Fracture characteristics of Fly Ash 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:** Use of Aluminium alloys as a substitution for auto parts made of ferrous alloys, has many positive aspects such as reduction of mass, lower fuel consumption and therefore reduced pollution. Several authors proved that addition a reinforcing phase to these alloys can significantly improve the tribological properties. The fly ash that comes out as an industrial solid waste can be utilized as reinforcing agent instead of dumping. In the present work A356 alloy reinforced with fly ash in 5%, 10% and15% by weight are studied for their mechanical properties, machinability and analyzed metallographically for fracture and failure characteristics.*

***Key words:** Fly ash reinforced MMCs; cutting forces; machining properties; mechanical properties; fracture toughness; fractography.*

I.INTRODUCTION

Composite materials are formed by mixing of two or more materials or phases of the same material. The composite has completely new, different and better characteristics compared to its constituents. The components do not blend with each other nor do they get dissolved, so there is a visible difference between them. Constituent materials have significantly different physical and chemical properties that remain separate and distinct within the finished structure. Essentially, the composites consist of the base (the matrix), which forms the continuous phase and whose content is much higher in comparison to that of the other materials, and reinforcement, i.e. material with which the desired properties of composites are to be achieved. The reinforcement forms the discontinuous phase. While the reinforcing material usually carries the major amount of load, the matrix enables the load transfer by holding them together.

Aluminium has useful properties such as high strength, ductility, high thermal and electrical conductivity but has low stiffness. Fly ash, on the other hand, is stiffer and stronger and has excellent high temperature resistance but is brittle in nature.

Fly ash usually refers to ash produced during combustion of coal and is captured by electrostatic precipitators It is one of the most inexpensive and low density reinforcements available in large quantities as solid waste by-product during combustion of coal in thermal power plants.

In the present study, A 356 with the theoretic density of 2760 kg/m^3 was used as a matrix material. Fly ash particulates with an average size of 25µm are used as reinforcement material. Magnesium was selected as a wetting agent to improve wettability between the matrix and the reinforcements during production of the composites.

II.EXPERIMENTAL METHODS

Fly Ash is added as reinforcement in proportions (5%, 10% and 15% by weight) to A356 alloy. The process used for production is stir casting technique.

2.0 Composite fabrication: A356 Aluminium alloy charge was melted in graphite crucible at 700 $\pm$ 20^{0}C stir casting machine (Figure 1). The reinforcement fly ash was preheated to remove moisture at 800ºC for 1 h before it was incorporated into the melt. A degassing tablet (coverall powder) was added to reduce the porosity. To enhance the wettability between the matrix and the reinforcements 1% magnesium by weight was added to the melt. The molten metal was stirred at the speed of 700 rpm with multi bladed stirrer made up of stainless steel coated with ceramic. The preheated fly ash particles were introduced into the molten metal at a constant rate. The stirring was continued for 10 more minutes after the completion of particle feeding. The melt mixture was allowed to maintain at 700ºC after this stage for 10 minutes without stirring and then was poured into the mould preheated at 500ºC for 30 min to obtain uniform solidification. T6 treatment was given to the cast test specimens following homogenization at 200^0 C for 20 hrs. The cycle of T6 heat treatment process is carried out by solutionizing for 8 h at (535±5)^{0}C and then quenched in water at ambient temperature and finally artificially aged at 180 °C for 6 h followed by air cooling.

Figure 1: Stir casting machine

2.1 Tensile Tests: Tensile tests were conducted at BDL laboratory in accordance to ASTM E8 standard specifications on Ø 12.5 mm cylindrical specimens. A 400 kN Instron make UTM (Figure 2) was used for experimentation. The ram speed 10 mm/min was maintained during the test.

Figure 2: 400 kN Instron make UTM

2.2 Cutting Force Measurements: Kistler's make tool dynamometer (Figure 3) was used for measurement of cutting forces were measured on facility at GITAM University.

Figure 3: Tool Dynamometer set-up

2.3 Fracture Toughness Tests: The newly commissioned 400 kN Instron Make fatigue testing machine (Figure 4) at GITAM University was used for conducting fracture toughness tests on SENB specimens according to ASTM E399.

