# TENSILE AND FRACTURE BEHAVIOR OF 6061 Al-Si Cp METAL MATRIX COMPOSITES

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**Abstract:** In this paper, fabrication of aluminum MMC by bottom pouring in mushy state with secondary roller processing has been presented. The echanical properties of 6061 aluminum alloy discontinuously – reinforced with fine particulates of SiCp is discussed. The influences of weight fraction of SiCp reinforcement on tensile strength and fracture toughness have been evaluated. Also crack path morphology has been studied to determine micro-mechanisms of failure and the influence of microstructure on crack growth characteristics.

**Keywords:** aluminum MMC, bottom pouring, secondary processing, fracture toughness.

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## 1. INTRODUCTION

The unique tailorability of the composite materials for the specific requirements makes these materials more popular in a variety of applications such as aerospace, automotive (pistons, cylinder liners, bearings), and structural components, resulting in savings of material and energy [1-7]. In this paper, 6061 Al/SiCp MMCs were produced by bottom pouring followed by secondary hot rolling. The aim of the present study is to investigate and the tensile and fracture behavior of 6061Al/SiCp metal matrix composites.

## 2. EXPERIMENTAL PROCEDURE

Aluminum alloy Al6061 with composition (weight percent) Mg - 0.9, Si-0.68, Cu-0.20, Mn- 0.10, Cr- 0.10 and Al- remainder was used as the matrix material. The reinforcement is silicon carbide particles of sizes 5.5μm, 12.2μm and 18.12μm in 5%, 10% and 15% by weight.

Stir casting was employed to manufacture composites [8, 9]. The preheated SiC particulates at temperature $800^0$C were added to the liquid metal. The mixture was stirred using graphite stirrer at 400 rpm to get uniform slurry. A stirring time of 15 min was allowed to enhance the wetting of particulates by the liquid metal. The temperature of the slurry was sufficiently raised above the melting range of the matrix alloy before pouring the composite melt into preheated cast iron die. The as-cast composite billets were hot rolled for 20 % reduction at 400$^{o}$C for 1 hour [10-15]. The hot rolling details of metal matrix composite (Al 6061 + SiCp) are shown in Table 1. Round tensile specimens with the gauge diameter 4.5 ± 0.1 mm and gauge length of 17.5 mm as per BS-18, as shown in Figure 1 were used for tensile testing.

Table 1: Hot rolling details of MMC

| Matrix + SiCp(wt%) | Size of SiCp (µm) | Thickness (mm) (In 15 Passes) | | Percentage Reduction % |
|---|---|---|---|---|
| | | Before rolling | After rolling | |
| 6061 + 5% SiCp | 18.15 | 21 | 16 | 23 |
| 6061 + 10% SiCp | 18.15 | 24.5 | 20.5 | 16 |
| 6061 + 15% SiCp | 18.15 | 20 | 16.5 | 18 |
| 6061 + 0% SiCp | -- | 20.5 | 16 | 22 |

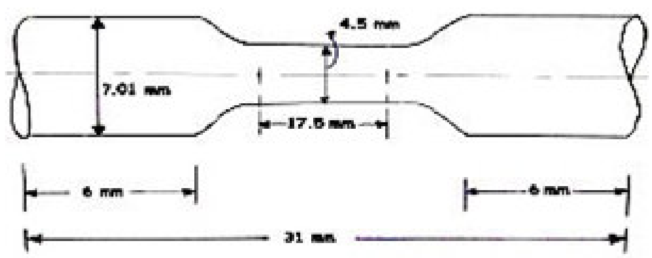

Figure 1: Tensile Specimen

## 3. RESULTS AND DISCUSSION

The tensile properties and fracture behavior of Al6061/SiCp metal matrix composites are discussed.

### 3.1 Microstructure

The optical micrograph of Al6061 alloy and composites with 5%, 10% and 15% SiC particles in rolling direction are shown below in figure 2. It is observed that the SiC particles are uniformly distributed in the composites. EDAX of 6061-alloy (Figure 3) shows that there is a loss of Mg and Si content during manufacturing metal matrix composites.

