Fabrication of AA 6351 + 5% SiC Composite using Stir Casting Process

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Abstract

Present article attempts to fabricate Aluminum Matrix Composites(AMC) using stir casting process. The matrix phase of composite consists of commercially available AA 6351 whereas the reinforcement phase will be of Silicon Carbide (SiC). The distribution of reinforcement particles within matrix, presence of any casting defects, agglomeration of reinforcement particles and other characteristics of fabricated composites has been investigated using Optical Microscope (OM) and Scanning Electron Microscope (SEM). The results of microstructure investigation revealed homogenous distribution of SiC particles within aluminum matrix with some particle free region. Apart from this, article also discusses about measured hardness of fabricated composites.

Keywords

Metal Matrix Composite, Aluminum Matrix Composites, Stir Casting, Microstructure, Silicon Carbide (SiC)

Introduction

Owing to the research and development in last few decades, Metal Matrix Composites (MMC) has been identified as advanced material which has capability to replace the conventional materials[1]. Broadly, it can be said that MMC fulfills several needs of industries such as transportation, aerospace, aircraft, electronics, electrical power transmission and automobile. For instance, in F – 16 aircraft, the doors made up of aluminum are now being replaced with silicon carbide (SiC) reinforced MMC and by doing so, enhancement in fatigue life was observed[2]. Apart from this, that MMC are used for fabrication of bicycle frames, diesel engine pistons, engine shaft, piston crown, components of brake, connecting rod, piston rings, cylinder liners, bearings, engine blocks, super conductors, and many more components[2-4].Due to several characteristics such as superior mechanical properties, higher strength, lower density, stable mechanical properties even at elevated temperature, better thermal properties, lower coefficient of thermal expansion, higher stiffness, better dimensional stability and many more, MMC have gained popularity in aforementioned industrial sectors[5-7]. Among several derivatives of MMC, particulate reinforced metal matrix composite finds wider application in engineering world[4]. In particulate metal matrix composites, light metals/alloys such as aluminum, magnesium, titanium, copper and many more acts as matrix phase whereas, particles of oxides, carbides, ceramics, organic compounds act as reinforcement phase[5, 8]. Among various combination of matrix and reinforcement, aluminum matrix reinforced with ceramic particles have been considered for present investigation. There exist several fabrication techniques such as centrifugal casting, squeeze casting, in-situ casting, powder metallurgy, diffusion bonding process and stir casting process using which bulk/volume MMC can be fabricated[9-13]. However, Brains et al.[14] and Taha[15]from their study reported stir casting process as simple, cost effect and comparatively cheaper procedure available for fabrication of MMC/AMC. Apart from this, it was also reported that stir casting process has capability of fabricating composites with complex shape without much constraints.

Surappa[16] and Soltani et al.[17] reported stir casting process to be better in every aspect and industries can implement the same for fabrication of MMC. Lee et al.[18] investigated the interfacial reaction occurred during fabrication of B_4C/AA 6061 using stir casting process. It was reported that interface of B_4C/Al showed presence of Al_4C_3/Ti, chromium diboride, magnesium oxide and TiB_2 precipitates. However, the interface didn't revealed presence of any deleterious precipitates such as AlB_2 or Al_3B_4.It should be noted that these deleterious precipitates formed in composites adversely affect the mechanical properties. Yu et al.[13] developed a stir casting route to fabricated large scale AA6061 + 31% B_4C composites and investigated the effect of process parameters on microstructure and mechanical properties of fabricated composites. For successful fabrication of AMC, vacuum stirring, reinforcement particles feeding and ingots cooling were the dominating criteria. Results of Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) revealed presence of B_4Cparticleswhich were embedded and homogenously distributed in aluminum matrix. Along with this, presence of

