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Characterization Of Mechanical And Tribological Behaviour Of Aluminium-Silicon Carbide-Titanium Dioxide Hybrid Metal Matrix Composites(MMC)

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***Abstract*—In current scenario, the exploitation of Aluminium matrix composites has been a challenging task for the researchers. In this research paper, the characterizations of mechanical and tribological behaviour of Aluminium matrix composites have been discussed. The different tests viz., impact test, hardness, and wear test have been accomplished. Based on the experimental investigations, it has been benefited that, by the addition of Titanium Dioxide and Silicon Carbide with Aluminium matrix alloy, there has been improvement in mechanical and tribological behaviour.**

***Index Terms*— Aluminium Matrix composites,Mechanical Charcterization, Tribological behaviour.**

I. INTRODUCTION

Materials that are used as raw material for any sort of construction or manufacturing in an organized way of engineering application are known as Engineering Materials. Everything we use in our daily life can be tailored to use for specific cases. This can be done efficiently if we know the property of each material beforehand. Hence, materials have been extensively tested for their properties and classified into broad groups. From this grouping one can know about the gross property of any group of material. The engineering materials available for design and manufacturing of products for several hundred years have been mainly metals and alloys like copper, cast iron, brass which have in wide spread use since the advent of civilization. Metals no doubt, possessed high strength, but certain limitations of metals drove the scientific community towards exploring the possibilities of use of other materials for engineering purposes. The most important drawback is the weight of metals, whose impact was felt in the aircraft industry, especially during the Second World War. In ship building, metals were the obvious choice, but here again were loaded with certain prohibitive factors, mainly their tendency to rust, requiring constant maintenance, which in turn lead to loss of ship availability. Heavy weights once again placed limits on their speed and increased fuel consumption. In case of warships, there is always a danger of mines and magnetic nature of steel was a concern to sailors. Metal Matrix Composites in general, consist of at least two components, one is the metal matrix and the second is the reinforcement. The matrix is defined as a metal in all cases, but a pure metal is rarely used as

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the matrix. It is generally an alloy. In the productivity of the composite the matrix and the reinforcement are mixed together. In the recent years, the development of Metal Matrix Composite (MMCs) has been receiving worldwide attention on account of their superior strength and stiffness in addition to high wear resistance and creep resistance in comparison to their corresponding wrought alloys. The ductile matrix permits the blunting of cracks and stress concentration by plastic deformation and provides a material with improved fracture toughness.

The high toughness and impact strength of metals and the alloys such as Aluminum, Titanium, Magnesium and, Nickel- Chromium alloys which undergo plastic deformation under impact is of interest in many dynamic structural applications of metallic composites. These materials have also been strengthened considerably by means of various strengthened principles (like grain boundary strengthening, cold working, solid solution strengthening etc.) to improve their properties. But these approaches are often found to affect the toughness and durability at elevated temperatures and/ or under dynamic service conditions. One of the important objectives of metal matrix composites, therefore, is to develop a material with a judicious combination of toughness and stiffness so as to decrease the sensitivity to cracks and flaws and at the same time increase the static and dynamic properties.

Successful development and deployment of MMCs are critical for reaching the goals of many advanced aerospace propulsion and power development programs. The specific space propulsion and power applications require high temperature, high thermal conductivity and high strength materials. Metal Matrix Composites also offer considerable promise to help automotive engineers to meet the challenges of current and future demands. It is thus evident from literature that we can successfully reinforce the SiC, TiO2, boron and graphite in the Aluminum matrix alloy. The reinforced Aluminum matrix alloys have made significant strides from laboratory toward commercialization. But the factors understanding that influence the physical and the mechanical properties of these materials is really a challenge because they are sensitive to the type and nature of reinforcement, the mode of manufacture and the details of fabrication processing of the composite after initial manufacture.