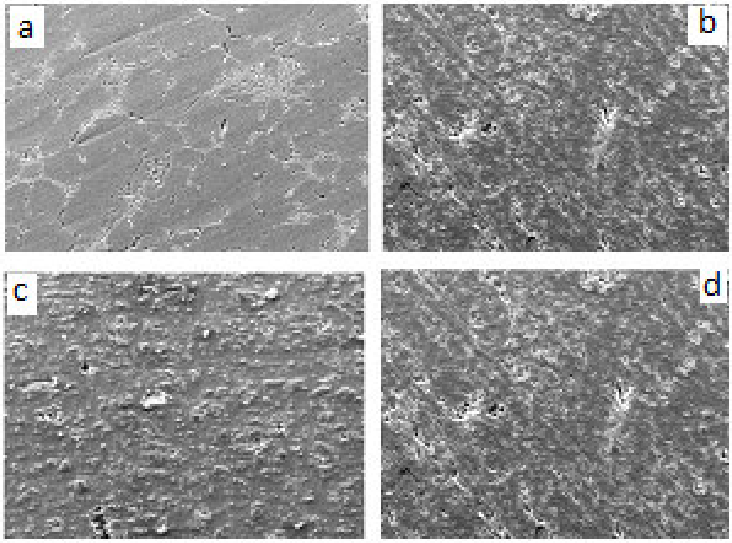


Figure 2: Optical micrographs (x200) (a) Al 6061 (b) Al6061/SiCp (5% wt ) (c) Al6061/SiCp (10% wt ) (d) Al6061/SiCp (15% wt )

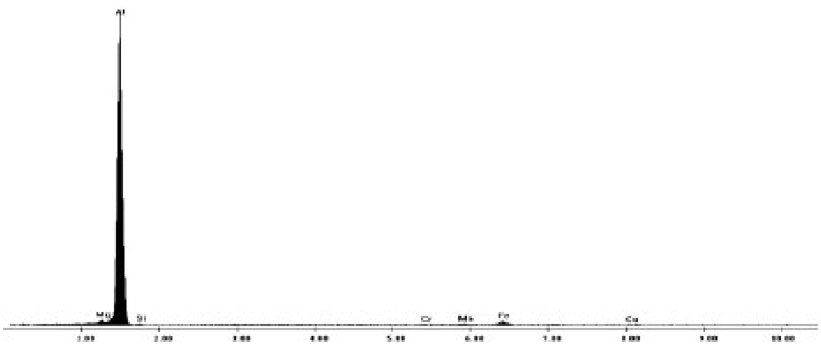


Figure 3: EDAX of AA 6061 alloy showing the loss of Mg and Si Content during stirring process.

## 3.2 Fracture Toughness Testing

Plane strain fracture toughness (KIC) tests were conducted on BiSS 50 KN servo hydraulic universal testing machine (UTM) using CTS as per ASTM E-1820. The conditional fracture toughness was calculated using following equation.

$$K_Q = \left[\frac{P_Q}{B.W^{1/2}}\right] f \left[\frac{a}{b}\right] \quad (1)$$

where, $K_Q$ = Conditional Fracture Toughness
B = Thickness of the specimen
W = Width of the specimen

## 3.3 Tensile Testing

The tensile properties such as 0.2% yield strength, ultimate tensile strength, and percentage elongation have been evaluated for Al 6061 base alloy (T6), composites are shown in table 2.