Mg_2Si was also reported. On comparing the tensile strength of AA 6061 + 31%B_4C with AA 1100 + 31%B_4C, enhancement in tensile strength by 112.5% was observed for AA 6061 + 31%B_4C composites due to higher strength of matrix. Rajendran and Suresh[19] fabricated hybrid composites in which aluminum alloys were reinforced with Silicon Carbide (SiC) and fly ash. Considering different weight fraction of SiC and fly ash, six different combination of AMC was fabricated. Due to variation in weight fraction of SiC and fly ash, different composition revealed variation in grain size and distribution of reinforcement particles. However, aluminum alloy reinforced with 10% SiC and 10% fly ash revealed proper grain growth with homogenously distributed SiC particles. Due to the same, enhancement in mechanical properties was reported. For all fabricated composites, thermal conductivity was found to be higher than 400 W/m.K, which was also matching the value required for engine block. Similarly, there exist several articles related to fabrication and characterization of stir cast AMC[20-22].

Present article focuses on fabrication of mono AMC using stir casting process. The article discusses about the fabrication procedure adopted for fabrication of AA 6351 reinforced with 5% weight fraction of SiC. The presence and distribution of SiC particles was observed using Optical Microscopy (OM) and SEM. Along with microstructural studies, hardness of fabricated composites was also investigated.

Experimental

Stir casting route was considered for fabrication of AMC. Experimental setup of stir casting process majorly consist of two components i.e. furnace and stirrer. Furnace used for melting matrix material is shown in figure 1. For the matrix material commercially available AA 6531 rods having 25.4 mm in diameter and 1000 mm in length has been considered. The chemical composition of AA 6351 is represented in table 1. For present study, AA 6531 matrix was reinforced with 5 % weight fraction of SiC having particles size of 100-120 μm.

Figure 1: Electrical Furnace used for melting matrix material

Elements	Si	Mg	Mn	Fe	Zn	Ti	Cu	Cr	Al
Amount (%)	1.2	0.67	0.58	0.5	0.2	0.2	0.1	0.05	Remaining

Table 1: Chemical Composition of AA 6351-T6

For fabrication of AA 6351 + 5% SiC, rod of AA 6351 was cut into small pieces, each having length of 100 mm approximately. Cut pieces of matrix weighted and a batch of 1000 was formed. Similarly, reinforcement particles were weight as per the weight fraction of reinforcement to be incorporated in matrix material i.e. 50 g. Figure 2 represents the batch of aluminum matrix and corresponding reinforcement particles. Before melting, the electric furnace was preheated to 180 °C and then the crucible consisting of matrix was inserted in furnace. The aluminum matrix was then heated up to 780 °C, which is higher than the melting point of aluminum. On successful melting, the molten matrix was stir in a manner such that vortex was created. In the meantime, SiC particles were preheated to 350 °C for 15 minutes and were added to the vortex created in molten aluminum. Along with SiC particles, 1 % of magnesium was also added to molten matrix. Addition of magnesium acts as wetting agent between matrix and reinforcement and thus improved the wettability. Wettability enables the molten aluminum matrix to maintain the contact with solid surface of SiC particles. The molten mixture was stir for 5 minutes at stirring speed of 300 rpm, as represented in figure 3. The stirrer was having 4 blades and angle between two blades were 60°. After stirring, slag formed on the top surface was removed and the molten mixture was poured into mould. Design of mould was such that the solidified cast component will have dimension of 100 × 100 × 10. On solidification, cast component was removed from mould.

Figure 2: Aluminium alloy and SiC particles as per weight fraction

Figure 3: Stirring of molten composite

Microstructural characteristics of fabricated composites were investigated using OM and SEM. The specimen required for each investigation was cut from fabricated and polished as per standard metallurgical procedure. For etching, Keller's reagent was prepared by mixing distilled water, nitric acid, hydrochloric acid and hydrofluoric acid in proportionate quantity. Keller's reagent was then applied on polished surface of specimen at room temperature and was dried out before microstructure examination.