It is generally agreed that the resistance to wear of MMCs is created by reinforcement and higher the volume fraction of particles the better the resistance will be however, there is an optimum value of the reinforcement which gives maximum wear resistance to the material. The principle tribological parameters that control the friction and wear performances of reinforced Aluminium composite can be classified into two categories. One is mechanical and physical factors and the other is material factor. The mechanical and physical factors has been identified as sliding velocity and normal load, whereas, with regards to the material factors they are volume fraction and type of reinforcements. The volume fraction reinforcement has the strongest effect on the wear resistance and this has been studied by many researches. Lot of research has been carried out to prepare MMCs by different type of reinforcements. The outcome of all these finding is that wear properties are improved remarkably by introducing hard intermetallic compound in to the Aluminium matrix.

The Literature Survey is carried out as a part of this work to have an overview of the production processes, properties and wear behavior of the Metal Matrix Composites. Composite structures have shown universally a saving of at least 20% over metal counterparts and a lower operational and maintenance cost. As the data on the service life of composite structures is becoming available, it can be safely said that they are durable, maintain dimensional integrity, resist fatigue loading and are easily maintainable and repairable. Composites will continue to find new applications, but the large scale growth in the market place for these materials will require less costly processing methods and the prospect of recycling will have to be solved. It has been reported that the energy consumed when Aluminium is recycled is only about 5% of that required in the primary production of Aluminium. There are, however, certain disadvantages associated with the recycling of Aluminium such as the presence of impurities, which to a large extent impair the mechanical properties of the recycled material. This problem can be overcome by a careful selection of the constituents and also the fabrication technique, as they can lead to the formation and piling up of intermediate phases that are detrimental.

There are many interdependent variables to consider in designing an effective MMC material. Since the upper bound on MMC properties is established by the properties of the matrix and reinforcement material, careful selection of these components is necessary.

Since 20th century, plenty of researches have been carried out on Al-MMCs. This chapter outlines some of the recent reports published in literature on mechanical and tribological behavior of Aluminium based MMCs.

Dwivedi et al. [1] have conducted a study with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. Matrix was Aluminium (98.41 C.P) and reinforcement was SiC(320 grit). He observed that two step mixing method of stir casting ensures the homogenious distribution of reinforcement in the sample. He also observed the improved mechanical properties up to 25% weight fraction reinforcement.

Kumar, et al. [2] have studied the mechanical and tribological behavior of Al-MMC. He concluded that density and hardness increased with increase in reinforcement weight fraction. He also investigated that the ceramic reinforced Al-MMCs will have better wear resistance than the unreinforced alloys.

Natarajan et al. [3] have carried out a study on optimization of friction and wear behavior of hybrid MMC using Taguchi technique. They have concluded that wear rate and co-efficient of friction are dominated by different parameters in the order of percentage of reinforcement, applied load, sliding speed, sliding time. They also found that 4.5 m/s sliding speed, 10 N applied load, 5 min sliding time and 15% of reinforcement are the optimum conditions for both wear rate and the coefficient of friction.

Meena et al. [4] in their study analyzed that tensile, impact strength and hardness increase with the increase in SiC reinforcement in Aliminium matrix.

Singh et al. [5] have studied the mechanical behavior of aluminium by adding SiC and alumina and they found that hardness, tensile strength, yield strength, ultimate strength increase with increase in reinforcement weigth fraction.

Chigal and Saini [6] have investigated in their study on Al6061/SiC that tensile strength increases with increase in reinforcement.

Mishra et al. [7] have studied the tribological behavior of Al/SiC MMC by Taguchi's technique. According to them, the size and type of reinforcement also has a significant role in determining the mechanical and tribological properties of the composites. The results revealed that particulate reinforcement is most beneficial for improving the wear resistance of MMCs.

Kumar and Singh [8] have done a Comparative Investigation of Mechanical Properties of Aluminium Based Hybrid Metal Matrix Composites.The result indicated that the there is an increase in the value of tensile strength, ultimate tensile strength, hardness value and flexural strength of newly developed composite having SiC and B4C particulates in comparison to the SiC, graphite reinforced composite.