Figure 4: Fracture toughness experiment on 100 kN Instron Fatigue Testing Machine with SENB specimen

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

III. RESULTS AND DISCUSSION

A considerable amount work has been reported on the properties and characterization of fly ash reinforced A356 alloy literature. But the evidence of fracture toughness are not found. In the present work an attempt is made to study and characterize these properties.

3.1 Mechanical properties: The yield and ultimate strengths of the composite were plotted against fly ash reinforcement in figure 5. A slight increase in the ultimate strength was observed initially till 10% fly ash addition and a slight decrease beyond. The yield strength increased continuously with particle reinforcement. The Young's showed pattern similar to yield strength (figure 6) as it is the measure of elastic deformation of tension test. In contrast to yield strength, the percentage elongation decreased with fly ash (figure 7).

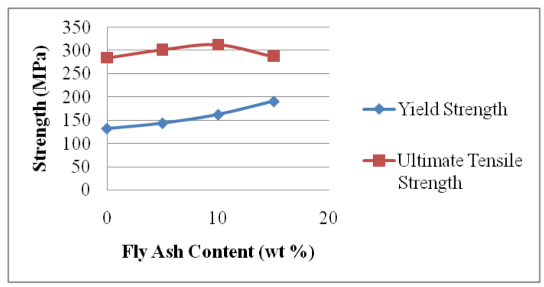


Figure 5: Variation of Strength with Fly Ash content

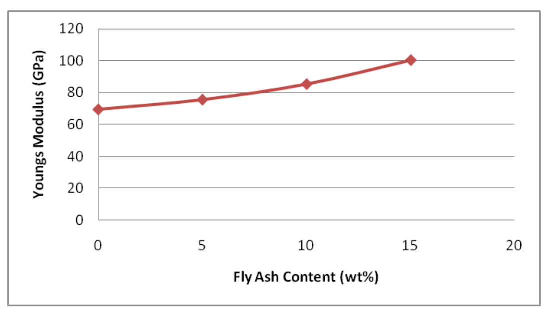


Figure 6: Variation of Young's Modulus with Fly Ash content

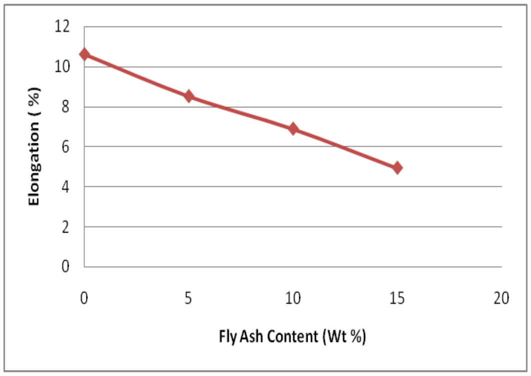
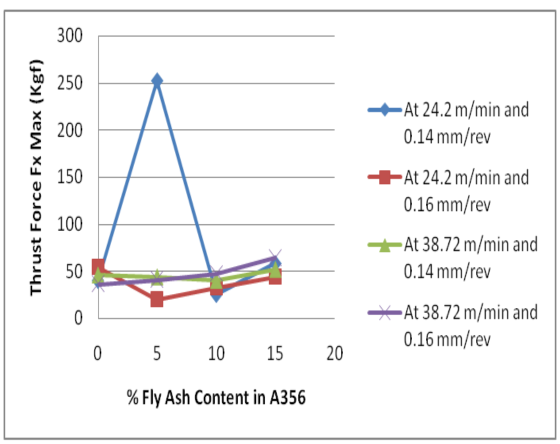


Figure 7: Variation of Elongation with Fly Ash content

3.2 Machining Properties: Three components of machining forces during oblique turning process using HSS tool with 20-15-12-10-5-5-1 signature. The approach angle selected is 70^0. The parameters used in cutting were cutting speed = 24.2 m/min (rpm = 350) & 38.72 m/min (rpm = 560), Feed = 0.14 & 0.16 mm/rev, depth of cut = 2 mm, diameter = 22 mm and length of turning = 140 mm respectively. The figures 8 through 10 depict the variation of maximum thrust, feed and radial force with wt% of fly ash reinforced. The maximum power consumption Vs. fly ash content is plotted in figure 11. Except few abnormalities, in most of the cases these cutting forces and power requirements reduced with increase in fly ash content to 10% and increased beyond this extent.



