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INVESTIGATION OF WEAR BEHAVIOR AND MECHANICAL PROPERTIES OF AI-SIC METAL MATRIX COMPOSITES

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ABSTRACT

This paper reveals the fabrication of aluminium silicon carbide metal matrix composite using stir casting method and various tests carried out and their outcomes. Generally metal matrix composites are formed with two constituents, one being a metal and the other material either being a different metal or other material like ceramic or organic compound. Metal matrix composites (MMC's) are generally costly but their performances justify the added cost. However various limitations exist during formation of the composite and is counteracted by considering the factors such as reactivity at the interface, volume fraction of the reinforcing material and type of reinforcing material being added. Aluminium silicon carbide metal matrix composite is prepared with Al 6082 as base material and SiC as reinforcement material. The weight of the reinforcement material is varied from 0 to 10% and different test samples are prepared. Various tests are conducted to evaluate the performance of the composite and the results obtained are discussed.

Keywords: Al 6082, aluminium silicon carbide, metal matrix composite, stir casting.

1. INTRODUCTION

Aluminium is the third most abundant element in earth and makes up to 8% of mass of crust. Aluminium is generally known for its low density. Due to easy availability, high strength to weight ratio, easy machinability, durability, ductility and malleability, aluminium is the most widely used non-ferrous metal. Aluminium has an attractive layer structure that has gained considerable amount of interest in the scientific community [1]. Research on industrial technology is growing at a very rapid rate and consequently there is an increasing demand and need for new materials. Particulate reinforced composites constitute a large portion of these new advanced materials. The choice of the processing method depends on the property requirements, cost factor consideration and future applications prospects. Incorporation of hard second phase particles in the alloy matrices to produce MMCs has also been reported to be more beneficial and economical due to its high specific strength and corrosion resistance properties. In the past, various studies have been carried out on metal matrix composites. SiC, TiC, TaC, WC, B4C are the most commonly used particulates to reinforce in the metal or in the alloy matrix or in the matrices like aluminium or iron, while the study of silicon dioxide reinforcement in LM6 alloy is still rare and scarce. However, very limited studies have been reported and the data available on the mechanical properties and fracture surface analysis are scarce and hence make this study a significant one [2]. The Sputter deposited Aluminium is well known for its solid lubricant properties due to a lamellar structure with only weak van-der-Waals bonding between the planes, but its properties degrade in humid air due to oxidation of Aluminium to MoO3 with resulting increased friction coefficient and decreased lifetime. Furthermore, adhesion on steel substrates is usually poor. Various studies have shown that adhesion and wear resistance can be improved by co-sputtering of metals as dopants and/or sub layers of multilayer films. Good results were observed like for example aluminium obtained by sputtering and Ti or WSe2 compared to pure aluminium coatings, friction in the pin-on-disk test was reduced to about 50% and the sliding distance was increased by a factor of 25 for Ti and 100 for WSe2 respectively. Silicon carbide (SiC) has been produced in the past to serve the functionality of abrasives. Its application ranges from abrasive and cutting tools to automobile and electronic field. Silicon carbide aluminium composites are fabricated in variety of forms from different alloy matrices and with different silicon carbide reinforcement levels. However reinforcement of SiC with aluminium shows considerable improvement in modulus and strength. Results of fracture analysis of many tensile specimens indicate that bonding between silicon carbide (SiC) and aluminium matrix is usually quite strong [3]. Further studies show that silicon carbide has good elastic properties with improved young's and shear modulus of hot pressed SiC [4]. Much work has been done on preparing heat resistant silicon carbide materials in fibrous form.

SiC on W and Sic on C were produced by chemical vapour deposition. These coated filaments are more expensive and the treatment for making such materials requires careful control. The results show improved tensile strength [5]. Also various studies on coated and non-coated particulate silicon carbide on aluminium alloys were studied. Differences in fracture characteristics of specimens containing coated and non-coated particles were observed. Particle size has an important property in determining mechanical properties [6]. Abrasive wear resistance of aluminium matrix composites containing Al203 and SiC was investigated using a dry sand/rubber wheel abrasion tester. Wear resistance of the composites were studied and revealed that the size of the particle has a direct effect on the wear when treated to a hardness of 57 HRC [7]. Aluminium composites also exhibit good tribological properties and a significant experimental data has been observed in dry sliding wear behaviour. Microstructure study and effect of

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composite coatings has direct relevance to tribological properties [8].