Chandra et al. [9] have investigated about the development of Aluminium Based Hybrid Metal Matrix Composites for Heavy Duty Applications and investigated the dry sliding wear behavior of aluminium alloy based composites, reinforced with silicon carbide particles and solid lubricants such as graphite/antimony tri sulphide (Sb2S3). The results revealed that wear rate of hybrid composite are lower than that of binary composite. The wear rate decreased with the increasing load and increased with increasing speed

Hamouda et al. [10] presented a paper on "Processing and characterization of particulate reinforced aluminium silicon matrix composite" and measured the value for the quartz particulate reinforced LM6 alloy composites and it has been found that it gradually increases with increased addition of the reinforcement phase. They also found that the tensile strength of the composites decreases with the increase in addition of quartz particulate. In addition, their research article is well featured by the particulate-matrix bonding and interface studies which have been conducted to understand the processed composite materials mechanical behavior and it was well supported by the fractographs taken using the scanning electron microscope (SEM).

Dhindaw et al. [11] presented a review paper on "Composite fabrication using friction stir processing" and describes the current status of the FSP technology in the field of composite fabrication with the main impetus on aluminum and magnesium alloys. He told the successful application of the FSP technique in generating surface and bulk composites firmly establishes it in the field of composite manufacturing. He also acknowledges that further efforts in this field and better understanding of the process characteristics can pave the way for the commercial success of this technology as well.

Ozsert & Findik [12] have presented a paper on "Dry sliding wear behavior of Al2O3/sic particle reinforced aluminium based MMCs fabricated by stir casting method" and found that hybrid and bimodal particle reinforcement decreased weight loss especially when SiC powder with larger grain size was used. His, microstructural examination showed that besides occurring coarse SiC particle reinforcement, a fine alumina particle reinforcement phase was observed within the aluminium matrix (A332). Furthermore he also told that the incorporation of hybrid and bimodal particles increased hardness of the composites with respect to the composite with fully small sized particles.

Deepak et al. [13] have presented a paper on "Preparation of 5083 Al-SiC surface composite by friction stir processing and its mechanical characterization" in which they reveals that the doping of 5083Al with hard

SiC particles through FSP leads to significant increase in hardness of the surface composite produced on FSPed sample layer. The wear resistance of FSPed sample is inferior to that observed for 5083Al in spite of its higher hardness. It may be attributed to high coefficient of friction and higher friction force observed during the wear testing of FSPed sample.

Akhlaghi and Mahdavi [14] have presented a paper on "Effect of the SiC Content on the Tribological Properties of Hybrid Al/Gr./SiC Composites Processed by In Situ Powder Metallurgy (IPM) Method" in which graphite acts as a solid lubricating agent and lowers the friction coefficient. However, it reduces the mechanical properties of the composite. The presence of hard SiC particles in these hybrid composites increases the hardness and strength and compensates for the weakening effects of graphite. Powder metallurgy (P/M) is an important processing technique for processing of these MMCs but requires a relatively long mixing time for obtaining a uniform distribution of graphite and SiC particles in the matrix alloy. The Al/Gr/SiC compacts were prepared by cold pressing of different powder mixtures and after sintering, the effects of SiC content on the density, microstructure, hardness and wear properties of the resultant hybrid composites was investigated.

Arun et al. [15] presented a paper on "Dynamic behaviour of hybrid aluminium6061 metal matrix reinforced with sic and fly ash particulates" and concluded that the ultimate tensile strength has enhanced with increase in Fly Ash weight percentage and compared to base metal it has increased by 23.26%. The fatigue life has also been increased with the increase in weight percentage of fly ash and it can be seen from S- N curve that SiC 6% give better results when compared to monolithic alloy.

Basavarajappa et al. [16] inspected in detail sliding speed, load, sliding distance, percentage of reinforcement and mutual effect of these factors, which manipulate the dry sliding wear performance of matrix alloy (Al-2219) reinforced with SiC.

