# Machining and fracture characteristics of SiC reinforced A356 alloy composites

*K.S.R.K. Srinivasa Rao[1], Research Scholar, GITAM University[1]*
*S. Kamaluddin[2], Principal, Chirala Engg. College, Chirala[2]*

***Abstract: Though monolithic light aluminum alloys posses very good specific strength, their suitability for aerospace and surface transportation is limited due to low hardness and wear resistance. Hence, these alloys are reinforced to produce components with proper particulates to enhance the above deficiencies. But reinforcement reduces fracture toughness and manufacturing of these metal matrix composites is another challenging task. In the present work A356 metal matrix composite (MMC) reinforced with SiC particles in the proportions of 5, 10 and 15 weight percentage are fabricated and investigated for machining and fracture characteristics. The fractographic analysis was carried out for evaluation.***
***Key words: SiCp reinforced metal matrix composites; cutting forces; machining properties; fracture toughness; fractography.***

## I.INTRODUCTION

Particulate reinforced aluminium matrix composites are fast emerging as engineering materials and competing with common metals and alloys. They have already gained significant acceptance because of higher specific strength, specific modulus and good wear resistance as compared to ordinary unreinforced alloys [1]. Reinforcing particles used in this study were silicon carbide added externally to Aluminum alloy A356 containing 7% Si, 0.3% Mg with 0.2% Fe (max) and 0.10% Zn (max). This alloy has very good casting and machining characteristics. Typically it is used in the heat-treated condition. Corrosion resistance is excellent and it has very good weldability characteristics. Mechanical properties are rated excellent particularly if given a solution and aging treatment (T6). Typically this alloy is used in castings for aircraft parts like high strength airframe and space frame structural parts, machine parts, truck chassis parts, high velocity blower, pump housings, impellers, high velocity blowers and structural castings where high strength is required [2]. It can also be used as a substitute for aluminum alloy 6061. It has good castability that makes it a logical choice for intricate and complex castings where light weight, pressure tightness and excellent mechanical properties are needed. Aluminium is also a ubiquitous element and one of the trace elements with moderate toxic effect on living organism. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without compromising much on the strength to weight ratio lead to the development of metal matrix composites. Silicon carbide (SiC) was originally produced by a high temperature electrochemical reaction of sand and carbon. Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. The properties of Silicon Carbide such a high elastic modulus, high strength, high hardness, high thermal conductivity, low thermal expansion, excellent thermal shock resistance, superior chemical inertness and mainly low density makes it suitable as the most popular reinforcement in Al alloy based MMCs. Any acids or alkalis or molten salts up to 800°C do not attack silicon carbide. The challenges and opportunities of aluminium matrix composites have been reported much better to that of its unreinforced counterpart (Surappa, 2003). The addition of reinforcing phase significantly improves the tribological properties of aluminium and its alloy system.

## II.EXPERIMENTAL METHODS

The base alloy under study A356 is used for fabrication of SiC reinforced composite samples for performing various experiments and tests to evaluate machining characteristics, mechanical properties and plain strain fracture toughness. Reinforcement is added in proportions (5%, 10% and 15% by weight) and stir casting technique is used to produce.

**2.0 Composite fabrication:** The Aluminium alloy was charged into the graphite crucible and heated to $700 \pm 20^{0}$C till the entire metal in the crucible was melted in stir casting machine (Figure 1). The reinforcement particles SiC were preheated to 700 - 800ºC for 1 h before incorporation into the melt to remove moisture. After the molten metal was fully melted degassing tablet (coverall powder) was added to reduce the porosity. Simultaneously, 1% by weight magnesium was added to the melt to enhance the wettability between the matrix and the reinforcements. The stirrer made up of stainless steel coated with ceramic was lowered into the melt slowly to stir the molten metal at the speed of 700 rpm. The speed of the stirrer can be controlled my means of regulator provided on the furnace. The preheated SiC particles were added into the molten metal at a constant rate during the stirring time. The stirring was continued for another 5-10 minutes even after the completion of particle feeding. After this stage the Al/SiC composite slurry is allowed to maintain at 700ºC for 10 minutes without stirring. Argon gas was purged into molten metal to avoid oxidation of the melt till the metal is transferred to ladle for pouring. The mixture was poured into the mould which was also preheated to 500ºC for 30 min to obtain uniform solidification. The cast specimens for various tests were homogenized at $200^{0}$ C for 20 hrs and given T6 treatment. In T6 process first the specimens are subjected to solution treatment for 8 h at (535±5) °C and then quenched in water at ambient temperature and finally artificially aged at 180 °C for 6 h followed by air cooling [3,4].