Pramila Bai and Biswas [9] reported that Si additions (4-24% Si) improved wear resistance of aluminium, no relationship between wear rate as a function of Si content was found. Eyre [10] commented that the etched surface of Al-Si alloys exhibited anti-wear and anti-seizure characteristics. This was a result of protruding Si phase contacting the steel counter face and thereby avoiding contact between Al matrix and counter face. Aluminium based silicon carbide particulate metal matrix composites with increased silicon carbide content enhances hardness and toughness. Due to this aluminium silicon carbide composite material can be used for power transmission gears [11].

2. EXPERIMENT

2.1 Sample preparation

Aluminium alloy 6082 is taken as the baseline material for this study. It is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. Alloy 6082 is known as a structural alloy. In plate form, 6082 is the alloy most commonly used for machining.

Table-1. Chemical composition of AL6082.

Chemical element	% Percent
Manganese(Mn)	0.40-1.00
Iron(Fe)	0.0-0.50
Magnesium(Mg)	0.60-1.20
Silicon(Si)	0.70-1.30
Copper(Cu)	0.0-0.10
Zinc(Zn)	0.0-0.20
Titanium(Ti)	0.0-0.10
Chromium(Cr)	0.0-0.25
Others(Each)	0.0-0.05
Others(Total)	0.0-0.15
Aluminium	Balance

As a relatively new alloy, the higher strength of 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. The chemical composition of aluminium alloy is as shown.

The aluminium grade of AL6082 is chopped to required size. Composite material fabrication is carried through stir casting. In the stir casting process, aluminium is taken as base material and silicon carbide as reinforcement material. Content of dispersed phase is limited (usually not more than 30 volume %). Melting of base material (Al) is carried out in the crucible and then kept in the stir casting furnace. The furnace is programmed to reach 800 degree Celsius and maintained for half an hour. Molten material is poured into preheated die and the cast was taken out and die was replaced. Desired amount of preheated SiC was added according to the requirements and the complete process was accompanied with continuous stirring. Hexamethyldiamine was added during the melting period to facilitate the function of degasser. The removal of slag was performed with help of stainless steel and G.I sheets. This was done to remove impurities and maintain proper fluidity of molten composite during pouring process. There are local clouds (clusters) of the dispersed phase due to difference in densities of dispersed and matrix phase. Distribution of dispersed phase may improve if the matrix is in semi-solid condition.

3. TESTING

Tensile specimens were prepared as per the ASTM E8M- 08 specification. Tensile tests were carried out with a 25 KN; electro-mechanical controlled Universal Testing Machine shown in Figure-1.

Hardness testing was carried out on all samples. Impact toughness of the material was determined with charpy (or) Izod test. The impact toughness of the metal is determined by measuring the energy absorbed in the fracture of specimen.

The cast samples were cut into pieces and their microstructure was examined using scanning electron microscope to check the distribution of SiC across the length. Figure-2 shows the sectioning lines of the MMCs cast samples.

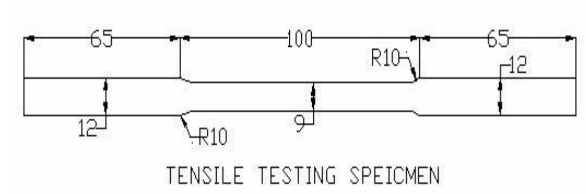

Figure-1. Tensile test specimen.
[All dimensions are in mm]

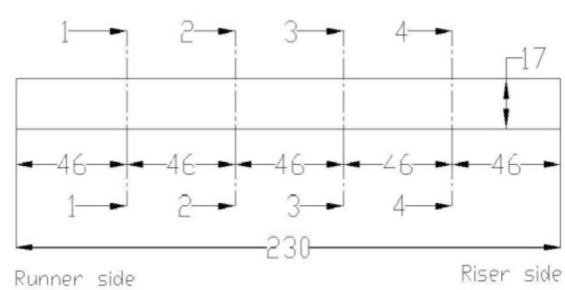

Figure-2. Sectioning lines of cast specimen.
[All dimensions are in mm]

X-ray diffraction (XRD) pattern of aluminium alloy matrix composites of different samples was carried

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out by X'PERTO PRO of PAN ANALYTICAL using CuK radiation.

Wear test was conducted in three ways of Experimental work on Aluminium matrix composites. In Wear test considering four variables in three levels of the way to conduct the experimental procedure.

4. RESULTS AND DISCUSSION

4.1 Hardness test

The effect of change in percentage of particles on the hardness of the composites is illustrated in Figure-3 and the values are given in Table-3.

Table-2. Experimental procedure for wear test.