II. Fabrication of Composites

The conventional experimental setup of stir casting essentially consists of an electric furnace and a mechanical stirrer. The electric furnace carries a crucible of capacity 2.5 kg. The maximum operating temperature of the furnace is 1000ºC. The current rating of furnace is single phase 230 V AC, 50 Hz. The aluminium alloy (Al 6061) is made in the form of fine scraps using shaping machine. It amounts to about 2.25 kg. The metal scraps are poured into the furnace and heated to a temperature just above its liquidus temperature to make it in the form of semi liquid state (around 600ºC). The mixing of Aluminium alloy is done manually for uniformity. Then the reinforcement powder that is preheated to a temperature of 500°C is added to semi liquid aluminium alloy in the furnace. Again reheating of the aluminum matrix composite is done until it reaches complete liquid state. Mean while argon gas is introduced into the furnace through a provision in it for few minutes. During this reheating process stirring is done by means of a mechanical stirrer which rotates at a speed of 150 rpm. The Aluminium composite material reaches completely liquid state at the temperature of about 800°C as the melting point of aluminium is 700ºC. Thus the completely melted Aluminium metal matrix composite is poured into the permanent moulds. Table 1 shows the hybrid composite specimens. The proposed samples and their composition are given in the following table.

TABLE I. HYBRID COMPOSITE SPECIMENS

SPECIMENS	**LM6 (%)**	**SiC (%)**	**TiO_2 (%)**
Aluminium matrix alloy (A)	100	0	0
Reinforcements with 2.5% weight fraction (B)	97.5	1.25	1.25
Reinforcements with 5% weight fraction (C)	95	2.5	2.5
Reinforcements with 7.5% weight fraction (D)	92.5	3.75	3.75

III. EXPERIMENTAL PRODECURE

LM 6 is a high purity alloy, which is used in castings where thinner more intricate sections are required. This alloy possesses high corrosion resistance and excellent castability making it suitable for marine fittings, water manifolds and road transport applications. LM 6 is a high Silicon Aluminium alloy which can be rather difficult to machine. This alloy is particularly suitable for castings that are to be welded. Silicon Carbide, also known as carborundum, is a compound of silicon and carbon. It is regarded as the second hardest material. Several researchers have investigated on Al-MMC using SiC as reinforcement and concluded that SiC enhances mechanical and tribological properties of the composite. Grains of SiC can be bonded together by sintering process to form very hard ceramics that are used in applications requiring high endurance, such as car brakes, car clutches and ceramic plates in bulletproof vests. Titanium dioxide is a naturally occurring oxide of titanium. The most important applications are paints, varnishes, paper, plastics, fibres and rubbers. The other application of titanium dioxide involve the production of cosmetic products, glass and glass ceramics etc Usually TiO_2 is used in Nano composites for the analysis purpose. Based on the past literature review it is understood that studies carried out on MMCs with TiO_2 reinforcement extremely limited.
The following are the tests that have been conducted.

Tensile test:

Tensile test also known as tension test is probably the most fundamental type of mechanical test we can perform on material. Tensile tests are simple, relatively inexpensive and fully standardized. By pulling on something, we shall very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, we shall find its strength along with how much it will elongate. Tensile Specimen has enlarged ends or shoulders for gripping. The important part of the specimen is the gauge section. The cross-sectional area of the gauge section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gauge length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gauge section, and the gauge length should be great relative to its diameter. Otherwise, the stress state will be more complex than simple tension.

Hardness Test:

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. The hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the hardness number. Therefore, hardness is important from an engineering standpoint because resistance to wear by either friction or erosion by steam, oil, and water generally increases with hardness. Hardness tests serve an important need in industry even though they do not measure a unique quality that can be termed hardness.

Chapry/Izod test

In the Izod impact test, the test piece is a cantilever, clamped upright in an anvil, with a V-notch at the level of the top of the clamp. The test piece is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed height, to give a blow of 120 ft lb energy. After fracturing the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount is read.

