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Synthesis and Analysis of Wear Depictions on Al 6061alloy reinforced with SiC/Graphite Particles Hybrid MMCs through Stir Casting

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Abstract: *The stir-casting method offers an efficient approach to produce higher-grade metal matrix composites (MMCs) using Al composites. Among the various methods available, stir-casting is frequently employed. This study focuses on the formation of Al6061/SiC+Gr hybrid MMCs, incorporating different weight percentages of SiC/Gr(2%, 4%, 6%, and 8%). The microstructures clearly revealed the uniform distribution of SiC/Gr particles in the Al matrix. The hardness of the in-situ Al-SiC/Gr based composites increased by 10.58%, 22.35%, 50.58% and 41.17% compared to the matrix with the addition of 2, 4, 6 and 8 wt.% SiC/Gr reinforcements, respectively. The tensile strength of the 2, 4, 6 and 8 wt.% SiC/Gr hybrid composites increased by 9.08%, 15.91%, 19.09% and 7.27%, respectively, compared to the matrix, whereas the ductility decreased by 8.9%, 12.5%, 18.75 % and 25%, respectively. A pin-on-disk tester was used to perform a dry sliding wear test at different loads and sliding speeds. In comparison to the Al matrix, the composite materials showed improved wear resistance. Furthermore, in the entire applied loads and sliding velocities, the wear rate decreased with the increase in SiC/Gr content. The composites displayed lower wear rates due to their high hardness and strong interfacial bonding between the in-situ reinforcement and the matrix alloy*

Keywords: Al6061 alloy; SiC; Gr; Hybrid composites; Microstructure; Wear analysis

I. INTRODUCTION

Composite materials do play a great significance and an effective role in many engineering industries applications because of the physical properties that are characterized by thermal properties. Thermal properties are one of prime physical properties of composites, which also include electrical, magnetics and optical properties. Thermal property of a material is its physical property related to application of heat energy and explain its response [1-6]. As a solid body absorbs energy in the form of heat, its temperature increases and its dimensions increase. Wear properties that are often critical in the practical utilization of solids. In this project we are developing and doing analysis on wear properties of Al6061 and SiC/Gr hybrid composites. Composite is combination of two basic constitutions namely matrix and reinforcement. In general, composites are formed of reinforcement (fiber, particle, flake, filler) enclosed in a matrix (metals, polymer and ceramics). The matrix holds the reinforcement to maintain the right form while the reinforcement improves the mechanical and wear properties of the matrix. The properties of composites are influenced by the material combinations utilized, the distribution of reinforcement within the alloy matrix, and the interface between the matrix and reinforcement. The features of composites are influenced by the size of the particle and how it is dispersed inside the matrix material, as well as by the volume or weight ratio between the matrix and reinforcement. Al, magnesium, copper, titanium, Al-lithium, and super-alloys are widely used as the matrix materials in these composites. Al-based metal matrix composites were extensively used in a number of different sectors [7-10]. The use of aluminium as a matrix material to form MMCs has developed in response to the desire for lightweight materials with high strength and stiffness. Reinforcing SiC, TiB_2, TiC, B_4C, SiC, SiC, and ZrO_2 containing minute ceramic particles results in aluminum-based MMCs.In order to gain the optimum properties, selection of good reinforcement and the matrix materials are not only sufficient, processing method also plays a significant role. There are different techniques available to produce AMMCs like powder metallurgy, squeeze casting, stir casting, chemical vapour deposition, pressure infiltration etc. Among these manufacturing techniques stir casting is the prevalent technique which has been used by many investigators since the process is cost-effective, and this process have greater hardness and refined micro structure grains than other techniques.The primary stage of having an incessant character is called the base metal (matrix). Matrix material is normally more ductile with low hardness and the capacity to hold the distributed stage and share loads within it. The composite matrix materialsmust be carefully selected in terms of its characteristics and reinforcements behavior. Since the matrix is such an important component of MMCs, it should be chosen based on its chemical compatibility with the reinforcements. The function of reinforcements in an MMC is to enhance its mechanical characteristics with a neat resin structure. The reinforcing material raises the composites strength and hardness while lowering the density of MMCs. The right reinforcement will help achieve better characteristics. When applying reinforcement to a metal matrix, particle size, type, processing technique, and chemical compatibility all play a role. Weight, shape, property Scale and volume fraction, and uniform dispersion in the base metal are all characteristics of reinforcements. Although the addition of reinforcements improves the material's properties, it does not make it isotropic. MMCs reinforced with particulates exhibit isotropic properties while still being cost-effective. A hybrid composite is created when the matrix is reinforced by two or more materials. There is a discontinuity at the interface, whether it be mechanical, electrical, or chemical. It possesses qualities that cannot be separated from any of its components. The contact between the reinforcements and the matrix needs to be wide and have strong adhesion. Contact between the matrix and the dispersed reinforcing particles is essential for the creation of composites. The reaction product occasionally displays poor MMC characteristics. In order to prevent such a tragedy, attention must be paid to two important factors: bonding strength and chemical reactions. The matrix alloy's composition and reinforcement project the interfacial response. It's possible that the blowhole and the surface's cleanliness will create some trouble. The strength of the composite material is inversely correlated with the distribution of the reinforcing components in the matrix alloy. The ability of the matrix alloy to support loads must be determined by the transmission of the dispersed ceramic particle via the contact. Therefore, dispersion reinforcements must be tightly welded to the matrix alloy in order to boost the strength and stiffness of the composite. The type of fracture is also influenced by the contact's strength. In contrast to a strong interface, which delivers strength and higher stiffness but consistently exhibits a smaller resistance to fracture, or brittle behavior, a weak contact produces low strength and stiffness but high fracture resistance. Intermetallic bonding may serve a variety of purposes, depending on the type of reinforcing materials utilized. Only a few dense atoms across, the intermetallic bonding is where the properties of the matrix alloy and the reinforcement particles alter. As a result, the interface commonly exhibits discontinuities in chemical, crystal, high stiffness, mechanical, and tribological properties as well as molecular structure [11-16].

