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Microstructural and Hardness Study of A390/20wt.% SiC Functionally Graded Metal Matrix Composite

Amal Vijay[1],*, Prem Kumar J.[2], S. Anoop Kumar[2]
[1]PG Scholar, Department of Mechanical Engineering, Sree Chitra Thirunal College of Engineering, Trivandrum, Kerala, India
[2]Associate Professor, Department of Mechanical Engineering, Sree Chitra Thirunal College of Engineering, Trivandrum, Kerala, India

ABSTRACT

Functionally graded materials are the upcoming new class of advanced materials, which exhibit gradual change in the microstructure and the composition in a definite direction, and hence variation in functional performance within a part. Functionally graded metal matrix composites (FGMMC) are FGM with metal and ceramic constituents. Aluminum-Silicon alloys are well-known for their unique combination of desirable characteristics, which includes excellent castability and less density combined with good mechanical properties. One such alloy that has been developed specifically for its wear resistance is the hypereutectic aluminum-silicon alloy A390. The research of wear behavior of this alloy at high temperatures has attracted attention in the past years. However, prospects of hypereutectic A390 alloy reinforced with SiC in a functionally graded manner are not discussed much in literature. The present study focuses on the development of A390/20wt.% SiC Functionally Graded Composite for high temperature tribological applications. The functionally graded A390/20% SiC is fabricated using centrifugal casting. The strengthening phases observed in the microstructural study are constituted by SiCp in the composite, which is formed in a graded manner confirming the FGMMC development. The hardness value showed a decreasing trend from outer to the inner region as expected from a functionally graded material. The hardness at the outer periphery of the developed FGMMC is also found to be higher than that of A390 alloy indicating higher wear resistance of the material.

Keywords: *A390/SiC, centrifugal casting, metal matrix composite, microstructure, hardness, SiC particles*

****Corresponding Author***
E-mail: mewanderlust3@gmail.com

INTRODUCTION

Functionally graded materials are an evolved class of engineering materials, which displays steady transitions in the microstructure and composition along a direction. This leads to the desired change in the functional enactment with advantages of the smooth transformation in the thermal stresses over the thickness and minimal stress concentration. These Functionally graded materials (FGMs) are finding applications in extreme conditions with high-temperature gradients. The advantages of FGMs are their improved and location-specific functional performance within a component [1–4].

FGMs can be produced by plasma spraying, sol-gel technique, Solid freeform technology, powder metallurgy, molten metal infiltration, and centrifugal casting methods are also used to produce FGMs. The centrifugal casting is a pressure casting method where the force of gravity when pouring the molten metal into the mold is increased by rotating or spinning the mold assembly. Centrifugal casting consists of producing castings by causing molten metal to solidify in rotating molds. The speed of rotation and melt pouring rate varies with the alloy and size and shape being cast. Centrifugal casting has greater reliability than stagnant castings. They are comparatively free from gas and shrinkage porosity. The operation involves the rotation of the mold at a specific speed while the molten metal is poured at a constant rate. A solidification rate is established which is determined by the degree of superheat of the molten metal, mold preheating temperature, speed of rotation and pouring rate. Along with this, fluid flow during pouring and solidification also determines the soundness and quality of the casting produced. The different densities of the matrix and reinforcements support in gradient structural formation [5–9].

There is an increase in demand for light-weight materials with high specific strengths in the automotive and aerospace industry which has escalated the development and use of metal matrix composites. Aluminum alloys are preferred because of their high specific strength and stiffness which has been used in automobile industries for making IC engine components, e.g., pistons, cylinder heads, and cylinder blocks. However, because of their poor wear resistance, the applications of aluminum alloys have been restricted. Javad et al. [10] studied the effects of stirring temperature, time and speed on the A390/SiC composite made by the compocasting method. From the microstructure, it can be seen that as temperature increases, both the accumulation of SiC particles and the accumulation of primary Si particles around the SiC particles also increase. Optimum particle uniformity and mechanical characteristics were obtained under conditions of 610°C, 550 r/min, and 20 min. Raj Kumar Singh et al. [14] studied the mechanical properties and microstructure on hypereutectic LM30−SiC. The microstructure shows a uniform dispersion of SiC particles and excellent bonding between the SiC particles and the matrix. The hardness of the composite is 17% more than that of the matrix alloy. The ultimate tensile strength and yield strength of the composite are found to be 38% and 30% greater than those of the matrix alloy. The wear rate escalates with applied load and abrasive size and does not vary with the sliding distance. The present study focuses on development of A390/20wt.% SiC Functionally Graded Composite. The processed FGMs is characterized for its graded microstructures, hardness evaluation [11–18].