Wear test:

A pin on disc tribometer consists of a stationary "pin" under an applied load in contact with rotating disc. The pin can have any shape to stimulate a specific contact, but spherical tips are often used to simplify the contact geometry. Coefficient of friction is determined by the ratio of the frictional force to the loading force on the pin. The pin on disc test has proved useful in providing a simple wear and friction test for low friction coatings such as diamond like carbon coatings on valve trains components in internal combustion engines.

IV. Microstructural Analysis Of Hybrid Composites

Microscopy implies obtaining magnified images to study the morphology, structure and shape of various features, including grains, phases, embedded phases, embedded particles, and so on. One of the oldest technique used for material analysis is electron microscopy. In this study Scanning Electron Microscope (SEM) is used for the analysis of the composites. Microstructural analysis was carried out to check the porosity, particle size and dispersoid concentration of reinforcement. And the SEM analysis was carried out for the samples before conducting any experiments on them. The following are the SEM images obtained during the analysis of different compositions.

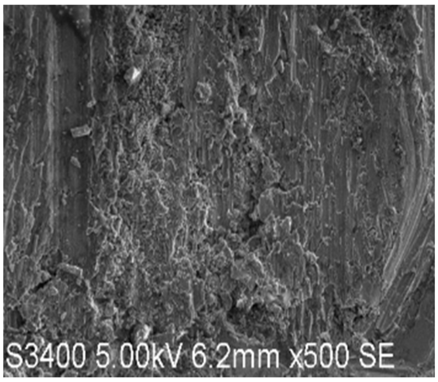

Figure 1: Specimen A

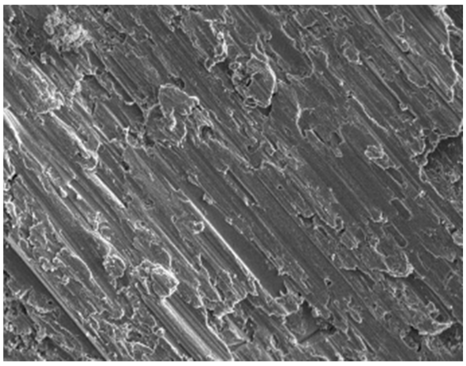

Figure 2: Specimen B

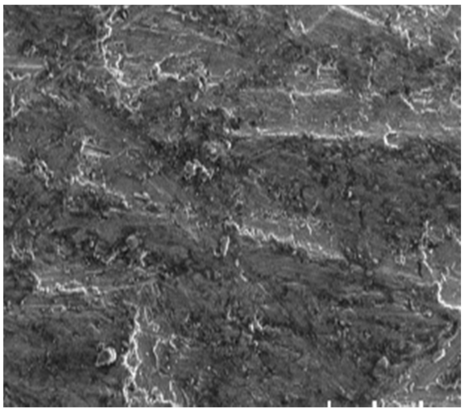

Figure 3: Specimen C

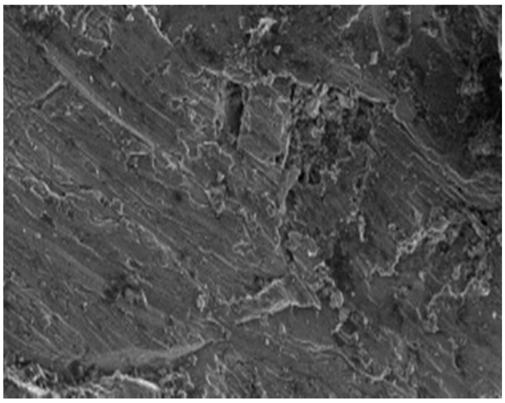

Figure 4: Specimen D

From figures 1 - 4, it has been observed SiC & TiO_2 are dispersed uniformly in the matrix constituent for all weight fractions. It can also be observed that the specimens have got minimum porosities in their composition

V. EXPERIMENTAL RESULTS & DISCUSSION OF MECHANICAL PROPERTIES

Since the results for LM6 material are already available experiments have been conducted by varying weight fraction of SiC and TiO_2 equally (1.25%, 2.5%, 3.75%). Tensile strength, hardness, impact strength and wear rate are recorded and tabulated.