S. No.	Composite material	Hardness brinell hardness			Mean hardness
		Trail 1	Trail 2	Trail 3	
1	AL6082	62	61	63	62
2	AL6082+5% SIC	69	68	68	69
3	AL6082+10% SIC	73	73	72	73

The complete ranges of hardness are calculated. The hardness test shows a marginal increase in hardness with the increase in the addition of SiC. The hardness test shows a greater increase with stir casting process. A peak hardness of 70 HV and 73 HV was obtained after casting of the matrix and 10 % composites respectively. The casting of the matrix and the composites further increases the hardness. The increase in hardness with the increase in percentage of particle fraction is due to the increase in the availability of specific surfaces of the particulates in the composites.

For the matrix alloy a peak hardness of 73 HV was achieved. However, with the addition of 10 % of SiC the level of increase in hardness began to decrease due to formation of voids.

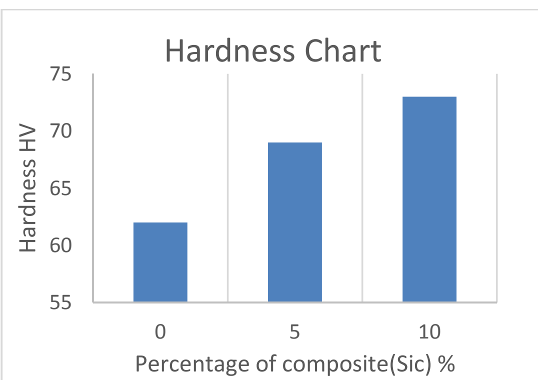

Figure-3. Variation of percentage of SiC average particle size 25 µm.

Table-3. Hardness of the matrix alloy and the -variation of Silicon carbide fraction - Average particle size 25 µm.

Symbol	Experimental variables	Level 1	Level 2	Level 3
A	Volume (%)	0	5	10
B	Load (Kg)	5	10	15
C	Sliding Distance (m)	500	1500	2500
D	Sliding Speed (m/s)	0.5	1.5	2.5

4.2 Tensile strength test

The tensile strength of the unreinforced alloy and the composites are given in Table-4. The percentage of elongation to fracture was decreasing with an increase in the Silicon carbide fraction. The yield strength of the composites was increasing with the increase in percentage of fraction upto 10 % of Silicon carbide. The addition of SiC particulates in the cast condition decreases the ultimate tensile strength of the composites; tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties. The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values, the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve.

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Table-4. Tensile strength of the matrix alloy and the composites in variation of percentage of particles particle size 25 µm.

S. No.	Composite material	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)
1	AL6082	55	125	3.1
2	AL6082+5%SIC	56	110	1.5
3	AL6082+10% SIC	58	87	0.8

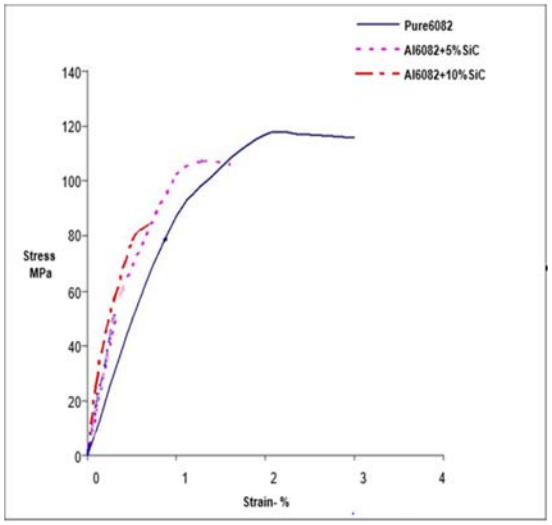

Figure-4. Stress strain curve of metal matrix and the composite Particle size 25 µm.

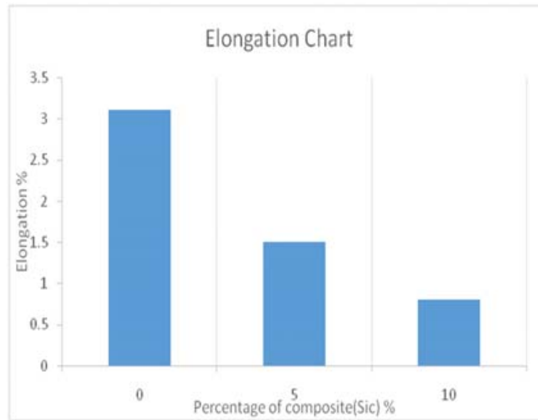

Figure-5. Elongation curve of metal matrix of Particle size 25 µm.