**2.1 Tensile Tests:** Tensile tests were conducted on Ø 12.5 mm cylindrical specimens (Figure 2) using 400 kN Instron make UTM (Figure 3), at BDL laboratory in accordance to ASTM E8 [5] standard specifications. The ram speed of the experiment was maintained at 10 mm/min.

Figure 1: Stir casting machine

Figure 2: Cast fingers Ø 22 mm x 140 mm for preparation of tensile specimens

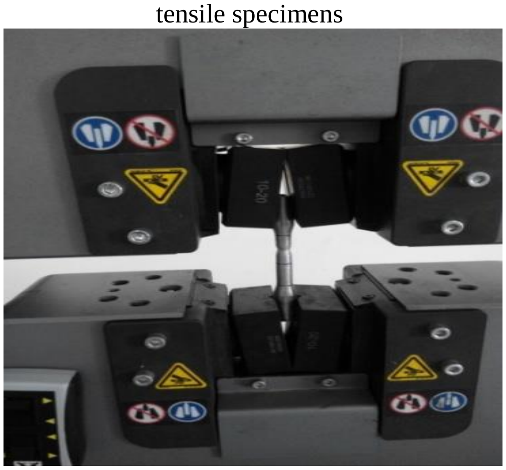


Figure 3: 400 kN Instron make UTM

**2.2 Cutting Force Measurements**: Cutting forces were measured on Kistler's make tool dynamometer (Figure 4) facility at GITAM University.

Figure 4: Cutting force measurement set-up

**2.3 Fracture Toughness Tests:** The fracture toughness tests were conducted on 400 kN Instron Make fatigue testing machine (Figure 5) at GITAM University on SENB specimens according to ASTM E399 [6].

Figure 5: Fracture toughness experiment on 100 kN Instron Fatigue Testing Machine with SENB specimen

**2.4 Fractography:** Fractographic studies were carried out in central facility of Osmania University on Hitachi make SEM.

## III.RESULTS AND DISCUSSION

**V**ery limited publications were found related fracture toughness the properties of SiC reinforced A356. In the present work an attempt is made to study and characterize these properties in addition to routine machinability and mechanical properties.

**3.1 Mechanical properties:** It is evident from figure 6, that the yield strength of the composite increased with SiC particle reinforcement fraction. This is due to increasing amount of the SiC phase in the composite where pinning of dislocation occurs. The ultimate strength increased with particle reinforcement in the beginning but later a slight decrease. This is perhaps because of the slightly faster rate of necking caused by larger interfacial area for higher reinforcement. The Young's modulus being the measure of the stress strain during early part of elongation (elastic deformation), showed similar pattern as that of yield strength (figure 7) i.e., increase with reinforcement content. By aforesaid obvious reasons, a continuous fall in percentage elongation with increase in SiC content can also be observed from the figure 8.

