Mechanical Properties and Wear Behaviour of Al–Si Alloy Based Alumina and Silicon carbide Reinforced Metal Matrix Composite

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ABSTRACT

Al–Si alloy matrix composites reinforced with different weight fractions of Al2O3 and silicon carbide particles up to 10 wt. % were fabricated by stir casting method. The effect of weight fraction of Al2O3, silicon carbide and mechanical and the wear behaviour of Al–Si alloy and its composites was investigated. The results showed that wear resistance of the investigated composites was improved and in the tensile testing the weight fraction of Al2O3 5% and SiC 5% gives the optimal values of the ultimate tensile strength. In present work Al-Si alloy reinforced with Al2O3 and silicon carbide MMCs materials are prepared by using stir casting technique have cost advantages over the composites made by other. Four different volume fractions (2.5%, 5%, 7.5% and 10%) of particulate SiC fixed volume of 5% Al2O3 are used in production of Al-Si alloy matrix composite at 700°C. The wear resistance of the composites with 2.5%, 5%, 7.5% and 10% SiC particles was higher than that of the Al-Si matrix alloy. Microstructures of the composites are studied by Scanning Electron Microscopy (SEM). Performing dry sliding wear test by using a pin-on-disc wear tester the wear and frictional properties of the metal matrix composites can be studied.

Key words: *Metal matrix composites, Al–Si alloy, Al2O3, silicon carbide and Stir casting*

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1. INTRODUCTION

Composites mean combination of two or more ingredients (metals/non-metals). There are few techniques and processes with which we can make these composites by assembling two or more pure materials. Basic needs for which we need to consider composites are mainly concerned with the enhancement of physical and chemical properties of the metal.

These Composites consist of metal alloy reinforced with continuous fibers or Particulate [1]. In the composite the metal is used as matrix material they are generally heavier in nature and they are having higher temperature bearing capacity than PMCs [2]. The basic attribute metal reinforced with hard ceramic particle or fiber is improved strength and stiffness. They have also increase have creep and fatigue resistance, increased hardness wear and abrasion, resistance. Metal matrix composite are wide range of application, in combustion chamber, nozzle, turbine, cable, heat exchanger, structural member due to their above attribute. The other material may be an alternate metal or that should be another material, for example, a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite material by taking Aluminum as matrix and Al_2O_3 & fly ash particulates as reinforced phase using stir casting technique, the aim involved in designing the metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix to prepare the cost-effective MMC [3]. The service temperature of composites is to be determined at various temperatures by the melting point, physical and mechanical properties [4].Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The selection of reinforcements becomes more important with increase in the melting temperature of matrix materials.

A metal matrix composite (MMC) is generally made of two types of material, the base material and the reinforce material the base material generally used are the aluminium alloys and the reinforcement material used are Sic, Al2O3, TIB2 etc. When there is a combination of at least three materials then, it is generally called a hybrid composite.

In the present work, the varying percentage of SiC and fixed percentage of Al_2O_3 is used as reinforcement material with the aluminum-silicon alloy.

Investigation of the effects of Al2O3 and silicon carbide reinforcing particles on microstructure and mechanical properties of aluminum-silicon alloy composites is the subject of the present study. In this study the aluminum-silicon alloy MMC was formed by using stir casting method.

2. MATERIALS

2.1 Silicon Carbide as Reinforcement

In the Silicon Carbide the main constituent compounds are carbon and silicon. It is initially produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is generally an abrasive and it has been produced and made into grinding wheel and other abrasive articles for more than one hundred years. Today the material has created into a high quality technical grade ceramic with great mechanical properties [5].

It is utilized as a part of abrasives, refractoriness, ceramic, and various high performance applications [6].The material can be made to work like electrical conductor and it has applications in resistance heating, flame igniters and electronic parts [6]. Silicon carbide is made of tetrahedral of carbon and silicon with solid bonds in the crystal lattice. This creates a hard and strong material.

