Evaluation of microstructural and mechanical characteristics of stir cast A356/ (0 to 20) wt.% SiC\textsubscript{p} composites

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Abstract. In this work A356/ (0-20\%) wt.% SiC\textsubscript{p} composites were prepared from A356 base alloy through the most economical casting route i.e., stir casting method. Silicon carbide of particle size 23 micron was used as reinforcement to prepare A356/10wt.%SiC\textsubscript{p} and A356/20 wt.% SiC\textsubscript{p} composites. Microstructure of A356 and A356/ (0-20)wt.% SiC\textsubscript{p} composites were examined using Leica optical microscope. Microstructural Examination showed that A356/(0-20)wt.% SiC\textsubscript{p} composites have uniform distribution of SiC particles apart from \(\alpha\) aluminium and eutectic Si compared to its base alloy. Hardness and tensile test were conducted for heat treated and as cast specimens. It was found that heat treated A 356 alloy and its composites have better hardness than as cast. Tensile tests were conducted on both alloy and its composites and found that brittle fracture was more likely to occur in composites wherein ductile fracture pre dominates in base alloy. XRD analysis of both alloy and its composites showed the major hardening phases such as Al\textsubscript{2}Cu, Mg\textsubscript{2}Si etc.

Keywords: A356 alloy, SiC reinforcement, stir casting method, composite, microstructure and mechanical properties

1. Introduction
Metal matrix composites are among the most prospective materials for engineering components due to its attractive physical and mechanical properties like high strength to weight ratio, wear resistance, stiffness, low creep rate, high elevated temperature endurance, thermal conductivity, seizure resistance, high strength for fatigue, resistance to corrosion and low thermal expansion coefficient. Due to its superior properties over monolithic materials, metal matrix composites are used in numerous applications in sectors such as automobile, aerospace, mining, machinery related to defence field, electrical sectors and other industrial applications [1, 2]. MMCs are produced by various techniques like powder metallurgy, liquid state fabrication like stir casting , pressure infiltration & spray code position etc. [3]. The most popular hard reinforcements used for making discontinuously reinforced MMCs are silicon carbide, alumina and soft reinforcement such as graphite [3, 4]. Reinforced composites can have four types of reinforcement: (i) Short fibre reinforcement (ii)Long and continuous fibre reinforcement (iii)whisker reinforcement (iv)reinforcement by particulates and all types of reinforcements in composites is carefully tailored to form high strength material [5].

These composites showed different strengthening mechanisms compared to monolithic materials or conventional materials. The problems connected with the fabrication of MMCs with continuous reinforcement and having damaged fibre, non-uniform microstructural pattern, contact between fibres
and considerable interfacial reactions could be prevented by using discontinuous reinforcements. MMCs with particle reinforcement are substantial because of their isotropic properties, cost efficiency, easiness and flexibility in production similar to the monolithic materials [6].

SiC particles have numerous advantages over reinforcing whiskers such as boron, alumina and graphite in aluminium matrix alloys. The major advantages of using SiC particles in aluminium matrix alloys includes low cost, corrosion resistance, high thermal conductivity, high machinability and good workability. Also SiC particles have the ability to form strong interfacial bond with aluminium alloy without the formation of intermetallics [5]. For the present study it is intended to develop discontinuously reinforced A356/(0-20%)wt.% SiCp MMCs by stir casting technique and examine the mechanical properties like hardness, tensile strength, ductility, and microstructural characteristics using optical microscopy and X-ray diffraction study.

2. Experimental details

2.1. Materials

A356 alloy was used to prepare and cast its composites. The chemical composition of A356 alloy is shown in Table 1. Application of A356 Alloys lies in the area of automotive, aerospace, electrical applications and industrial sectors due to its better castability, resistance to corrosion, and higher strength and hardness after heat treatment [7]. The SiC particles of 10 wt. % and 20 wt. % of particle size 23 µm which was procured from Carborundum Universal Limited, Kochi, Kerala were added and composite having an average density of 2.62 g/cm³ is obtained.

