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Mechanical and tribological properties of Al 7075 /SiC/ Graphite hybrid composites processed by powder metallurgy technique

Atla Sridhar, K.Prasanna Lakshmi

***Abstract**: The metal matrix composite strengthened with ceramic material of carbide (SiC) has smart mechanical characteristics. Metal-based composites, however, demand progress in their friction and tribological characteristics. In this work-study an effort is made to design a completely new material through the method of metallurgy by adding graphite, which acts as a solid lubricant. This study explored the effect of graphite on the tribological behaviour of hybrid composite Al 7075/5 wt. % SiC / X wt. % graphite (X=10, 5 and 0). The research confirms the performance of wear properties by incorporating graphite into the composite. The sic-graphite reinforced Al 7075 (aluminium alloy 7075) was studied. Metallurgy route was used to prepare the composites. Microstructures, the mixture of materials, wear and wear resistance properties were analyzed by optical micro cope and scanning electron microscope, XRD, and pin-on-disc apparatus. The freshly developed metal composite has significant improvement in tribological properties with a mixture 5% silicon carbide (SiC) and 5% graphite. The experimental investigations confirm that a sliding distance of one thousand meters and a sliding velocity of 1.5 m / s with an applied load of 5 N leads to minimum wear loss of 0.01062g and coefficient of friction as 0.1278*

***Keywords:** Al 7075, Graphite, Powder metallurgy, Metal matrix composites, Mechanical and Triboloigical properties.*

I. INTRODUCTION

Aluminium Metal matrix composites acquire several advantages among other b metal alloy materials, composites are mainly metallic alloys reinforced with mostly ceramic materials[1,2].Alloys of lightweight metals (aluminum (Al), magnesium (Mg) and titanium (Ti) are the standard metal all oys (Matrix) used. Other metal alloys have been used, such as zinc (Zn), copper (Cu) and stainless steel.
Silicon carbide (SiC), zirconium(Zr), tungsten carbide (WC), carbon nano tube (CNT), graphite (Gr), aluminium oxide (Al_2O_3), Silica(SiO_2) and boron carbide (B_4C) are a selection of the reinforcement particulate that has been considered. However Silicon carbide and aluminum oxide are often used compared to other artificial reinforcing particulates. Usually all researches are focused on the wear properties of the aluminium alloy and amongst the various ceramic reinforcements, SiC is used with several materials and resulted in improved wear properties [3]. SiC particulates strengthened AMCs are well-known for more strength and wear resistance compared to conventional alloys [4]. Increase in volume of silicon carbide and its size decreases the particular wear rate of AA6061/SiC composites. Each mechanical strength and wear resistance of Al alloy will increase with an increase in silicon carbide particulates [5].
However, the resultant increase in silicon carbide content in composites makes machining tough. Self-lubricating (Gr, MoS_2) particulates are well matched to the machining problem, and their additions improve the mach inability and wear and frictional properties of composite. The aim of the current research is to fabricate aluminium based hybrid composite reinforced with hard and soft solid lubricating nanoparticles by mechanical mixing and metallurgy techniques. The microstructures of prepared composites are examined by using of X-ray diffraction measurements (XRD), optical microscope (OM), scanning electron microscope (SEM), and mechanical properties were measured through density and hardness tests and evaluation of the dry sliding wear behavior of the prepared hybrid composites by pin on disc apparatus.

II. METHODOLOGY

The hybrid composite specimens were produced by the powder metallurgy technique. In the current research work Al7075 alloy was used as the base metal matrix and SiC(27–33 μm) as reinforcing material with the composition of Al 7075 - 5 wt.% SiC - X wt.% Gr(X = 0, 5 and 15 wt. %). The Matrix material (supplied by Prabhu Copper Restricted, Mumbai, and Maharashtra, India,) used in the present experimental investigation is Aluminium 7075 (Al 7075). The composites were processed by powder metallurgy route. Powder metallurgy (PM) is a mechanism of metalworking te chnic to form mechanical parts with great efficiency are pro duced from metal powders.At room temperature, the metal p owder was first squeezed into product form.This will be carr ied out by heat-treatment (sintering) which, which can be se en in fig.1, causes the powder fragments to fuse with each ot her without melting.The components developed by PM have appropriate physical and mechanical properties while fully meeting the requirements of functional performance.PM part s ' are well suited for industrial applications include self-lubr icating bearings and a large scope of designed models like b earings, gears, brake pads, and cams etc.