II. MATERIALS AND METHOD

Aluminum alloy 6061, commonly known as Al6061 or simply 6061, is one of the most widely used and versatile aluminum alloys. It belongs to the 6xxx series of aluminum alloys, which are heat-treatable and known for their excellent combination of strength, machinability, and corrosion resistance. Al6061 is a popular choice in various industries, including aerospace, automotive, marine, and general engineering applications. The chemical composition of Al6061 typically includes 97.9% aluminium, 0.6% silicon, 1.0% magnesium, 0.28% chromium, 0.2% iron, 0.25% copper, 0.15% zinc, and trace amounts of other elements. The addition of these alloying elements contributes to the unique properties of Al6061.Aluminum alloy 6061 is a widely available and versatile material that meets the demands of diverse applications requiring a balance of strength, machinability, and corrosion resistance. Its popularity is likely to continue as industries seek lightweight and durable materials for various engineering and manufacturing needs.

Silicon Carbide (SiC)is a compound composed of silicon and carbon atoms. It is known for its remarkable hardness, high thermal conductivity, excellent chemical resistance, and low thermal expansion coefficient. SiC is a covalent material, which means it has strong atomic bonds resulting in exceptional mechanical strength and stiffness. These properties make SiC ideal for use in extreme environments, where conventional materials may fail.Graphite (Gr) is an allotrope of carbon with a unique layered structure. It consists of carbon atoms arranged in hexagonal sheets, which are loosely bound together by weak van der Waals forces. Graphite exhibits exceptional electrical conductivity, lubricity, and thermal stability. Its high electrical conductivity makes it suitable for electrical and thermal management applications.

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The stirrer assembly consisted of a graphite stirrer, which was connected to a variable speed vertical drilling machine with range of 100 to 250 rpm by means of a steel shaft. The stirrer was made by cutting and shaping a graphite block to desired shape and size manually. The stirrer consisted of four blades at an angle of 90 degrees apart. Clay graphite crucible was placed inside the furnace. The graphical representation of stir casting. The capacity of the electrical resistance furnace used was up to 450 rpm.