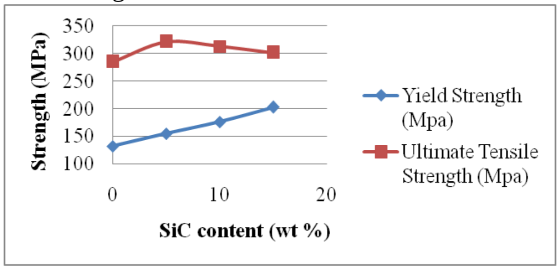



Figure 6: Variation of Strength with SiC content

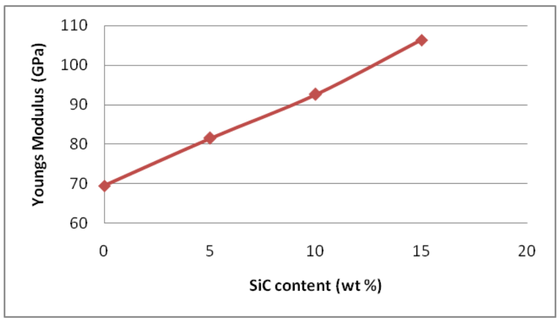



Figure 7: Variation of Young's Modulus with SiC content

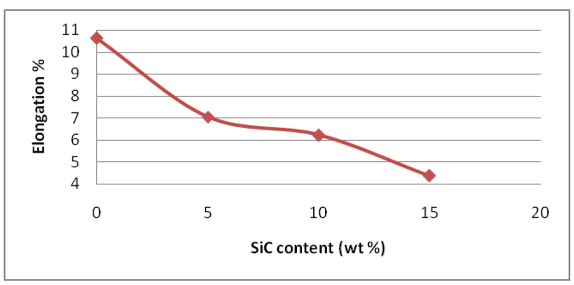



Figure 8: Variation of Elongation with SiC content

**3.2 Machining Properties:** In order to study all the three components of machining forces, oblique turning process is selected with an approach angle of $70^0$. HSS tool with 20-15-12-10-5-5-1 tool signature is used cutting. The cutting parameters used are rpm = 350 (cutting speed = 24.2 m/min) & 560 (cutting speed = 38.72 m/min), Feed = 0.14 & 0.16 mm/rev, while depth of cut being 2 mm and diameter & length of turning specimen being 22 & 140 mm respectively. The variation of maximum thrust force, feed force and radial force with wt% SiC particle reinforcement were represented in the figures 9 through 11. All the three maximum force components (thrust force, feed force and radial force) were observed to be minimum at 5% SiC for all cases of speed and feed except one case with higher cutting speed (38.72 m/min) and higher feed rate (0.16 mm/rev). The maximum power consumption has shown similar trend (figure 12). In this case these force components remained practically constant or shown slight increase at lower content of SiC but marginal increase was observed at higher content. The surface average roughness values (Ra) was almost same in all cases between 8-11 µm after machining. This clearly indicates that the machinability is excellent when 5% SiC was added.

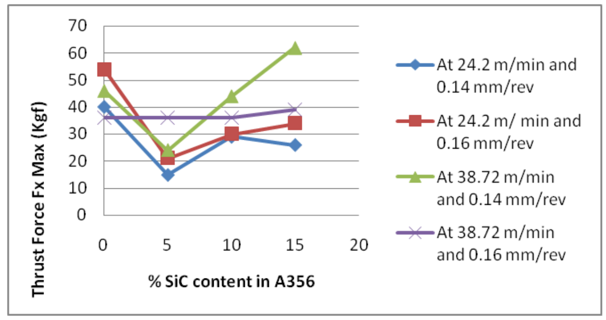



Figure 9: Variation of Maximum Thrust Force with SiC content

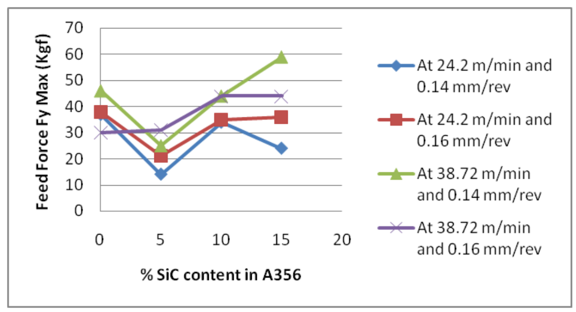



Figure 10: Variation of Maximum Feed Force with SiC content

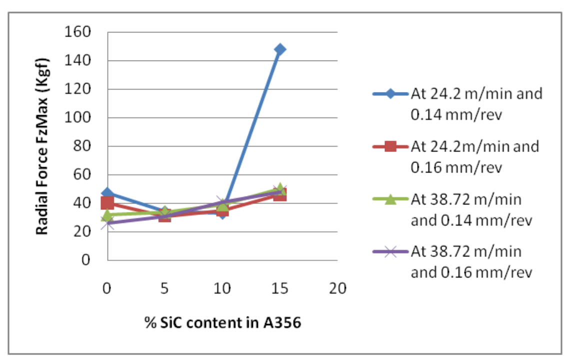



Figure 11: Variation of Maximum Radial Force with SiC content

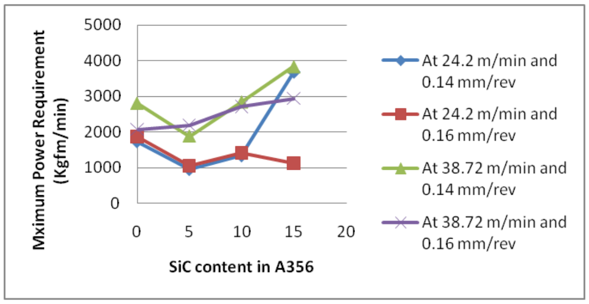



Figure 12: Variation of Maximum power requirement with SiC content

**3.3 Plain Strain Fracture Toughness:** The $K_{IC}$ tests were conducted on single edge notched bend (SENB) specimen as shown in figure 13. The permitted dimensions as per E399 for B = 8 mm specimen, W = 32 mm, Span = 70 mm and notch depth = 1.5 mm were used. The pre-cracking was done to limit a = 2 mm on 100 kN Instron make fatigue testing machine.

