Investigation on mechanical behavior and material characteristics of various weight composition of SiCp reinforced aluminium metal matrix composite

Sivachidambaram Pichumani1*, Raghuraman Srinivasan 2, Venkatraman Ramamoorthi 3
1PhD Research Scholar, Corresponding Author, 2Professor, 3Professor, School of Mechanical Engineering, SASTRA University, Thanjavur, India – 613401, sivachidambaram@mech.sastra.edu, 2raghu@mech.sastra.edu, 3venkat@sastra.edu.

Abstract
Aluminium – silicon carbide (Al - SiC) metal matrix composite is produced with following wt % of SiC reinforcement (4%, 8% & 12%) using stir casting method. Mechanical testing such as micro hardness, tensile testing and bend testing were performed. Characterizations, namely micro structure, X-ray diffraction (XRD) analysis, inductive coupled plasma – optical emission spectroscopy (ICP-OES) and scanning electron microscopy (SEM) analysis, were carried out on Al - SiC composites. The presence of SiC on Al - SiC composite is confirmed through XRD technique and microstructure. The percentage of SiC was confirmed through ICP-OES technique. Increase in weight percentage of SiC tends to increase micro hardness, ultimate strength & yield strength but it reduces the bend strength and elongation (%) of the material. SEM factrography of tensile tested fractured samples of Al - 8% SiC & Al – 12% SiC showed fine dimples on fractured surface & coarse dimples fractured surface respectively. This showed significant fracture differences between Al - 8% SiC & Al - 12% SiC. From the above experiment, Al - 8% SiC had good micro hardness, ultimate strength & yield strength without significant loss in elongation (%) & bend strength.

1. Introduction
Aluminium alloys are used for light weight applications such as aerospace industries and automobile industries. This is due to the excellent properties of aluminium alloy such as higher stiffness (higher strength to weight ratio) [1], higher thermal conductivity and corrosion resistant [2]. But it have low melting point, lesser thermal stability, comparatively lesser tensile and fatigue strength than the steels [3]. Aluminium composite material was manufactured with improved strength and without altering basic properties of aluminium alloys [4]. In composite material, matrix phase is major constituent and reinforcement is minor constituent [5]. Here reinforcement phase added with matrix phase form composite material. Aluminium matrix can combined with various reinforcements such as SiC [6], TiB2, TiC, B4C, Al2O3, MgO and fly ash [7,8].

Manufacturing of aluminium metal matrix composite uses various methods such as powder metallurgy, spray coating, electroplating and stir casting process [9]. Stir casting method of production is more economical and it is also suitable for mass production. Stir casting process mainly used for manufacturing for whiskers & particulate type reinforcement in metal matrix composite [10]. SiC reinforcement widely used as reinforcement for aluminium metal matrix composite due to lesser density difference and higher wettability between aluminium and SiC [11, 12]. Preheating of matrix and reinforcement before casting was done separately [13, 14]. When metal matrix reaches its melting temperature and becomes molten metal, reinforcement is poured and stirred using mechanical stirrer to form homogeneous mixture of Al - SiC composite [15, 16].

This work reveal mechanical behaviours such as tensile strength, bending load, micro hardness of the Al - SiC composite with various weight percentage of SiC (4%, 8% and 12%) and to check the homogeneous distribution SiC reinforcement on aluminium matrix using microstructures, ICP-OES and EDAX. SEM factography and XRD pattern to validate the mechanical behaviour and homogeneity of SiC reinforcement on aluminium matrix.

2. Experiments
Using stir casting machine aluminium with different wt% of SiC (4%, 8% and 12%) was added after the preheated temperature as indicated in table 1[13, 14, 15]. During the molten aluminium, 2% of magnesium was added to increase the wettability. Then SiC was added slowly and molten aluminium was stirred until all the SiC particle was poured into it. Coverall was added finally
to remove the slag to get pure cast of Al - SiC composite. Permanent mould was also preheated as mentioned in table 1 to get cold shunt free casted product. Final product of casted product and whole the process were shown in figure 1.