Properties of Silicon Carbide

 Low density

 High strength

 Low thermal expansion

 High thermal conductivity

 High hardness

 High elastic modulus

 Excellent thermal shock resistance

 Superior chemical inertness

Table 1.1: Detailed Properties of Silicon Carbide

Properties	Value	Properties
Melting Point (°C)	2200-2700	Linear coefficient of expansion (10^{-6} K)
Limit of application (°C)	1400-1700	Fracture toughness (MPa-$m^{1/2}$)
Moh's Hardness	9	Crystal structure
Density (g/cm^3)	3.2	Linear coefficient of expansion (10^{-6} K)

2.2 Alumina as Reinforcement

Aluminium oxide it is typically known as alumina, its robust ionic atomic bonding that giving rise to its acceptable material characteristics. It is found in many crystalline phases that all revert to the foremost stable hexagonal alpha phase at elevated temperature. Alpha phase is that strongest and stiffest of the oxide ceramics [10].Its high hardness, wonderful non-conductor properties, refractoriness and good thermal properties create it the material of alternative for a large range of applications. High purity alumina is usable in both oxidizing and reducing atmosphere to 1925 ^{o}C. Weight loss in vacuum varies from 10-7 to 10-6 g/cm2 sec over a temperature range of 1700 ^{o}C to 2000 ^{o}C [7].

It resists attack by all gases except wet fluorine then is resisting in accordance with every frequent reagents except hydrofluoric acid and phosphoric acid. The composition of the ceramic body can be changed according to enhance specific appropriate material characteristics. An example would be additions of chrome oxide or manganese oxide according to enhance hardness and change color. Other additions can be made to enhance the ease and consistency over metal films fired according to the ceramic because of subsequent brazed then soldered assembly. [7]

Detailed properties of Alumina are shown in Table 1.2

Table 1.2: Properties of Alumina

99.5% Aluminium Oxide		
Mechanical	**Unit of measure**	**SI Unit**
Density	gm/cc (lb/ft^3)	3.89
Elastic	GPa	375
Shear	GPa	152
Bulk	GPa	228
Poisson's	-	0.22
Fracture	MPa•m$^{1/2}$	4
Hardness	Kg/mm^2	1440
Compressive	MPa	2600

Table 1.3: Aluminium Alloy Composition by Weight percent

Sample Name	Ai-Si Alloy	Al_2O_3 wt. %	SiC wt. %
As Casted Ai-Si Alloy	As Casted Al-Si alloy	0	0
Comp-1	Al-Si alloy	5	2.5
Comp-2	Al-Si alloy	5	5
Comp-3	Al-Si alloy	5	7.5
Comp-4	Al-Si alloy	5	10

