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TENSILE AND FRACTURE BEHAVIOR OF 6061 Al-SiC_p METAL MATRIX COMPOSITES

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ABSTRACT

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. In this paper, fabrication of Aluminum MMC by liquid metallurgy route (Bottom pouring) in mushy state with secondary processing is discussed. The structure, mechanical properties of 6061 aluminum alloy discontinuously – reinforced with fine particulates of SiC_p is discussed in particular. The influences of weight fraction of SiCp reinforcement on tensile strength and fracture toughness have been evaluated. The underlying mechanisms governing the fracture behavior during tensile and fracture toughness tests have been discussed. Also crack path morphology was 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,

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 [1,2]. In this paper, fabrication of 6061 Al/SiCp MMC by liquid metallurgy route (Bottom pouring) in mushy state, with secondary hot rolling is discussed. The Aim of the present study is to investigate and compare the tensile, fracture behavior and micro-mechanisms of failure in Al-6061 unreinforced alloy and metal matrix composites.

2. MATERIAL USED

Aluminum alloy AA 6061 T6 with composition (weight percent) Mg - 0.8-1.2, Si- 0.4-0.8, Cu- 0.15-0.4, Mn- 0.15Max, Cr- 0.04-0.35 and Al- remainder is used as the base matrix. The dispersoids used are silicon carbide particles of sizes 5.7µm, 12.6µm and 18.15µm in 5%, 10% and 15% by weight.

3. PROCESSING OF MMC

Fig.1 (a-c) shows the schematic of rheocasting or stircasting (bottom pour) set up which was fabricated for the composite processing. About 2 kilograms of the AA 6061 alloy is cleaned and loaded in the silicon carbide crucible and heated to above its liquidus temperature. The temperature was recorded using chromel-alumel thermocouple. To maintain the solid fraction of about 0.4, the temperature of the melt was lowered before stirring. The specially designed mechanical graphite stirrer is introduced into the melt and stirred at ~ 400 rpm **(Fig 2)**. The depth to which the impeller was immersed is approx $1/3^{rd}$ the heights of the molten melt from the bottom of the crucible [3]. The preheated (800^0C) SiC particulates (18.15µm) were added through a preheated pipe by manual tapping into the slurry, while it was being stirred. **Table 1** gives the rheocasting details. A post-addition stirring time of 15 min was allowed to enhance the wetting of particulates by the metal. The temperature of the slurry was sufficiently raised above the melting range of the matrix alloy before pouring the composite melt into preheated permanent mould. **Fig 3** shows as-cast MMC in different mould shapes to facilitate testing.

Table.1 Rheocasting Details of MMC

Sr.No	**Composite System**	**SiCp Size (μm)**	**Preheat Temp of SiC_P**	**Total Stirring time**	**Pouring Temp. (^{0}C)**
1	6061+5% SiCp (wt%)	18.15	800^{0}C	15min	730
2	6061+10% SiCp (wt%)	18.15	800^{0}C	15min	700
3	6061+15% SiCp (wt%)	18.15	800^{0}C	15min	633

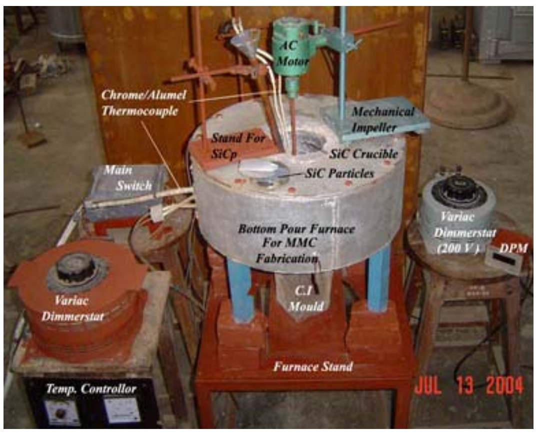
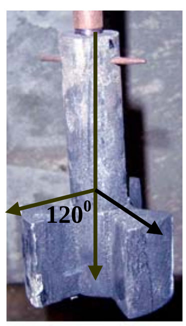


Figure. 1(a) shows the schematic of rheocasting or stircasting set up (bottom pour), **(b)** Graphite stopper for bottom pour arrangement.