Results and Discussion

To understand the distribution of reinforcement particles in aluminum matrix, microstructural investigation of fabricated AA 6351 + 5% SiC was performed. Figure 4 represents micrograph image obtained using OM. In the micrograph, the rounded black spots embedded in aluminum matrix represent SiC particles. It can be observed that those SiC particles are uniformly distributed within the matrix of aluminum. The preheating of reinforcement particles has proven beneficial and due to the same, reinforcement particles were found to embed within aluminum matrix. The preheating of SiC particles not only helps in removing the moisture from reinforcement particles but also avoids the thermal mismatch between molten aluminum and SiC particles. Also, the addition of SiC particles directly into vortex formed in molten matrix has proven beneficial towards homogenous distribution of SiC. Additionally, addition of magnesium as wetting agent had helped in enhancing wettability between matrix and reinforcement. It has been reported that addition of wetting agent and preheating of reinforcement particles tends to remove impurities, desorption of gas, avoids settling of reinforcement particles and alters the surface composition due to formation of oxide layer on surface[23].

Figure 4 represents dendritic like structure which were formed during solidification phase. Aluminum alloys are known for higher cooling rate and provides enough undercooling. This undercooling will increase nucleation site with reduction in dendritic arm spacing. Small nuclei formed during nucleation will mechanically block each other during growth process and thus results in fine and uniform dendritic structure. On higher magnification, as represented in figure 5 it was observed along with SiC, the fabricated composites were found to have Mg_2Si and Al-Mg-Si phase. The thin, black and needle shape phase in microstructure represents Mg_2Si. These Mg_2Si phase were observed near Al/SiC interface or were embedded in α-Al. Apart from this, slightly transparent phases present in microstructure of AA 6351 + 5% SiC represents ternary eutectic phase i.e. Al-Mg-Si. Similar observations were also reported by other researchers[24-26].

