Experimental investigations on mechanical behavior of aluminium metal matrix composites

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Abstract. Today we are widely using aluminium based metal matrix composite for structural, aerospace, marine and automobile applications for its light weight, high strength and low production cost. The purpose of designing metal matrix composite is to add the desirable attributes of metals and ceramics to the base metal. In this study we developed aluminium metal matrix hybrid composite by reinforced Aluminium7075 alloy with silicon carbide (SiC) and aluminium oxide (alumina) by method of stir casting. This technique is less expensive and very effective. The Hardness test and Wear test were performed on the specimens which are prepared by stir casting techniques. The result reveals that the addition of silicon carbide and alumina particles in aluminium matrix improves the mechanical properties.

1. Introduction

The wear behaviour and hardness plays an important role in selecting the metal matrix composites for using in various industries, automobiles etc. Aluminium (Al) based metal matrix composites i.e., AMCs is widely using in aerospace, automotive and agricultural industries etc. For the study and conducting experiment, first we should know about the Metal Matrix composites. A composite material is a material composed of two or more constituents. The constituents are combined at a microscopic level and are not soluble in each other. Generally, a composite material is composed of reinforcement (fibers, particles/ particulates, flakes, and/or fillers) embedded in a matrix (metals, polymers). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. The most primitive man-made composite materials are straw and mud combined to form bricks for building construction [1].

Metal matrix composites (MMCs), like all composites; consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. Generally, there are two phases either a fibrous or particulate phase in a metallic matrix. For e.g. Al_2O_3 fiber reinforced in a copper matrix for superconducting magnets and SiC particle reinforced with in the Al matrix composites used in aero space, automotive and thermal management applications [2].

For many researchers the term metal matrix composites is often equated with the term light metal matrix composites (MMCs). Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. In traffic engineering, especially in the automotive industry, MMCs have been used commercially in fiber reinforced pistons and aluminium crank cases with strengthened cylinder surfaces as well as particle strengthened brake disks. These innovative materials open up unlimited possibilities for modern material science and development; the characteristics of MMCs can be designed into the material, custom-made, dependent on the application [2].

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy are common.

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different particulates/ fibres used in composites have different properties and so affect the properties of the composite in different ways.
Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. The chief source of aluminium is bauxite ore. Its Atomic number is 13. Aluminium is a soft, durable, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. Aluminium is nonmagnetic and non-sparking. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded. Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation.

The aluminium alloy Al-7075 has been selected as the matrix material is more compatible with the reinforcement and has good mechanical property and castability at the alloy level itself. The application of the alloy in automobile and aircraft application itself indicated that it is the proper selection. The material is also having good response to age hardening, heat treatment process and precipitation hardening. The reinforcement selected as alumina (Al_2O_3) in the form of particle size 50 micron to 150 micron. It is more stable with aluminium and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to form oxides. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite. The Silicon carbide has been selected as the next ceramic which is a carbide type of ceramic. The SiC has good lubricating effect along with it reduces the noise and vibration during the relative motion. Aluminium7075 is an aluminium alloy in which zinc is a primary alloying element. The composition and properties of aluminium7075 is shown below;

Table 1: Composition of AL7075 [3]

ELEMENT	Cu	Cr	Mn	Mg	Si	Ti	Zn	Fe	Al
PERCENT (%)	1.6	0.15	0.3	2.5	0.4	0.2	5.5	0.5	88.85

Table 2 : Properties of Aluminium 7075 [3]

Mechanical properties	value
Hardness –Brinell	150
Ultimate tensile strength	572MPa
Tensile yield strength	503Mpa
Elongation at beak	11%
Modulus of Elasticity	71.7Gpa
Poisson's ratio	0.33
Fatigue strength	159Mpa

Silicon carbide (SiC), also known as carborundum, is a compound of silicon and carbon with chemical formula SiC. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components, floor tiles etc. Structural and wear applications are constantly developing. Silicon carbide is composed of tetrahedra of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide having 16-100grit size [2].