3. EXPERIMENTAL PROCEDURE

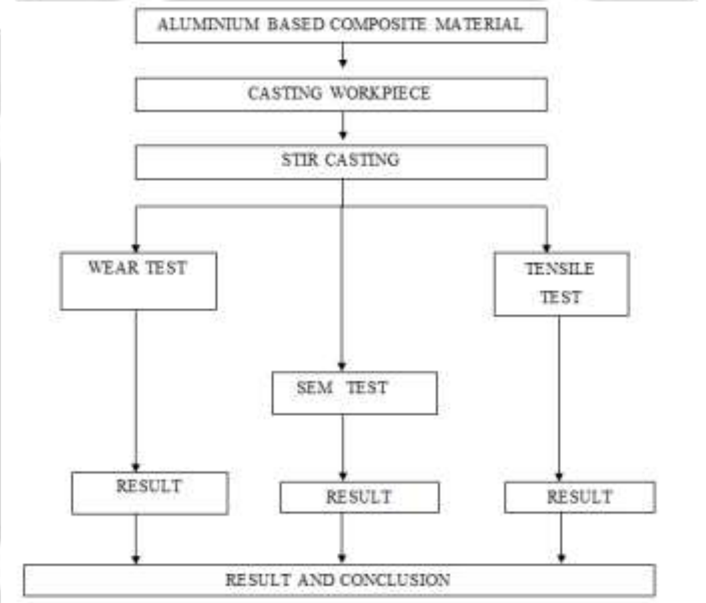


Figure 3.1: Flow Chart Experimental Techniques followed

4. EXPERIMENTAL SETUP AND PROCEDURES

In a stir casting process, the reinforcing phase is to be distributed into molten matrix by using mechanical stirrer [8]. Mechanical stirring is play an important role in the furnace element of this process. The resultant molten alloy which is to be obtained from the process, with the ceramic particles, this can be used for die casting, permanent mould casting, and sand casting. Stir casting is generally suitable for suitable for manufacturing composites which is having up to 30% volume fractions of reinforcement [8].The cast composites are generally sometimes further to be extruded to reduce the porosity, refining the microstructure, and to homogenize the distribution of the reinforcement [9].

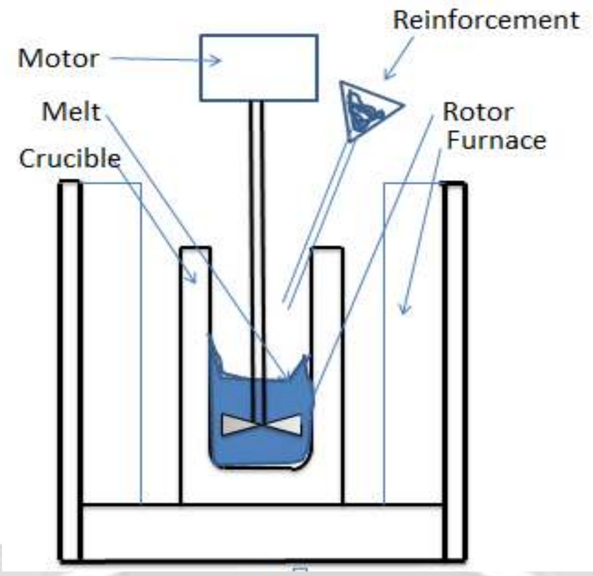


Figure 4.1: Stir casting labelled sketch

This is generally a two-step blending procedure and it is utilized as a part of the production of aluminium. The existing strategies for the metal matrix composite manufacture techniques, the stir casting is used for the most of the parts and this is the most practical process. Therefore, stir casting is as of now the most widespread commercial approach for producing aluminium based composites. An open hearth furnace was utilized for melting and blending the materials in the base, round and hollow graphite crucible, the manufacturing procedure is regular mechanical mixing for the distributive blending of the reinforcement in the matrix. For the work, another stir caster was produced to create MMC. The mixing equipment for this stage comprised of a Driving motor is capable of for generating a rotational speed of range of 600 rpm, a control part for the vertical movement of the impeller and an exchange tube utilized for presenting the ceramic powders in the melt. Adjusted Al-Si combination with Al2O3 and SiC were melted in graphite crucible. In the meantime the Al-Si compound was preheated in a muffle furnace set at 1100°C for around 2 hour to remove surface contaminations and support the adsorption of gases. The clay particles were then emptied gradually and consistently into the liquid metal and the melt was stirred at 600 rpm.for preparing metal matrix composites by the stir casting technique, there are a few factors that need extensive consideration, including the difficulty of achieving a uniform distribution of the matrix material, wet ability between the two fundamental substances, porosity which is a casting defect is also taken into consideration in the cast metal matrix composites and chemical reaction which takes place between the reinforcement material and the matrix alloy.

5. RESULTS AND DISCUSSION

5.1 Tensile Strength Test

Tensile tests were used to assess the mechanical behaviour of the composites and matrix alloy. The composite and matrix alloy rods were machined to tensile specimens with a diameter of 16mm and gauge length of 10 cm. Ultimate tensile strength (UTS), often it is called the tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to Significantly contract.