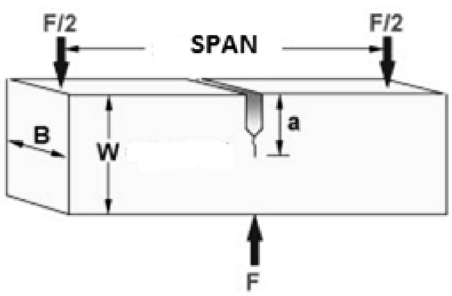



Figure 13: Single Edge Notched Bend (SENB)

The plain strain fracture toughness $K_{IC}$ values for composites were plotted in figure 14. A sharp drop can be observed with addition of SiC reinforcement at start. But further increase in SiC content had a little effect.

**3.4 Fractography:** The SEM fractographic images were captured at $10^5$ magnification in various locations for these composites and their analysis is tabulated in table 1 through 5. The first location is the zone of pre-crack here, termed as zone-I; the second location is the immediate neighborhood of pre-crack and is zone-II; the zone-III is transition zone; next to it inter-granular cleavage region zone-IV followed by the trans-granular cleavage region zone-V.

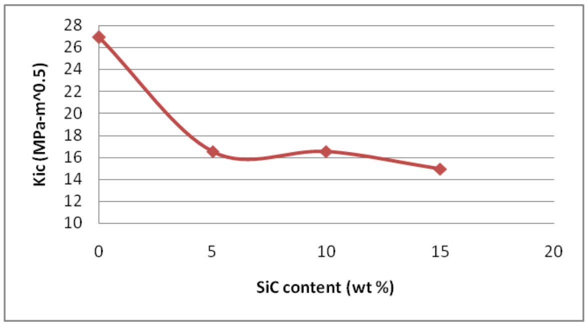
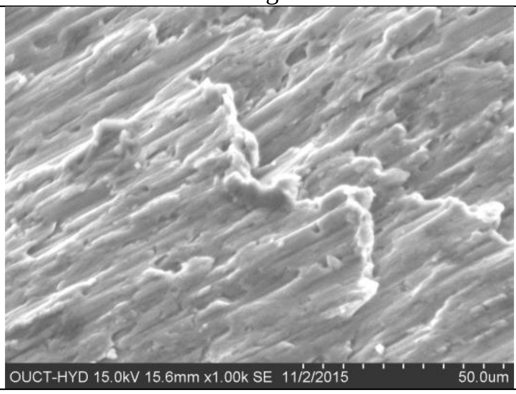



Figure 14: Variation of Plain Strain Fracture Toughness with SiC content

Table 1: SEM fractographs captured in Zone-I

| Composite | Image | Prediction |
|---|---|---|
| Monolithic A356 |  | Intrusions and protrusions associated with fatigue pre-cracking. |