EXPERIMENTAL DETAILS

Materials and Preparation

The A390 is a hypereutectic cast aluminum alloy that was used for the synthesis of the FGM. The alloys are cut into small pieces to fit inside crucible of the furnace. The alloys cut is cleansed with water to remove dirt and impurities and then allowed to dry at room temperature. The standard properties of A390 alloy are given in Table 1. SiC particles of average particle size of 23 μm were used as reinforcements. Ultrasonic cleaning is done by using distilled water followed by acetone and finally, they are dried before storing. The particles are preheated at 500°C for 2 hours before the powder addition process. Silicon carbide is

Table 1. *Alloying elements in %.*

Details of alloy	**Alloying elements in %**						
	Si	**Cu**	**Mg**	**Fe**	**Mn**	**Zn**	**Al**
A390 Standards	18	4.5	.55	1.3	0.10	0.10	78–80

composed of tetrahedral silicon atoms and carbon with strong bonds in the crystal lattice. This creates a very hard and strong material. SiC particles are denser than aluminum alloys with a high melting point. By the addition of SiC particles the effective hardness, thermal properties, and wear resistance properties of soft aluminum alloys can be improved. To enhance the wettability of the SiC with the alloy 2% Mg was added to the melt while casting. The alloy, SiC, and Mg were weighed to a maximum of 3kg.

The alloy and A390 were added Bottom pouring stir casting furnace (Table 1). The SiC particles are put to the powder preheating furnace. The composite melt synthesis was carried out in a 5 kg capacity furnace. The melt temperature was maintained in the range of 730–740°C. For proper mixing and consistency of the MMC melt, the steady vortex was maintained by the rotating the stirrer at a speed of around 350–450 rpm. In the powder preheating furnace, the cleaned and dried SiC particles were preheated to 500°C, for 2–3 hours, before adding to the melt. After the mixing of the SiC particles, the melt was still stirred and the temperature of 730–740°C was maintained at for almost 20–30 minutes. Circular disc shape mould of dimension 240 mm diameter and a thickness of 28 mm are used for FGMMC cast preparations. The mould was preheated for 2 hours at a temperature of 350°C. Just before pouring, the mould fixed on the shaft of the vertical centrifugal casting machine was kept in rotation with a speed of 1300 rpm. At a melt temperature of 740°C, MMC melt was uniformly and steadily poured into the rotating mould to obtain FGMMC castings. After cooling, the castings were removed from the moulds and cleaned. The standard specimens were prepared from the desired locations of the casting for detailed characterization.