Table 1: Composition of hybrid composites

Composition Sample	**Wt. % of Composition**
Sample1	Al6061
Sample2	Al6061+2%SiC+2% Graphite
Sample3	Al6061+4%SiC+4% Graphite
Sample4	Al6061+6%SiC+6% Graphite
Sample5	Al6061+8%SiC+8% Graphite

III. TESTING OF THE HYBRID COMPOSITES

The developed hybrid composites are subjected to microscopic investigation to examine the microstructure. Study of microstructure comprises of optical microscopic study, EDS study, SEM study of tensile fractured surfaces and worn-out surfaces of wear specimen. The uniformity of reinforcement distribution, which is influenced by the manufacturing and processing techniques employed, is the most crucial component in the production of hybrid composites. An optical microscope was used to conduct metallographic investigations of the resulting composite materials in order to study the distribution of reinforcements inside the aluminium matrix. On a typical universal lathe machine, the cast composite specimens were mechanically ground into 10 mm diameter and 10 mm heights. For microstructural analyses, the samples were polished on 200, 400, and 600-grid emery paper. The microstructure test samples received metallographic polishing. The specimen was subjected to micro structural tests after having its surface thoroughly cleaned with hydrogen fluoride as an etchant in order to obtain an equal distribution of reinforcement particles in the aluminium matrix. The experiments were conducted using an inverted optical microscope with a 100X–1000X magnification range.

Optical microscopic examination examined the basic information about the microstructure of developed MMCs. The optical microscope employed for this purpose was Olympus and having following specifications: NIKON- ECLIPSE LV 150 Japan optical metallurgical microscope, magnification range of 100X – 1000X with 360^{o} rotatable analyzer slider for reflected light and objective lens of 5X to 100X. For the microstructural examination, the samples were polished using the standard metallographic method. One end of the specimen underwent polishing with abrasive sheets of different grades from 100 to 120^{o}F. It was then followed by cleaning the specimens by soaking them in kerosene and polish with velvet cloth. Specimens are then polished with diamond paste and then etching is carried out using the Keller's reagent. Polished surfaces of specimens were positioned in the optical microscope for observation.

The wear rate of the developed hybrid composites was evaluated using wear testing. The experimentation followed the recommendations of ASTM G 99-05. Machines were used to form test samples with dimensions of 8mm in diameter and 30mm in length. The computerized testing apparatus pin-on-disc (Version-EV00, WTE 165 model) of disc size 165 mm and thickness 8mm (Material: EN31) was used to test having s speed range of 200 rpm to 2000 rpm, operates at load from 5N to 100N and frictional force up to 100N.

IV. RESULTS AND DISCUSSIONS

4.1 Microstructure

Significant improvements in mechanical characteristics were observed mainly due to the restructured grain structure, whereas increased splitting was mainly due to the presence of refurbishing particles that reduced the elongation properties and improved cargo capacity. Studies of particle additions found that with heterogeneous nucleation of the reinforcement grains, mechanical characteristics improved with the development of the precise structure. Composite characterization refers to the wide-ranging and general method by which composite structure and properties are analyzed and evaluated to ensure that materials meet performance criteria for various applications. In scanning electron microscopy, Figure 1 shows the slicked pattern observed systematically, with different magnifications and measurements. Analyses of 100X magnification of the microscopic structure show that the deformation observed can be attributed to the formation of a solid SiC/Gr solution.

The visible dark grey area is determined to be the solid solution of the reinforcement particles with the rest of the area being the Al alloy matrix. The dark and white part in the image of the microstructure, as shown in Figure 1 a, explains the aggregation of SiC/Gr particles. Comparison of microscopic illustrations on Al alloy and divergence breaks was observed in both samples. However, the dendrite arm distance was not as large as the reinforcing-parts inhibition width during solidification, as seen in figure 1 b. Dendrite arm distance in the composite was observed in both samples. Particulate involvement in matrix molecules greatly improves its microstructure, weakening roughness when freezing of the primary dendrites. Ni3S4 particles mainly pass through primary dendrite boundaries of the Al alloy though some are found in aluminum slab. Porosity in the cluster region of SiC/Gr particles was seen frequently after small scale engraving. Processing of microstructures on the silicon surface throughout the SiC/Gr particles occurred.