Table 1: Process parameter for stir casting process

| Process parameter                        | Value    |
|-----------------------------------------|----------|
| Stirrer speed                           | 350 rpm  |
| Stirring time                           | 600 seconds |
| Preheating time                         | 90 minutes |
| Stirring temperature                    | 775 °C   |
| Preheating temperature of SiC            | 775 °C   |
| Preheating temperature of SiC            | 900 °C   |
| Preheating temperature of Aluminium     | 450 °C   |
| Preheating temperature of permanent mould| 300 °C   |
| SiC, Mg & coverall - powder feed rate   | 2-3 g/s  |

Figure 1: Base material

Microstructures were observed in different magnification ranges using high transmission trinocular metallurgical microscope, KYOWA-ME-LUX 2. It consists of a computer coupled CCD camera for capturing and storing microstructure images. Samples were prepared using standard metallographic procedure the welded samples were prepared for microstructure observation. Micro hardness was measured using Shimadzu micro Vickers hardness tester according to the standard of ASTM E 384.

Tensile test was carried out using computerized universal tensile testing machine, FIE model - UTN 40 with a capacity of 40 KN. The specimens were tested according to the ASTM E8 standard. Specimen of sub sized sample with length of 100mm, width of 30mm, thickness 5mm and gauge length of 50mm were considered. Figure 2 showed the sample before tensile testing and after tensile testing.

Figure 2: Tensile sample before testing
Bend test was also performed using same machine with the standard of ASTM E190 on sub sized sample with dimensions of 100mm x 30mm x 5mm (L x W x T). XRD analysis was carried out using Rigaku (MiniFlux-300) X-ray diffractometer employing Cu-Kα source and Ni filter to restrict Cu-Kβ rays. Diffraction patterns were recorded between 2θ values 10° to 120° at scan speed of 10° per min with 0.010 step sizes.

Inductive Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) used for identifying the percentage of chemical composition in the weld zone region. SEM factography and EDAX was observed using scanning electron microscope of Vega3 Tescan, Japan make for tensile tested samples with different magnification.

3. Result

3.1 Micro hardness

Figure 3 showed the Vickers micro hardness for pure aluminium 1100 series, Al - 4% SiC, Al - 8% SiC and Al - 12% SiC in different region of the stir casted composite materials. In this average pure aluminium showed micro hardness value of 25.9HV, Al - 4% SiC showed 36.7HV, Al with 8% SiC reinforcement increased the micro hardness value of 49.3 and 12% SiC addition showed maximum micro hardness of 57.5. This showed increase in weight percentage of SiC increase the micro hardness value of aluminium metal matrix composite. From the trail values it is decided that the SiC reinforced aluminium metal matrix composite with various weight % such as 4, 8 and 12 had uniform micro hardness value throughout the casted material.

![Figure 3: Vickers Micro Hardness](image)

3.2 Tensile properties

![Figure 4: Tensile test result - ultimate tensile strength, yield strength and elongation (%)](image)
Figure 4 depicts the tensile test result of pure aluminum, Al - 4% SiC, Al - 8% SiC and Al - 12% SiC. All conditions shown above were tested for 3 times to get average value. Pure aluminium had ultimate tensile strength (UTS) of 60MPa, yield strength (YS) of 40MPa and elongation (%) of 30%. During increase in wt% of reinforcement as 4%, 8% & 12% - yield strength & ultimate strength were increased but elongation % had decreased. This showed decrease in ductility while increase in wt% of reinforcement.

Al - 4% SiC had nearly UTS – 80MPa, YS – 50MPa & el (%) – 20%. Al - 8% SiC had near value UTS – 100MPa, YS – 70MPa & el (%) – 18%. Finally Al - 12% SiC showed near value of UTS – 115MPa, YS – 100MPa & el (%) – 10%. This showed Al - 12% SiC had loss 66% of originality ductility of the material compared to pure aluminium to increase the UTS and YS values up to 200%.