4.3 Impact test

The Charpy impact test, also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness the composites are given in Table-5.

Table-5. Impact test results.

S. No.	Composite material	Impact test charpy test			Average force (Nm)
		Trial 1	Trail 2	Trail 3	
1	AL6082	6.2	6.1	5.9	6.06
2	AL6082+5%SIC	8.2	8	7.5	7.9
3	AL6082+10% SIC	8.5	8.7	8.8	8.6

4.4 Porosity and density result

4.4.1 Variation of percentage of particles

The variations of density with the variation of percentage of particles are shown in Figure-6 and the values are given in Table-4.4. The density and the porosity of the samples increase with the increase in percentage of particle fraction in cast condition. The increase in density of the composites is due to the higher density of the reinforcement. The increase in porosity with the increase in percentage of particle fraction is be due to the increase in microspores and interspaces between the matrix and the reinforcement. The decrease in porosity is due to the accelerated reaction, reduction in microspores and interspaces between the matrix and the reinforcement. The density of the samples shows a lower increasing trend with the particle fraction of 0 % to 10 % of SiC. The reason is due to the increase in the presence of microspores and interspaces with the increase in percentage of particle fraction.

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Table-6. The density and porosity content of the composites in variation of percentage of particles- Average particle size 25µm.

S. No	Composite material	Calculated density (G/Cm^3)	Experimental density (G/Cm^3)	Percentage of porosity (%)
1	AL6082	2.7	2.647	1.948
2	AL6082+5%SIC	2.724	2.649	2.722
3	AL6082+10% SIC	2.74	2.66	3.202

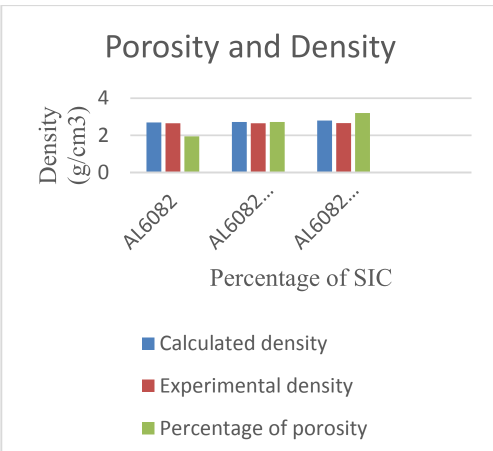
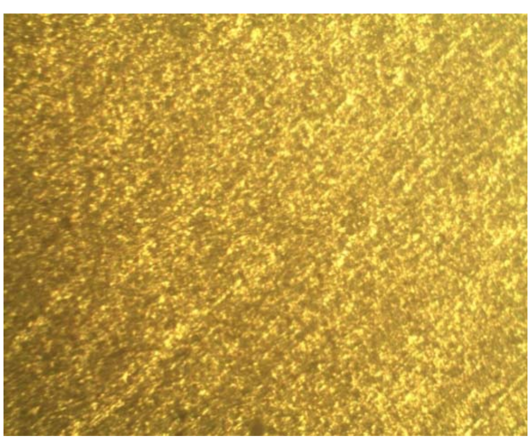


Figure-6. Variation of density with the variation of percentage of particles - Average particle size 25µm.

4.5 Micro structure results

The microstructure analysis of the composite was carried out using optical microscopy. Figures 7, 8, 9 illustrate their structure in different magnification. The comparison of the microstructure images of the 2 specimens shows the random distribution of the inter-metallic spacing in the matrix and it also tells us about the grain orientation and distribution.

It was observed that the reinforcement had more randomness and diffused inter-metallic spacing than it was seen that alumina particles were deposited on the aluminium matrix. Alumina has a certain attraction towards aluminium.



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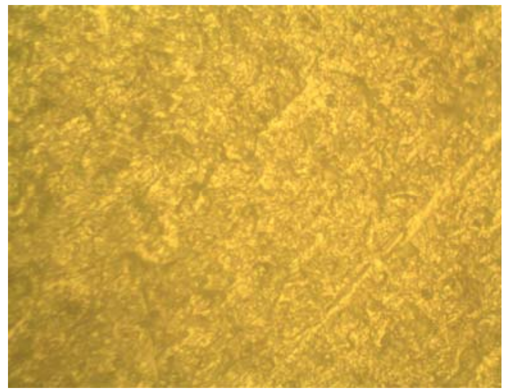

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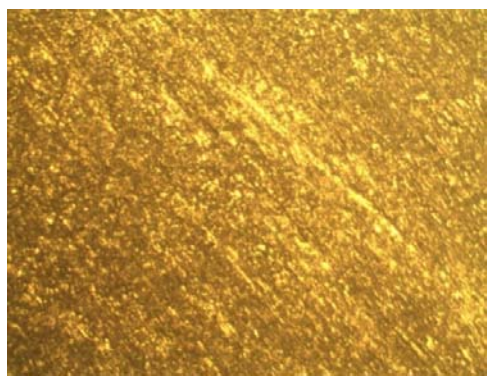
Figure-7. Microstructure of the cast composite Al6082.



