Characterization of High performance Al 5083/SiC_P/Fly ash hybrid metal matrix composite for advanced Aerospace Applications

Dr U N Kempaiah [1], Santhosh N [2], D Harshith Kumar [3], Amogh H Chelgeri [4],Vishnu P[5], Siddhesh Raorane[6]

[1] Professor, Department of Mechanical Engineering, UVCE, Bangalore University, Bangalore.

[2] Assistant Professor, Department of Aeronautical Engineering, NMIT, Bangalore.

[3, 4] U G Student, Department of Mechanical Engineering, Brindavan College of Engineering, Bangalore.

[5,6] U G Student, Department of Aeronautical Engineering, NMIT, Bangalore

Abstract- **The present work involves the development of hybrid Metal Matrix Composite materials by combining the desirable attributes of Metals, Ceramics and Industrial waste. Usually, when at least two reinforcement phases are present, it is called a hybrid composite and our work predominantly concentrates on characterization of these hybrid composite materials. Aluminium Metal Matrix Composites with Silicon carbide particle reinforcements are finding increased applications in aerospace, automobile and underwater vehicles. In the present work, Aluminum 5083 is used as the matrix material into which SiC_P and fly ash are added as the reinforced material. The results of an experimental investigation of the mechanical properties of reinforced aluminum alloy (Al 5083) composites samples, processed by stir casting route are reported in this paper. Each set chosen for our work had three types of composite samples with 3, 5 and 7% of Silicon carbide and 2% of Fly ash that was kept constant throughout. A graphite crucible and a cast iron permanent mould were used to prepare the samples. The mechanical properties studied were the tensile strength, compressive strength, ductility and hardness. It was found that the tensile strength, compressive strength and hardness of the aluminum alloy (Al 5083) composites increased with the increase in weight fraction of reinforced silicon carbide up to 5% SiCp and gradually decreased with further increase in weight fraction of reinforcement. Morphology of the composite and particle distribution were investigated by optical microscopy and scanning electron micrographs.**

Keywords: **Aluminum alloy (Al 5083), Fly ash, Hybrid Metal Matrix Composites, Mechanical properties. Silicon Carbide (SiCp).**

1. INTRODUCTION

A composite material is a ‘material system’ composed of a combination of two or more micro or macro constituents that differ in form, chemical composition and which are essentially insoluble in each other [1].One constituent is called as Matrix Phase and the other is called reinforcing phase. Reinforcing phase is embedded in the matrix to give the desired characteristics .The addition of high strength, high modulus refractory particles to a ductile metal matrix produces a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metal matrix composites (MMCs) are the forerunners amongst different classes of composites. Over the past two decades, Metal Matrix Composites (MMCs) have been transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance. MMCs offer a unique balance of physical and mechanical properties. It is well known that the elastic properties of the metal matrix composites are strongly influenced by micro-structural parameters of the reinforcement such as shape, size, orientation, distribution and volume or weight fraction [2]. Among the variety of manufacturing processes available for processing of discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product [3].

5XXX series Aluminium alloy contain high percentage of magnesium in HCP structure at 650^{O}C. Magnesium acts as strengthening agent, improves wettability of aluminium and has high corrosion resistant properties [4]. The challenges and opportunities of aluminium matrix composites have been reported much better to that of its unreinforced counterpart. The addition of reinforcing phase significantly improves the tribological properties of aluminium and its alloy system. The thinking behind the development of hybrid metal matrix composites is to combine the desirable properties of Aluminium, silicon carbide and fly ash. Aluminium have useful properties such as high strength, ductility, high thermal and electrical conductivity but have low stiffness, whereas silicon carbide and fly ash are stiffer and stronger and have excellent high temperature resistance but they are brittle in nature. Silicon carbide particulates have attained a prime position among the various discontinuous dispersoids available for the synthesis of MMC. This is due to the fact that introduction of SiC particulates to the aluminium matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. The density of SiC_P (3.2 g/cm^3) is nearer to that of aluminium alloy AA6061 (2.7g/cm^3). The resistance of SiC Particulates to acids, alkalis or molten salts up to 800 degree Celsius makes it a good reinforcement candidate for aluminium based MMC. Furthermore, SiC_P is easily available and has good wettability with aluminium alloys [5].