The microstructure had a viscous solution from the Al alloy, with some unspecified non-metallic additions. The combined surface appeared to include small boulders, with the whole dendritic form being clearly visible at 200X. Microstructural qualities of the metal matrix Al combination composites rely basically on the idea of lattice amalgam fortification, their holding, and dissemination. The present discussion relies upon 6 wt. % fortresses since mechanical properties are optimum in the 6 wt. % of SiC/Gr. Further augmentation in the stronghold substance (to 8 wt. %) lead to at the care group improvement which self-destructs the mechanical properties due to the distinction between the thickness and higher percentage of reinforcement

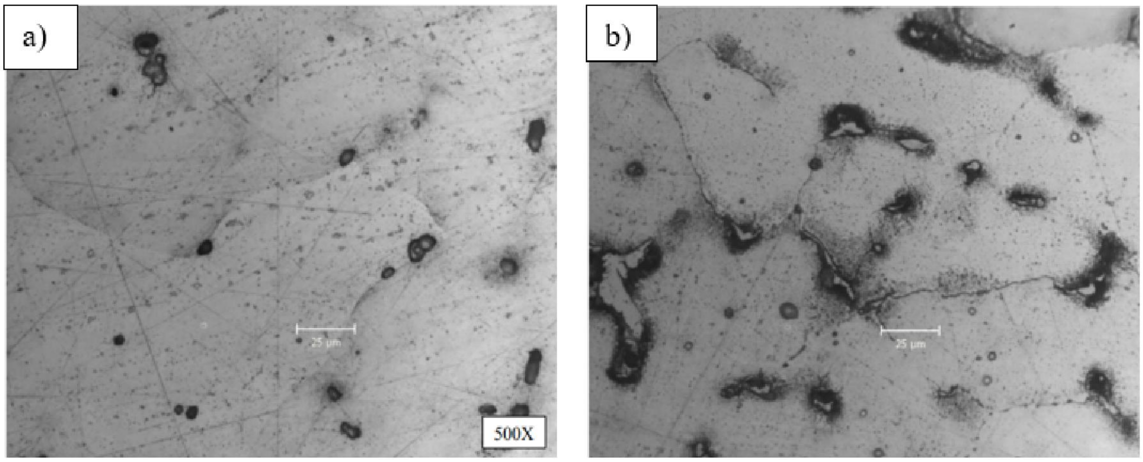

Figure 1: Microstructure of Base alloy

4.2 Effect of the wear rate by load

A pin-on-disc device can be used to calculate the rate of wear of composite materials. Hybrid composites rate of wear is calculated for a range of loads, including 10, 20, 30, and 40 N at a constant 400 rpm sliding speed and a 1000 m sliding distance. Before and after the test, the test specimen's volume was documented, and the volume loss was determined. Figure 2 displays the change in composite wear rates under loads of 10, 20, 30, and 40 N. The matrix metal Al6061 has a larger volume loss than reinforced composites.Gr and strong ceramic SiC particles are used to slow down wear. Gr decreases the wear rate of composite materials by generating a stable, impossibly thin coating on the tribo surfaces.

Wear loss increases because of an increase in load. This indicates that load and wear rates are proportional. When load increased from 10N to 40N, there was a loss of volume of the composites by an average of 55%. The increase in load makes the SiC particulates squeeze out the composites, causing a break or rupture on the surface layer.Plastic deformation of the samples occurs at higher loads and leads to severe wear of the composites. The incorporation of the lubricating action of Gr and hard SiC particles improve the wear resistance of composites. Wear resistance is enhanced up to 60% compared to unreinforced Al6061 matrix alloy.

4.3 Effect on wear rate due to sliding speed

The sliding speed is a major parameter for examining a wear rate MMCs. Sliding speed may enhances or diminishes the wear resistance of composites which depends on matrix materials and reinforcements. Composite wear rates were calculated for sliding speeds of 100, 200, 300, and 400rpm with a constant load of 40N and a constant sliding distance of 1000m.Composite wear rates at different sliding speeds are shown in Figure 3.