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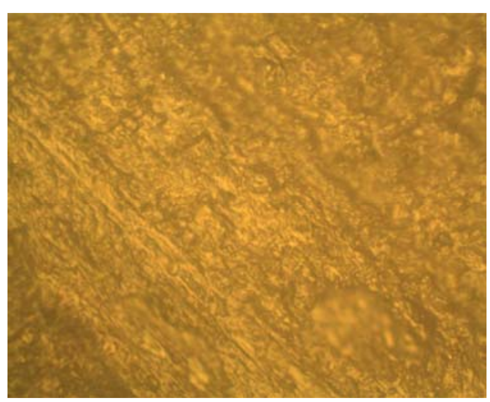

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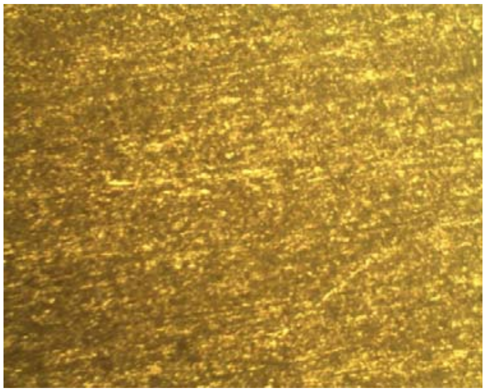
Figure-8. Microstructure of the cast composite Al6082+5%SIC.



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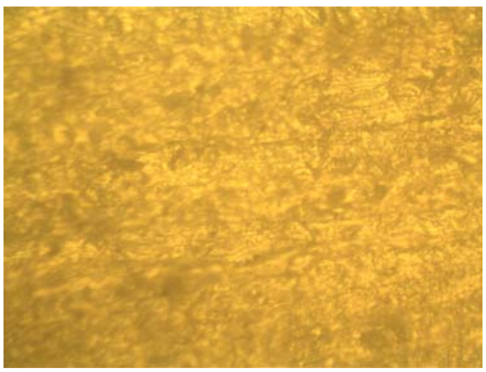

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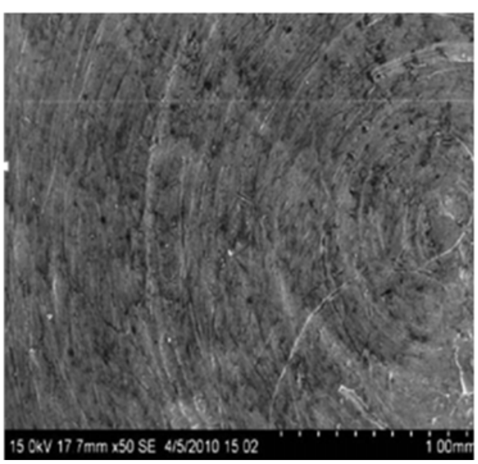
Figure-9. The microstructure of the cast composite Al6082+10%SIC.

4.6 Sem result

Aluminium composites from the figures it can be observed that, the distributions of reinforcements in the respective matrix are fairly uniform. Further these figures reveal the homogeneity of the cast composites. The microphotograph also clearly reveals the increased filler contents in the composites. Cracks are also seen in the microstructure. Figures 10, 11, 12 are presented with the microphotographs of Casting of AL6082 and SIC.



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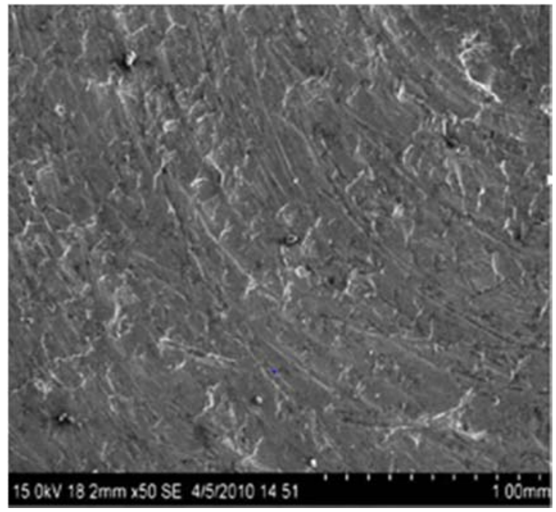