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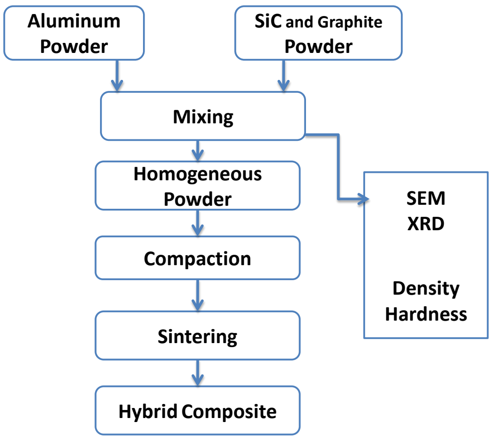

Figure 1: powder metallurgy process chart

III. EXPERIMENTAL PROCEDURE

A. Specimen Preparation:

At first, the received powders were dried out at 115 ºC in a muffle furnace for 1 hr to remove the moisture and other contaminations present. The following three steps are followed in sequence in the PM method: mixing (or mixing), compacting, and sintering. Blending / Mixing: Preparation of a homogeneous combination of elemental metal powders or alloy powders.

B. Blending:

In the Laboratory, a high-energy ball milling machine was used to blend the powders as shown in fig.2. Mechanical alloying is performed for 60 hrs, duly maintaining the conditions such as powder to ball weight ratio as 1:10, at a speed 300 rpm and cycle time of 5 min.

C. Compacting:

A required quantity of homogenously mixed powder placed in an appropriate die and pressed or compacted at a compression range of 700Mpa and the same can be observed in fig. 3. The required compressing range relies on the particle attributes, size, shape, and the blending mechanism, and also the type of die wall lubricant used. usually, the entire process takes place at ambient atmospheric conditions. This strengthens and densifies the loose powder into a die mold model. As it emerges from the die, the compact has the processed product's shape and size.

D. Sintering

This method includes heating the material to above recrystallization temperature and below the melting point of the base alloy component, generally in a regulated environment, during this phase the base metal becomes smooth and the particulates of reinforcement and matrix fuse around each other. It is possible to carry out further additional finishing procedures, but the component produced by powder metallurgy may not generally require additional finishing procedures. The appropriate samples produced are shown in fig.4. Scanning electron microscope (SEM) was used to examine the samples, which is a significant testing tool and performs a metallographic qualitative evaluation. SEM's micrographs show grain size, crystal structure, particulate shape and their distributions throughout the base metal matrix.

Figure 2: ball mill powder in toluene medium

Figure 3: uni-axial compaction under UTM

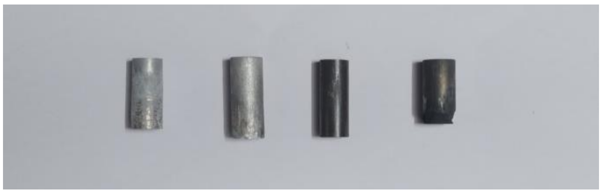

Figure 4 prepared composite specimens

E. Density and hardness:

The mixture rule evaluated the density of the composites samples. The samples were first evaluated in air and subsequently calculated water and density values. Similar outcomes [10, 13, 17, and 19] have been noted. On the Rockwell hardness analyzer, the hardness tests were conducted. With the following as testing parameters, 1/16th diameter of ball indenter, 100 Kgf load applied with the holding time for 20 secs , like that each specimen has been tested to find its hardness.

F. Dry sliding behaviour:

The dry sliding behavior experiments were conducted as per the ASTM G99 standards with the help of pin on disc apparatus (Ducom, PR20LEPHM 300 model, IIT Hyderabad. India).