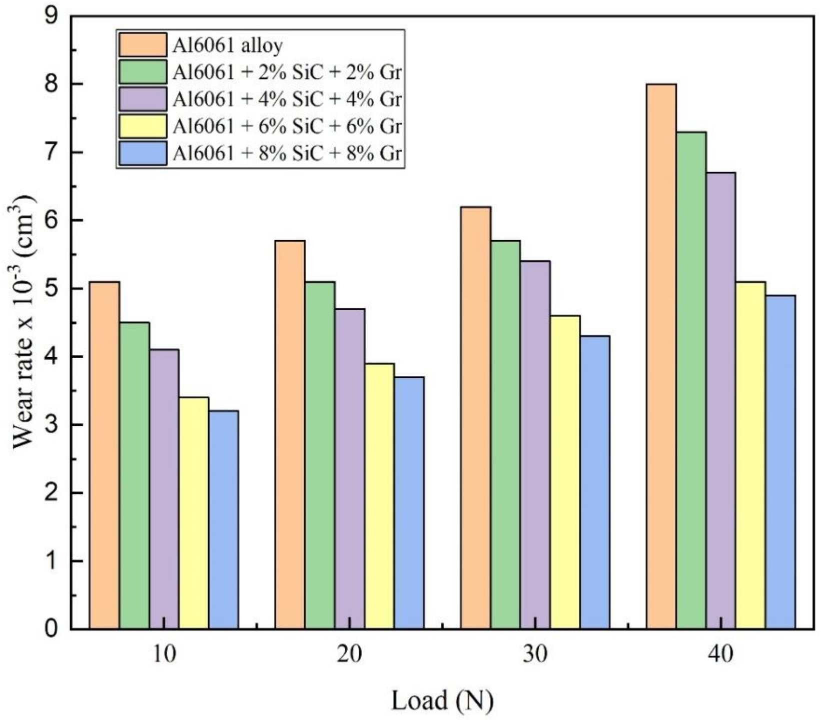

Figure 2: Wear loss in composites under different loads.