Fig 1(c): Shows Bottom pour facility in SiC crucible



Graphite Stirrer

Fig.2: Graphite stirrer

Fig 3: shows as-cast MMC in different mould shapes to facilitate testing

3. SECONDARY PROCESSING OR HOT ROLLING

The as-cast composite billets were hot rolled for (16 - 23 % reduction) at 400^{o}C for 1 hour and 45 minutes in order to get rid of the porosities induced during primary processing **(Fig 4)**. It also improves the distribution of the reinforcement in the matrix. Secondary processing improves distribution of SiC_P in the matrix, imparts directional properties, whereby mechanical properties are improved. Edge cracks in rolled billets were observed after final reduction during rolling. The Hot rolling details of Metal Matrix Composite (AA6061 + SiC_p) are shown in **Table 2.**

Table.2 Hot Rolling Details of MMC

S.No	Matrix + SiCp (wt%)	Size of SiCp (µm)	Thickness (mm) (In 15 Passes)		Percentage Reduction %
			Before Rolling	After Rolling	
1	6061+ 5% SiCp	18.15	21	16	**23**
2	6061+10% SiCp	18.15	24.5	20.5	**16**
3	6061+ 15% SiCp	18.15	20	16.5	18
4	6061+ 0% SiCp	--	20.5	16	22

Fig 4: As-cast Composite Rolled Billets

4. SPECIMEN PREPARATION

Round tensile specimen with the gauge diameter 4.5 ± 0.1 mm and gauge length of 17.5 mm as per BS-18, as shown in **Fig 5** were used for tensile testing. The Compact Tension (CT) specimens for K_{IC} and Fatigue Crack Growth Rate (FCGR) (da/dN) determination are prepared in LT direction with notch and intended direction perpendicular to the rolling direction as per ASTM E-1820 and ASTM E-647 standards as shown in **Fig 6.**

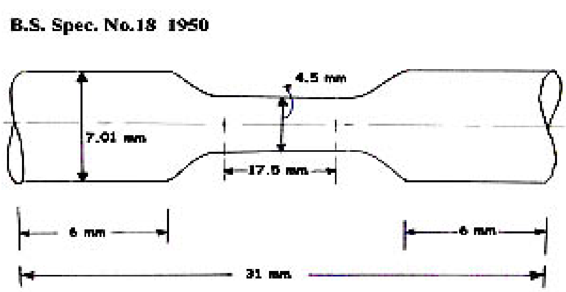


Fig: 5 Tensile Specimen

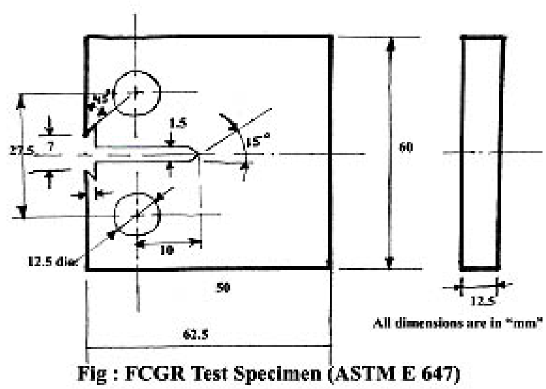
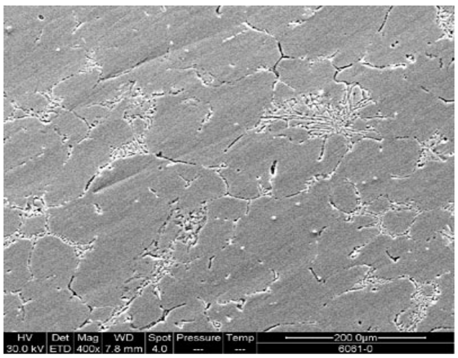