3.3 Plain Strain Fracture Toughness: The K_{IC} tests were conducted using 100 kN Instron make fatigue testing machine on single edge notched bend (SENB) specimen as shown in figure 12. The dimensions were selected as permitted by ASTM E399 and the availability of casting dies. The specimen dimensions are B = 8 mm, W = 32 mm, Span = 70 mm and notch depth = 1.5 mm. The pre-cracking was limited to a = 2 mm.

Figure 8: Variation of Maximum Thrust Force with Fly Ash content

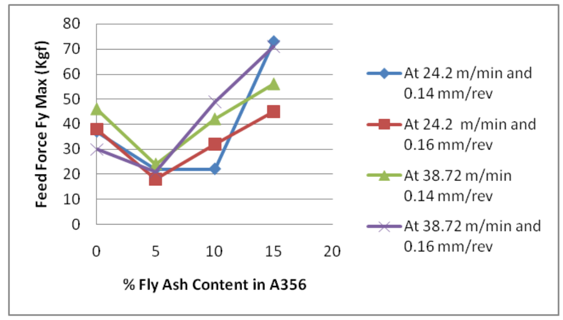


Figure 9: Variation of Maximum Feed Force with Fly Ash content

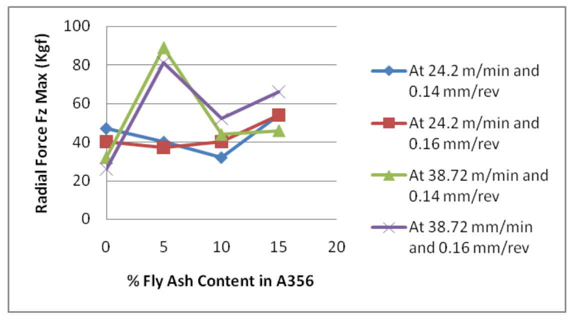


Figure 10: Variation of Maximum Radial force with Fly Ash content

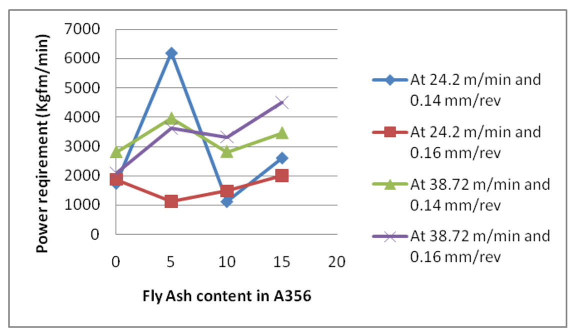


Figure 11: Variation of Maximum power requirement with Fly Ash content

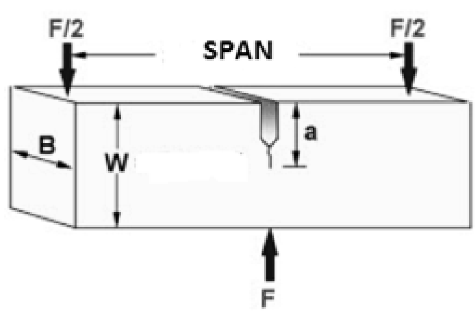


Figure 12: Single Edge Notched Bend (SENB) specimen

The variation of plain strain fracture toughness (K_{IC}) values for composites Vs. fly ash content were plotted in figure 13. A considerable drop was observed with addition of fly ash reinforcement in the begining. Further increase in our experimental range had no effect.

3.4 Fractography: The SEM studies of fractographs taken in various locations for these composites after fracturing. The analysis is tabulated in table 1 through 5. The first location termed as zone-I is the zone of pre-cracking; the second location is termed as zone-II is the immediate neighborhood of pre-crack in the direction of crack propagation; the third zone is transition zone and indicated as zone-III; next to it is zone-IV, the transgranular cleavage region followed by zone-V, the intra granular cleavage region. The magnification used was $X10^5$.