Table 3: Properties of Silicon Carbide [3]

Property	**values**
Melting Point °C	2200-2700
Hardness(k g/mm2)	2800
Density(g/ cm3)	3.1
Coefficient of thermal expansion(micron/m °C)	4.0
Fracture Toughness	4.6
Poisson’s ratio	0.14
Colour	Black

The chemical formula of aluminium oxide is Al_2O_3. It is commonly referred to as alumina, or corundum in its crystalline form, as well as many other names, reflecting its widespread occurrence in nature and industry. Alumina (Al_2O_3) is the most cost effective and widely used material in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes. With an excellent combination of properties and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications. Its most significant use is in the production of aluminium metal, although it is also used as an abrasive due to its hardness and as a refractory material due to its high melting point [2].

Table 4 : Properties of Aluminium Oxide [3]

Property	values
Melting Point °C	2072
Hardness(kg/m m2)	1175
Density(g/cm3)	3.69
Coefficient of thermal expansion(micron/m °C)	8.1
Fracture Toughness	3.5
Poisson’s ratio	0.21
Colour	White

2. Experiment

The matrix material Al-7075 obtained in the form of ingots. The ingots are cleaned to remove the impurity, dust and oil and heated in graphite crucible in induction furnace. The quantity of alumina and the reinforcement are shown in table 3.The melting temperature was held a t 720°C and the reinforcement heated separately at 8500°C being added to the melt. The constant stirring of the melt carried out with alumina stirrer to get uniform distribution of the ceramic particles. The stirring was carried out for 10 minutes and the melt was poured in to graphite mould [3]. The stir casting process is shown in below figure1.

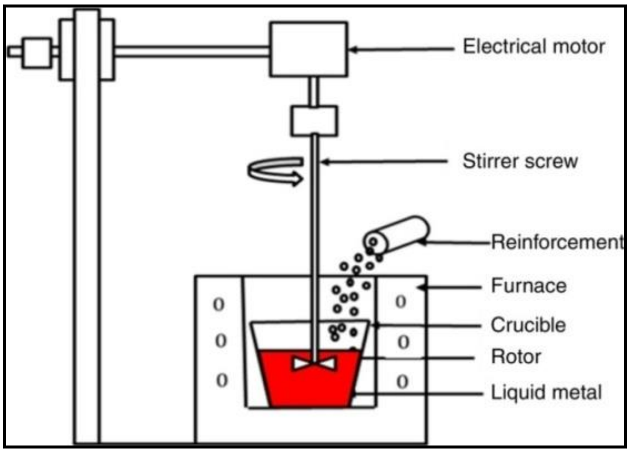


Figure 1 : Stir casting technique

The composition percentage is chosen from the literature and the most common percentage is used in the most of the literature was selected and is given below. According to volume fraction the percentage of reinforcement of silicon carbide and aluminium oxide is varied in steps of 5% to 15%. The weight of reinforcement is based on the weight of matrix material.

Table 5: specimen composition for varying volume fraction [3]

Specimen Code	**AL -7075**	**Al_2O_3**	**SiC**
1	100%	0	0
2	90%	5%	5%
3	80%	10%	10%
4	70%	15%	15%

2.1 Specimen preparation

Castings that are taken out from the mould having a diameter of 12mm and length 100mm and another casting having a diameter of 25mm and length 100mm. These castings are machined in a conventional lathe to a diameter of 10mm and length 35mm and polished in 1000grit emery paper for making wear test. The another casting is reduced to 24mm diameter and 1inch length and polished in a dry and wet polishing machine to get a high surface finish and making a hardness test on the specimen. These specimen are prepared according to ASTM standard for testing. The wear test and hardness tests are performed on the specimens and the readings are recorded.

3. Results and Discussions

The castings of circular cross section of 25mm diameter and 100mm length have been casted. The specimens were machined to reduce the diameter to 24 mm and length to 1inch for microstructure characterization and hardness test. All the tests are carried out as per ASTM standards. The Specimens were grinded and polished with 300, 600, 900 and 1000 grit emery paper followed by dry and wet polishing in polishing machine. The hardness test is conducted through vicker's hardness tester having a microscope of magnification 10X and 40X.