Fig 6: Compact Tension (CT) specimens for K_{IC} and FCGR determination

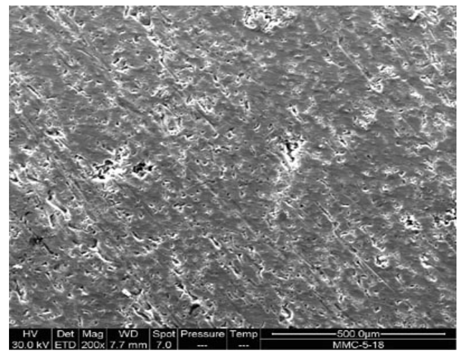
5. RESULTS AND DISCUSSION:

5.1 MICROSTRUCTURE

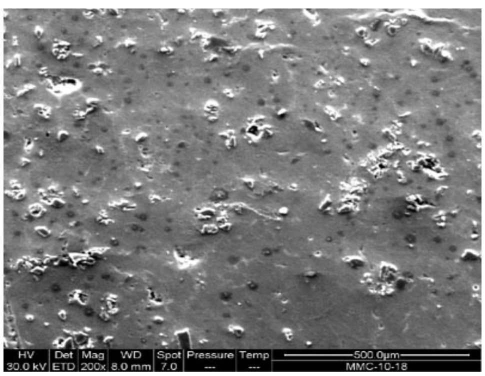
The optical micrograph of AA 6061 alloy and composites with 5%, 10% and 15% SiC particles in rolling direction are shown below in **fig 7 (a-e)**. EDAX of 6061-alloy shows that there is a loss of Mg and Si content during stirring process of MMC processing.



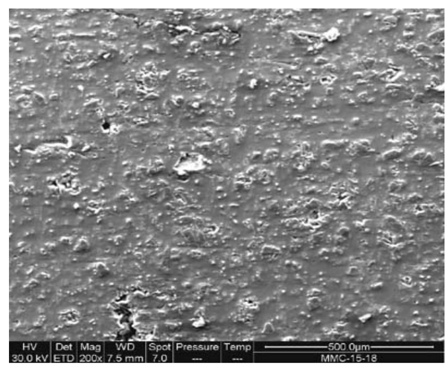
(a) AA 6061 (x 400)



(b) AA 6061 / **5%** wt SiCp / 18µm (x200)



(c) AA 6061 / **10%** wt SiCp / 18µm (x200)



(d) AA 6061 / **15%** wt SiCp / 18µm (x200)

(e)

Fig 7 (a-e) optical micrographs of (a) AA6061 (b) 5%wt SiCp (c) 10%wt SiCp (d) 15%SiCp Composites (e) EDAX of AA 6061 alloy showing the loss of Mg and Si content during stirring process.

5.2 FRACTURE TOUGHNESS TESTING

Plane strain fracture toughness (K_{IC}) tests were conducted on BiSS 50 KN servo hydraulic Universal Testing Machine, using CTS as per ASTM E-1820. The conditional fracture toughness was calculated using following eqn.

$$K_Q = \frac{P_Q}{B.W^{\frac{1}{2}}} f\left(\frac{a}{w}\right) ,$$

K_Q = Conditional Fracture Toughness

B = Thickness of the specimen
W = Width of the specimen

Table 2: Fracture Toughness results of base matrix and Composite

Composite System	B (mm)	W (mm)	$\frac{a}{w}$	$f\left(\frac{a}{w}\right)$	P_Q (KN)	K_Q Mpa√m
AA 6061 + 0% SiCp	12.5	50	0.51	10.02	3.24	K_Q= 11.64
AA 6061 + 5% SiCp (18μm)	9	36	0.5	9.61	---	K_Q ~ 9.8

