt.% in steps of 3wt.% of garnet and 3wt.% Carbon particulates. Reinforcements were introduced evenly into the molten metal alloy by means of feeding attachments. The size of garnet and carbon 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, iron 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)

Table 1. Chemical composition of matrix material (Al-alloy LM 13)

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

Table 2. Chemical composition of garnet

Elements	Al	Al_2O_3	Fe	FeO	Si	SiO_2	O
% by wt	10.84	20.48	33.66	43.30	16.93	36.21	38.57

Table 3. Thermo physical properties of chill materials

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
Iron	7.80	40	47.5
Silicon carbide	3.21	120	750

standards, and were dried in an air furnace. 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.

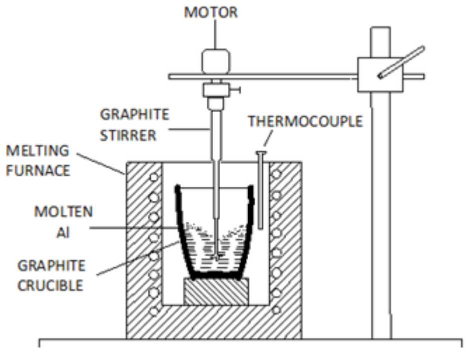


Figure 1: Stir casting setup

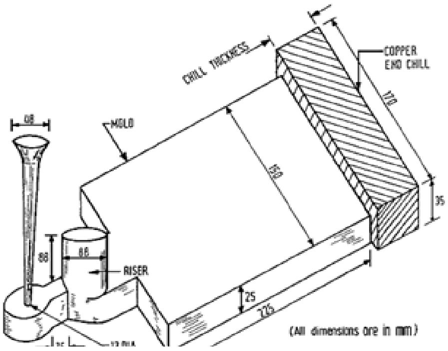
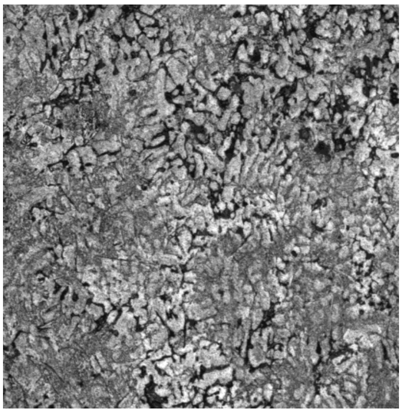


Figure 2: Mold used for casting specimens

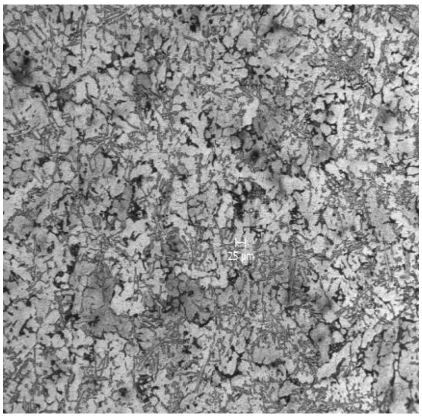
3. RESULTS AND DISCUSSIONS

3.1 Microscopic examination

The mechanical properties of composite materials are strongly dependent on micro structural

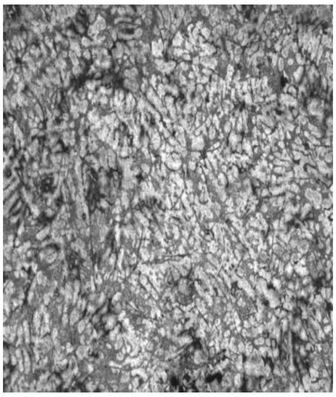


(a) Copper chill

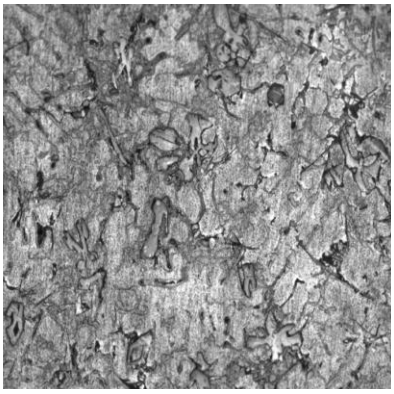


(b) Steel chill

(c) Iron chill



(d) Silicon carbide chill



(e) Without chill

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 aluminum alloy-garnet-carbon particulate composites in moulds containing copper, steel, iron and silicon carbide end chills by dispersing garnet-carbon particles in molten aluminum alloy above the liquidus temperature. The dispersoid being added ranges from 3 to 12wt.% in steps of 3wt.%. Cast composites with 9wt% garnet-3wt% carbon exhibits highest values for tensile strength and hardness. Figure 3 shows the optical micrographs of aluminum composites reinforced with 9wt% garnet-3wt% carbon with different chill materials. Figure 3(a) shows microstructure of 9wt.% garnet and 3wt% carbon using Copper chill. 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 Garnet and Carbon in the matrix, and no void and discontinuities were observed. There is a good interfacial bonding between the particles and matrix material.

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 different types of chills of 25 mm thickness. It is evident from this plot that for a particular chill, the UTS of the composite increases as garnet content is increased up to 9 % by weight, beyond which it drops again. It is evident from these results that the HMMCs with the highest UTS is the one 9wt% cast composite with a copper chill, followed by those cast with a steel chill, iron chill, silicon carbide chill and 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 steel, iron, silicon carbide and no-chill in that order. The results confirm the positive relationship between UTS and the dispersiod content. There is therefore no advantage in reinforcing the Al matrix with garnet contents above 9 wt % as far as UTS is concerned.