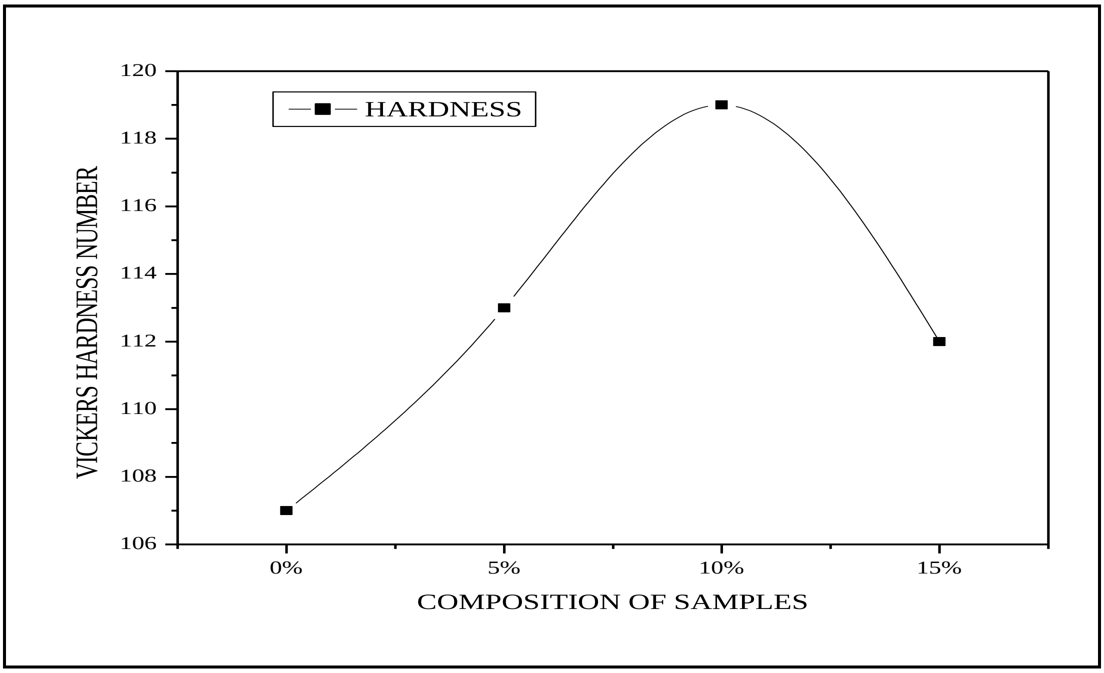


Fig 2: Graph of Percentage composition v/s Vickers Hardness Number

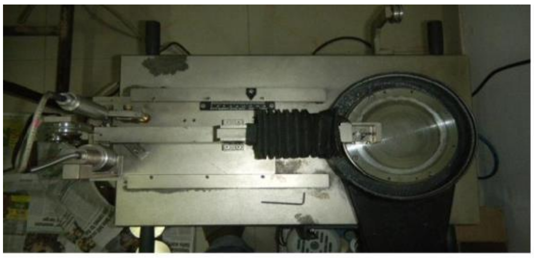
Table 6 : vicker's hardness number for various composition

COMPOSITION	MEAN HARDNESS NO
Pure AL7075	107
Al7075+5%(SiC and Al_2O_3)	113
Al7075+10%(SiC+Al_2O_3)	119
Al7075+15%(SiC+Al_2O_3)	112

The Graph and Hardness table shows that pure aluminium having low hardness number and then the hardness number increases as the percentage of reinforcement increases upto 10% of reinforcement and the hardness number decrease at 15% reinforcement. Hence from the above data we can say that the strength of the AMC is more at 10% of reinforcement of silicon carbide and aluminium oxide. Wear test carried out on 'wear and friction monitor TR-20 supplied by DUCOM, Bangalore. Rotating disc against the loaded pin was used to determine the wear loss of the material at various conditions. The wear simulations confirms to ASTM standards. Tests are conducted in dry conditions and with rotating motion. The test parameter includes load, speed, temperature, roughness, shape and wear track etc.