The coal combustion waste product fly ash produced by thermal power plants, is an increasingly urgent problem associated with their storage and disposal. On the other hand, fly ash presents a unique natural source of the particulate material for light-weight low-cost composites. This is because of the combination of its low price along with low density, attractive physical and mechanical properties, and advantageous spherical shape, which is very expensive to produce it in an artificial way. Therefore, information on the reactivity of fly ash with different molten metal's is of high practical importance [6].

2. MATERIAL AND METHODS

2.1 Procurement of Material

Required amount of 99.9 % pure metallurgical grade Al 5083 alloy in billet form were procured from PMC Metal Corporation and cut into small pieces for the convenience of melting it in the graphite crucible of stir casting furnace.

Particulates of silicon carbide of 15 microns size were procured from Snam abrasives and particle size was predetermined by particle size analyzer.

C-type fly ash was procured from KPCL Thermal power plant at Yermarus, Raichur District.

2.2 Fixing the Proportions of Constituent Elements

From extensive literature survey and thorough evaluation of earlier statistical charts, the proportion of constituents was fixed for preparing the composites and evaluating its characteristics.

The compositions of different constituents are as shown in the table – 1 below

SAMPLE	I	II	III
Al 5083	95 %	93 %	91 %
SiCp	3 %	5 %	7 %
Fly ash	2 %	2 %	2 %
Total	100 %	100 %	100 %

Table 1: Gives the different proportions of Composites

2.3 Fabrication of composites

Composites were fabricated in electrical resistance furnace fitted with vortex generator that is colloquially referred to as stir casting furnace. The graphite crucible was loaded with calculated quantity of Al 5083 alloy and the temperature was maintained at 850^{o}C which is 200^{o}C more than the melting temperature of Al 5083 alloy.

After molten state of Al 5083 alloy was obtained, effective degasification was carried out by adding hexachloroethane (C_2Cl_6). The slag formed on the surface of molten metal was scooped out. This pure form of molten metal was reinforced with preheated mixture of Silicon carbide and fly ash. The extent of introduction of weighted quantity of the preheated reinforcement particles in the molten alloy was achieved by constant stirring of the mixture using a vortex generator. I.e. Total amount of reinforcements required was calculated and introduced into melt in 3 stages rather than introducing all at once to ensure good wet ability of particles with the molten alloy. At every stage, before and after introduction of reinforcement particles, mechanical stirring of the molten alloy for a period of 20 minutes was achieved by using zirconium-coated steel impeller. The stirrer was preheated before immersing into the melt, located approximately to the depth of 2/3 height of the molten metal from the bottom and run at a speed of 400rpm. The molten metal matrix composite was poured into the mould cavity. This mould was preheated to about 400^{o}C so as to minimize the casting defects. The casting rods obtained had diameter of 22 mm and length of 220 mm.

2.4 Specimen preparation

The specimens were prepared according to ASTM standards. The tensile test was conducted on these samples according to ASTM E8-95 standards at room temperature, using a Universal Testing Machine (INSTRON). The specimens used were of diameter 12.5 mm and gauge length 62.5 mm, machined from the cast composites with the gauge length of the specimen parallel to the longitudinal axis of the casting. The compression test was conducted as per ASTM E9 Standards. The specimens used for compression tests were of diameter 15mm and length 20mm machined from cast composites. The Brinell hardness test was conducted in accordance with the ASTM E10 standards. Impact specimen was cut as per ASTM-E23 standards by diamond blade using CNC machine. The wear test was conducted as per ASTM G99 standards. The specimen used for wear tests was of diameter 8 mm and length 32mm.