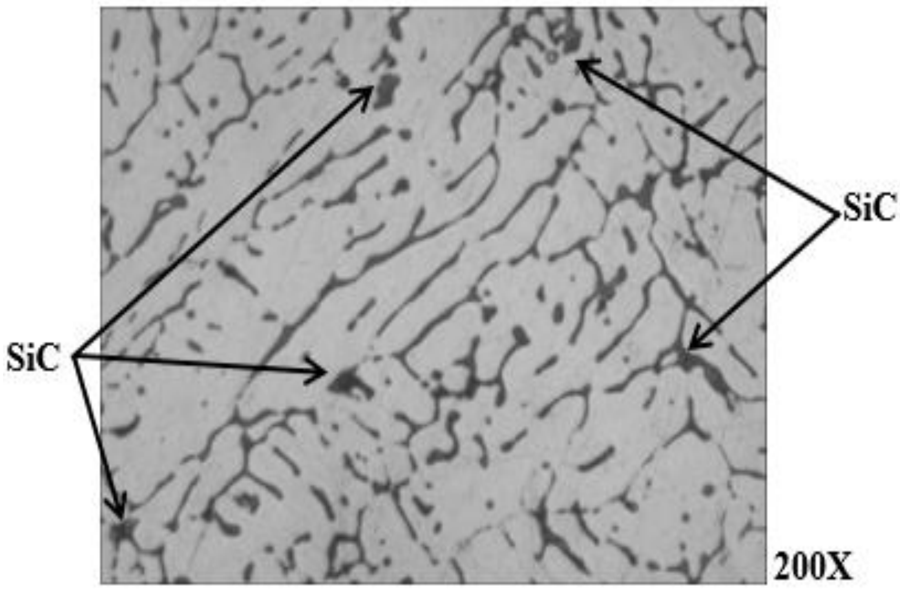

Figure 4: Optical Microscopy (OM) of AA 6351 + 5% SiC

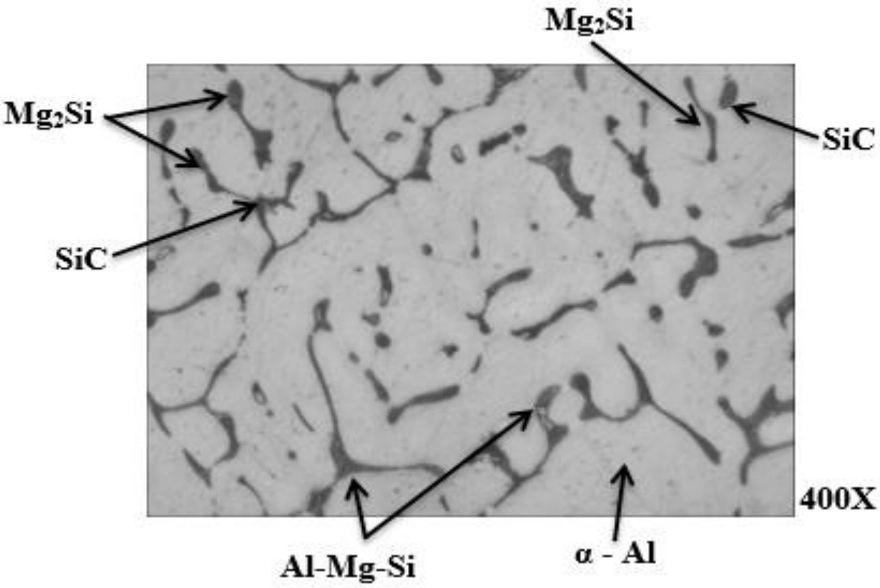

Figure 5: Presence of SiC, Mg_2Si and Al-Mg-Si in AA 6351 + 5% SiC observed using Optical Microscopy (OM)

Similar phases were reported from SEM images of AA 6351 + 5%SiC composites. Apart from this, SEM image represented in figure 6 also revealed few particles free region. Particle free regions can be observed due to lower weight fraction of reinforcement particles. Similar observation was also reported by Shabani et al.[27] and Raj and Thakur[28]. Raj and Thakur[28] also reported that increase in weight fraction of reinforcement particles reduces the particle deficient region and causes uniform/homogenous distribution of reinforcement particles. Figure 7 represents SEM images taken at higher magnification. Even at higher magnification, SEM micrographs of fabricated composites didn't reveal any presence of clusters/agglomeration of SiC particles. Earlier it has been reported that increase in weight fraction of reinforcement particles tends to generate few clusters/agglomeration of reinforcement particles. Due the stirring, reinforcement particles tends form clusters with matrix which is termed as agglomeration of reinforcement particles. Increase in weight fraction of reinforcement particles tends to increase the density difference which makes stirring difficult. This difficulty in stirring restricts the motion of reinforcement particles within molten matrix and thus results in agglomeration of reinforcement particles. Apart from this, SEM micrograph didn't reveal presence of any deleterious phase which affects mechanical properties of fabricated composites. The hardness test was conducted at a load of 62.5 Kg with a dwell period of 2.5

sec. Due to addition of SiC particles in AA 6351 alloy, enhancement in hardness of fabricated composite was observed. The measured hardness of AA 6351 was 54 HB and that of AA 6351 + 5% SiC was 61 HB. The ceramic particles are known for their hardness and thus addition of SiC particles in light weight alloys tends to enhance the final hardness of composites. Along with this, the enhancement in hardness was observed due to absence of any casting defects, agglomerated SiC particles and deleterious phase.