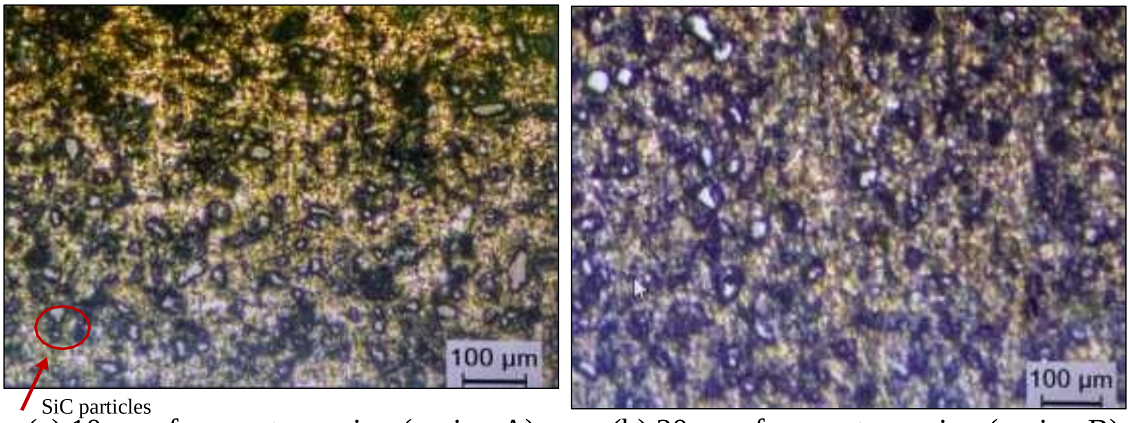
RESULTS

Microstructural Evaluation

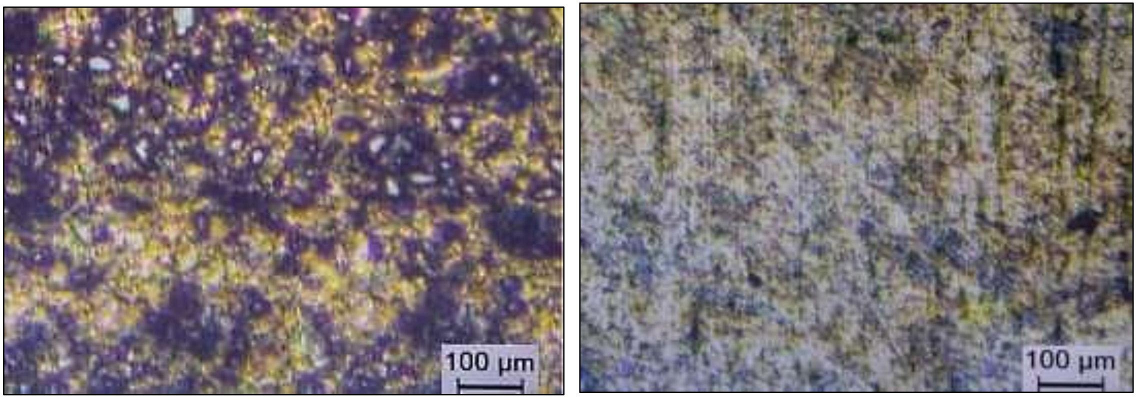
Figure 1 shows the microstructure of the A390 alloy centrifugally cast ring. The micrographs are taken from the outer to the inner periphery in a radial direction. In the alloy, volumes of Si and Cu were significant, more volume of SiCp and primary silicon phases are formed, and effective diffusions are visible in the microstructure. Due to the pressure force generated during the centrifugal casting process by the molten melt the grain size of the outer region was finer than the inner region. A squeeze effect is produced by the solidification edge which acts from the outer region to the inner region and by the pressure force which acts from the inner region to the outer region. In the inner regions, more primary silicon phases of less density are concentrated due to the centrifugal effect.

The particle rich zone nearer to the outer periphery of the casting shows a higher concentration of SiCp than the inner and a clear transition region in between is also visible. The microstructural characteristics of the matrix alloy also changes from outer to inner region. The grain size of the aluminum in the particle accumulated zone is very fine, which becomes coarser towards the interior. The occurrence of a high-volume fraction of SiC particles interrupts the growth of primary aluminum and also the shear caused by the transition of ceramic particles during solidification breaks the branches of dendrites to form fine structure (Figure 2).

Fig. 1. *Specimen used for the microstructural study.*



(a) 10 mm from outer region (region A) (b) 20 mm from outer region (region B)



(c) 30 mm from outer region (region C) (d) inner region (region D)

Fig. 2. *The micrographs of the A390–20 wt.% SiC FGMMC ring taken from the outer periphery to the inner zones.*

Hardness Behaviour

The variations of the Brinell hardness values (BHN) in the cast sample are from inner to outer zones of A390–20 wt.% SiC FGMMC rings were shown in Figure 3 The hardness value varies in proportion to total volume fraction of SiC particles in the A390–20 wt.% SiC FGMMC rings. A390 is a hyper eutectic Al-Si cast alloy with 18% Si. In this FGM due to the centrifugal casting process, two different gradations of opposite nature are obtained, i.e., less dense primary Si will diffuse towards the inner and high-density SiCp will move towards the outer regions. With this diffusion, the outer region is accumulated more with the SiCp particles.