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Counter disc material used is EN 32 steel, before performing wear test the surfaces of the pins and disc materials are cleaned with toluene. Sliding velocity in meter per second (m / s), sliding distance in meter (m) and applied load in Newton (N) were the wear parameters chosen for the experiment. Thus, each parameter has been evaluated at three levels and process parameters are provided in Table 1 along with their values at three levels.

Table. 1: different ranges of process parameters

Parameter	Range 1	Range2	Range3
Load (N)	5	10	15
Sliding speed (m/s)	0.5	1	1.5
Sliding distance (m)	1000	2000	3000

Tests were performed without the use of any lubrication at room temperature. Specimens with a diameter of 6 mm and a hight of 25 mm were prepared and polished from the sintered samples. The prepared specimen (pin) contact surface must be flat and should be in close contact with the revolving disc. The pin is retained against such a revolving EN32 metal disk (hardness of 68-72 HRC) throughout the experiment by exerting pressure which serves as a counterweight and helps to balance the pin.

For all experiments within the range of 80–160 mm, the tr ack diameter has been changed and the constraints like load, sliding velocity, and sliding distance have been altered with in the range given in Table 1.The Weight loss for each specimen (pin) was measured by weighing the pin before and after the test with 0.0001 g accuracy. The fixed wear rate was measured from the applied normal load and tangential load obtained from strain gauges. Fig.5 shows the block diagram of the pin-on-disk device used for research work.

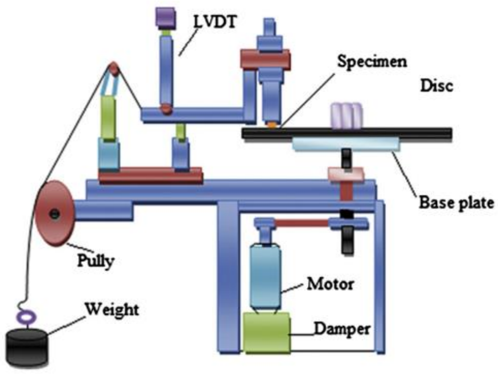
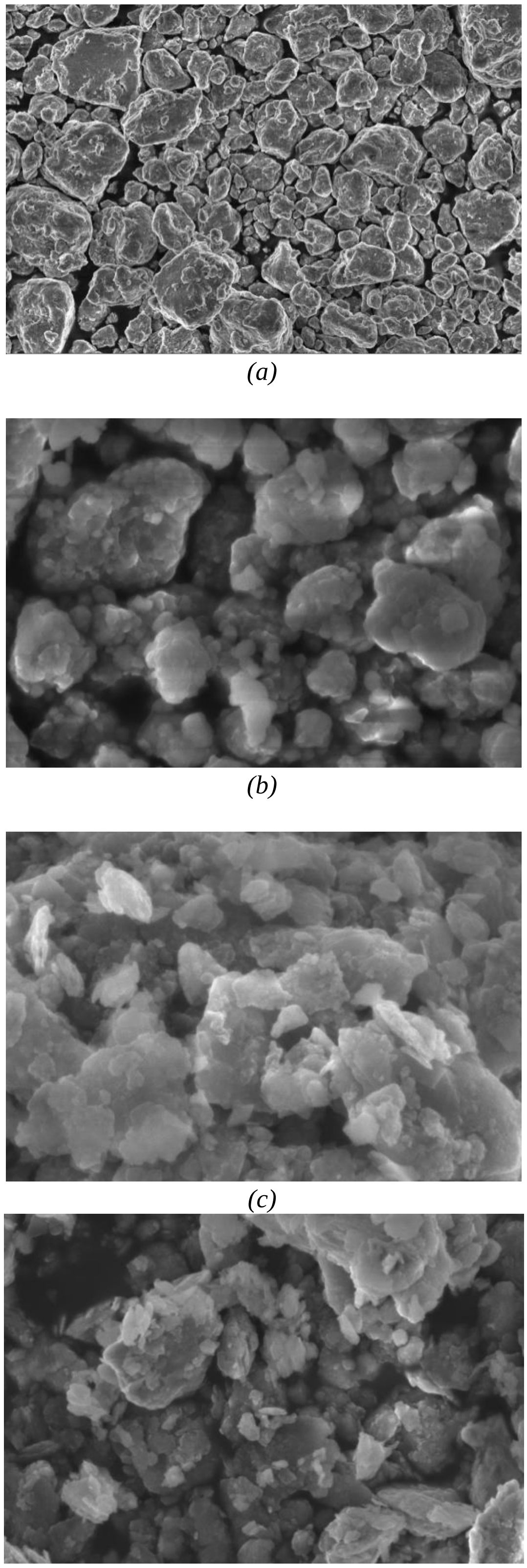


