Influence of Processing Parameters in SiC_p – Aluminium Alloy Composite Produced by Stir Casting Method

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Abstract

Metal matrix composites are gaining wider acceptance in aerospace and defence industries due to their starving need for lightweight – high strength materials. The control of processing parameters is very important in order to obtain good quality casing with minimal defects. In this study the influence of processing parameters on the properties of SiC particle reinforced aluminium alloy (Al- 10%Si- 0.6%Mg) composite was investigated. The composites are prepared by stir casting method. This method involves mixing of SiC_p in the molten aluminium alloy aided with mechanical agitation. The processing parameters that were investigated include melt temperature and stirring speed. Specimens produced were subjected to mechanical testing. Microstructure observed through scanning electron microscope and optical microscope was correlated to the observed mechanical behavior. The results show that the melt temperature appears to have little effect on the mechanical properties and particle settling. SEM photographs show that there is particle clustering at low melt temperature.

INTRODUCTION

Metal matrix composites, (MMCs) are gaining much importance in the field of aerospace and automotive industries due to their high strength to weight ratio, high elastic modulus, high specific stiffness, high temperature resistance and good wear resistance. The commonly used metallic matrices include light metals such as aluminium, magnesium, titanium and their alloys. The incorporation of ceramic reinforcements like SiC, Al_2O_3, B_4C, TiC etc., in the form of either continuous / discontinuous fibres, whiskers or particulates improves the strength & stiffness of the metals & alloys [1]. Among the various MMCs, aluminium alloy based composites (AMC) are widely considered by the researchers because of their high strength-light weight combination along with good corrosion resistance. As a result, AMCs are increasingly finding their application in the fields of electronics, aerospace and automobile.

Those MMCs, which are reinforced with discontinuous reinforcement such as particulates, whiskers or short fibres, are termed as Discontinuously reinforced Metal Matrix Composites (DRMMCs). Different methods have been adopted for fabrication of these DRMMCs and the process details are most often proprietary in nature. Among them, the conventional foundry based processes are more favourable in obtaining near net shape components at high production rates and at low costs. In recent years, the stir casting technique has attracted the interest of many researchers. Rheocasting, Compo casting, Disintegrated Melt Deposition are the variants of the

stir casting technique. This technique involves incorporating the ceramic particles into the melt and stirring by means of a mechanical impeller.

There are many reports on SiC_P reinforced Al alloy but they consider different alloy system/different processing methods. Not much has been known about the effect of processing parameters on the synthesis of sound MMCs via stir casting method. In the present investigation, the influence of processing parameters, namely melt temperature and stirring speed on the quality of SiC_P - Al alloy composites has been studied.

EXPERIMENTAL WORK

The matrix material used in the present study is the commercial LM9 aluminium alloy. The nominal chemical composition in wt% of the matrix alloy is given in Table 1. The reinforcement used is particulates of silicon carbide (hence forth referred to as SiC_P) of average size 35μm. In the present study, the aluminium matrix composites with 10 wt% SiC_P were prepared using stir casting method. The experimental setup consists of an electrical resistance heating furnace, a variable speed motor driven mechanical impeller with speed indicator, a thermocouple for measurement of melt temperature.

Table 1. Nominal chemical composition of aluminium alloy

Element	*% Si*	*% Mg*	*% Cu*	*% Zn*	*% Al*
Wt%	10.31	0.34	0.10	0.003	Reminder

Approximately, 1000 gms of aluminium alloy was placed in a graphite crucible and heated to 730°C. 10 wt% of SiC_p were pre heated to 900°C in a separate muffle furnace for a soaking period of one hour. The particles were then added manually at a rate of 13-15 gms per minute using a feeder through the vortex created by stirring the molten metal. The stirrer was placed at 0.75H from the bottom of the crucible where H is the depth of the melt at rest. The stirrer speed was varied between 400 to 700 rpm at an interval of 100 rpm. After completion of SiC_P addition, the stirring was continued for 20 minutes. Prior to particle addition, 1 wt% of Mg powder was added in small packets (wrapped in an aluminium foil) into the melt in order to improve the wettability. The composite melt was finally poured into cast iron die preheated to 250°C. Cylindrical specimens of 50mm diameter and 150mm length were obtained. Similarly, composite specimens were manufactured for melt temperatures 800°C and 850°C. All composite specimens were solutionised at 530°C for 1 h and then artificially aged for 8 h at 180°C (T6 condition).

The amount of SiC particles in the matrix is estimated by chemical digestion method. This involves dissolving the composite piece of known weight in Hydrochloric acid solution. The residue collected was filtered, dried and weighed. Weighing was carried out using electronic balance (METTLER model AE200) with an accuracy of 0.0001gm. The weight fraction of SiC in the composite sample was then calculated.