3. EXPERIMENTAL TESTS

3.1 Microstructure

The performance of the composite is highly influenced by its microstructure. The physical properties depend on the microstructure, reinforcement particle size, shape and distribution in the alloy. The Distribution of reinforcement phase in the matrix phase was examined using optical microscope and scanning electron microscope. The micrograph shown in figures distinctly give a fair bit of idea of the extent of reinforcements getting dispersed in the aluminium 5083 matrix.

3.2 Optical Microscopy

Samples of small size approximately 5 to 8 mm thickness are used for micro structural examination under optical microscopy. Samples were mounted using cold mounting acrylic resin and allowed to set. The surface preparation was done by successively grinding the specimens on 1/0, 2/0, 3/0 and 4/0 emery papers for getting a flat surface. Further the ground sample was polished on velvet cloth using Alumina suspension and final polish was given using diamond paste on special velvet cloth meant for diamond polish to obtain a mirror finish. Etching was carried out on the samples with the following Keller‘s etchant.

$$2ml\ HF + 10ml\ HNO_3 + 20ml\ H_2O$$

The surface of the specimen is swabbed for a few seconds until the shining surface turns to a dull finish. The specimen is immediately washed with water, then surface treated with a drop or two of ethanol and then dried. The sample is placed on specimen support of the optical microscope (Dewinters) and structures studied at suitable magnifications and images grabbed.

The same procedure is repeated for the other samples to view and capture the microstructures and study for the dispersions of silicon carbide and fly ash in the Aluminium matrix phase .