Tensile test:

The tensile test specimens were machined according to the design. After testing the obtained values are tabulated below to plot the graph.

TABLE II. TENSILE TEST RESULTS

Specimen	**Tensile strength(N/mm^2)**
A	160
B	170.232
C	189.716
D	198.99

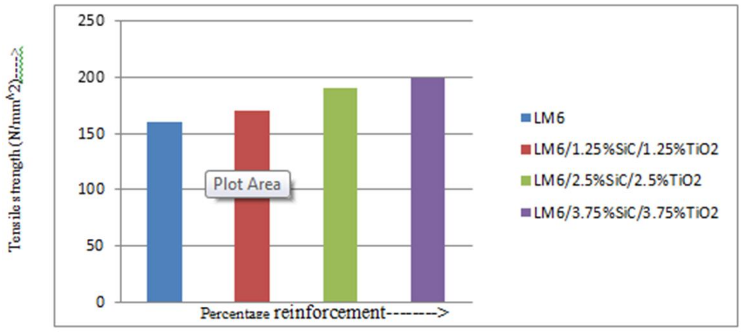

Figure 5: Effect of percentage reinforcements on tensile strength

Fig 5 indicates the effect of percentage reinforcement on tensile strength of the composites. As the weight fraction of the reinforcement increases, the tensile strength of the composite increases. The maximum tensile strength of 198.99N/mm2 is obtained for specimen D i.e. LM6/3.75%SiC/3.75%TiO2 and the minimum tensile strength of 160N/mm2 is obtained for pure matrix alloy (LM6). It can be inferred that SiC and TiO2 are very effective in improving the tensile strength of the composites.

Hardness test:

Hardness values of the samples were measured using Brinell hardness testing machine. The ball diameter is 5mm and load applied for testing is 250Kg

TABLE III. HARDNESS TEST RESULTS

Type of test	**Specimens**	**Hardness number**
Brinell Hardness Test	A	55
	B	77.9
	C	84.8
	D	90.2

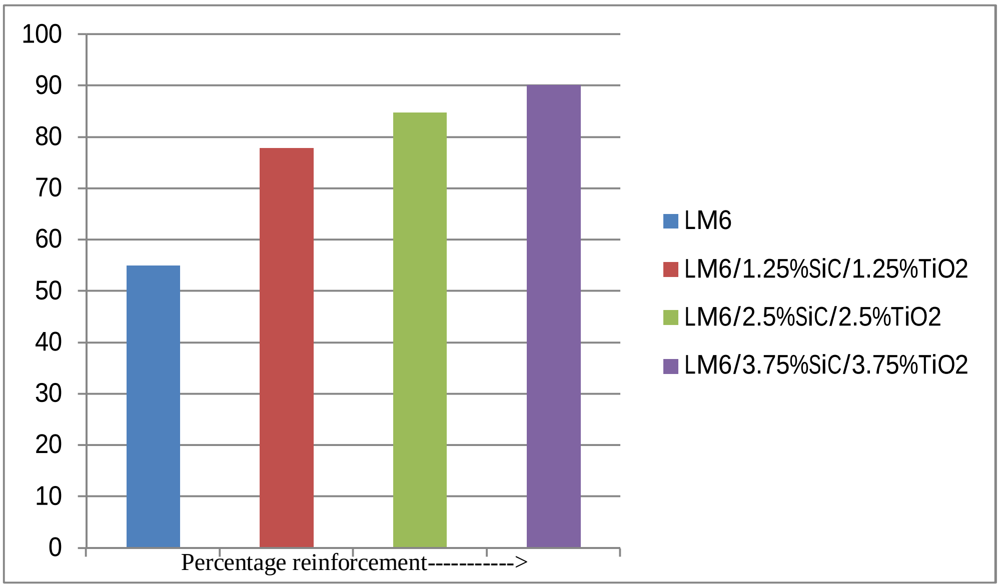

Figure 6: Effect of percentage reinforcements on hardness

Fig 6 shows the effect of reinforcement on hardness of the composites. It is being observed that hardness of LM6 has increased with increase in weight fraction of reinforcement. Addition of reinforcement particles in the melt provides additional substrate for the solidification to trigger thereby increasing the nucleation rate and decreasing the grain size. The Brinell hardness of AMCs was found to be maximum (90.2 BHN) for the Composite with 3.75% of SiC and 3.75% TiO2. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites.