3.3 Bending load

| Bending Load (KN)                          |
|-------------------------------------------|
| Pure Aluminium                           |
| Al - 4% SiC composite                     |
| Al - 8% SiC composite                     |
| Al - 12% SiC composite                    |
| 3.06 KN                                   |
| 2.43 KN                                   |
| 1.89 KN                                   |
| 1.27 KN                                   |

Pure aluminium had highest bending load which indicates that pure aluminium had higher ductility than Al - SiC composite. Increase in wt % of SiC reinforcement as 4%, 8% & 12% in aluminium matrix showed decrease in bending load as 2.43KN, 1.89KN & 1.27KN. This confirms the increase in wt% of SiC reinforcement in aluminium matrix decreases the ductility of Al - SiC composite.

4. Discussion

4.1 XRD

Raw material such as aluminium, SiC, magnesium, coverall (flux used to remove slag from the cast during stir casting process) were checked using X-ray diffraction (XRD) technique for identifying the phases present in the raw material before stir casting was depicted in figure 5. From the XRD pattern of raw material, it is clear that there is no metallic phase formation between the aluminum, magnesium and SiC. This also indicates that all raw materials are pure. Coverall had different phase were observed CaCl2, CaF2, NaF, NaCl.

![Figure 5: XRD result for raw material for Al - SiC composite](image_url)
Stir casted Al - SiC composite with different composition of SiC with aluminium was also evaluated and it shown in figure 6. From the base material XRD pattern it is clear that aluminium had strong affinity with magnesium to form aluminium magnesiate Al\(_{12}\)Mg\(_{17}\) [18, 19]. During the stir casting SiC remains unchanged and it was clear that it didn’t form any new phases neither with aluminium nor with magnesium [20]. Coverall performed as slag removing agent did not had any chemical effect on base material because coverall’s phase were not identified in base material as depicted in figure 5. Aluminium in Al - 4% SiC composite had highest peak inestity compared to other composites such as Al - 8% SiC & Al - 12% SiC which indicates that aluminium in Al - 4% SiC have higher composition than other composite. SiC had intensity was observed in Al - 12% SiC XRD pattern. This showed that higher composition of SiC were present Al - 12% SiC than other composite. Very small and tracable amount of carbon were identified on all XRD patterns of Al - SiC composite. This showed that presence of SiC reinforcement on aluminium matrix in Al - SiC composite is confirmed.

4.2 ICP-OES

Inductive coupled plasma – optical emission spectroscopy (ICP-OES) techniques showed chemical composition only solid phase material in Table 3. Here increase in wt% of SiC showed increase in chemical composition of silicon (Si) & consistently same amount of Si was observed at different spot of the casted material. But carbon in SiC, cannot be identified through this technique [21]. In this techniques atom number higher than 8 (oxygen) can only be indentified so carbon present as carbide with silicon cannot be identified. This technique validate that the presence and homogeneous distribution of the SiC reinforcement over aluminium matrix in Al - SiC composite.

| Material Description | Chemical Composition |
|----------------------|----------------------|
|                      | Al  | Si  | Mg  | Zn  | Mn  | Cu  | Fe  | Sn  | Ti  |
| Pure Aluminium       |     |     |     |     |     |     |     |     |     |
| Top                  | 99.24 | 0.133 | 0.001 | 0.01 | 0.005 | 0.01 | 0.494 | 0.087 | 0.016 |
| Middle               | 99.41 | 0.148 | 0.007 | 0.04 | 0.008 | 0.02 | 0.278 | 0.072 | 0.014 |
| Bottom               | 99.31 | 0.152 | 0.005 | 0.03 | 0.006 | 0.01 | 0.392 | 0.08 | 0.012 |
| Pure Magnesium       |     |     |     |     |     |     |     |     |     |
| Top                  | 0.34 | 0.007 | 99.6 | 0.03 | 0.014 | 0.001 | 0.007 | - | - |
| Middle               | 0.52 | 0.004 | 99.4 | 0.05 | 0.016 | 0.002 | 0.01 | - | - |
| Bottom               | 0.67 | 0.003 | 99.2 | 0.09 | 0.018 | 0.006 | 0.012 | - | - |
| Al - 4% SiC          |     |     |     |     |     |     |     |     |     |
| Top                  | 95.50 | 2.45 | 1.24 | 0.013 | 0.004 | 0.01 | 0.69 | 0.086 | 0.012 |
Middle & 95.39 & 2.32 & 1.28 & 0.02 & 0.008 & 0.06 & 0.82 & 0.078 & 0.02  
Bottom & 95.33 & 2.51 & 1.22 & 0.016 & 0.006 & 0.04 & 0.78 & 0.082 & 0.018  
**Al - 8% SiC** & Top & 93.86 & 4.35 & 1.15 & 0.01 & 0.008 & 0.01 & 0.51 & 0.082 & 0.016  
& Middle & 93.12 & 4.72 & 1.32 & 0.02 & 0.012 & 0.02 & 0.68 & 0.092 & 0.018  
& Bottom & 93.51 & 4.92 & 1.02 & 0.01 & 0.008 & 0.01 & 0.42 & 0.088 & 0.012  
**Al - 12% SiC** & Top & 90.59 & 7.15 & 1.59 & 0.015 & 0.006 & 0.01 & 0.54 & 0.083 & 0.015  
& Middle & 91.49 & 6.65 & 1.28 & 0.012 & 0.004 & 0.02 & 0.45 & 0.072 & 0.018  
& Bottom & 90.70 & 6.72 & 1.68 & 0.022 & 0.008 & 0.05 & 0.72 & 0.092 & 0.011  