5.3 TENSILE TESTING

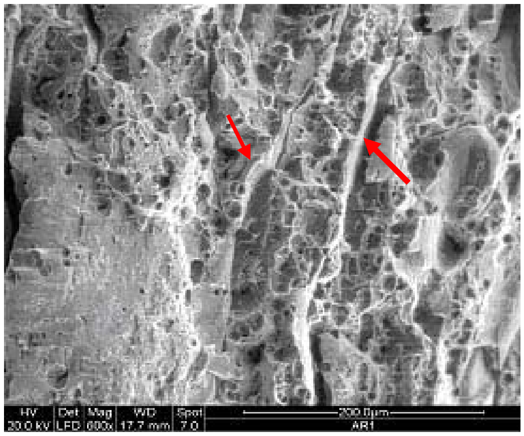
The tensile properties such as 0.2% yield strength; ultimate tensile strength and percentage elongation have been evaluated for AA 6061 base alloy (T6), Annealed 6061 alloy and composites and are shown in **Table 3**

Condition (Rolled)	**%Elongation**	**0.2% Y.S (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

Table 3: Tensile Properties

5.4 FRACTOGRAPHIC ANALYSES AND DISCUSSION

The fracture surfaces of AA-6061 unreinforced alloy and Al-6061/SiCp MMC (both in rolled condition), that failed during fracture toughness tests and tensile tests were investigated for identifying the micro mechanisms of failure **(Fig 8 – 11)**. Samples after mechanical testing were cut to the specified dimensions and then ultrasonically cleaned in acetone and examined the fractured surfaces in ESEM at RSIC, IIT Bombay.



AA 6061 alloy having mixed mode type of tensile fracture displaying complicated array of facets and isolated dimples.

Lots of cracks are present with river line patterns, very few dimples are present. Overall it is Brittle fracture

Fig 8: Tensile Fractographs for AA6061 Matrix alloy

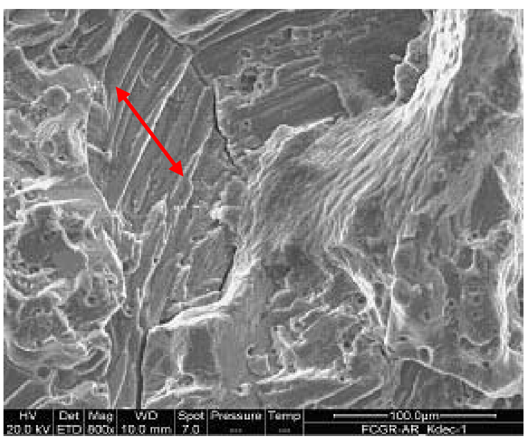


Fig 9: Brittle striations with Internal Cracks and river lines are present in **K_{IC} Test** for AA6061 Matrix alloy.

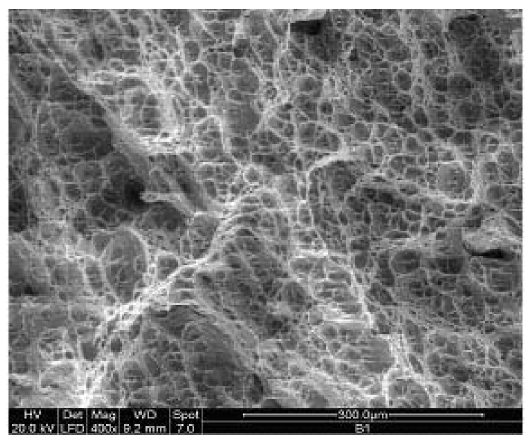
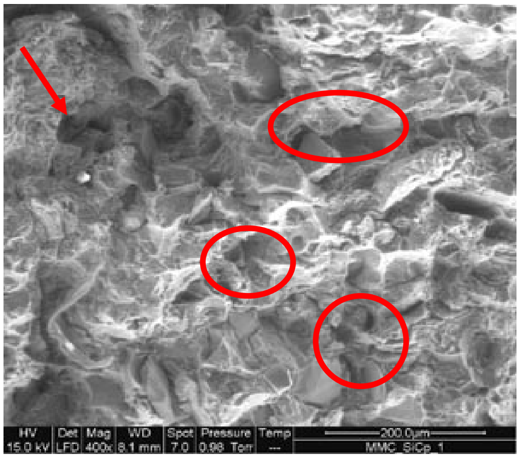
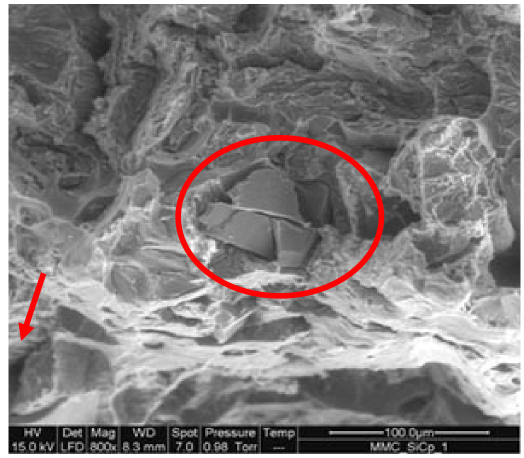