Impact test:

Charpy-Izod test is carried out to determine the amount of energy absorbed by the composite during fracture. The specimens were machined according to the standard dimension and subjected to test. The following table shows the impact strengths of the composites.

TABLE IV. IMPACT STRENGTH OF COMPOSITES

Sl.No.	**Specimens**	**Impact strength(J)**
1	LM6	6
2	LM6/1.25%SiC/1.25%TiO2	6.5
3	LM6/2.5%SiC/2.5%SiC	7.2
4	LM6/3.75%SiC/3.75%TiO2	7.5

Fig. 7 indicates the effect of reinforcement on impact strength. It has been observed that the impact strength of LM6 has been increased with addition of SiC and TiO2. The maximum impact strength of 7.2 J was obtained for the specimen D i.e. for the composite with 3.75% SiC and 3.75%TiO2 of weight fraction.

VI. Evaluation Of Tribological Properties

Wear test:

Wear test is conducted on Pin on disc machine for varying load condition (range of load= 1kgf to 3kgf) and maintaining the time and speed constant. The disc was run for 400 seconds at 500 RPM. The values are tabulated and specific wear rate is calculated for each specimen.

From the fig 8, it can be observed that specific wear rate of composite decreases with the increase in weight fraction of reinforcement. That implies the resistance for wear is increasing with the addition of reinforcement. The minimum specific wear rates (maximum resistance) of 100.5, 52.7, 43.7 mm3/Nm were observed at 10, 20 and 40N respectively for the specimen with 3.75% weight fraction of SiC and 3.75% weight fraction of TiO2. Since the Silicon Carbide exhibits excellent wear resistance (acts as a dry lubricant), wear resistance of the composites increased with the increase in weight fraction of reinforcement. It can be said that TiO2 also possess good wear resisting property