### 4.3 EDAX

EDAX results of Al - 8% SiC & Al - 12% SiC were showed in figure 7. Chemical quantification with microscopy image showed that Al - 8% SiC had 88.5% of aluminium, 9.5% of SiC and nearly 2% of magnesium. Al - 12% SiC composite had 84% of aluminium, 14% of SiC and nearly 2% of magnesium. This showed that there was little amount error percentage between wt% percentage of SiC added during stir casting and value evaluated through EDAX technique. Even though % of deviation observed it was clear that this result support the above techniques such as XRD & ICP-OES. This EDAX technique again validates the presence of SiC and it also clearly quantifies the percentage of SiC reinforcement in aluminium matrix in different wt% of Al - SiC composite.

![Figure 7: EDAX result](image-url)

### 4.4 Microstructure

Figure 8 showed the micro structure of Al - 4% SiC, Al - 8% SiC & Al - 12% SiC on various places of the stir casted material. It showed that the SiC reinforcement distributed uniformly throughout the casted component [22]. Here SiC distribution didn’t show any segregation [23]. This result again confirms that the distribution of SiC reinforcement on aluminium matrix is homogeneous which previously confirmed using XRD, ICP-OES, EDAX techniques.
Figure 8: Microstructure for different weight percentage of (4, 8 & 12) of Al - SiC composite

4.5 SEM fractography

Figure 9: SEM fractography
From figure 9, SEM fractography of tensile fractured sample of Al - 8% SiC & Al - 12% SiC was observed. Al - 8% SiC showed fine dimple fractured surface but in Al - 12% SiC had coarse dimple fractured surface. This showed Al - 8% SiC is more ductile than the Al - 12% SiC which validate the tensile test, micro hardness and bending test results.

5. Conclusion
From this study presence of SiC reinforcement had confirmed using XRD techniques for various wt% of Al - SiC composite. Wt% of SiC reinforcement in aluminium matrix was quantified using ICP-OES and EDAX method. Homogeneous presence of SiC reinforcement in Al - SiC composite was confirmed using ICP-OES and microstructural images at various spots of casted product.

Mechanical testing such as tensile strength, bending load and micro hardness were evaluated. Highest ultimate tensile strength of 115MPa, yield strength of 100MPa and micro hardness of 57.5 was observed on Al - 12% SiC composite. Bending load - 2.34KN & % elongation – 22% were observed on Al - 4% SiC composite.

Increase in wt% from 4 to 12 by SiC on Al - SiC composite showed increase in ultimate strength, yield strength & micro hardness value but decrease in % of elongation & bending load. It is conclude that increase in strength through SiC reinforcement on Al - SiC composite in cost of ductility of the material.

Al - 8% SiC fracture tensile specimen showed fine dimple fracture. Al - 12% SiC fractured tensile specimen showed coarse dimple fracture which confirmed the loss of ductility for increase in strength of the Al - SiC composite.

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