Table 5.1: Tensile strength result

Specimen	Yield strength N/mm^2	UTS N/mm^2	Elongation (%)
As Casted Ai-Si Alloy	100	160	3.93
Comp-1	95	158	2.81
Comp-2	132	182	4.45
Comp-3	130	170	2.17
Comp-4	129	148	2.15

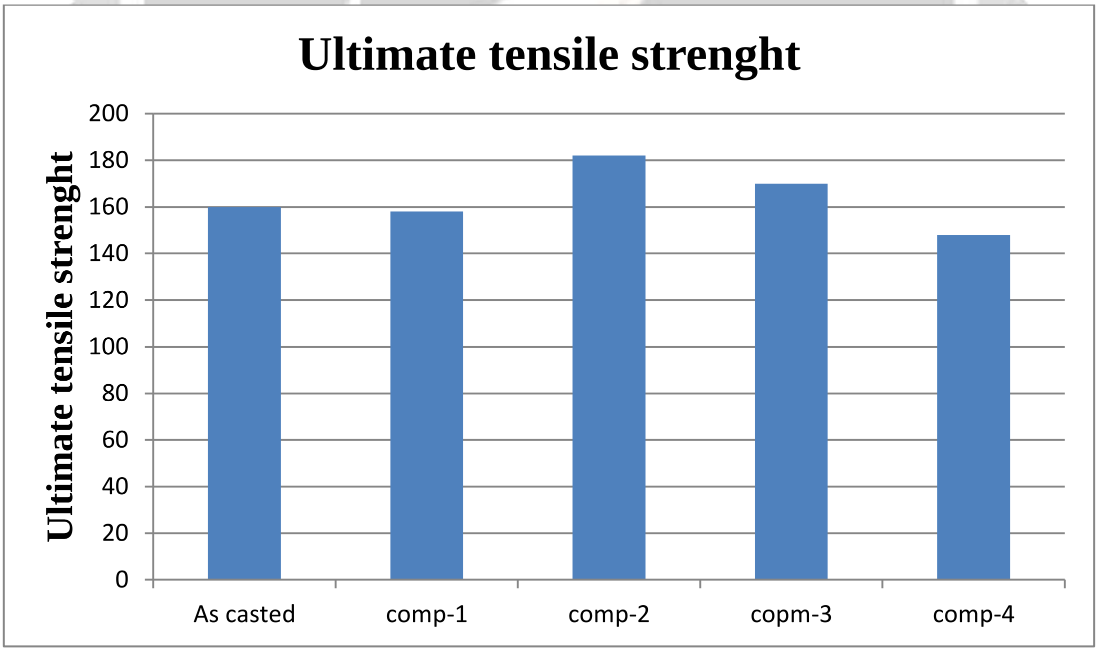


Figure 5.1: Comparison of ultimate tensile strength of different samples

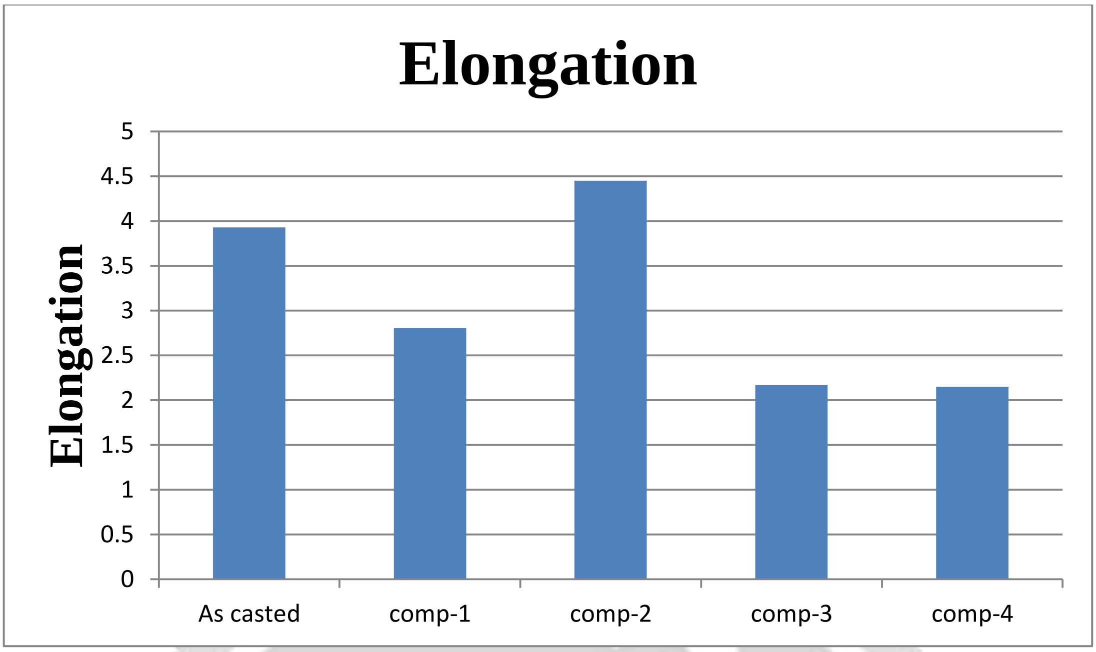


Figure 5.2: Comparison of Elongation of different samples

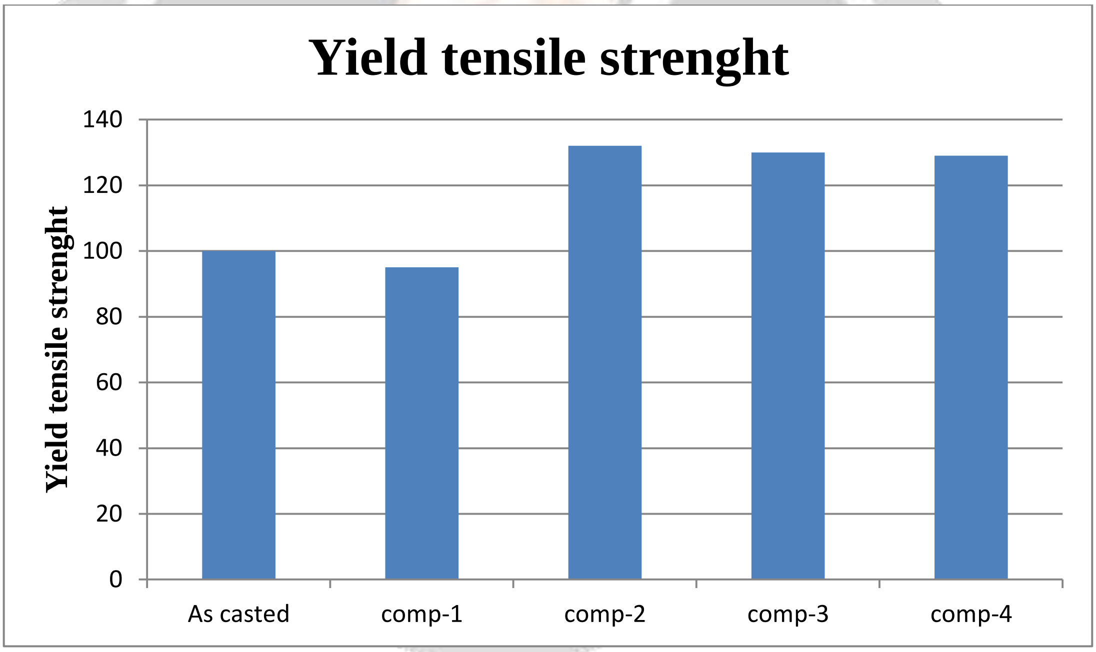


Figure 5.3: Comparison of Yield tensile strength of different samples

It appears from the above observation that UTS and Yield strength, the weight fraction of Al_2O_3 5% and SiC 5% sample gives the optimal values and further reinforcement results in decrease in UTS and Yield strength. It is also found that elongation tends to decrease with increasing particles wt. percentage, which confirms that silicon carbide and alumina addition increases brittleness but the weight fraction of Al_2O_3 5% and SiC 5% sample gives the optimal value of elongation which has the maximum value of UTS and yield strength.