The stir casting method was used to prepare the required composites and it was selected due the following advantages; low production cost, easy preparation and control better interfacial bonding between particle and matrix, almost matching to shape required and wide selection of materials [8, 9].

| Table 1. Chemical composition of A356 alloy |
|-----------------|-----------------|-----------------|-----------------|
| Alloy Si Mg Cu Fe Mn Others Al |
| A356 7 0.45 0.2 0.2 0.1 0.4 Bal |

2.2. Composites Preparation and its Metallurgical characteristics

Stir casting technique, the most economical casting route was used to fabricate A356/10wt.%SiCp&A356/20wt.%SiCp composites [10]. In this process the A356 alloy was melted in a crucible kept inside the stir casting furnace at a temperature of 700°C and turbine type stirrer blade was immersed into the melt gradually and speed was increased and temperature was lowered to obtain the semisolid state. Magnesium of 2 weight percentage was added into the molten slurry for wettability enhancement of SiCp particles in A356 matrix alloy [11].

Preheated SiCp particles at 500°C was put into the melt and well stirred. The temperature of melt, i.e. composite slurry was decreased to semi solid state at 590°C and stirring speed of 300 rpm maintained for 5 minutes during SiC particle addition. Degassing was done by dipping and stirring with Hexachloro ethane (C₂Cl₆) to the melt. The composite slurry was poured in to the metallic mould made of cast iron of size 60 x60 x300 mm³ after heating it above the liquidus temperature. Solution heat-treatment at 500°C for 6 hours was done for the cast material and water quenched at room temperature followed by precipitation hardening at 190°C for 12 hours.
The heat treated samples were mirror polished using disc polishing method with diamond pastes of sizes 6µm and 3µm as abrasives. Keller's reagent was used to etch the prepared samples and observed using Leica Optical Microscope. The images were captured at suitable magnification and uniform distribution of SiCp particles could see in the microstructure as shown in the figure 2(a, back).

2.3. Mechanical and Physical properties
Tensile test for the alloy and its composites were conducted using computerized tensile testing machine. Specimens were prepared according to ASTM E8 standard for the tensile test. The values of ultimate tensile strength, percentage elongation and yield strength are obtained using the above analysis. Brinell hardness testing machine was used to test the hardness of alloy and composites. Brinell hardness number (BHN) can be obtained using the equation:

$$BHN = \frac{2 \times F}{\pi \times D \times \left(D - \frac{D^2 - d^2}{2}\right)^{0.5}}$$

where F is in Newton (N), D is the diameter of the ball indenter (mm) and d is of indentation diameter in mm.

Indentations were made on samples using ball indenter at 500 Kg of load for 30sec dwell time. The specimen surface was machined and polished to 400 grit size. The distance between the centres of indentations was maintained greater than half the diameter of the indentation. The indentation diameter was converted into the hardness values from a standard table for a particular load and type of indenter. The density was determined by Archmedian principle for the alloy and composite.
3. Results and discussion

3.1. Microstructure
Aluminium alloy A356 was used to prepare A356/(10-20)wt.% SiC<sub>p</sub> composites. The microstructures of heat treated A356 alloy is showed in Fig. 2 (a). The A356 alloy microstructure exhibited eutectic silicon of fine nature and primary alpha-Al dendrites in the region of interdendritic (Fig. 2 (a)). The microstructures of heat treated A356/10wt. %SiC<sub>p</sub> and A356/20wt.%SiC<sub>p</sub> composites exhibits uniform distribution of SiC particles in the matrix (Fig 2(b) and 2(c)). The micrographs of A356/10wt.%SiC<sub>p</sub>, A356/20wt.%SiC<sub>p</sub> composites mainly showed α-Al, eutectic mixture and SiC particles.

![Microstructure Image](image1)

**Figure 2.** Optical microstructure of (a) A356 alloy, (b) A356/10wt. %SiC<sub>p</sub> composite and (c) A356/20wt.%SiC<sub>p</sub> composite under T6 heat treated condition.