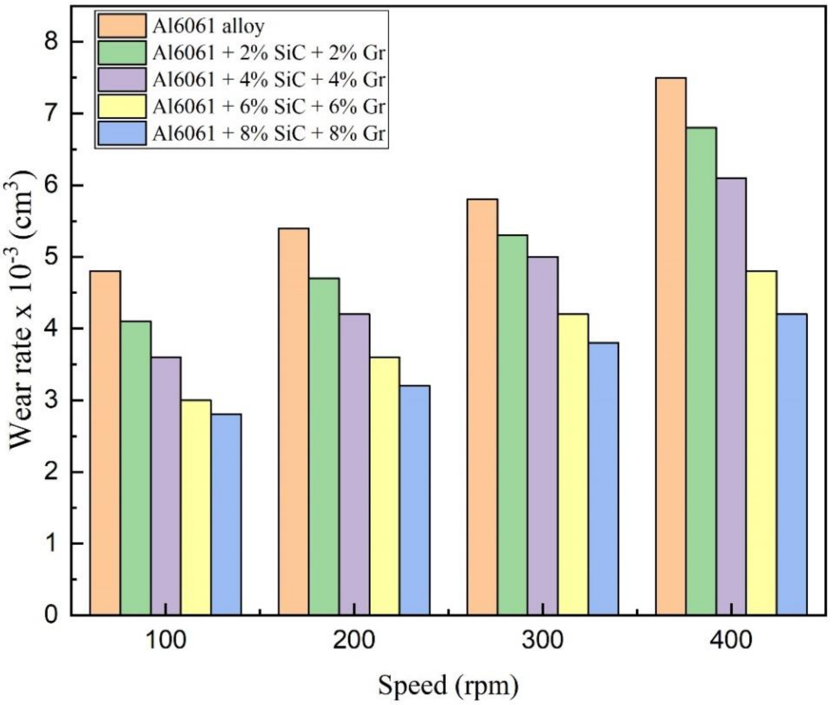

Figure 3:Thewear rate composites at various sliding speeds

The wear resistance of the composites is enhanced by the Gr and SiC particles. In comparison to reinforced alloys, the unreinforced alloy wears more quickly. Figure 3 demonstrates how the wear rate increases along with the sliding speed. When the sliding speed was increased from 100 to 400 rpm, the wear rate rose by 30%. It is evident that the sliding speed is directly linked to the wear rate because as the sliding speed increases, the temperature of the sliding surface increases, allowing Gr and SiC particles to escape from the surface layer. As a result, the material degrades rapidly as the sliding speed rises due to the frictional heat produced between rubbing surfaces. This study shows that the addition of Gr and SiC particles boosts the wear resistance by up to 60%.

4.4 Coefficient of friction of composites

Figures 4 and 5 shows the COF at different loads and speeds. COF gradually declines with integration of Gr and SiC particles in an alloy. Grparticulates have a lubricating behaviour that makes a layer on the rubbing surface and lowers the COF of composites. Also, hard and tough SiC particles are well enough to withstand the load and avoid the particles to peel off from surface during friction. But as the load on rubbing surface increases during friction there will be an increase in COF is noted and revealed in Figures 4 and 5. The average COF of composites under different loads and speeds. With Gr and SiC added, there is a clear reduction in friction for different speeds and loads. As compared to Al6061 alloy unreinforced, hybrid composites demonstrate lower coefficients of friction regardless of the speed and load conditions. Al6061 alloy showed high COF, and reinforced composites showed low COF under a variety of speeds (100, 200, 300 & 400 rpm) and loads (10, 20, 30 & 40 N). By creating a thin lubricant film on the composite surface and minimising the amount of metal-to-metal contact produced by friction, Gr lowers the coefficient of friction. This demonstrated that Gr functions on the surface of the composite as a lubricant. Thus, it has been shown that the tribological properties of composites are improved by the addition of Gr and SiC.