5.2 Wear Test Result

In the Wear test DUCOM TR-20 pin-on-disc wear test machine is used and the wear disc material of disc EN 31 hardened to 60 HRC is used. The pin was placed against the counter face which is a rotating disc (EN31 steel disc) and having the wear track diameter of 100 mm. The wear test which is conducted for all specimens and 40 N for 10 minutes is used in this test.Wear tests were carried out for a total sliding distance of approximately 1200 m under similar conditions as discussed above. For this test the test specimen used is a rod and having the 12 mm diameter.

Table 5.2: Reading of pin-on-disc wear test machine

S. No	Initial weight (Gram)	Final Weight (Gram)	Loss in Weight in 40N load (Gram)
As Casted Ai-SI Alloy	25.8764	25.75676	0.11964
Comp-1	15.8745	15.77046	0.10404
Comp-2	18.2684	18.1922	0.0762
Comp-3	25.3681	25.30054	0.06756
Comp-4	22.2374	22.17908	0.05832

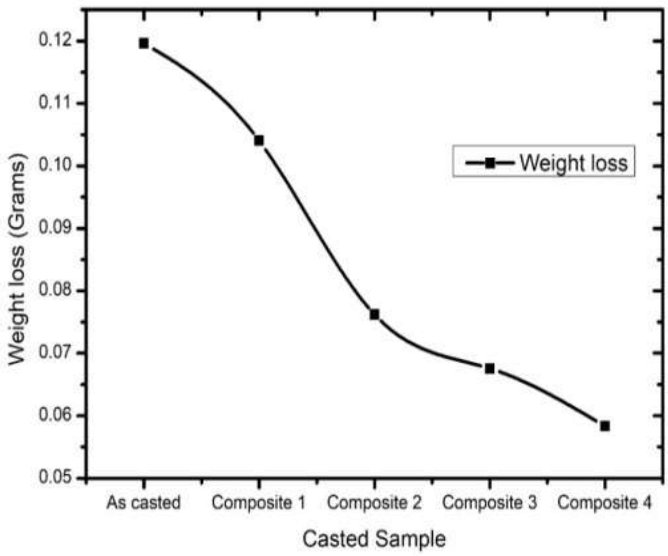
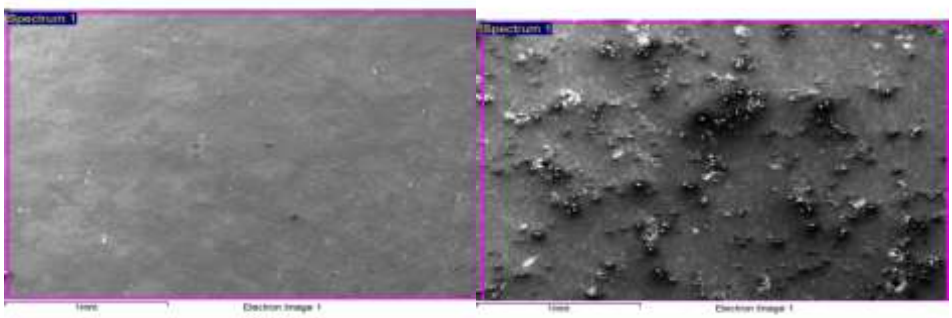


Figure 5.3: Comparison of weight loss of different composites

5.3 SEM Observation

The SEM images show the uniform distribution of the metal matrix composite reinforcement also the inter metallic formation in the reinforced composites, the pore formation of the Al-Si alloy, SiC and alumina reinforced composite in a different composition. Below figures shows the distributions of reinforcements in the respective matrix are fairly uniform.