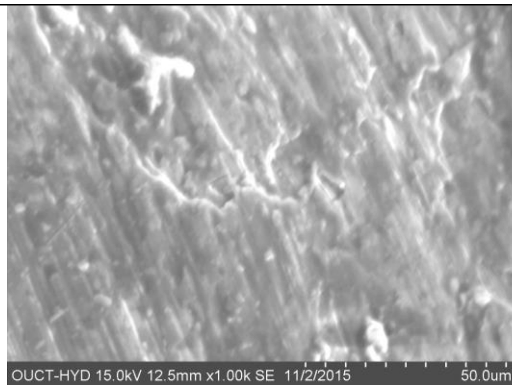
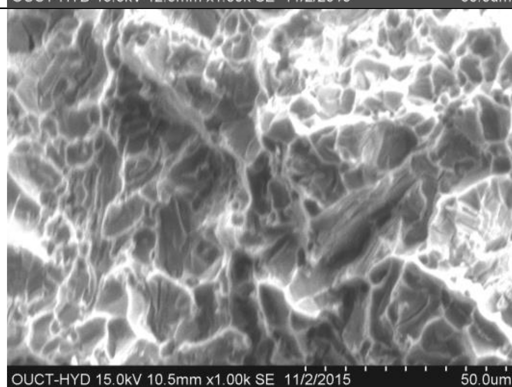
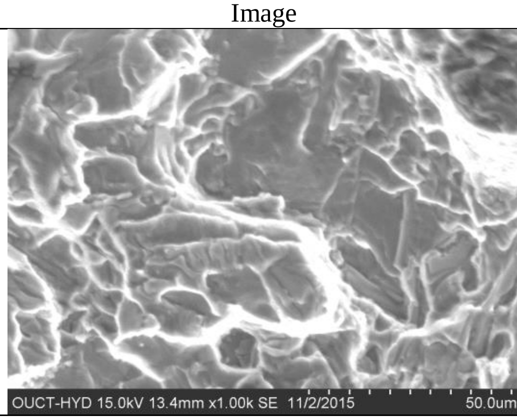
| | | |
|---|---|---|
| A356 + 5% SiC |  | Intrusions and protrusions associated with fatigue pre-cracking. The presence of SiC particles can be visualized. |
| A356 + 10 % SiC |  | Dimple formation started in fatigue pre-cracking region. |
| A356 + 15% SiC |  | Fatigue micro striations in the matrix. SiC particles are seen embedded in matrix. |

Table 2: SEM fractographs captured in Zone-II

| Composite | Image | Prediction |
|---|---|---|
| Monolithic A356 |  | Stable crack growth surrounding micro pores. |

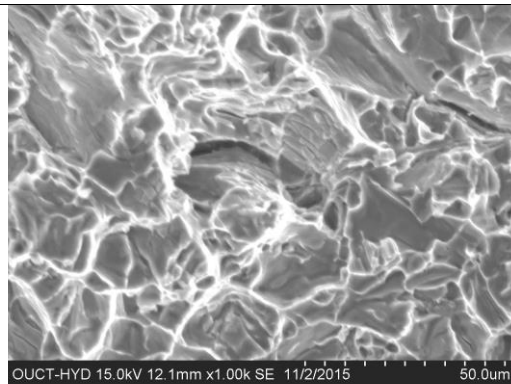
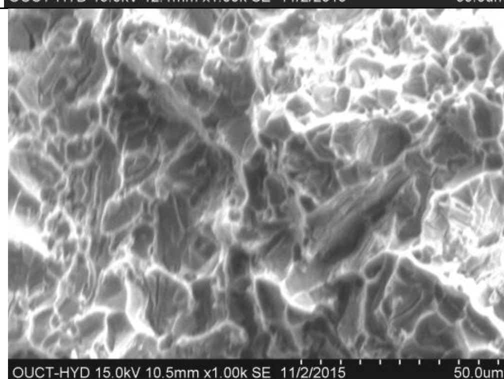
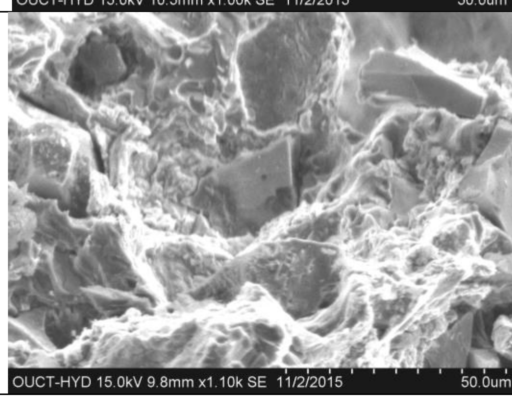
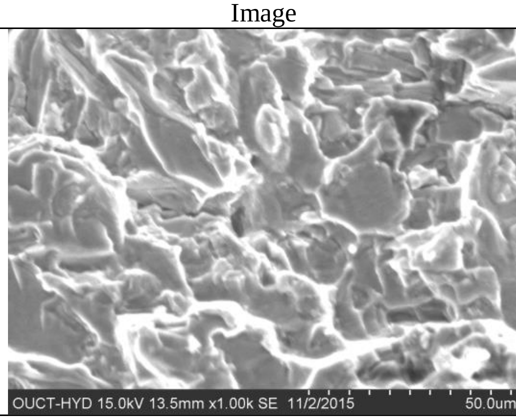
| | | |
|---|---|---|
| A356 + 5% SiC |   | Stable crack growth at reinforcement interface. |
| A356 + 10 % SiC |   | Stable crack growth at reinforcement interface. Relatively more number of interfaces due to higher SiC content. |
| A356 + 15% SiC |   | Stable crack growth at reinforcement interface. Large size micro cracks are associated with particle agglomeration due to very high reinforcement. |