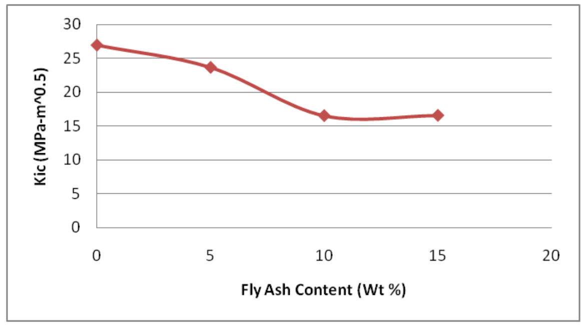
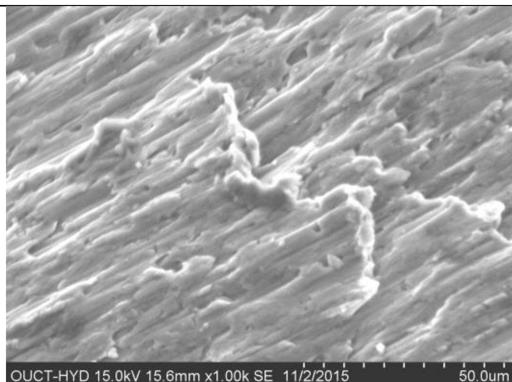
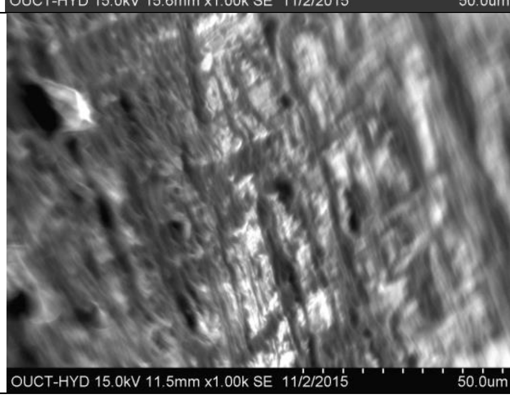


Figure 13: Variation of Plain Strain Fracture toughness with Fly Ash content

Table 1: SEM fractographs of Zone-I

Composite	Image	Prediction
Monolithic A356		Fatigue intrusions and protrusions associated with pre-cracking.
A356 + 5% Fly Ash		Fatigue intrusions and protrusions associated with pre-cracking. The fly ash particles are seen.

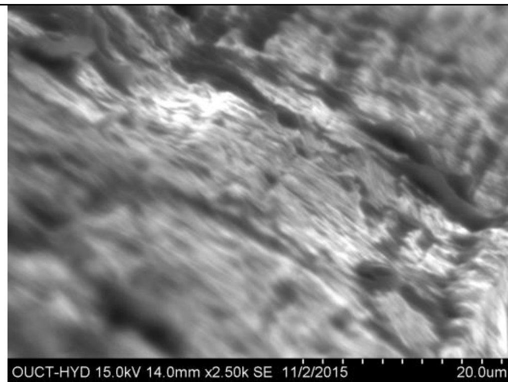
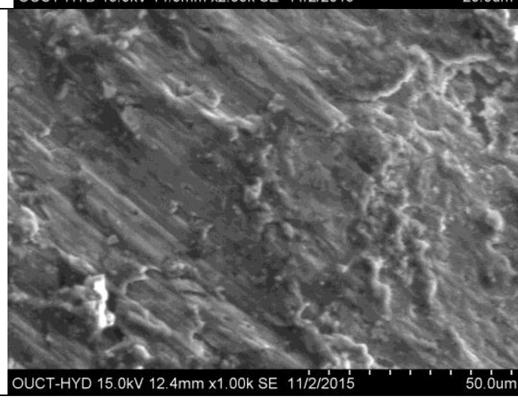
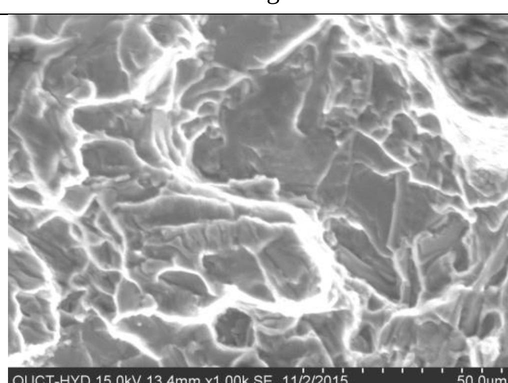
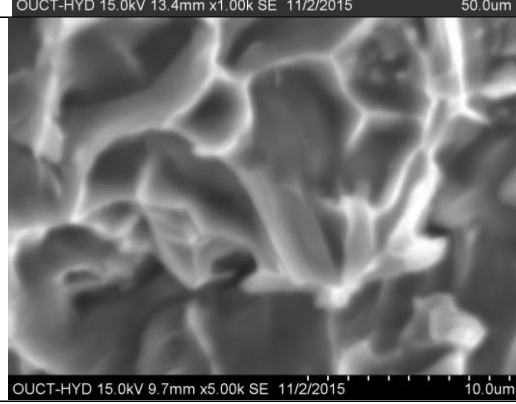
A356 + 10 % Fly Ash		Appearance of dimple formation in fatigue pre-cracking region.
A356 + 15% Fly Ash		Fly ash particles embedded in matrix with fatigue micro striations