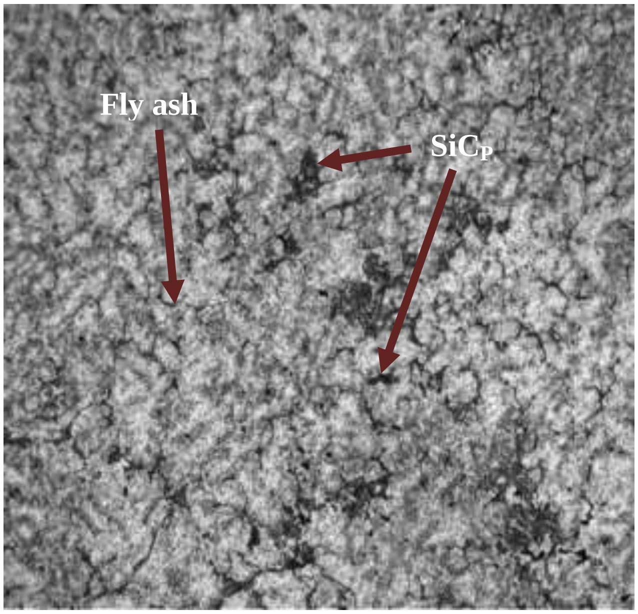

Figure 1: Microstructure of Al 5083 with 3% SiCp(15µm)and 2% Fly ash

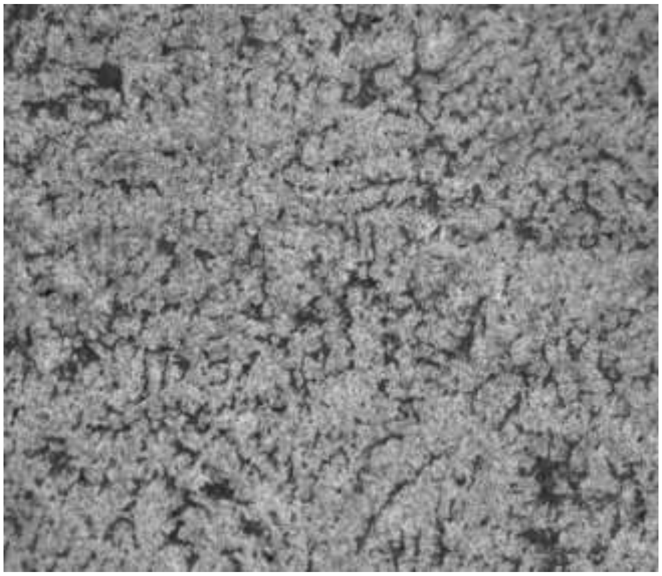

Figure 2 : Microstructure of Al 5083 with 5% SiCp(15µm) and 2% Fly ash

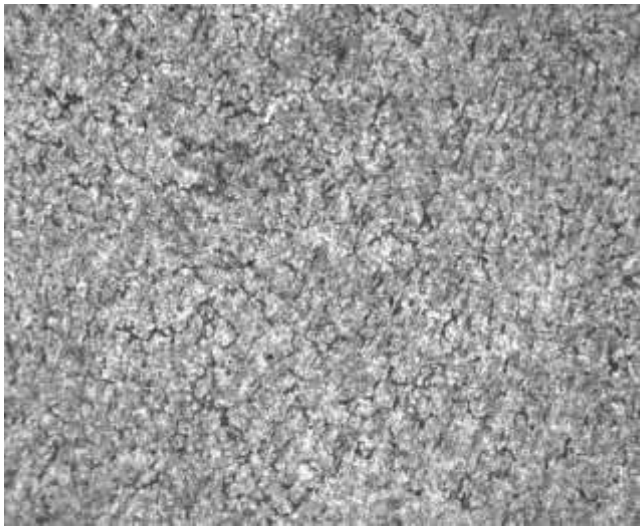

Figure 3 : Microstructure of Al 5083 with 7% SiCp(15µm) and 2% Fly ash

It is observed from above figures that there is a fairly uniform distribution of the reinforcing phase in the matrix alloy, with quite a few agglomerations. Further it is observed that the size of the grain has reduced with increase in the percentage of the reinforcing phases. This can be attributed to the fact that fly ash of some extent acts as a grain refiner.

3.3 Scanning Electron Microscopy

SEM on the samples was carried out on the S-3400N Hitachi scanning electron microscope. Samples were polished on emery papers and cloth and etched using the standard etchants similar to the optical microscopy. The instrument had a resolution of 3nm at 30KV. The instrument used both the principle of secondary electron detection and back-scattered electron detection. The samples were loaded in the proper sequence and the specimen chamber closed. SEM pictures at suitable magnifications are taken.

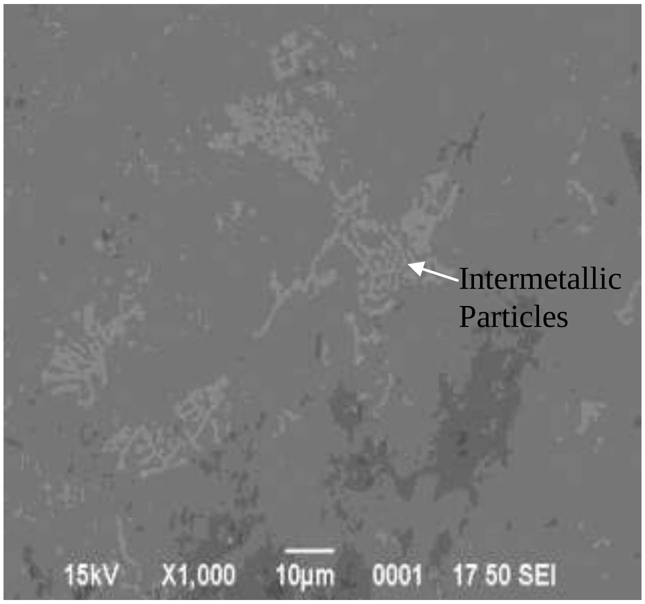

Figure 4: SEM Image of Al 5083 with 3% SiCp (15µm) and 2% Fly ash.