Table 3: SEM fractographs captured in Zone-III

| Composite | Image | Prediction |
|---|---|---|
| Monolithic A356 |   | In this zone the failure mode is in transition from ductile mode to brittle mode. |

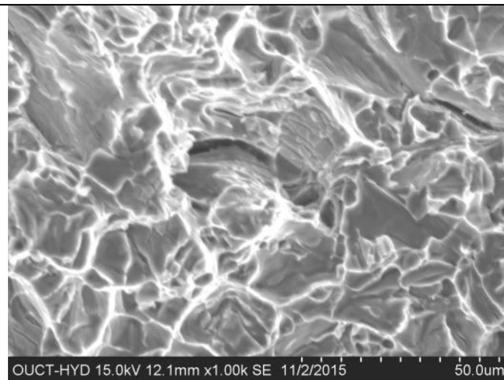
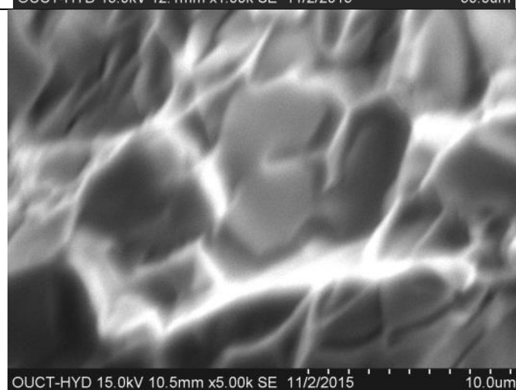
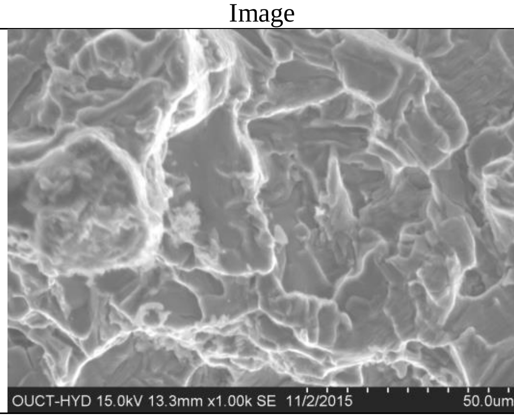
| | | |
|---|---|---|
| A356 + 5% SiC |   | In this zone the failure mode is in transition from ductile mode to brittle mode. |
| A356 + 10 % SiC |   | In this zone the failure mode is in transition from ductile mode to brittle mode. |
| A356 + 15% SiC |   | In this zone the failure mode is in transition from ductile mode to brittle mode. |

Table 4: SEM fractographs captured in Zone-IV

| Composite | Image | Prediction |
|---|---|---|
| Monolithic A356 |   | The highly fractured rough surface in brittle zone of inter-granular. |