Table 2: SEM fractographs of Zone-II

Composite	Image	Prediction
Monolithic A356		Stable crack growth appears surrounding the micro pores.
A356 + 5% Fly Ash		Stable crack growth in the vicinity of reinforcement interface.

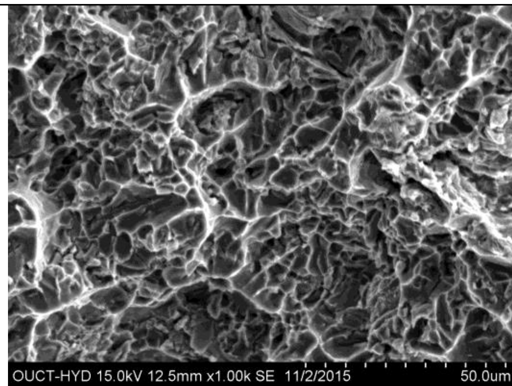
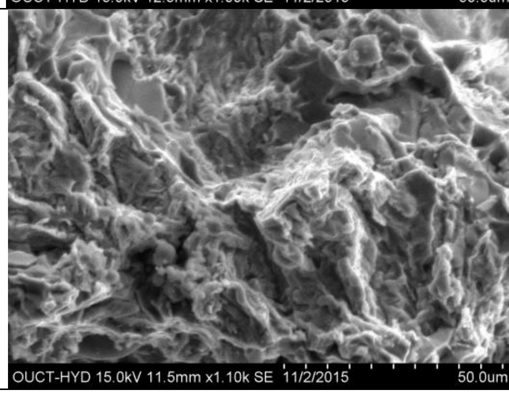
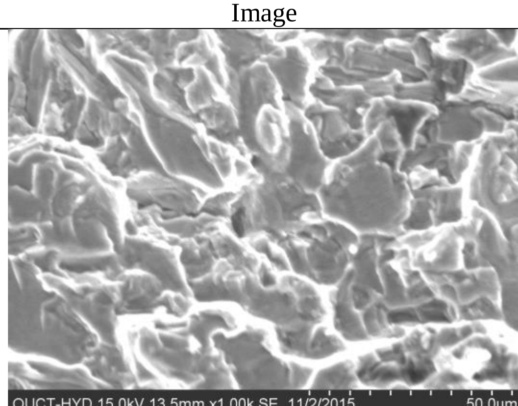
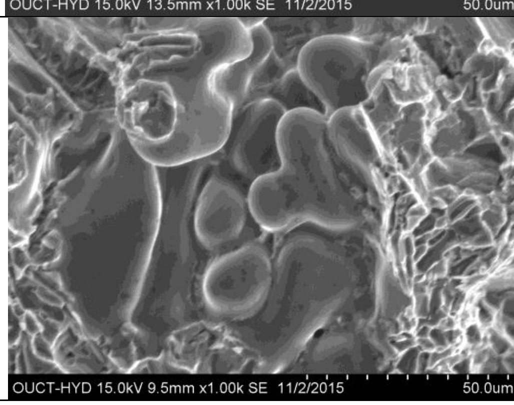
A356 + 10 % Fly Ash		Stable crack growth due to many interfaces at higher fly ash content.
A356 + 15% Fly Ash		Stable crack growth at reinforcement interface. Large size micro cracks are associated with particle agglomeration due to very high reinforcement.

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% Fly Ash		In this zone the failure mode is in transition from ductile mode to brittle mode.