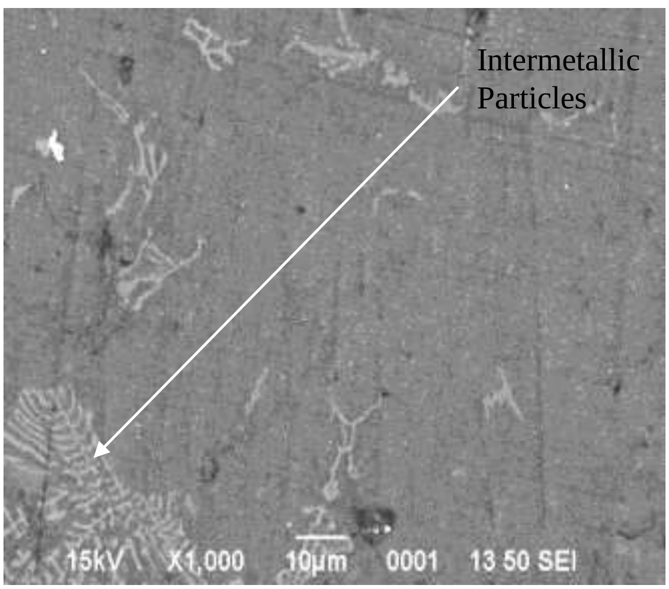

Figure 5: SEM Image of Al 5083 with 5% SiCp (15µm)and 2% Fly ash

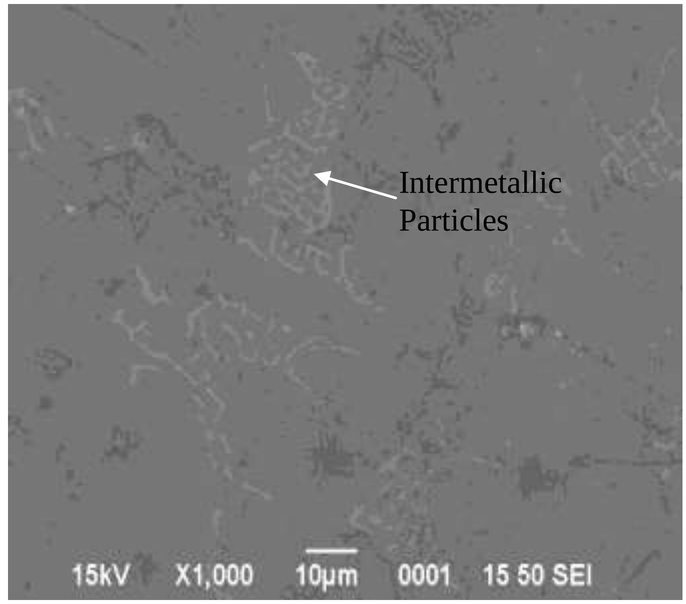

Figure 6: SEM Image of Al 5083 with 7% SiCp (15µm) and 2% Fly ash

The above SEM micrographs from fig 4 to fig 6 shows formation of intermallic partiles formed due to reaction between silicon carbide and fly ash .

3.2 Hardness

Brinell hardness test was carried out on Al 5083 SiC, Fly Ash composites and average of three reading for each specimen was calculated and reported. Fig 7 shows the variation of Brinell hardness number with respect to different percentage of reinforcement. Al 5083 reinforced with 5% SiC shows greater Brinell hardness number compared to Al 5083 (3% SiC+ 2% Fly Ash). As the reinforcement percentage has increased Brinell hardness number has increased up to 5% SiC Composition Composite beyond which it decreases for Al (7% SiC).