Figure 3: Wear and Friction monitor

It is very much essential and close approximate the actual conditions encountered the wear tests, however the most sliding wear tests were carried out using pin-on-disc (Ducom TR-20-PHM-400) type wear testing machine, with a large number of variables, which affect the wear mechanism and wear rate Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine .The The pin samples which are obtained after machined and polished were 35 mm in length and 10 mm in diameter. The surfaces of the pin samples was slides using emery paper prior to test in ordered to ensure effective contact of fresh and flat surface with the steel disc. The samples and wear track were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate was calculated according to Wear measurement by mass change. In this experiment was conducted with various parameters such as load, speed, distance, time etc.



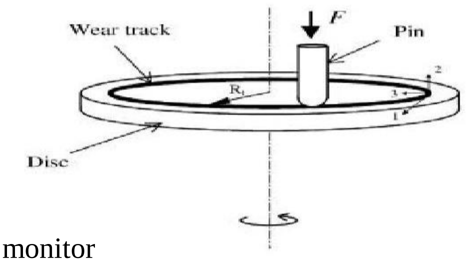


Figure 4. Wear and friction monitor

Table 7 : Numbers Indicating Samples

Identification Number	Sample
1	Pure Al7075
2	Al7075+5%
3	Al7075+10%
4	Al7075+15%

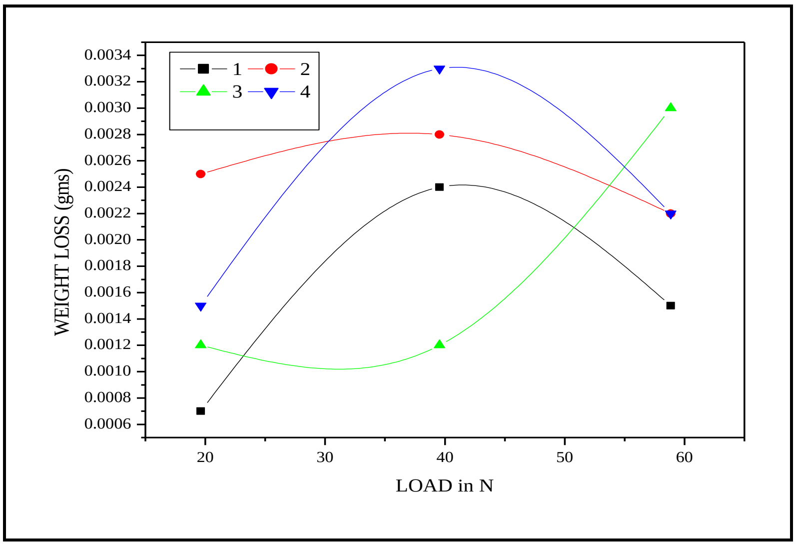


Figure 5 : Graph of Load v/s weight loss

Figure 5 Shows the Graph Plotted for 200 RPM having sliding distance=282.74m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm shows that weight loss is less at 2kg of load, at 4kg weight loss increases and at 6kg again the weight loss decreases.