Figure 5 pin-on-disc apparatus setup

IV. RESULTS AND DISCUSSION

A. SEM Analysis:

The polished specimen pictures were captured within the scanning microscopy with varied magnification and scale. Figs. 6 (a-d) represent the SEM image of hybrid composite of Al 7075, Al 7075 + 5 wt. % SiC, Al 7075 + 5 wt. % SiC + 5 wt.% Gr and Al 7075 + 5 wt. % SiC + 10 wt. % Gr respectively. The SEM image concludes that a homogenous mixture of Al 7075, SiC and therefore the homogeneously distributed graphite over base alloy matrix. The image with minimum dark zone reveals the minimum porousness formation level within the specimen.



(a)

(b)

(c)

(d)

Figure 6 (a-d): SEM micrographs of sintered composites (a) Al 7075, (b) Al 7075 -5% SiC, (c) Al 7075-5 SiC-5% Gr, (d) Al 7075-5 SiC-10% Gr

B. XRD Analysis:

Fig.7 shows the outcomes of X-ray diffraction (XRD) for the developed hybrid composites.

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These findings show the involvement of aluminum (in the biggest valleys), and tiny peaks show the existence of silicon carbide particles and Graphite. In hybrid composite material, an obviously visible graphite peak may be noted. The rise in carbon peak intensity is obvious with the composite's growing graphite content. Also obvious is a gradual marginal change of the Al peaks to greater corners with a weight percent rise in the graphite content. Fig. 5represents there is no oxidation taking place during sintering the samples. For all hybrid nano-composites, the phases detected by the XRD observation have been identical. All such trends indicate that particles of reinforcement in the aluminum matrix are well spread. The XRD pattern revealed the existence in the hybrid nano-composite of aluminum, Gr (C) and SiC particulates.

C. Density and hardness:

From Table 2, it can also be noted that the composite density is greater than that of the base alloy; in addition, the density improves with an increased proportion of the reinforcement content. This rise in Al 7075–SiC composites density is primarily attributed to SiC's greater density than Al7075 base alloy.. As the SiC content decreased, the density of the Al 7075–SiC composite material improved.

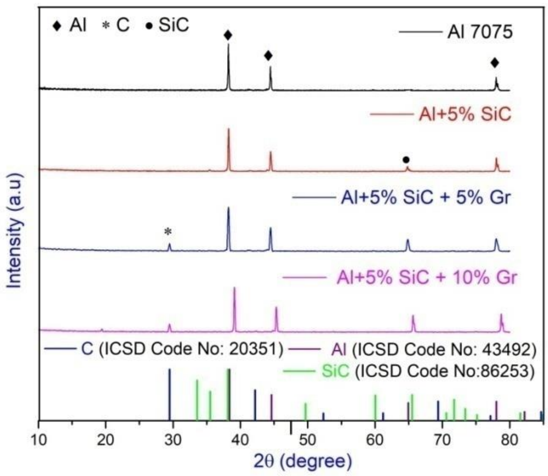

Figure 7: XRD analysis

***Table:2** Mechanical properties*

S. N o	Composition	Densit y	Hardn ess
1	Al7075	2.81	74
2	95% Al7075 + 5% SiC	2.93	77
3	90% Al7075 + 5% SiC + 5%	2.86	73
4	85% Al7075 + 5% SiC +	2.84	68

From the constructed Graph Fig. 7& 8 shows that, it also Observed a reduction in density with Gr reinforcement incre ases. It can be directly attributed to the addition of Gr's redu ced density . This can be acknowledged that with the increas e in weight percent of Gr reinforcements, the composites ' h ardness was worse.