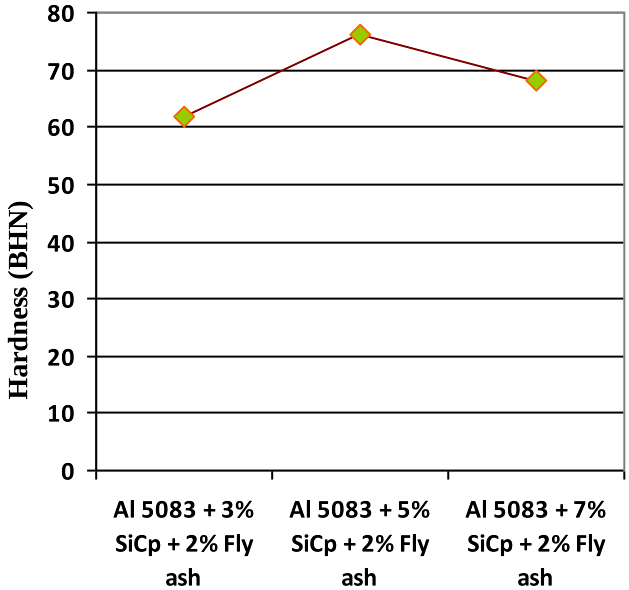

Figure 7: variation of hardness with the weight fraction of Silicon carbide and fly ash.

3.3 Tensile test

Tensile testing, also known as tension testing is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Figure shows the variation of ultimate tensile strength of the hybrid metal matrix composite with the different weight fraction of Silicon carbide particles. It can be noted that the tensile strength increases with the increase in the weight fraction of the silicon carbide up to 5% Weight due to increase in hardness. The decrease in the tensile strength of the samples with further increase in weight percentage of silicon carbide is due to the poor wet ability.

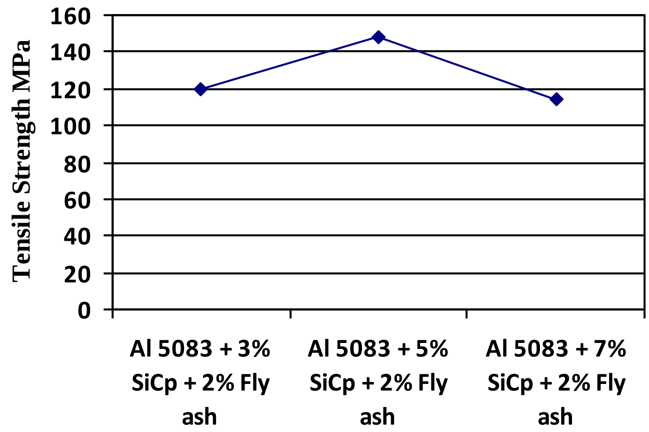

Figure 8: variation of ultimate tensile strength with the weight fraction of Silicon carbide and fly ash.

3.4 Compression test

A compression test determines behaviour of materials under crushing loads. From the fig 9, it can be observed that the compressive strength increased with an increase in the weight fraction of the silicon carbide with constant weight fraction of fly ash upto 5% wt of SiCp. This is due to the hardening of the base alloy by the fly ash particles. The decrease in the compressive strength was observed as the silicon carbide wt% increased beyond 5 percent .

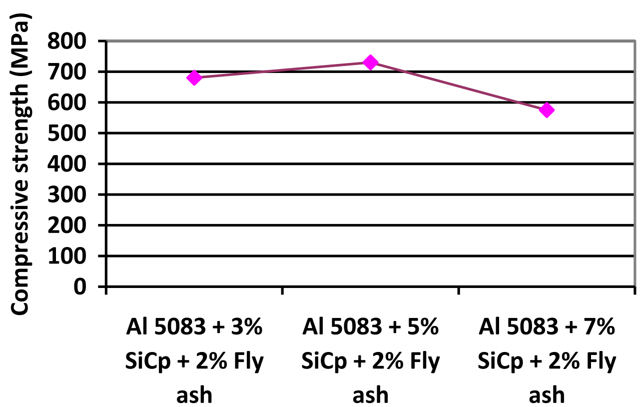

Figure 9: shows variation of compressive strength with the weight fraction of Silicon carbide and fly ash.

3.5 Impact test

The result of the Charpy impact energy for Al 5083 metal matrix composite reinforced with (3%, 5%, 7% SiC) and 2% Fly ash are tabulated in Figure 10.