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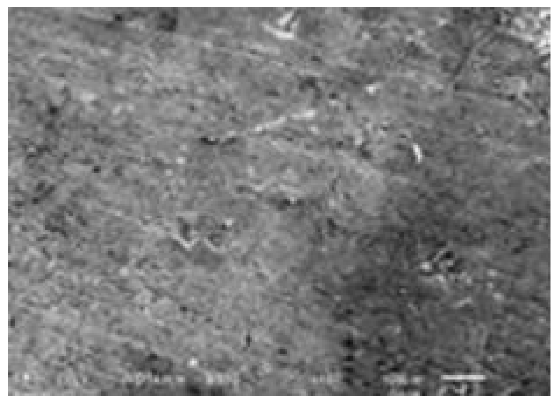
Figure-10. SEM images of the cast composite Al6082.



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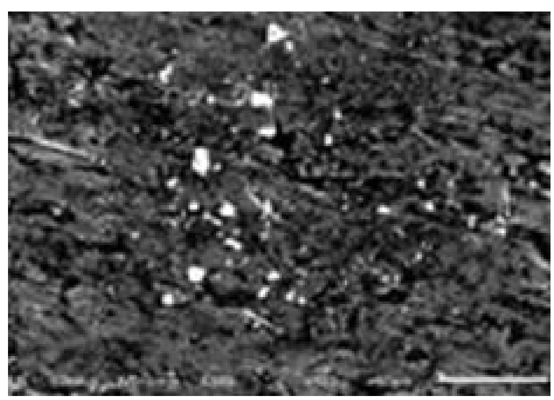

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Figure-11. SEM images of the cast composite Al6082+5%SIC.

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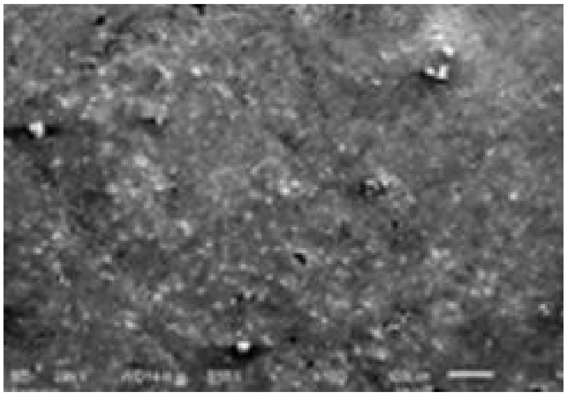

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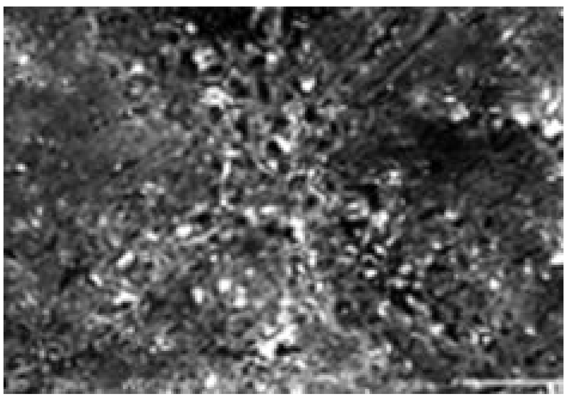

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Figure-12. SEM images of the cast composite Al6082+10%SIC.

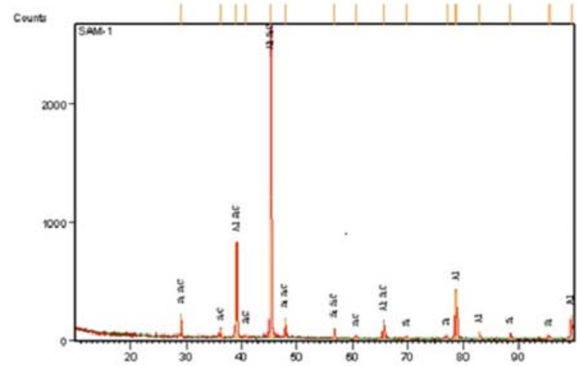

Figure-13. X-ray diffraction pattern of the AL6082.