The effective variation of a property at a location depends on the localized concentrations of each phase. Due to centrifugal pressure force and other parameters like porosity and agglomerations the grain refinement is achieved. The maximum hardness value in the particle rich zone was 146.1 BHN for 20% SiC FGMMC in the as-cast condition. From the transition zone towards the inner zone, the hardness value slowly decreased from a higher value to moderate and reaches a minimum of 99.52 BHN. This was due to the fewer presence of SiCp particles at the inner zone and the presence of primary silicon in the inner region. (Table 2). The minimum hardness due to the presence of primary silicon phases in the inner regions was 97.22 BHN in the as-cast condition. The maximum hardness value in the particle rich zone was 146.1 BHN for 20% SiC FGMMC in the as-cast condition. For 20% SiC FGMMC in the transition region (15 to 40 mm away from outer region towards inner region) the hardness value changes between 142.1–104.4 BHN in the as-cast condition. The test results show a maximum Hardness of 146.1 BHN at location 10 mm from outer and minimum hardness 97.22 BHN at location 50 mm from the outer region (Nearer to the inner region). Variation in Brinell Hardness along the distance in the radial direction was plotted. The graph shows a decreasing trend in the hardness value due to the variation in the volume of SiC particles present.

Table 2. *Calculation of BHN at various locations.*

Region	Distance from the outer periphery (mm)	Diameter of indentation (mm)	Brinell Hardness Number 2 (kgf/mm)
A	5	0.77	131
	10	0.73	146.1
	15	0.74	142.1
B	20	0.74	142.1
	25	0.78	127.6
C	30	0.85	106.9
	35	0.84	109.6
	40	0.86	104.4
D	45	0.88	99.52
	50	0.89	97.22
	55	0.88	99.52

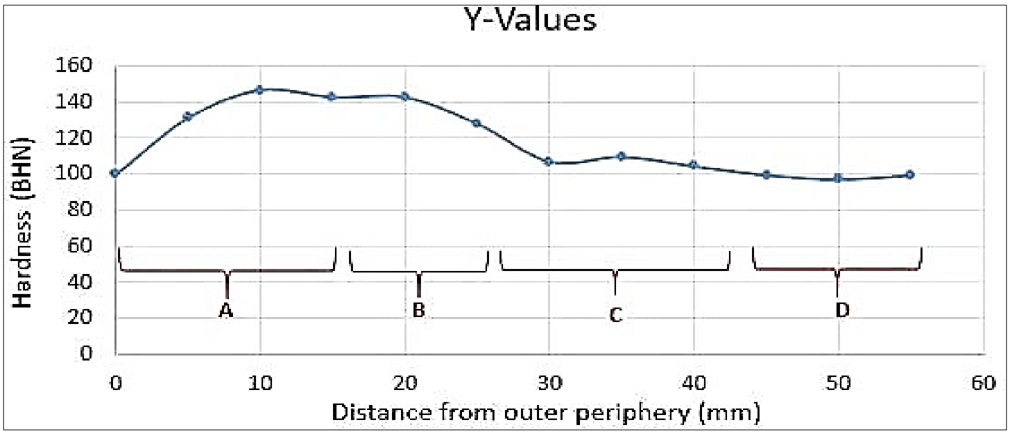


Fig. 3. *Variation in the hardness of the A390–20wt.% SiC FGMMC from outer region to the inner region.*

CONCLUSIONS

Al-SiCp functionally graded metal matrix composites with a gradient distribution of SiC particles near the outer region of the casting have been successfully casted by centrifugal casting method. The microstructure evaluation shows the formation of functional graded SiCp particle distribution from the outer region to the inner region of the casting. The test results show maximum hardness of 146.1 BHN at location 10mm from outer periphery and minimum hardness 97.22 BHN at location 50mm from the outer periphery (Closer to inner periphery). The hardness curves show that the hardness value varies in proportion to the volume fraction of the primary silicon phase. The hardness value varies in proportion to the total volume fraction of SiC particles. The high-density SiCp is moved towards the outer regions during the centrifugal casting process. The diffusion has enriched outer regions with SiCp. The presence of a large volume of SiC particle and the grain refinement in the outer region provides a hardness 146.1 BHN. The hardness at the outer periphery (146.1BHN) of the developed FGMMC is also found to be higher than that of A390 (110BHN) alloy indicating higher wear resistance of the material.

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