Figure 5 shows the plot of UTS of chill cast composites v/s various chill materials. The tensile strength of 12% garnet and 3% carbon reinforced hybrid composite is actually lesser than that of the hybrid composite reinforced with 9% garnet and 3% carbon. The possible reason could be; increased agglomeration of the reinforced particles and increased porosity content as the particle percentage increases. Agglomeration of particles leads to the microclusters and the loosely packed particles in the clusters makes the material as weaker structure and hence reduction in tensile strength [10]. The presence of porosity in 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 Vickers hardness testing machine. A precision diamond indenter is impressed on material at a load of 50 grams for 10 secs. Figure 6 and 7 shows hardness of chilled HMMCs cast with different wt. % of garnet using various types of chills with different volumetric heat capacity. 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 (up to 9 wt.% garnet). 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 to presence of harder garnet 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. Figure 8 shows the plot of hardness of composite with various wt % of dispersiod content which confirms the positive relationship between hardness and the dispersiod content. Hardness of 3wt% garnet-3wt% carbon cast hybrid composite is lower and increases as garnet content is increased up to 9 % by weight, beyond which it drops again for the one cast with a copper chill, followed by those cast with a steel chill, iron chill, silicon carbide

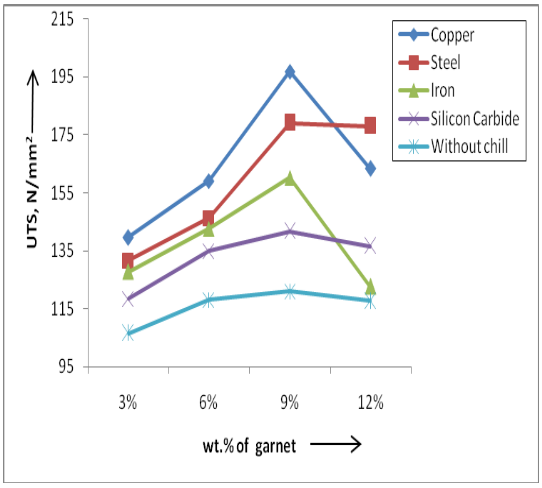


Figure 4: Plot of UTS v/s wt % of garnet

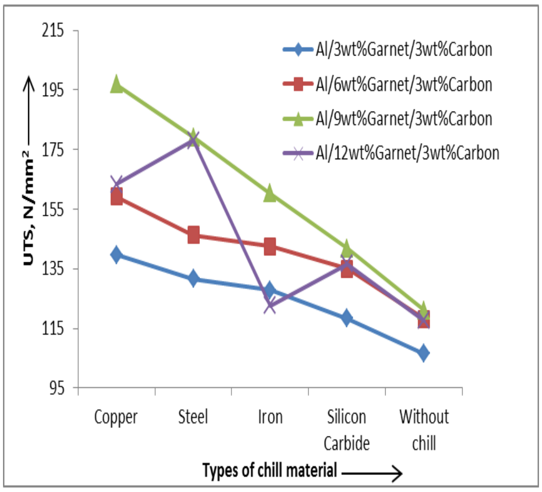


Figure 5. UTS of different cast composites v/s various chill materials.

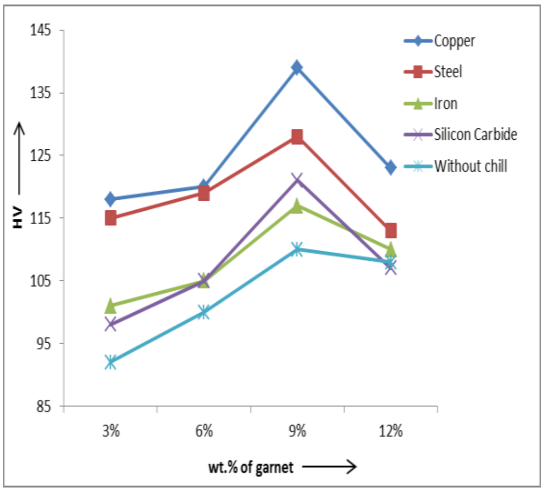


Figure 6. Hardness v/s wt. % of garnet

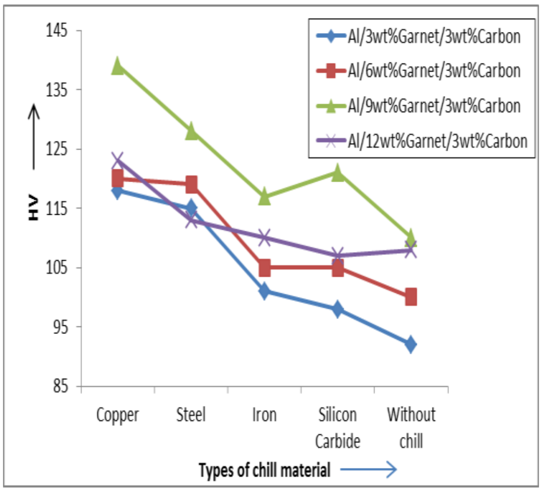


Figure 7. Hardness of various cast composites with different chill materials.

chill and a no-chill in that order. 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 than that of the remaining counterpart and the combination 9wt% garnet and 3wt% carbon give superior hardness value.

4. CONCLUSIONS:

- Aluminum matrix garnet-carbon reinforced composites were successfully cast by stir casting route using different 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 with steel, iron, silicon carbide and 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 with the use of steel, iron, silicon carbide and composite without chills.
- A dispersoid content 9wt% Garnet+3wt% carbon with copper chill was found to increase the mechanical properties, and therefore, it is considered as the optimum limit.

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