Tension tests were conducted on the samples that were manufactured by varying the melt temperature. Tension tests were performed using Instron tension testing machine at a strain rate 0.5 mm/min. Cylindrical tensile samples with a gauge section of 6mm diameter and 50mm gauge length were used.

Sections from the composite specimens were subjected to microstructural evaluation using optical microscope with image analyzer model NEOPHAT. The fractured surfaces of the tension tested specimens were examined under JEOL Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSION

The incorporation of SiC_p in the matrix at different speeds were studied (Fig. 1). It is observed that with increase in stirring speed from 400 rpm, the amount of SiC_p entrapped in the composite increases and reaches a peak value of 9.6 wt % at a stirring speed of 500 rpm. Increasing the stirring speed further to 700 rpm, leads to a reduction in amount of SiC incorporation. A similar variation has been documented by Tham et al [2] for a composite produced by disintegrated melt deposition method.

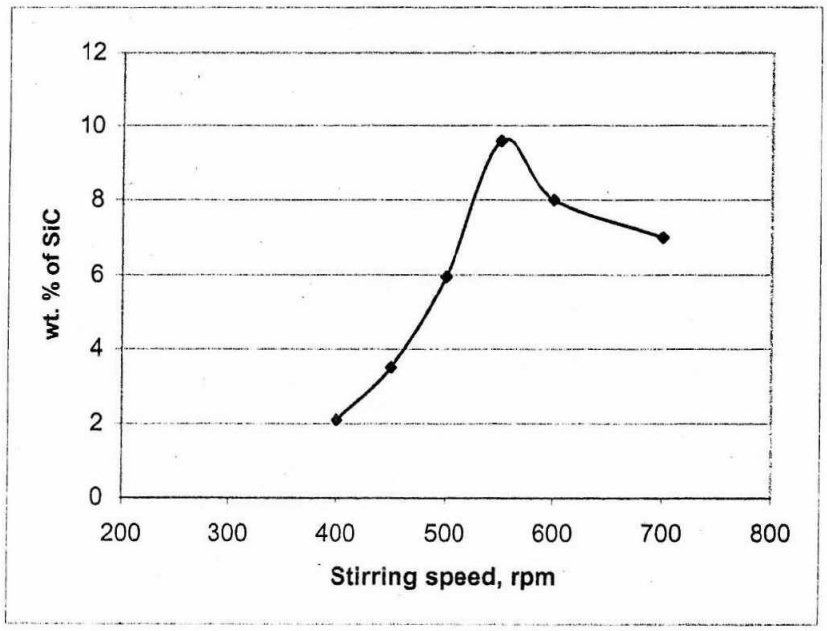

Fig. 1. Variation of SiC_p incorporation with stirring speed.

The development of vortex due to stirring is observed to be helpful for transferring the particles into the matrix melt as the pressure difference between the inner and outer surface of the melt sucks the particles into the liquid. However, introducing the particles from air to the stirred melt through vortex sometimes picks up atmospheric air, which must be removed by proper degassing, which otherwise may result in porosity in the cast composite. In this study, at low stirrer speed, the vortex formed was minimum owing to the reason that the mechanical force in less to overcome the viscosity of the melt. Hence, entrapment of particle inside the melt is less. However, once the speed increases the vortex formation is effective and more of SiC_p are trapped in. If the stirring speed is raised further to 600/700 rpm, melt is agitated and majority particles of the particles were pushed towards the sides of the crucible. This is because of the difference in

centrifugal force from the inner to outer part of the crucible. Also in this vigorously stirred melt, entrapment of gases is high leading to high porosity and poor wetting of particles by the melt.

The microstructures of Al-Si alloy/10 wt% SiC_p-T6 composites is shown in Fig. 2. The SiC_p are almost angular in shape and it is observed in common that the particles tend to surround porosities, if any, present in the matrix. Microstructural studies conducted on the samples revealed the presence of dentritic equiaxed grain structure. The particle entrapment is minimal at low stringing speed of 400 rpm (Fig. 2a). At stirring speed of 500 rpm particle incorporation and their distribution is good. The matrix-reinforcement interfacial integrity is good for the composite produced in this speed range (Fig. 2b). It is evident from the micrograph that there is no cavity/rim formed surrounding the particles in the matrix, which leads to good bonding. At stirring speeds above 500 rpm, the microstructure revealed presence of pores and particles surrounding the pores. The distribution of the particles is not uniform (Fig. 2c-d). The properties of the MMCs depend not only on the particle type and size but also on their distribution and bonding with the matrix. Hence it is very important to control the process parameters to have good distribution of particles and their wetting by the matrix.