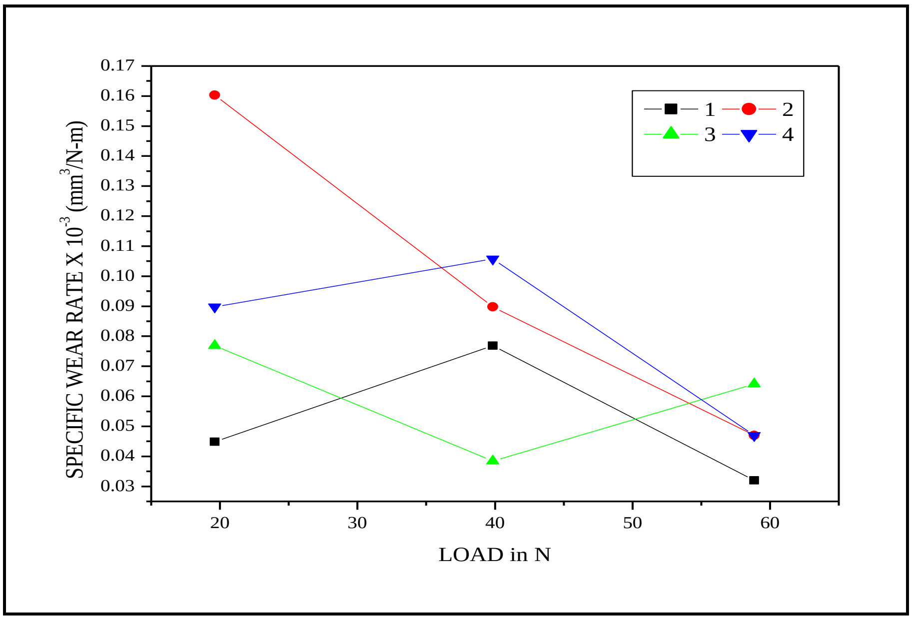


Figure 5.1 : Graph of Load v/s Specific Wear Rate

Fig.5.1 Shows the graph plotted for 200 RPM having sliding distance=282.74m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm shows gradual decrease of specific wear rate as the load is applied.

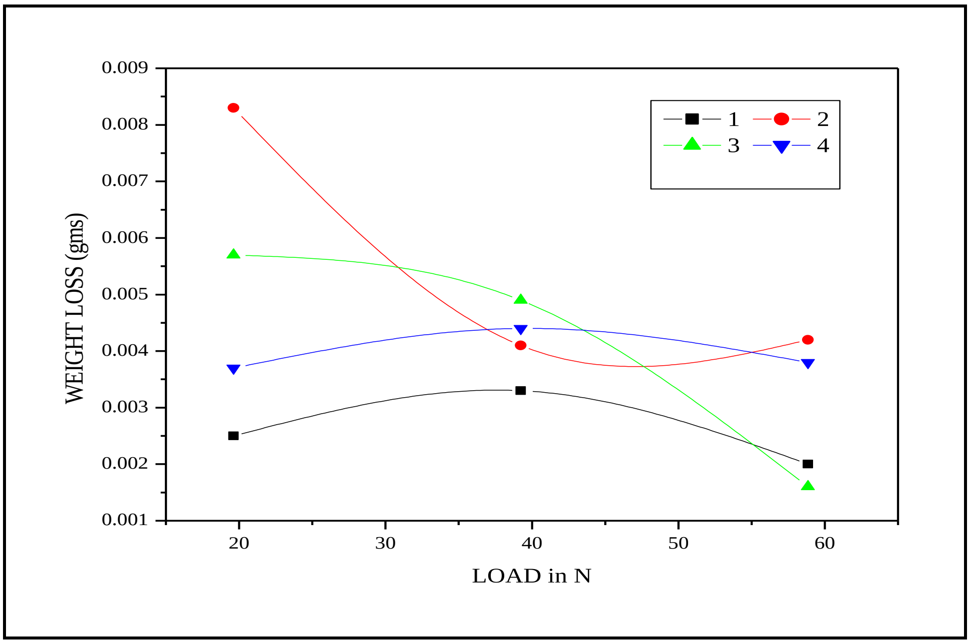


Figure 6 : Graph of Load v/s Weight loss

Fig.6 Shows the Graph plotted for 400 RPM having sliding distance=565.48m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm shows that as the load increases the weight loss decreases.