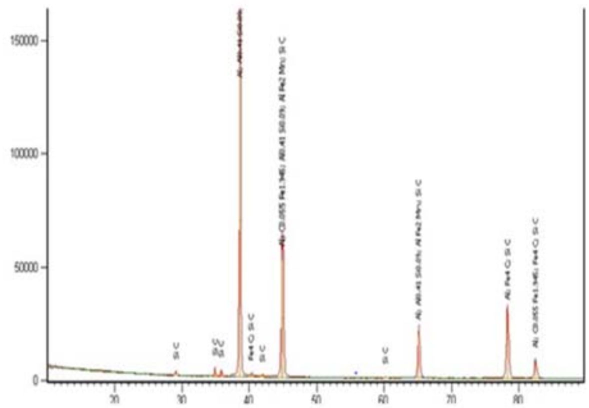

Figure-14. X-ray diffraction pattern AL6082+5%SiC.

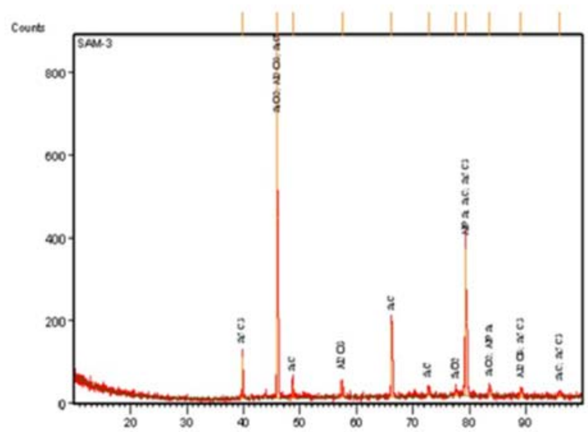

Figure-15. X-ray diffraction pattern AL6082+10%SiC.

4.7 X-ray diffraction analysis

An X-ray diffraction (XRD) pattern of aluminium metal matrix composites were shown in given figure numbers 13, 14, 15 X-ray diffraction of different samples was carried out by X'PERT PRO of PAN ANALYTICAL using CuK α radiation. In XRD, the physical content of the constituents present in the samples are indicated in the form of a graphs and tables shows the name and percentage of element/ compound present in respective samples in Table-7.

Table-7. X-ray diffraction pattern with particulate size of 25μm.

S. No.	Composite material	Scale factor	Weight fraction (%)
1	AL6082	0.507	82.9
2	AL6082+5%SIC	0.007	5.1
3	AL6082+10% SIC	0.013	4.5

4.8 Wear test report

Sliding Wear Analysis shows the variation of wear rate with composition for SiC. Apparently pure aluminium exhibits the highest wear loss whereas gray cast iron shows the lowest wear loss, for the given set of applied load and sliding speed employed. Al-based composite shows a decrease in wear rate with increasing content of SiC reinforcement which acts as obstacle to shear deformation. While material is getting slid on the counter face wear rate is much higher than gray cast iron.

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Also, SiC acts as load-bearing element in the matrix. This supports the work reported elsewhere in SiC-reinforced Al-10%Si alloy shows that temperature rise during sliding is more for pure aluminium and its composites than that of gray cast iron.

It is well known that aluminium exhibits high thermal conductivity (237W/mK) and it reduces with increasing addition of SiC, while gray cast iron has relatively low thermal conductivity (70W/mK)

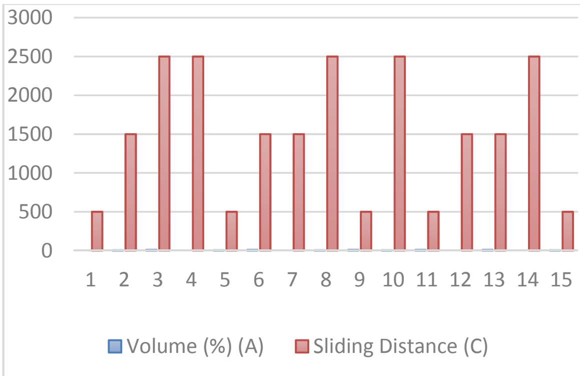

Figure-16. Volume Vs Distance.

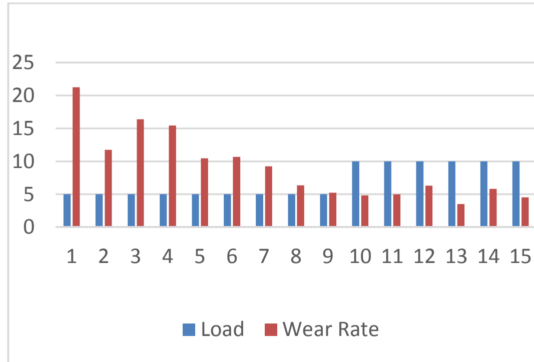

Figure-17. Load Vs Wear rate.