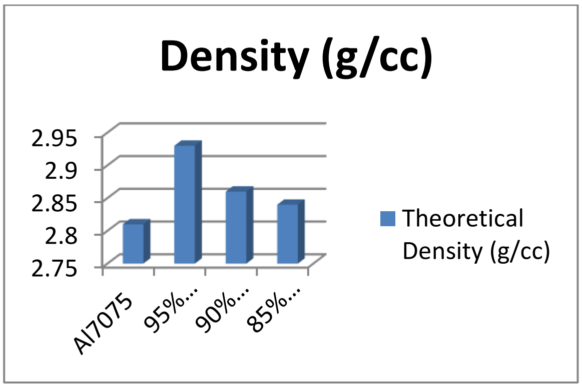

Figure 7

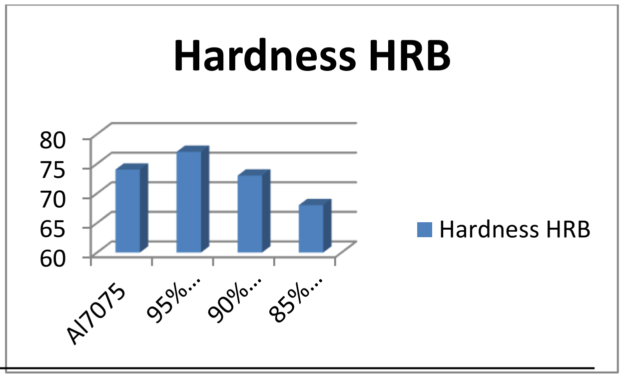

Figure 8

The reduction in hybrid composite hardness is due to the following factors. (I) Low Particulate Reinforcement Hardne ss of Gr. (ii) Uniform nano-composite distribution of Gr. (iii) reduced density contributing to a reduction in hardness.

D. Dry Sliding behavior:

Applied load ranges of 5–15 N, sliding distance ranging from 1000–3000 m and sliding speeds of 0.5–1.5 m / s. To calculate the wear rate, the pin-on-disk device was performed at a steady sliding velocity of 0.5 m / s and a constant sliding distance of 1000 m. For Al 7075 + 5 wt. % SiC, Al 7075 + 5 wt. % SiC + 5 wt. % SiC + 5 wt. % SiC + 5 wt. % Gr and Al 7075 + 5wt. % SiC + 5wt. % Gr were calculated.

The wear loss for all four sample combinations improved with regard to the load applied. A lowest wear rate of 0.01395 g and the low coefficient of friction is 0.1476 obtained by Al + 5 wt. % SiC+ 5 wt. % Gr sample at 5 N normal applied load. Figure 9(a) shows sample behavior for wear rate versus normal applied load, and wear rate rises for all four combinations with applied load. Figure 9(b) also demonstrates the connection between the coefficient of friction and the load applied, and the friction coefficient improved with the load applied. Table. 4 show the wear loss and coefficient of friction results under a steady applied load of 5 N and 1000 m sliding distance. Wear loss and coefficient of friction were noted to be minimal in elevated sliding velocity and its graphs are shown in figures 9(c) and 9(d) respectively. For Al 7075 + 5 wt. % SiC+ 5 wt. % Gr specimen at sliding speed of 1.5 m /s, the lowest wear loss of 0.00918 g and lowest coefficient of friction 0.1053 are recorded.