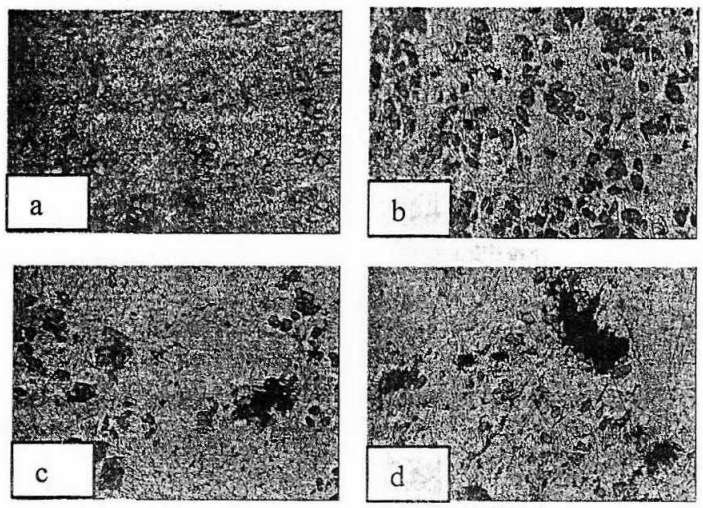

Fig. 2. Microstructure of SiC_p – Al alloy composites manufactured at different stirring speeds a) 400 rpm b) 500rpm c) 600 rpm d) 700 rpm (50X)

The result of this portion of study suggests that, for this impeller design, type and position, the optimized speed is 500 rpm. Further experiments were carried out at this stirring speed for different melt temperatures.

The composite specimens produced by varying the melt temperature were subjected to mechanical testing and the resultant strength and percentage elongation are listed in Table 2. The reported strength values are the average of three specimens. Melt temperature here is referred to as the pouring temperature.

Table 2 : Effect of melt temperature on mechanical properties of 35 μm size 10 wt% SiC particulate reinforcement

Sl. No.	*Melt temperature (°C)*	*UTS, MPa*	*% Elongation*
1	730	270	4
2	800	302	4
3	850	257	3.5

The strength value is less (270 MPa) for the melt temperature of 730°C. As the melt temperature is increased to 800°C the strength value recorded is high, and it is about 302 MPa. When melt temperature was still increased to 850°C the strength value decreases. At low melt temperature (730°C) the wettability and hence the bonding is poor. Hashim et al [3] have conducted series of wettability tests and found that improper wetting leads to reduction in strength.

At higher temperature (850°C) particle settling is more pronounced. This result matches with the findings of Ourdjini et al [4] who used SiC_p in Al alloy using semi solid dispersion technique. From his study, it was found that the particle settling is more pronounced as the melt temperature is increased and finer particle (~25μm) settle even faster. This is attributed to the higher energy gained by the particles at higher temperature which make them travel faster and easier in the liquid melt. Also at higher temperatures the extent of reaction between the matrix and the reinforcement is higher and the reaction product $MgAl_2O_4$ and MgO crystals appear on the SiC particle. The interfacial reaction depletes Mg content in the matrix thus reducing the amount of Mg_2Si available during precipitation hardening which lead to reduction in strength of the composite.

The scanning electron microscope images of fractured surfaces of the tension tested samples are shown in Fig. 3. Particle clustering is pronounced in the specimens poured at the low melt temperature of 730°C (Fig. 3a) which results in non uniform distribution of the particle and ultimately resulted in low strength values. Fig. 3b revealed decohesion at the interface between the brittle SiC_p and the aluminium matrix as the dominant failure mechanism. Fig. 3c shows evidence of typical ductile failure with dimple surfaces with void and coalescence.

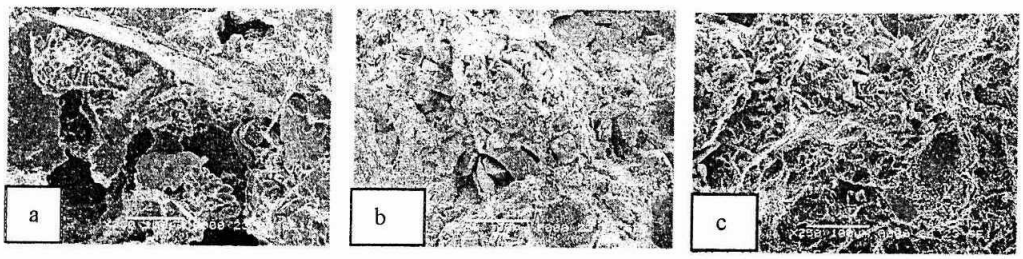

Fig 3. SEM Fracture morphology showing a) particle clustering b) decohesion at the matrix/reinforcement interface c) dimpled fracture surface

Conclusions

1. Al-Si alloy/10 wt% SiC_p composites were fabricated using stir-casting technique by varying the stirring speed and melt temperature.

2. Study on particle incorporation revealed that highest amount of particles are entrapped and distributed uniformly at stirring speed range of 500 –550 rpm.
3. Highest UTS was achieved when the melt temperature was 800°C owing to proper wetting of the reinforcement by the melt and lesser interfacial reaction.

References

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