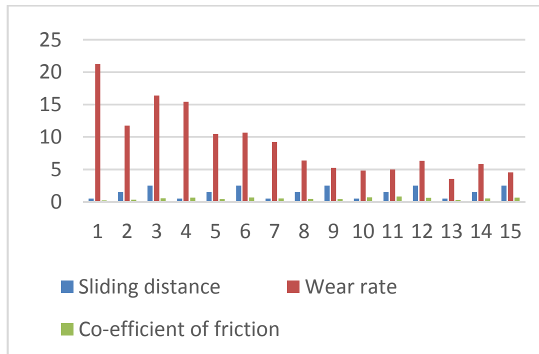

Figure-18. Wear rate.

Table-8. Wear composition results.

S. No.	Volume (%) (A)	Load (B)	Sliding distance (C)	Sliding speed (D)	Specific wear rate	Co-efficient of friction
1	0	5	500	0.5	21.236	0.225
2	5	5	1500	1.5	11.742	0.336
3	10	5	2500	2.5	16.388	0.551
4	0	5	2500	0.5	15.425	0.639
5	5	5	500	1.5	10.469	0.413
6	10	5	1500	2.5	10.687	0.669
7	0	5	1500	0.5	9.240	0.523
8	5	5	2500	1.5	6.354	0.444
9	10	5	500	2.5	5.236	0.423
10	5	10	2500	0.5	4.823	0.686
11	10	10	500	1.5	4.980	0.821
12	0	10	1500	2.5	6.324	0.627
13	10	10	1500	0.5	3.521	0.268
14	0	10	2500	1.5	5.833	0.536
15	5	10	500	2.5	4.539	0.645
16	0	10	500	0.5	7.456	0.664
17	5	10	1500	1.5	3.234	0.251
18	10	10	2500	2.5	3.087	0.225

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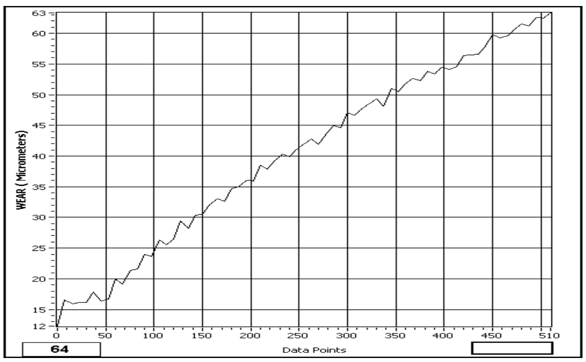
19	10	15	1500	0.5	10.579	0.432
20	0	15	2500	1.5	12.451	0.596
21	5	15	500	2.5	7.685	0.285
22	0	15	500	0.5	7.544	0.278
23	5	15	1500	1.5	8.268	0.349
24	10	15	2500	2.5	5.215	0.233
25	5	15	2500	0.5	5.956	0.265
26	10	15	500	1.5	6.834	0.275
27	0	15	1500	2.5	5.116	0.228



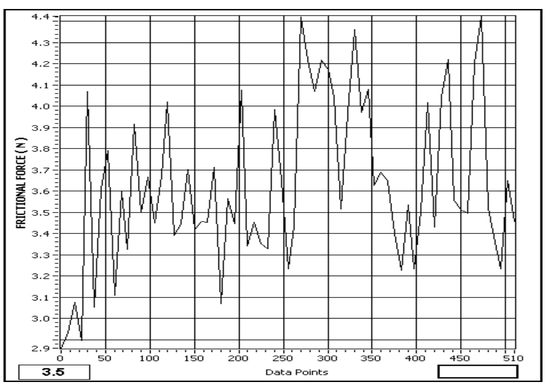


Figure-19. Frictional force Vs Data points.

5. CONCLUSION

The microstructure examination from scanning electron microscope of the cast composite revealed uniform distribution of particles. The Addition of silicon carbide (SiC) particles resulted in increase in density and porosity and it further increases with increase in percentage of particle fraction. Hardness of Al-SiC composite increases with increase in percentage fraction of SiC particles. Due to formation of weak compounds in the interface of the matrix and silicon carbide reinforcement, the ultimate tensile strength of composites decreases with increase in silicon carbide (SiC) fraction of cast composite. Wear rate reduced with increasing content of silicon carbide reinforcement which acts as obstacle for shear deformation.

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