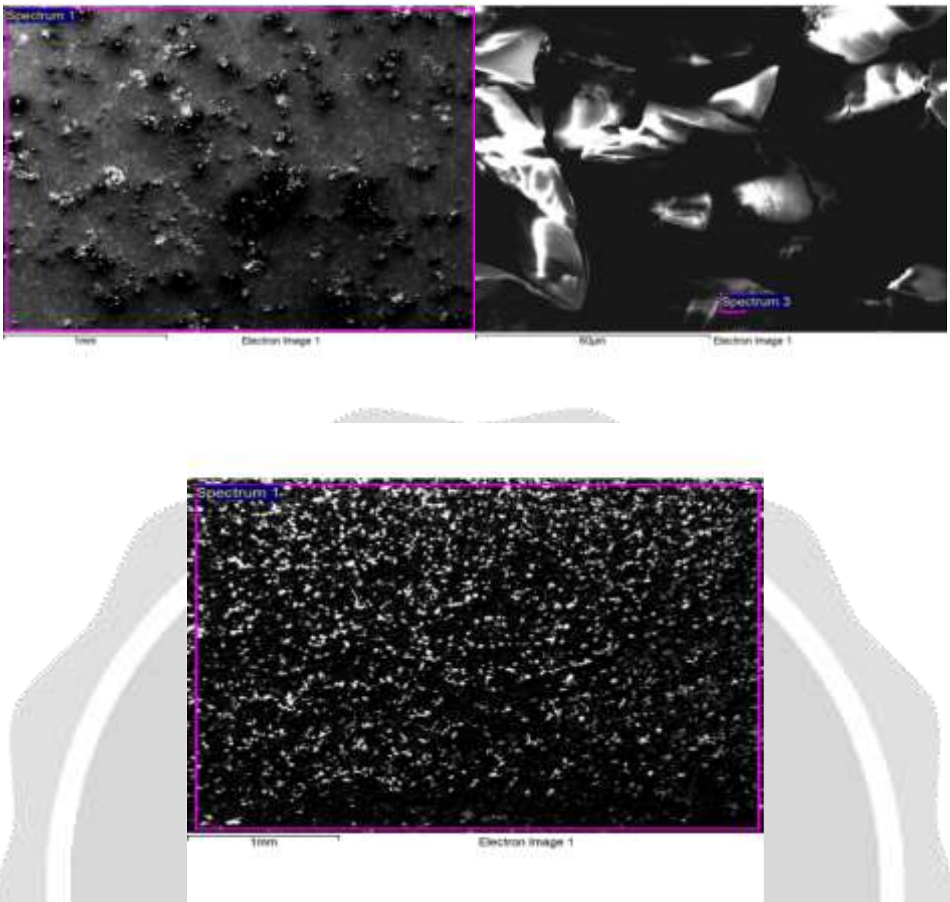


Figure 5.4: SEM micrographs shows the surface of MMC of As Casted alloy, Composite 2(2.5% SiC and 5% Al_2O_3), Composite 4(10% SiC and 5% Al_2O_3), Alumina and SiC particles