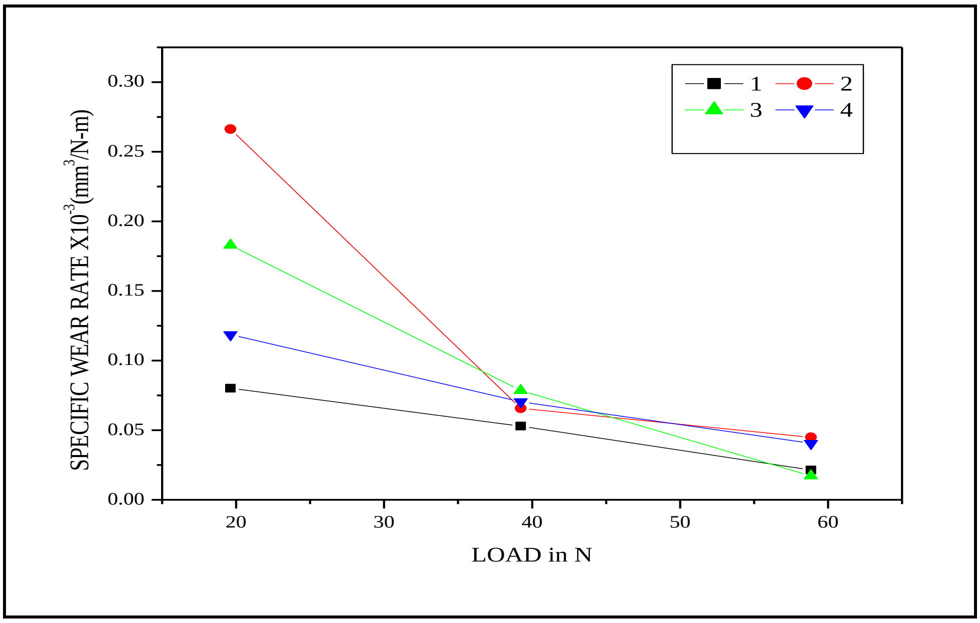


Figure 6.1: Graph of Load v/s Specific Wear Rate

Fig.6.1 Shows the graph plotted for 400 RPM having sliding distance=565.48m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm and it shows that as the load increases specific wear rate decreases.

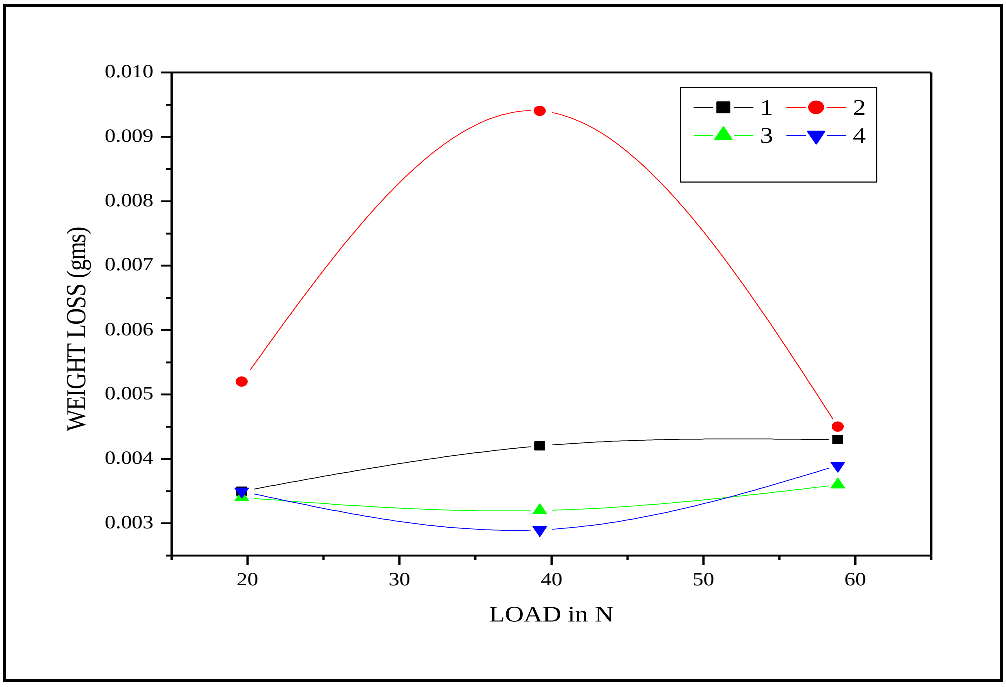


Figure 7: Graph of Load v/s Weight Loss

Fig.7 shows the graph plotted for 600 RPM having sliding distance=848.23m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm and shows that load increases to 4kg weight loss is increases for line 1 and 2 and weight loss decreases for the lines3 and 4. At 6kg load the weight loss decreases for line 2 and increases for the remaining lines.