3.2. Hardness
Brinell hardness test was used to obtain the hardness of as cast and heat treated samples. It was found that heat treated specimens shows more hardness than as cast ones. This increase in hardness of heat treated samples were attributed to the hardening phases such as Al<sub>2</sub>Cu and Mg<sub>2</sub>Si during precipitation hardening, which was evident from the XRD result of A356 alloy and its composites (Fig 4). Heat treatment of alloys and its composites caused precipitation hardening which in turn results in spheroidisation of crystals of silicon and increase in bonding between aluminium and silicon and it hinders the nucleation of cracks and propagation [12] and leads to increased wear resistance. The hardness of A356/20wt.%SiC<sub>p</sub> composite, A356/10wt.%SiC<sub>p</sub> composite, and A356 alloy was found to
be 127BHN, 114 BHN & 104 BHN respectively. The reason for increased hardness of the two A356/(10-20)wt.% SiC<sub>p</sub> composites and its alloy after heat treatment was caused by SiC particles addition along with the formation of hardening precipitates like Mg<sub>2</sub>Si, CuAl<sub>2</sub>.

![Brinell Hardness of A356 alloy and A356 composites (10-20) wt.% SiC<sub>p</sub> in as cast and heat treated condition](image)

**Figure 3.** Brinell Hardness of A356 alloy and A356 composites (10-20) wt.% SiC<sub>p</sub> in as cast and heat treated condition

### 3.3. Tensile test

The tensile strength of A356 alloy and its composites was obtained by Universal testing machine. The tensile strength of A356 alloy, A356/10wt.%SiC<sub>p</sub> composite & A356/20wt.%SiC<sub>p</sub> composite was measured to be 239N/mm<sup>2</sup>, 193 N/mm<sup>2</sup> & 116 N/mm<sup>2</sup> as shown in Table 2. The ductility (% elongation) of A356 alloy was found to be 3.2 %. It was noticed that A356/20wt.%SiC<sub>p</sub> and A356/10wt.%SiC<sub>p</sub> composites exhibited brittle failure during tensile testing compared to the ductile failure of alloy. The reason was due to the homogeneous mixture of SiC particles in the A356/10wt.%SiC<sub>p</sub> and A356/20wt.%SiC<sub>p</sub> composites and was responsible for the decreased tensile strength of the composites compared to its alloy.

**Table 2:** Mechanical test results of alloy and its composites

| Test Material | A356/20wt.%SiC<sub>p</sub> Composite | A356/10wt.%SiC<sub>p</sub> Composite | A356alloy |
|---------------|--------------------------------------|--------------------------------------|-----------|
| Mechanical properties | Heat treated | Heat treated | Heat treated |
| Tensile strength, N/mm<sup>2</sup> | 116 | 193 | 239 |
| Density, g/cc | 2.60 | 2.64 | 2.69 |
| Ductility (%) | - | - | 3.2 |
4. Conclusion

1. A356/ (10-20)wt.% SiC\textsubscript{p} composites were successfully prepared by stir casting technique using A356 alloy and SiC\textsubscript{p} particles sized 23\,\mu m. The microstructure of A356 alloy showed the presence of eutectic silicon and alpha-Al whereas the microstructure of A356/10wt.%SiC\textsubscript{p}, A356/20wt.%SiC\textsubscript{p} composites exhibits the presence of uniformly distributed Silicon carbide particles apart from the other two phases.

2. Brinell hardness of composites was found to be increased due to the addition of wt.% SiC particles. The hardness of A356 alloy and composites in heat treated condition were found higher in comparison with as cast condition and was due to the presence of SiC particles and formation of phases during precipitation hardening such as Mg\textsubscript{2}Si and CuAl\textsubscript{2} which is evident from XRD results. On the other hand tensile strength of A356 alloy was found to be 239 N/mm\textsuperscript{2} whereas A356/10wt. %SiC\textsubscript{p} & A356/20wt. %SiC\textsubscript{p} composites showed tensile strength of 193 N/mm\textsuperscript{2} and 116 N/mm\textsuperscript{2}.

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