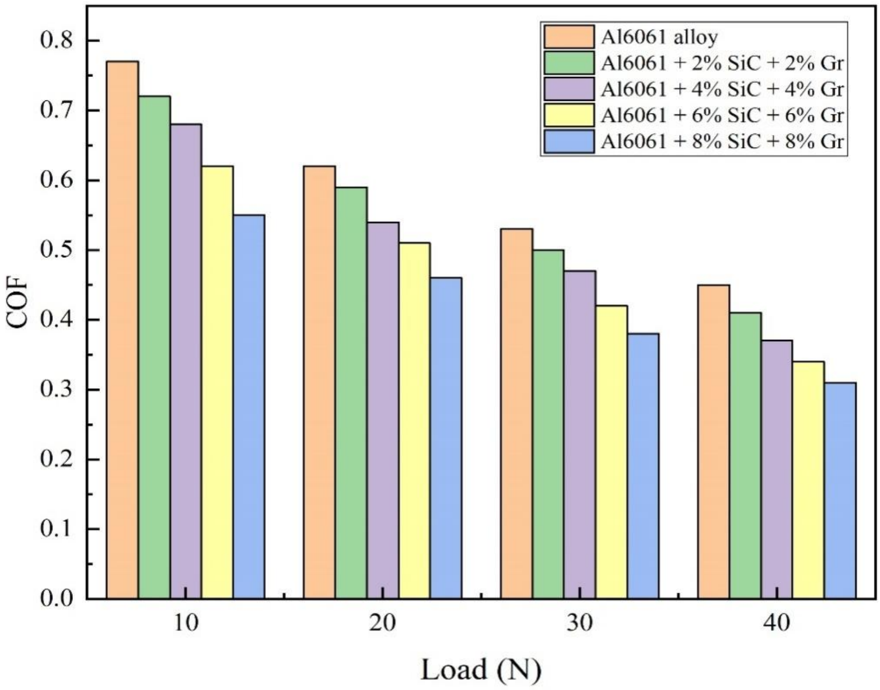

Figure 4: Friction coefficient at different loads

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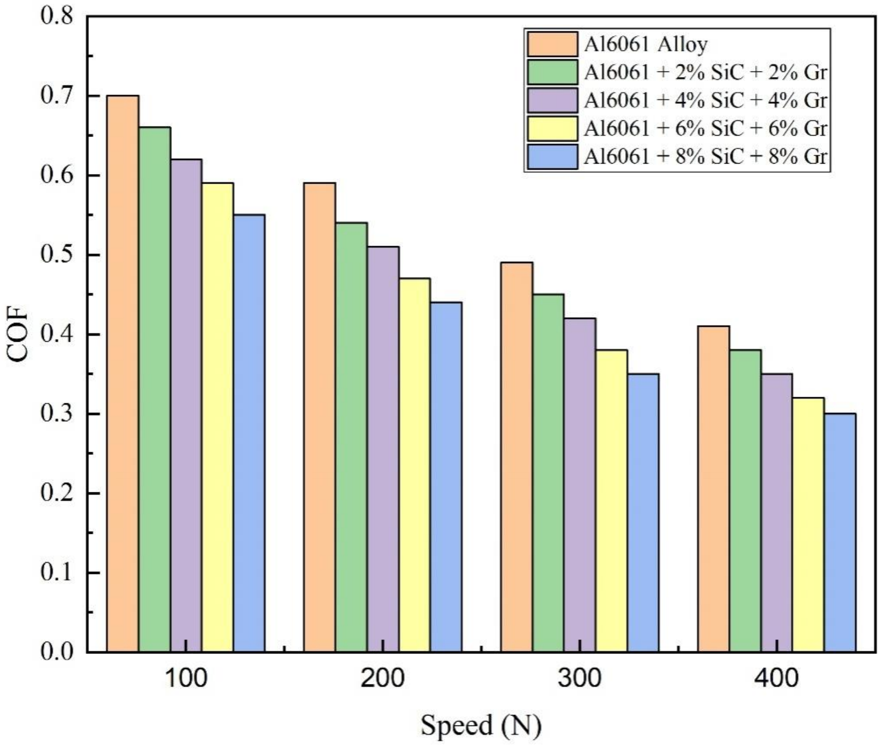

Figure 5: Friction coefficient at different sliding speeds

V. CONCLUSION

The main contributions of this project work have been summarized and the scope for future work listed at the end of this chapter.

Microstructure SEM analysis showed uniform distribution of SiC/Gr particulates with the smallest number of porosities and agglomeration was observed. The fine grains dendrite structure was formed by adding SiC/Gr particulates.

Formation of fine dendrite structure was observed in all metal matrix composite specimens due to faster solidification and density change of the composites by metal casting. The same was also observed in thermal conductivity tests.

Agglomeration of hard ceramic particles was observed in higher composites i.e. 8 wt. % SiC/Gr due to higher volume rations and insufficient stirring time and speed.

The wear rate was indirectly impacted by silicon carbide and graphiteparticles. Wear was minimal with a higher volume % of reinforcement because an increase in the addition of reinforcement reduces the distortion of the cast specimens.

The sliding distance and wear rate were shown to be directly correlated, meaning that as the sliding distance grew, so did the wear rate. The matrix material thermally softens and lowers the bonding effectiveness of the reinforcements with the base alloy at a greater sliding distance (1500 m), increasing wear.

The wear rate of the hybrid composites similarly increased as the load and sliding distance increased, although it slightly decreased when the sliding speed increased. At 10, 20, 30, and 40 N loads, the wear rates of hybrid composites are 37.25%, 35.08%, 30.6%, and 38.75% lower than those of Al6061 alloy.

Wear rate has increased by 30% from a sliding speed of 100 rpm to 400 rpm. It is clear that sliding speed is directly proportional to wear rate because higher sliding speeds cause the temperature of the sliding surface to increase, allowing graphite and silicon carbide particles to escape the surface layer.

Inverse relationships exist between coefficient of friction and applied load, sliding speed, and weight fraction of reinforcement (SiC/Gr). With an increase in applied load, sliding speed, and distance, as well as the percentage of reinforcements, the coefficient of friction dropped.

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