Table 2: Mechanical properties of different composites

| Condition (Rolled) | %Elongation | 0.2% YS (Mpa) | UTS (Mpa) |
|---|---|---|---|
| AA6061 (T6) | 22 | 289.91 | 328.5 |
| AA6061 (Annealed) + 0% wt. SiCp | 35 | 56.12 | 135.6 |
| AA 6061 + 5% wt. SiCp (18μm) | 1.8 | 52.1 | 52.8 |
| AA 6061 + 10% wt. SiCp (18μm) | 1.2 | 40 | 40.5 |
| AA 6061 + 15% wt. SiCp (18μm) | 0.4 | 50 | 53.4 |

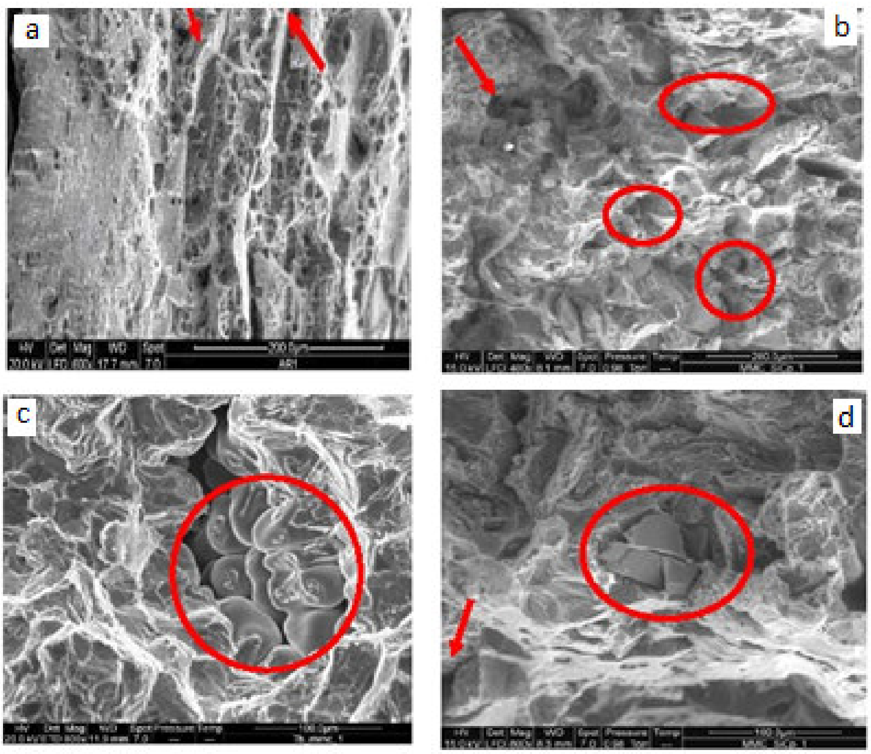


Figure 4: Tensile fractograph of (a) Al 6061 matrix alloy (b) Al 60615% SiCp (c) Al 6061/10% SiCp (d) Al 6061/15% SiCp

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## 3.4 Fractographic Analyses and Discussion

The fracture surfaces of Al 6061 unreinforced alloy and Al 6061/SiCp MMCs that failed during fracture toughness tests and tensile tests were investigated for identifying the micro mechanisms of failure. Figure 4a reveals very few dimples and cracks in Al 6061 matrix alloy. The nature of fracture is ductile. Fractograph shown in figure 4b of Al 6061/5% SiCp reveals dimples, less in number and shallower when compared to matrix alloy. In Al 6061/10% SiCp composite (figure 4c), the mode of fracture is mainly interface debonding and particle faction [5]. In Al 6061/15% SiCp composite (figure 4d), the fraction of dimples decreases with increasing SiC content resulting reduced plastic strain. Particle matrix interface decohesion along with some tear ridges is observed in the matrix region.

Hot rolling of MMC causes coarse dendritic cell structure displaying shrinkage cavities. These cavities are formed due to SiC particles. This type of failure is a brittle failure**.** The presence of tear ridges in AL 6061/SiCp MMC indicates that there is a constraints on the plastic flow of matrix imposed by SiC particles due to which the matrix in the interparticle regions undergoes extensive localized plastic strain [6]. The fractured particles as well as interface decohesion [7] can induce voids in the matrix which may result in lower fracture toughness and tensile properties in 15% SiCp MMC.