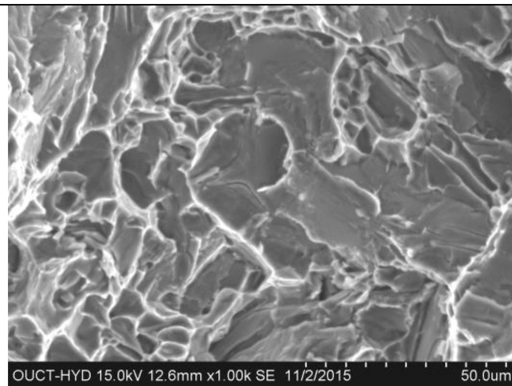
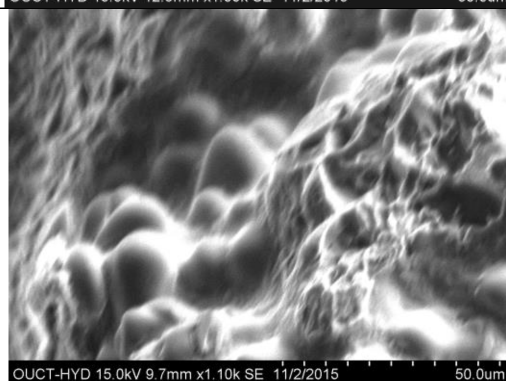
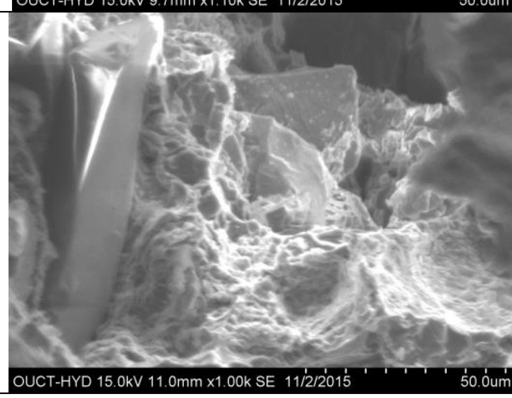
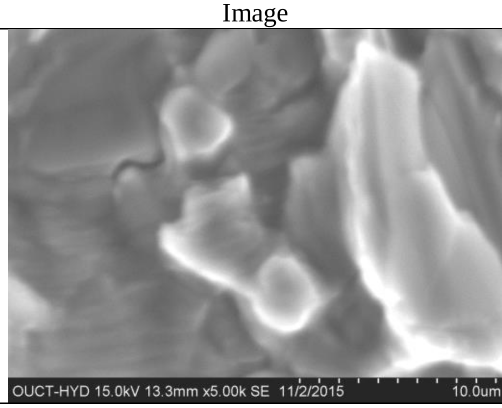
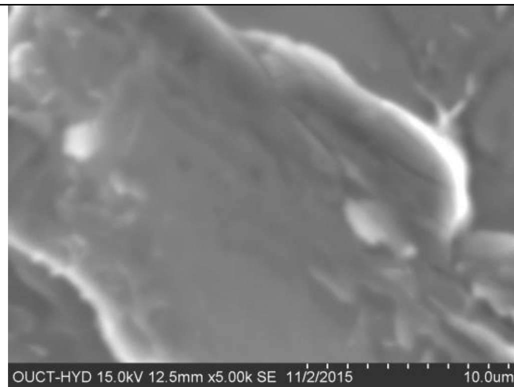
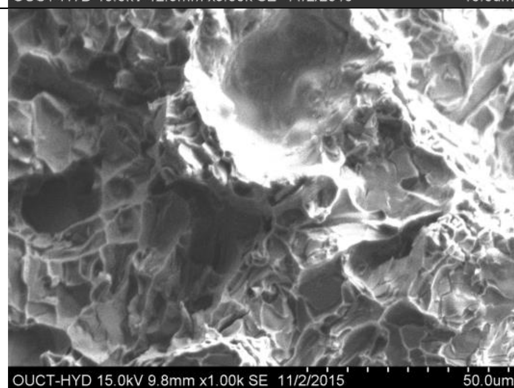
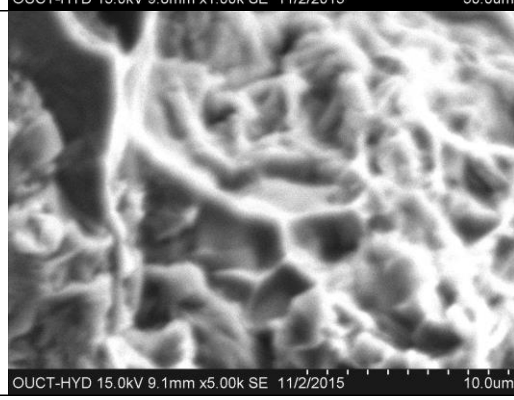
| | | |
|---|---|---|
| A356 + 5% SiC |  | This Zone is visualized by inter-granular cleavage. |
| A356 + 10 % SiC |  | This Zone is visualized by inter-granular cleavage. |
| A356 + 15% SiC |  | This Zone is visualized by inter-granular cleavage. |

Table 5: SEM fractographs captured in Zone-V

| Composite | Image | Prediction |
|---|---|---|
| Monolithic A356 |  | This Zone is visualized by trans-granular cleavage. |

| | | |
|---|---|---|
| A356 + 5% SiC |  | The highly fractured rough surface in brittle zone of trans-granular cleavage. |
| A356 + 10 % SiC |  | The highly fractured rough surface in brittle zone of trans-granular cleavage. |
| A356 + 15% SiC |  | The highly fractured rough surface in brittle zone of trans-granular cleavage. |

## IV.CONCLUSIONS

The A356 alloy reinforced with SiC samples with varying reinforcement content were successfully produced to study machining and fracture characteristics. The addition of SiCp as reinforcement had lead to better machining properties with 5% addition by weight. More addition did not yield any further advantage. The yield stress had also similar effect. The majority of loss in ductility and fracture toughness has occurred with addition of reinforcement 5% by weight. Further addition had not deteriorated these values. The maximum strength and the best machinability were achieved with addition of 5% SiC reinforcement to A356 alloy. Further increase of reinforcement had no added advantage.