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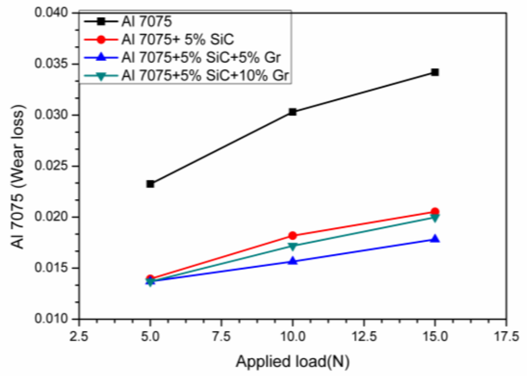
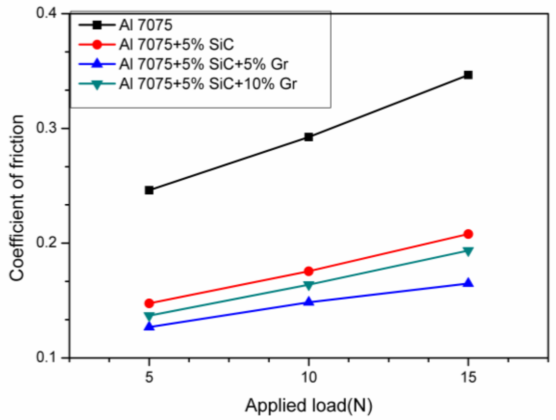
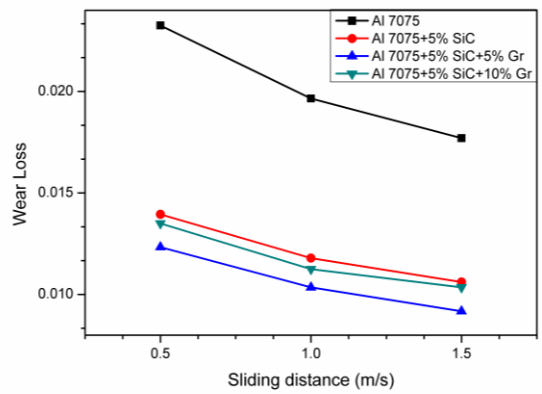


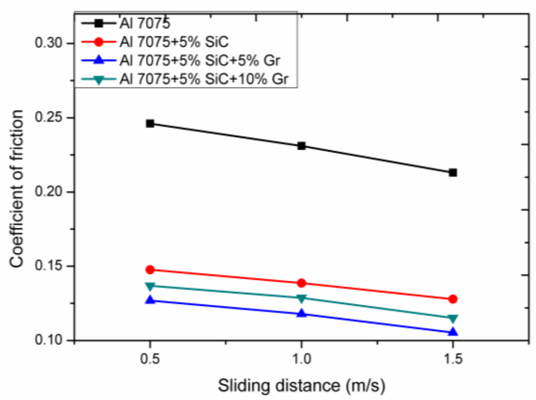
(a)



(b)



(c)



(d)

Figure 9(a-d): (a)wear loss Vs applied load, (b): coefficient of friction Vs Applied load, (c) waer loss Vs sliding distance, (d) coefficient of friction Vs sliding distance.

The adhesion wear is found at a higher sliding speed and the protective layer for the composite is produced on the surface at a minimum sliding range by an oxide layer that generates high cohesive forces on the contact surfaces. The heat generation enhanced with increasing sliding velocity during friction contact. The aluminium alloy matrix leads to plastic deformation, developing an oxide layer at high temperature, allowing smooth sliding on the surface of the disk, and reducing wear loss at greater speeds.

V. CONCLUSION

During this investigation, the various types of Al 7075 hybrid composites are generated by the solid metallurgy route . The addition of Gr as a solid lubricant has resulted in significant wear and tribological performance. Within the studied variations of Al 7075 + 5 wt. % SiC, Al 7075 + 5 wt. % SiC + 5 wt. % Gr and Al 7075 + 5 wt. % SiC + 10 wt. % Gr, wear and surface resistance properties depended upon the proportion of Gr. the mixture of Al 7075 + 5 wt. % SiC + 5 wt. % Gr has shown minimum wear loss and les frictional co-efficient at the constant sliding speed of 0.5 m/s and constant sliding distance of 1000 m. Similarly, the minimum wear loss and co-efficient of friction were determined at a sliding speed of 1.5 m/s with the constant applied load of 5 N and sliding distance of 1000 m. The experimental studies reveal that further addition of 10% Gr within the hybrid composite doesn't facilitate to enhance the wear properties. The study can be designed to experiment and is also extended to optimize the composition where light weight, mechanical and tribological properties are critical because of the scope of work in the future.

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I Dr. K Prasanna Lakshmi , PhD, working as Associate Professor of Mechanical Engineering Mechanical Engineering Department, JNTU college of engineering Manthani. 15 years of teaching experience in teaching and research. My research intrest is production engineering, especially Automation in manufacturing, composites.

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