## 3.5 Validation of Uniaxial Tensile Test using ANSYS

Material model validation consists of modeling the same uni-axial tensile test from which the stress-strain data points have been recorded. The tensile test conditions were validated using ANSYS software [15]. The tensile specimen was meshed with plane 42 elements as shown in figure 5. The maximum displacement of Al 6061 matrix alloy is 1.694 mm as shown in figure 6.

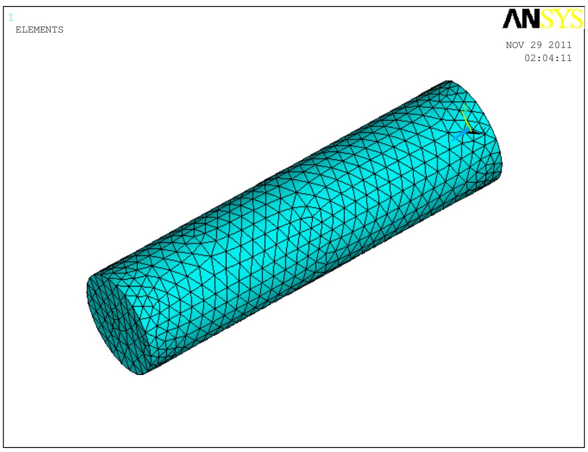


Figure 5: Meshing tensile specimen

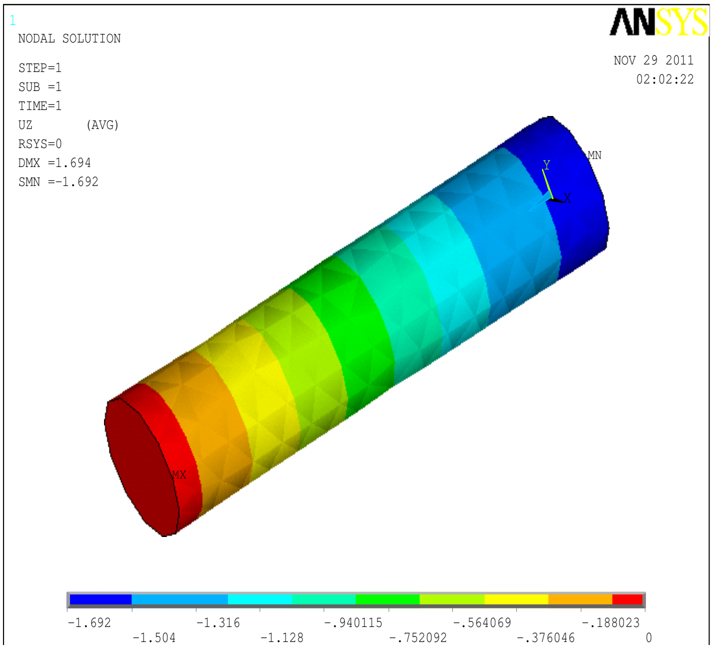


Figure 6: Displacement of Al 6061 matrix alloy

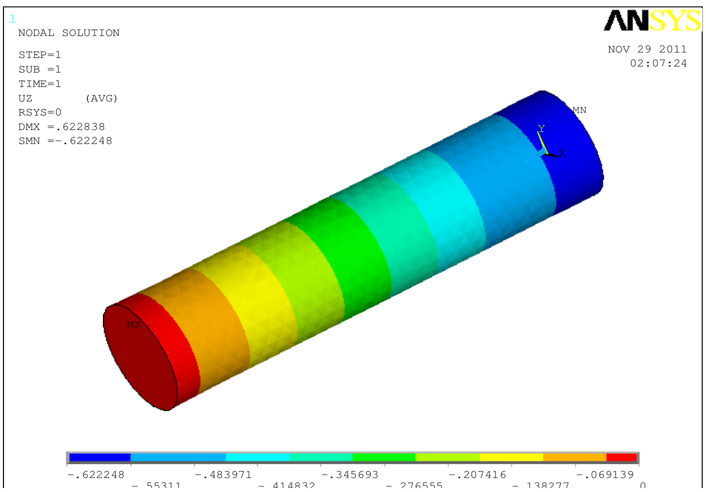


Figure 7: Displacement of Al 6061/5% SiCp composite