6. DISCUSSION

The Discussion part elaborates the overall short discussion of manufacturing process, result and conclusion of the present research work of Metal Matrix Composites. In present work the Metal Matrix Composites are the combination of Al-Si alloy, SiC and Al_2O_3 particles in different compositions. The Al-Si alloy, SiC and Al_2O_3 based MMCs were produced with the stir casting method by using muffle furnace. There are four specimens are produced after the manufacturing of the composites. These composites are the Al-Si alloy (As casted), A2(Al-Si +2.5% SiC+ 5% Al_2O_3), A3(Al-Si +5% SiC+ 5% Al_2O_3), A4(Al-Si +7.5% SiC+ 5% Al_2O_3), and (Al-Si +5% SiC+ 5% Al2O3) .There was the following tests performed on these composites material specimen are as: Wear Test, Tensile Strength Test and Scanning Electron Microscope. From the above graph it is clearly seen that as the reinforcement increases in the different composites the weight loss in the composites decreases. The As casted alloy is not having any reinforcement thus it has maximum weight loss and remaining composites which have reinforcement each composite is superior than its previous one and the composite 4 is superior to the remaining composite. It appears from the above observation that UTS and Yield strength, the weight fraction of Al2O3 5% and SiC 5% sample gives the optimal values and further reinforcement results in decrease in UTS and Yield strength. It is also found that elongation tends to decrease with increasing particles wt. percentage, which confirms that silicon carbide and alumina addition increases brittleness but the weight fraction of Al2O3 5% and SiC 5% sample gives the optimal value of elongation which has the maximum value of UTS and yield strength. The Scanning Electron Microscope represents the microphotographs of casted Al 6063, SiC and Graphite composites. it is observed that, the distributions of the reinforced composite particle are fairly uniform. There are the cracks are also seen in the microstructure.

7. CONCLUSION

The conclusions drawn from the present investigation are as follows:

1) MMCs (metal matrix composites) of Al-Si alloy matrix comprises of different percentage content of reinforcement material aluminium oxide and silicon carbide are made under stir casting.

2) Specimen will be put under different testing machines and respective results will be found out for the each specimen.

3) Comparison will be done on the basis of specimen's result against the tests done on them; specimen of composition which gives best result will be optimal.

4) The results confirmed that stir formed Al-Si alloy (As casted) with SiC and Al_2O_3 reinforced composites is clearly superior to base Al-Si alloy (As casted) in the comparison of wear strength.

5) It is found that elongation tends to decrease with increasing particles wt. percentage, which confirms that silicon carbide and alumina addition increases brittleness but the weight fraction of Al2O3 5% and SiC 5% sample gives the optimal value of elongation which has the maximum value of UTS and yield strength.

6) Al-Si alloy matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of SiC & Al_2O_3 particles.

7) It appears from this study that UTS and Yield strength, the weight fraction of Al2O3 5% and SiC 5% sample gives the optimal values and reinforcement after this composition results in decrease in UTS and Yield strength.

REFERENCES

[1] Ahmad, Z. (November 2011), Corrosion behaviour of aluminium metal matrix composite 385-406

[2] Bal, P.K. (May 2014), thermal conductivity of cement kiln dust filled epoxy composites. Rourkela: National institute of technology.

[3] Dewangan, S. K. (2015), Mechanical properties of Aluminium 6063 Alloy based Graphite Particles. International journal for scientific research & development, 369-373.

[4] Kumar, A. (Apr-2016). A Review on Mechanical and Tribological behaviours of stir cast copper –silicon carbide matrix composites. International research Journal of engineering and technology, 2658-2664.

[5] Boopathi, M. (August 2014). Dry Sliding wear, co-efficient of friction and international journal of mechanical & mechatronics engineering, 44-53.

[6] Kulkami, A. S. (2016). Coupled thermal and structural analysis of imperial journal of interdisciplinary Research, 1188-1194.

[7] Friend C. M. (1987). The effect of matrix properties on reinforcement in short alumina fiber aluminium metal matrix composites. Journal of Material Science, Volume 22, Number 8, pp 3005-3010

[8] Kumar, R. (December 2014). Processing of aluminium matal matrix composite (AMMC). Ipasj international journal of mechanical engineering, 17-25.

[9] Pullareddy, M. (2016). Experimental investigation on Al 7075, TiB2, TiC, Metal Matrix Composie to find power Consumption and MMR while Machining. JSRSET, 1329-1337.

[10] Kumari, S. (2013). Effect of TiO2 Addition in Al2O3: Phase evolution, Densification, Microstructure And Mechanical Properties Rourkela: National institute of technology