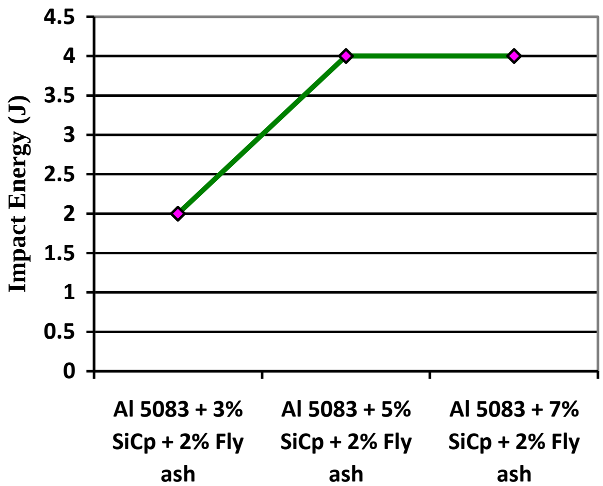

Figure 10: shows variation of Impact energy with the weight fraction of Silicon carbide and fly ash.

From Figure 10, it can be distinctly concluded that maximum charpy impact energy is observed for Al 5083(5% SiC + 2% Fly ash) and Al 5083(7% SiC + 2% Fly ash).It has been observed that the impact strength increases with increase in % wt of SiCp in the metal matrix because the hardness of the composite material will decrease by increasing impact load absorption capacity.

3.6 Wear behavior

Sliding wear behaviour of composite is as ahown in fig 11 and fig 12. As shown in figure, the composite with 3% Sicp and 2% fly ash the wear increases uniformly with increase in load from 60 microns to 109 microns and corresponding friction force also increases gradually with increase in load from 20 N to 50 N. The wear increases uniformly with increase in load from 42 microns to 106 microns for 5% sicp composite and corresponding friction force also increases gradually with increase in load from 20 N to 50 N, however the wear has come down as compared to 3% SiCp due to the addition of Silicon carbide which makes it hard to wear out. The wear increases uniformly with increase in load from 27 microns to 83 microns and corresponding friction force also increases gradually with increase in load from 20 N to 50 N, however the friction force has come down with increasing speed and it gradually increases with the increase in percentage of silicon carbide particulates from 3% to 7% since addition of silicon carbide particulates makes it hard to wear out the sample.

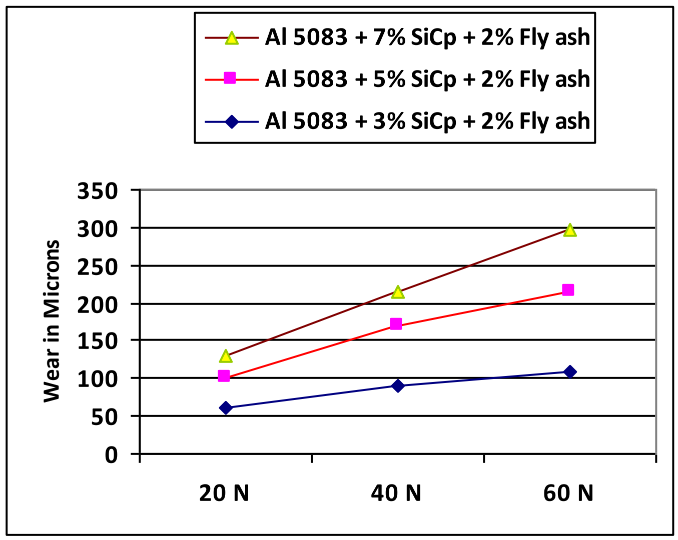

Figure 11: shows variation of wear for varying load with the weight fraction of Silicon carbide and fly ash.