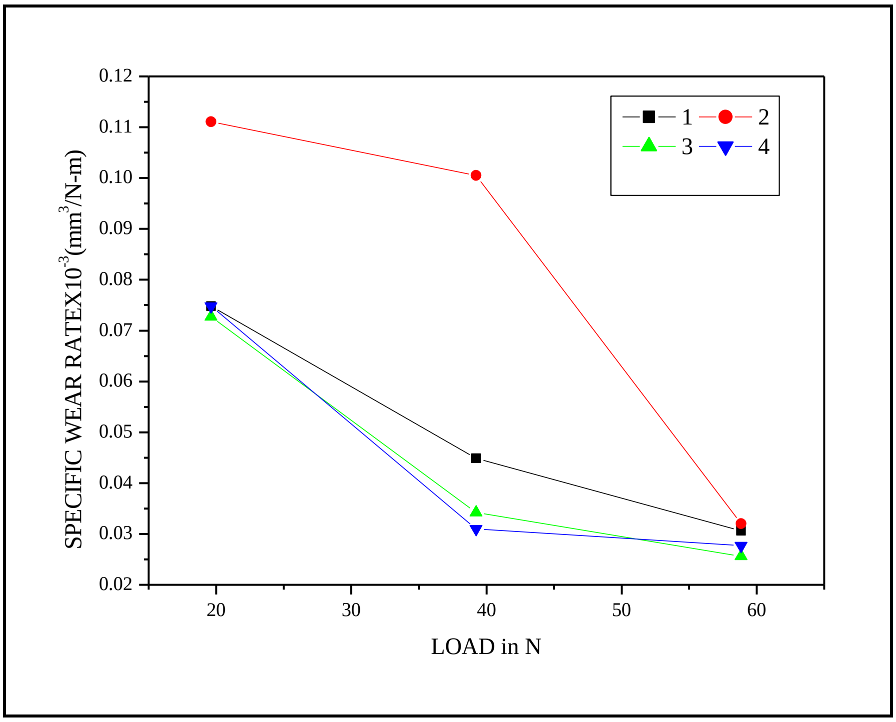


Figure 7.1: Graph of Load v/s Specific Wear Rate

Fig.7.1. Shows the graph plotted for 600 rpm having sliding distance 848.23m, time= 5minutes, sliding velocity=0.9424m/s, track diameter=90mm and shows that as the load increases gradually the specific wear rate decreases.

Aluminium 7075 alloy matrix composites with combined reinforcement of SiC and Al_2O_3 have exhibited improved mechanical properties compared to the composites reinforced with either sic and alumina alone. Hardness of the composite increase because of increase in ceramic phase due to addition of sic particulates. Oxidation resistance of matrix material was significantly improved using sic particulate with addition of Al_2O_3.

4. Conclusion

From the above research work, it is concluded that -

- By stir casting technique the hybrid metal matrix composite can be developed effectively.
- Wear rate found to increase with increase in load and sliding distance. Amount of wear reduces at higher speed than at lower speed of disc.
- The addition of Sic as secondary ceramic reduction in the noise and vibration during the motion.
- By analysing all the graphs and hardness number we can conclude that aluminium metal matrix composite is having higher strength when 10% of silicon carbide and aluminium oxide is added to aluminium7075 alloy.

IOP Conf. Series: Materials Science and Engineering **149** (2016) 012121 doi:10.1088/1757-899X/149/1/012121

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