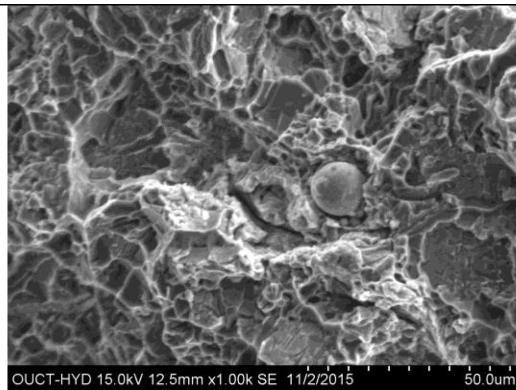
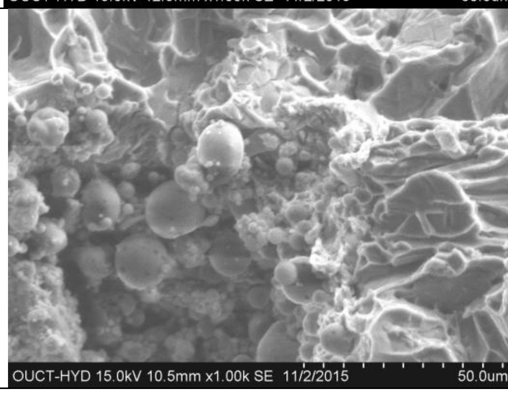
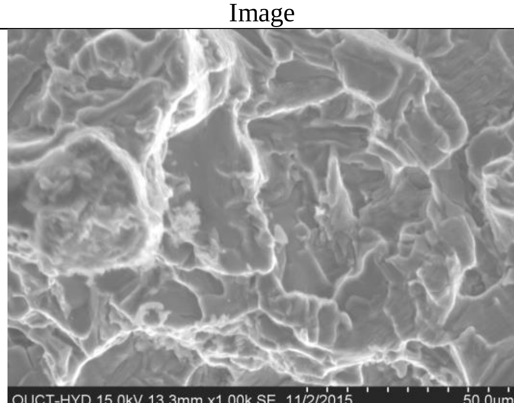
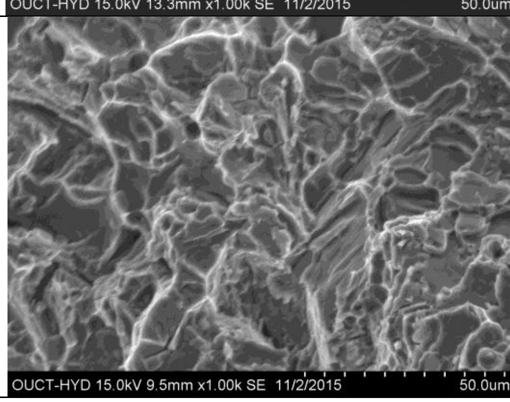
A356 + 10 % Fly Ash		In this zone the failure mode is in transition from ductile mode to brittle mode.
A356 + 15% SiC		In this zone the failure mode is in transition from ductile mode to brittle mode.

Table 4: SEM fractographs captured in Zone-IV

Composite	Image	Prediction
Monolithic A356		This Zone is visualized by trans-granular cleavage.
A356 + 5% Fly Ash		This Zone is visualized by trans-granular cleavage.