The maximum displacement of Al 6061/5% SiCp composite is 0.622 mm as shown in figure 7. The maximum displacement of Al 6061/5% SiCp composite is 0.240 mm as shown in figure 8. The maximum displacement of Al 6061/5% SiCp composite is 0.186 mm as shown in figure 9.

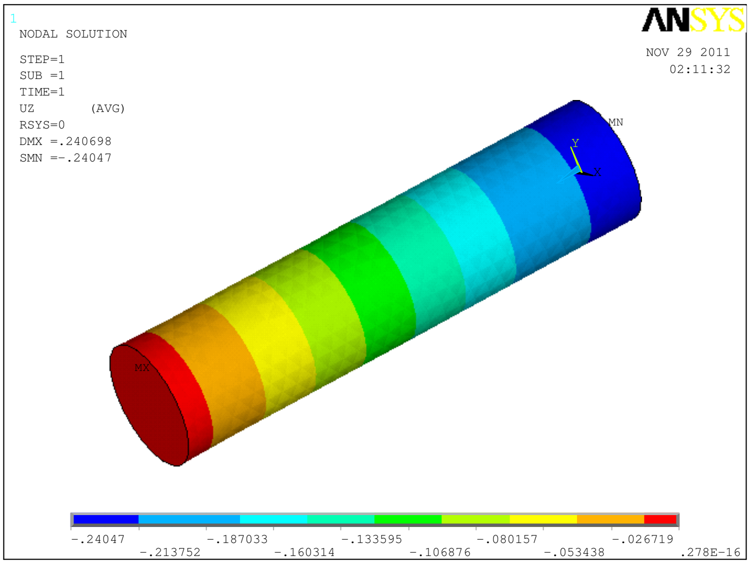


Figure 8: Displacement of Al 6061/10% SiCp composite

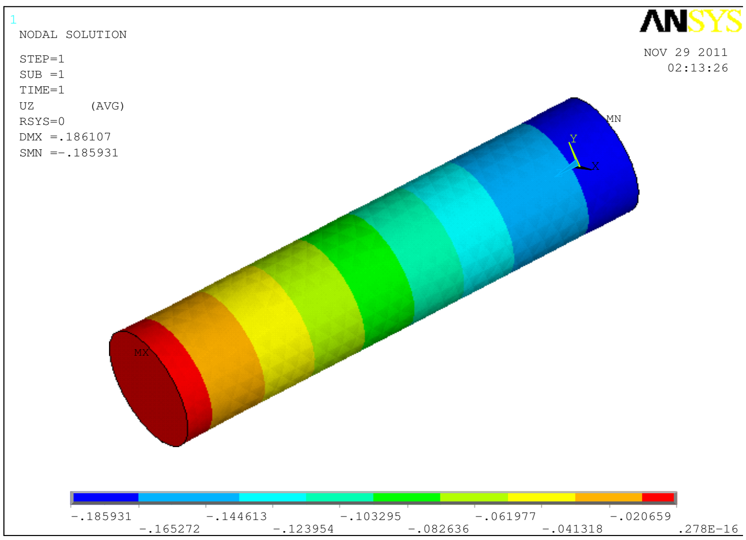


Figure 9: Displacement of Al 6061/15% SiCp composite

## 7. CONCLUSIONS

The mechanical properties of metal matrix composites after hot rolling were not significantly improved due to the presence of shrinkage cavities and particle cracking. It has been observed that there is a loss of Mg content during stirring of MMC fabrication and hence decreases in mechanical properties. The brittle fracture is observed in Al 6061/SiCp composites.

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