**Acknowledgements:** Authors wish to acknowledge the Departments of Mechanical Engineering and Industrial Engineering, GITAM University, Visakhapatnam for extending support and facilities to conduct experiments. They are also grateful to Central Research Facility at Osmania University, Hyderabad.

**REFERENCES**

[1] Dr. Pradeep K. Rohatgi "Mechanical Properties – Structure Correlation for Commercial Specification of Cast Particulate Metal Matrix Composites Comprehensive Report 1999-2002" December, 2002, University of Wisconsin-Milwaukee.

[2]Shashi Prakash Dwivedi, et. al. "Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting" J Braz. Soc. Mech. Sci. Eng., March, 2014.

[3]Shashi Prakash Dwivedi, et.al., "Comparison of Microstructure and Mechanical Properties of A356/SiC Metal Matrix Composites Produced by Two Different Melting Routes", International Journal of Manufacturing Engineering, Volume 2014, Article ID 747865, 13 pages http://dx.doi.org/ 10.1155/2014/747865

[4]Awadh B. Pandey, et. al., "Affordable Metalmatrix Composites For High Performance Applications" A Publication of TMS ASTM

E8-04, "Standard Test Methods for Tension Testing of Metallic Materials".ASTM E399-09 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness $K_{Ic}$ of Metallic Materials1".

[5]K.Jayakumar, et. al., "Processing and end milling behavioural study of A356-SiCp Composite" Materials Science Forum, 2012, ISSN: 1662-9752, Vol. 710, pp 338-343.

[6]K. Jayakumar, et.al., "Effect of SiCp Reinforcement on Machinability of A356 Alloy Metal Matrix Composites", Applied Mechanics and Materials, 2016, ISSN: 1662-7482, Vol. 852, pp 142-148.

[7]Mohammad M. Ranjbaran, "Experimental investigation of fracture toughness in Al 356-SiCp aluminium matrix composite", American Journal of Scientific and Industrial Research, ISSN: 2153-649X, 2010, 1(3): 549-557.

[8]M. Möser, et. al., "Fractography with the SEM (Failure Analysis)", Chapter 15 Metal Sci. 15 (1981) 154.

[9]J. Pokluda, P. Andera, "Micro-mechanisms of Fracture and Fatigue", ISBN: 978-1-84996-265-0, Chapter 2, Springer, 2010.

[10]NASA Technical Memorandum- 100745 "Fracture Toughness of SiC/Al Metal Matrix Composite" 1989.

[11]K.K. Alaneme, A.O. Aluko "Fracture toughness (K1C ) and tensile properties of as-cast and age-hardened aluminium (6063)–silicon carbide particulate composites" Scientia Iranica, Transactions A: Civil Engineering Vol.19, 2012 p.p. 992–996.

[12]Zhenzhong Chen, et. al., "The Role of Particles in Fatigue Crack Propagation of Aluminum Matrix Composites and Casting Aluminum Alloys" J. Mater. Sci. Technol., Vol.23 No.2, 2007, p.p. 213-216.

[13]K. Gall,et.al., "The influence of modified intermetallics and Si particles on fatigue crack paths in a cast A356 Al alloy" Blackwell Science Ltd. Fatigue Fract Engng Mater Struct 23, 2000, p.p.159–172.

[13]J.B. Jordon, et. al., "Microstructural Inclusion Influence on Fatigue of a Cast A356 Aluminum Alloy" Metallurgical and Materials Transactions A, Volume 41A, February 2010, p.p.356-363.

[14]W.T. Becker, "Fracture Appearance and Mechanisms of Deformation and Fracture" University of Tennessee, Emeritus; S. Lampman, ASM International. www.bzfxw.com.

[15]J. Gilbert Kaufman, "Fracture Resistance of Aluminum Alloys (#06042G) - Notch Toughness, Tear Resistance, and Fracture Toughness" The Aluminum Association, ASM International, 2001.