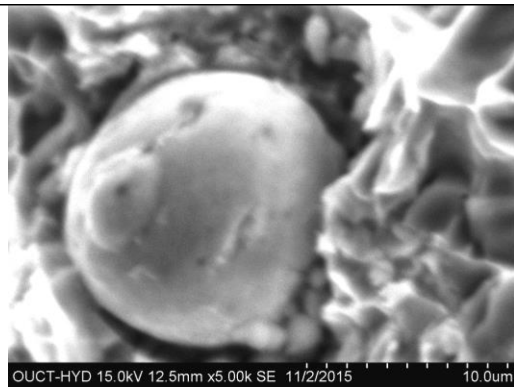
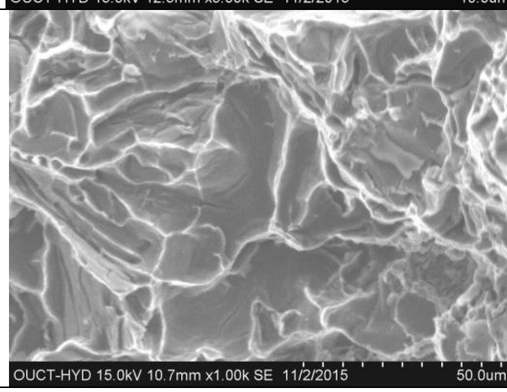
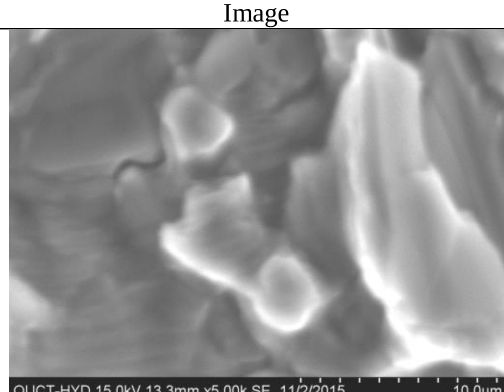
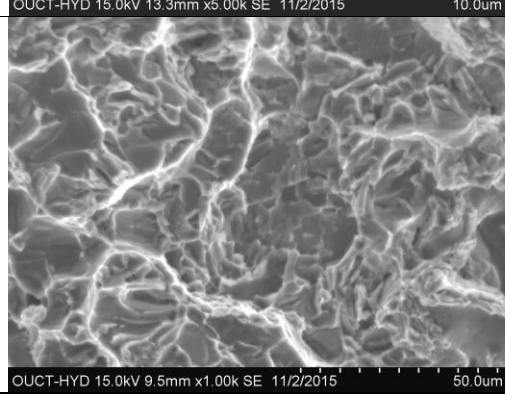
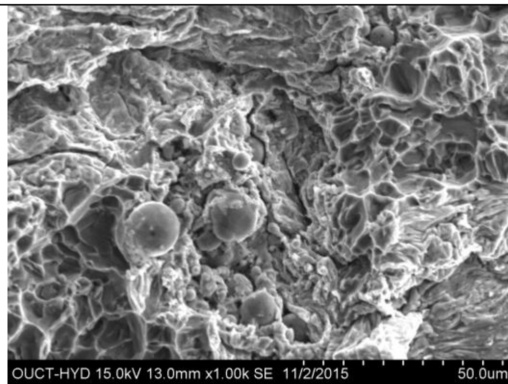
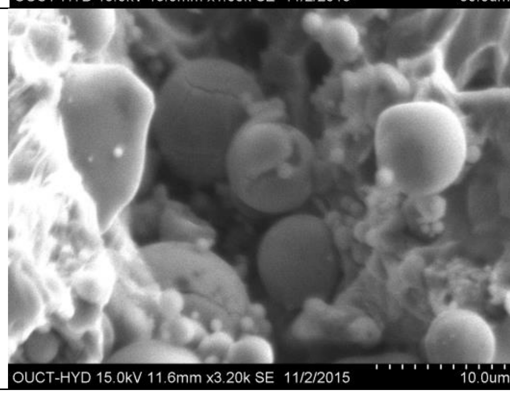
A356 + 10 % Fly Ash		This Zone is visualized by transgranular cleavage.
A356 + 15% Fly Ash		This Zone is visualized by trans-granular cleavage.

Table 5: SEM fractographs captured in Zone-V

Composite	Image	Prediction
Monolithic A356		The highly fractured rough surface in brittle zone of inter-granular.
A356 + 5% Fly Ash		The highly fractured rough surface in brittle zone of inter-granular.

A356 + 10 % Fly Ash		The highly fractured rough surface in brittle zone of inter-granular.
A356 + 15% Fly Ash		The highly fractured rough surface in brittle zone of inter-granular.

IV.CONCLUSIONS

The machining and fracture characteristics of fly ash reinforced A356 alloy samples with varying reinforcement content were studied after successfully fabricating. Addition 5 to 10% of fly ash by weight as reinforcement had lead to better machining properties. Further advantage was not gained with higher addition. The mechanical properties such as yield stress, ultimate stress too had similar effect. The major loss in ductility and K_{IC} values has occurred with addition of fly ash between 5 to 10% by weight. Further addition had not worsened these properties. The best machinability and optimum mechanical properties were achieved with addition of 5 to 10% fly ash reinforcement to A356 alloy.

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

References:

[1] Nilesh S. Zagade, "Study of Mechanical Behaviour of Aluminium Matrix Composite by Analytical and Experimental Approach" International Engineering Research Journal (IERJ) Special Issue 2 Page 1150-1154, 2015, ISSN 2395-1621.