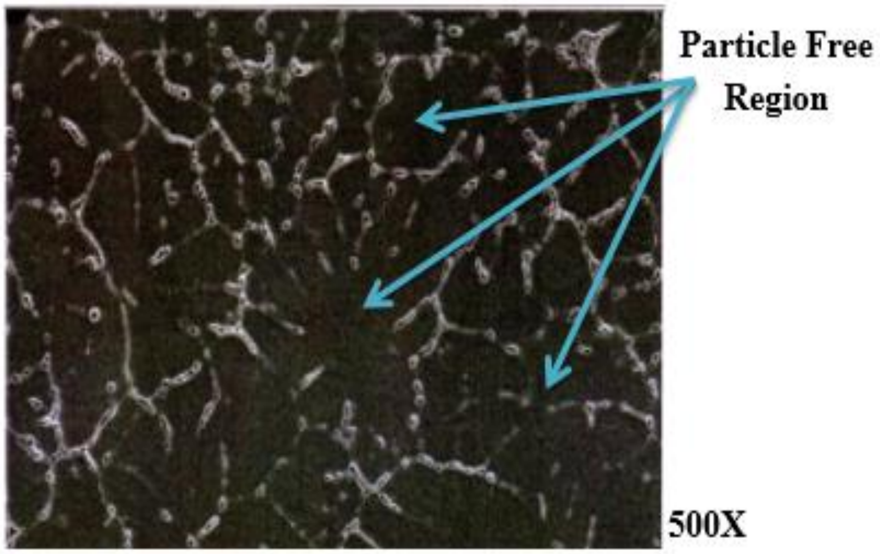

Figure 6 : SEM Micrograph of AA 6351 + 5% SiC

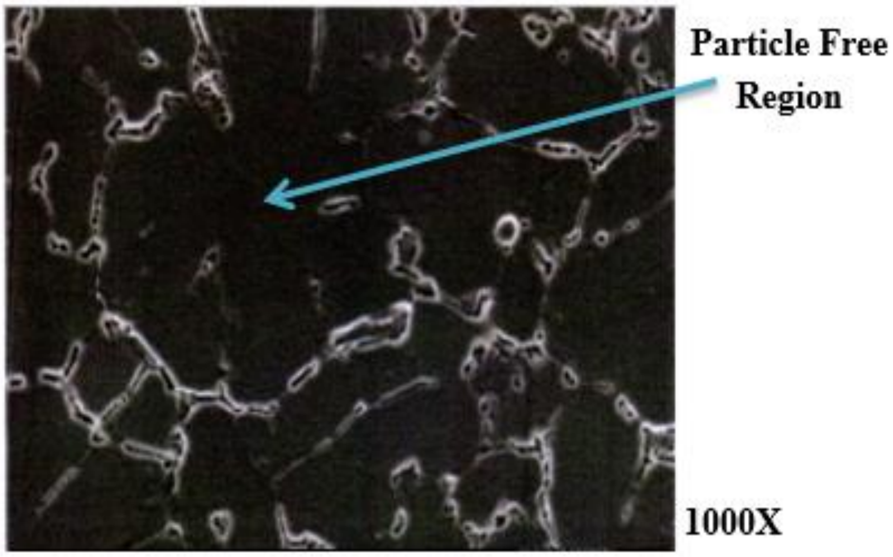

Figure 7 :Cluster free microstructure of AA 6351 + 5%SiC observed in SEM micrograph of AA 6351 + 5% SiC

Conclusion

The present study can be concluded as follows:

- Stir casting process possess potential to fabricate AMC with matrix of AA 6351 and reinforcement phase of Silicon Carbide (SiC). However, it becomes necessary to have control over several process parameters such as stirring speed, stirring time, stirring temperature and melting temperature of alloy.
- Optical Microscopy and Scanning Electron Microscopy reveled presence of SiC particles which were embedded in aluminum matrix. Owing to preheating of SiC particles and addition of magnesium as wetting agent, proper interfacial bonding between matrix and reinforcement along with homogenous distribution of reinforcement particles was reported. However, due to lower weight fraction of reinforcement particles, some particles free regions were observed.
- Enhancement in hardness of fabricated composite was observed due to addition of SiC particles and absence of agglomeration/clusters of reinforcement particles, presence of deleterious phase and casting defects such as void, grooves or tunnel defects

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