Fig 10: AA6061 Matrix alloy (overload region in K_{IC} Test) showing equiaxed dimples of various sizes.



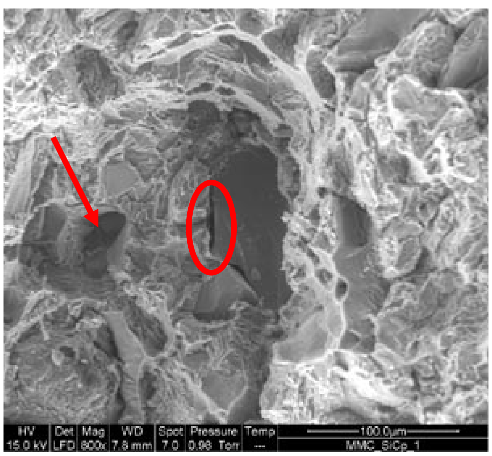
(a)

5% SiCp shows dimples, less in number and shallower when compared to matrix alloy (**Fig 8**). Mainly the mode of failure here is VNG along particle interface.



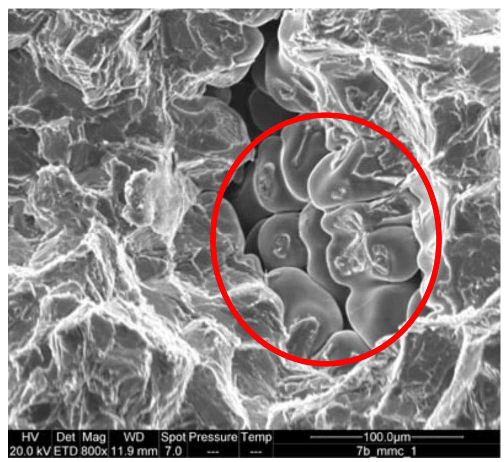
(b)

With 10% SiCp, the mode of fracture is mainly interface debonding and particle fraction. Some porosity is also observed due to less %age reduction in rolling.



(c)

With 15% SiCp, fraction of dimples decreases with increasing SiC content and hence reduced plastic strain. Particle matrix interface decohesion along with some tear ridges is observed in the matrix region.



(d)

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.

Fig 11 (a-d): Tensile Fractographs of AA6061/SiCp MMCs **(a)** 5% SiCp **(b)** 10% SiCp **(c)** 15% SiCp

The presence of tear ridges in 15% 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, but on a macroscopic level the specimen fails in a brittle manner. The fractured particles as well as interface decohesion can induce voids in the matrix which may result in lower fracture toughness and tensile properties in 15% SiCp MMC.

6. 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. Also it has been observed that there is a loss of Mg content during stirring of MMC fabrication and hence decrease in mechanical properties. The plane strain fracture toughness K_{IC} of the MMC is observed to be comparable with unreinforced matrix alloy in annealed condition. Unreinforced alloys 6061 in rolled condition has high toughness and therefore, crack arrest capability. They may therefore, be considered as potential candidate materials for automobile and aerospace sectors where high strength with reduced weight and high crack arrest capabilities will contribute to crash worthy design of automobile/aircraft structures. One can optimally exploit the properties of such materials by making Metal Matrix Composites with proper choice of secondary process for better life of the component.

References

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