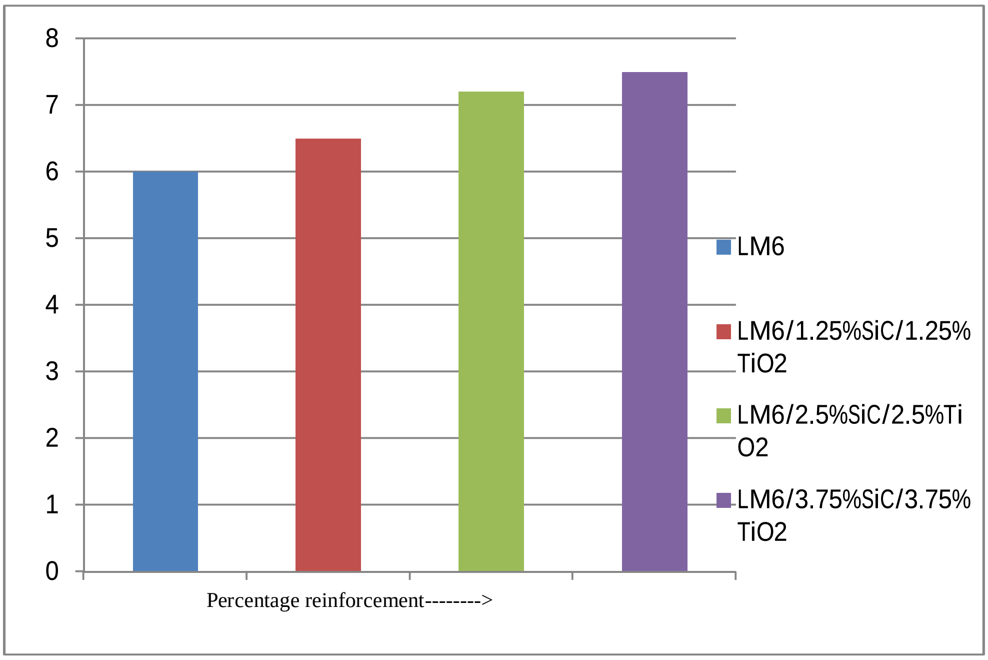

Figure. 7. Effect of percenta ge reinforcements on impact strength

Table V. Volume Loss And Specific Wear Rate Of Samples

Load (N)	Speed RPM	Distance (km)	Time Second	Volume loss mm^3 (*1000)				Specific wear rate $mm^3/(Nm)$			
				A	B	C	D	A	B	C	D
10	500	1	400	1960.3	1256	1055	1004.8	199.8	125.6	105.5	100.5
20	500	1	400	2211.6	1456.9	1155.5	1055.4	112.7	72.848	57.77	52.77
40	500	1	400	3015.9	2059.8	1858.88	1750.6	76.85	51.490	46.47	43.76

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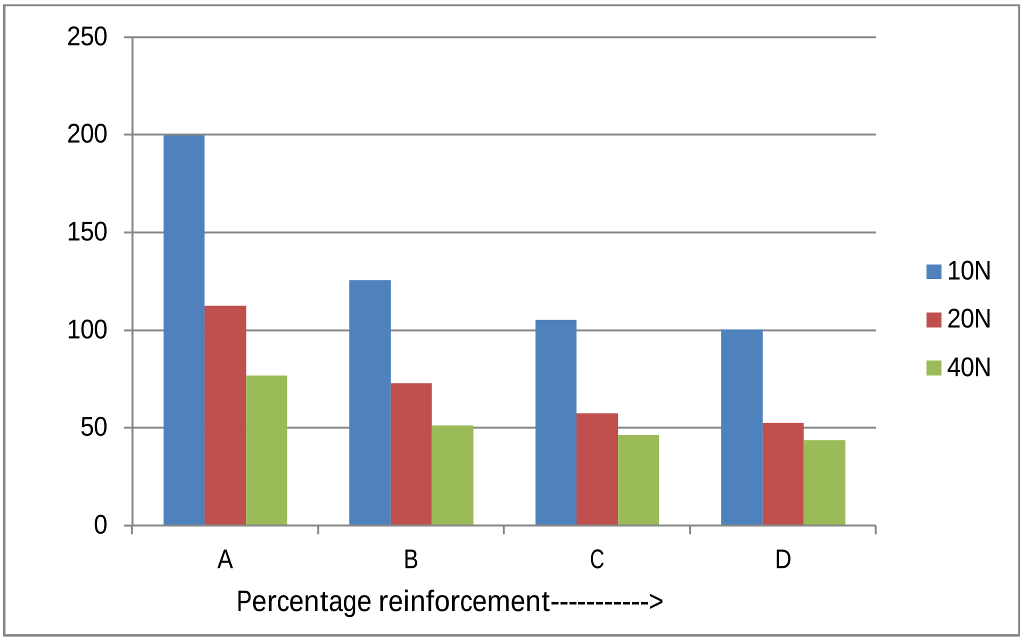

Figure 8. Effect of addition of reinforcements(wt%) on specific wear rate

VII. CONCLUSIONS

The hybrid composites were successfully fabricated by stir casting method subjected to different tests to evaluate mechanical and tribological properties. From the analysis the following conclusions can be drawn.

- The tensile strength of the composites increases with increase in weight fraction of SiC and TiO2.
- The hardness of the composite also increase with increase in weight fraction of SiC and TiO2.
- SiC and TiO2 enhance the impact strength of composites.
- The wear resistance of the composites increases with the increase in weight fraction of SiC and TiO2 as they act as excellent dry lubricators.

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