[2] Grigorios Itskos, et. al., "Pressure Infiltration Technique for the Synthesis of A356 Al/Fly Ash Composites", World of Coal Ash (WOCA) conference, May 9-12, 2011, Denver, CO, USA.

[3] S. G. Kulkarni, J. V. Meghani, Achche lal, "Effect of fly ash Hybrid Reinforcement on Mechanical Property and Density of Aluminium 356 Alloy" Procedia Material Science 5(2014) 746 – 754.

[4] Ajit Bhandakkar, R. C. Prasad, Shankar M. L. Sastry, "Elastic Plastic fracture toughness of aluminium alloy AA6061 fly ash composites" Adv. Mat. Lett. 2014, 5(9), 525-530.

[5] Ajay Singh Varma, N. M. Suri and Suman Kant, Effect of Process parameter of AL – 6063 based fly ash composites using Taguchi" International Journal of Applied Engineering Research, ISSN 0973 – 4562 Vol. 7 No. 11 (2012)

[6] Shuvendu Tripathy, "Studies on Aluminium – Fly ash Composite Produced by Impeller Mixing" 2009

[7] Abhijit Dey and Krishna Murari Pandey, "Characterization of Fly ash and its Reinforcement Effect on Metal Matrix Composites: A Review" Rev. Adv. Mater. Sci. 44 (2016) 168-181.

[8] Grigorios itskos, et. Al., "Incorporation of High – Ca Fly ash Particles into A356 Al by stir casting Technique and Characterization of the Fabricated Composites" World of Coal Ash (WOCA) Conference – May – 9-12, 2011 in Denver, CO, USA.

[9] H. C. Anil Kumar, H. S. Hebbar and K. S. Ravi Shankar, "Mechanical Properties of Fly Ash Reinforced Alluminium alloy (A16061) Composites.

[10] Ajit Bhandakkar, R. C. Prasad, Shankar M. L. Sastry,

"Fracture Toughness of AA2024 Aluminium Fly ash metal Matrix Composties" International Journal of Composite Materials 2014, 4 (2): 108 – 124.
[11] Grigorios Itskos, et. al., "Incorporation of High – Ca Fly ash Particles into A356 AL by Stir Casting Technique and Characterization of the Fabricated Composites" World of Coal Ash (WOCA) Conference, May – 9- 12, 2011, Denver, CO, USA.
[12] J. Babu Rao, D. Venkata Rao and N. R. M. R. Bhargava, "Development of light weight ALFA composites" International Journal of Engineering, Science and Technology Vol. 2, No. 11, 2010, pp. 50 – 59.
[13]Ajit Kumar Senapati, Purnachandra Mishra, Bharat Chandra Routara, "Use of Waste Fly Ash in Fabrication of Aluminium Alloy Matrix Composites" International Journal of Engineering and Technology.
[14] Hanumanthe Gowda, P. Rajendra Prasad, "Evaluation of Mechanical Properties of A356 Alloy Based Hybrid Composite at Different Aging Conditions" International Journal of Science and Research Publications, Volume 6, Issue 8, August, 2016 ISSN 2250 – 3153.
[15] D. P. Mondal, et. Al., "High Temperature compressive deformation behavior of aluminium syntactic foam" Material Science and Engineering A 534 (2012) 521 – 529.
[16] P. K. Rohatgi, D. Weiss and Nikhil Gupta, " Applications of Fly Ash in Synthesizing Low – cost MMCs for Automotive and other Applicant" Low cost composites in vehicle manufacture.
[17] Gowri Shankar M. C. et. Al., "Individual and combined Effect of Reinforcements on Stir Cast Aluminium Metal Matrix Composites A – Review" International Journal of Current Engineering and Technology ISSN 2277 – 4106.
[18] T. P. D. Rajan, et. Al., "Fabrication and characterization of AL – 7si – 0.35Mg / fly ash metal matrix composites processed by different stir casting routes" Composites Science and Technology 67 (2007) 3369 – 3377.
[19] P. K. Rohatgi, et. Al., "Friction and Abrasion Resistance of Cast Alluminium alloy – Fly ash Composites"
[20] A. Thirugnanam, et. Al., "Micro structural aspects and fracture behavior of A356 / 357 Alloys an overview" Trans. Indian Inst. Met. Vol. No. 58, No. 5, October 2005, pp. 777 – 787.