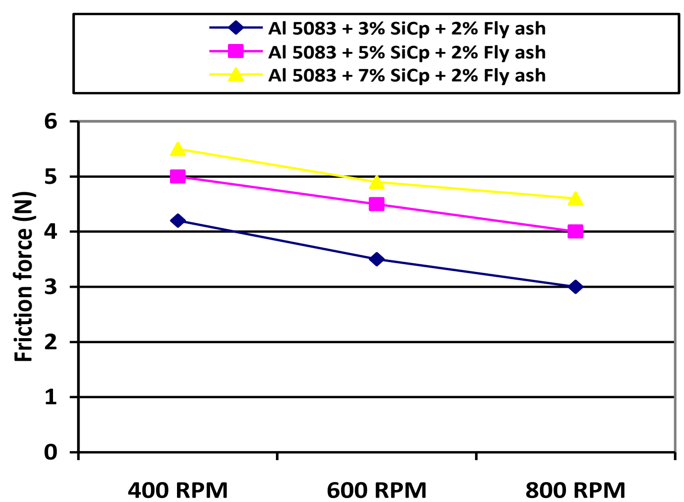

Figure 12: shows variation of friction force for varying speed with the weight fraction of Silicon carbide and fly ash.

CONCLUSION

- The hardness of the high performance hybrid MMCs increases linearly with increasing the weight fraction of SiC particulates up to 5% beyond which it decreases.
- The tensile strength of the hybrid composites increases on increasing the weight fraction of Silicon carbide particulates up to 5% beyond which it decreases since addition of silicon carbide after certain limit increases brittleness of the material.
- The yield strength of the hybridized Aluminium Metal matrix composites with fixed weight fraction of fly ash and varying weight fraction of Silicon carbide increases with Increase in the weight fraction of silicon carbide up to 5% beyond which it decreases drastically due to the phenomenon of embrittlement of the material with increased Addition of Silicon carbide particles.
- The compression strength of the hybrid composites increases initially with the addition of silicon carbide particulates up to 5% but decreases substantially beyond 5% due to increases addition of silicon carbide.
- Micro structural observation suggests that electromagnetic stirring action produces cast high performance hybrid Aluminium 5083/Fly ash/SiCp MMC with smaller grain size and there is a good particulate matrix interface bonding.
- The wear in general decreases with increase in the percentage addition of Silicon Carbide Since it makes the composite harder.
- The friction force increases with increase in load but decreases with increase in speed of rotation of the abrasive disc.
- The wear characteristics from the tabulated data show that there is decrease in wear of the hybrid composites with increase in the composition of silicon carbide given that fly ash composition remains constant.

REFERENCES

[1]Sajjadi SA, Ezatpour HR, Beygi H. “Microstructure and mechanical properties of Al–Al2O3 micro and nanocomposites fabricated by stir casting”. In: Proceedings of 14th national conference on Materials Science and Engineering, Tehran, Iran; 2010. pp.325.

[2]Suresh, S.Venkateswaran, S.Seetharamu, “Influence of cenospheres of fly ash on the mechanical properties and wear of permanent moulded eutectic Al-Si alloys,” materials Science-Poland, Vol.28, No.1,2010.

[3] International journal of contemporary practices (ISSN: 2231-5608 VOL.2 Issue 1)

[4]Development and testing of Al5083 alloy reinforced by SiCparticles.International Journal of Scientific Research Engineering & Technology (IJSRET)Volume 2 Issue 11 pp 697-704 ISSN 2278 – 0882by Amir Hussain Idrisi, VikasDev Singh, Vipul Saxena.

[5] J. Sobczak, N. Sobczak and P.K. Rohatgi, in: R. Ciach (Ed.), Advanced Light Alloys and Composites, NATO ASI Series, vol. 59, Kluwer Academic Publishers, Dordrecht, The Netherlands, (1998), pp 109.

[6] J. Sobczak, N. Sobczak, G. Przystas, Utilization of Waste Materials in Foundry Industry on Example of Fly Ashes. State of the Art and Application Perspectives, Foundry Research Institute, Cracow, Poland, (1999).

[7] International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.3, Issue.1, Jan-Feb. 2013 pp-381-385 ISSN: 2249-6645.by G.N.lokesh, M.Ramachandra, K.V.Mahendra, T.Sreenith.

