Journal of Mines, Metals and Fuels, *71(9): 1262-1270; 2023. DOI: 10.18311/jmmf/2023/35445*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Tribological and Mechanical Properties of Al 6061/SiC/GO Hybrid Composites Produced with Stir Casting

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Abstract

A constant prerequisite for technological advancement is the improvement of composite materials' mechanical properties. In this study, stir casting was used to create hybrid Aluminium Matrix Composites (AMC). To enhance the mechanical properties, silicon carbide and graphite were used as reinforcement. AMC are made by adding different volume fractions of SiC (3%, 6%, 9% and 12%), whereas composites use a fixed volume fraction of graphite (5%). Mechanical Properties like Hardness, Tensile and wear characteristics of the manufactured AMC samples were evaluated. Under various loads 10N-40N and sliding velocities 0.6m/s-2.0 m/s the wear rate was calculated. The mechanical characteristics of manufactured AMCs are compared with Al 6061 alloy. From the experimental results, the addition of silicon carbide and graphite particles improve the mechanical characteristics. The wear rate increases with increase in applied load. However, sliding velocity surges up to 1.8 m/s before sharply declining.

Keywords: *Aluminium Matrix Composites, Graphite and Silicon Carbide Reinforcement, Stir Casting, Wear Testing*

1.0 Introduction

AMC are useful manufacturing materials with strong tensile, compressive, hardness, and stiffness properties. These materials are more resistant to abrasion when compared to other alloy materials. These resources are used in a variety of structural applications across a range of industries, including automotive, marine, and aerospace[1,2]. Due to density and electrical resistance is low, corrosion resistance, machinability and strength are high, and properties of Al 6061 are the most commonly used matrix material. Its application has been constrained, though, by lower wear resistance. SiC particulate and Al 6061 fiber reinforced composites have seen significant advancements in their properties in current years. The process of stir enables the uniform application of reinforcement to the base material, agglomeration scattering, and reduces the[3,4] flows like cracks that have an impact on the physical as well as the composites' mechanical behavior.

Baradeswaran *et al.*[5] found that as Gr content increased, tensile stress and hardness decreased. Idrisi *et al.*[6] produced different fractions of AMC SiC microparticles such as 5% 10% and nanoparticles using the stir casting technique. Gears were made from developed AMCs after that tested by using a special wear test rig under various functional loads. The AMC with 2% nanoparticle reinforcement has demonstrated the highest wear resistance. Al 7075/

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Al_2O_3 composite was created by Baradeswaran *et al.*[7] using a liquid metallurgy method, and Gr particles were added to see how they exaggerated the composite wear properties. They claimed that Gr reinforced composites outperformed Al 7075/Al_2O_3 composites in terms of wear resistance. The consequence of Graphite (Gr) particles on the behavior of Al6061/TiB2 composite materials made using stir casting procedure was examined in the literature[8-12]. In comparison to Al-6061 & Al-6061/TiB_2, the characteristics of the hybrid composite, such as physical and mechanical properties were enhanced. The wear characteristics of Al-7075 were enhanced by Gr is a primary reinforcement, and it was additional enhanced by SiC as a second reinforcement. In the literature the study of the wear characteristics of composite material made by powder metallurgy was investigated by Ravindran *et al.*[13]. The authors found that both the Gr and SiC reinforced composites significantly outperformed the Al 2024 alloy in terms of wear behavior. Also they identified that, the micro hardness of the Al/Gr was lesser than the base metal and that it decreased as more Gr reinforcement was added. Al/(SiC+Gr) composites, on the other hand, had greater hardness than base metal and Al/Gr composites. The literature makes it clear that, the important emphasis was the mechanical characteristics of reinforced Gr and SiC. Materials made with various alloys, but there is little available research regarding the hybrid Gr/SiC composites. There are publications where Al 6061 alloy has been used as the foundational material when making Gr/SiC. This idea has served as the inspiration for the current work. Al6061 alloy's formability and ability to weld make it appropriate for a variety of general-purpose uses. Type 6061 has a high strength and corrosion-resistance. These materials are especially helpful alloy in mechanical and civil applications. In this study, stir casting was used to create hybrid Al 6061 Gr/SiC composites. The experimental results like tensile strength, hardness and wear characteristics were assessed.

2.0 Material and Methods

2.1 Materials

In the present investigation, SiC particle average size is 40m and graphite particle average size 75m were used as reinforcement materials for the creation of composites. Al 6061 was used as the matrix material. Al 6061 alloy Ingots were purchased from AMCs are made by varying volume fractions of SiC such as 3%, 6%, 9% and 12%. Composites with fixed volume fraction of graphite (5%) were used in the study.

Nano wings were used to purchase both reinforcements. Specimens that have been machined to have a 20mm diameter and a 10mm thickness. According to Table 1, the matrix material's chemical makeup. Table

Table 1. Aluminum-6061 material composition

Element	Al	Mg	Si	Fe	Cu	Ch	Zn	Ti
Weight Percent	95.9- 98.5	0.8-1.2	0.4-0.8	0.7	0.15-0.4	0.04-0.35	0.04-0.35	0.1

Table 2. Reinforcement and matrix materials properties

	Tensile strength (MPa)	Density (gm/cm^3)	Modulus of elasticity (GPa)	Coefficient of thermal expansion ($10^{-6}/{}^0C$)
Aluminum	183	2.70	70	22
Silicon carbide	582	3.30	342	4.8
Graphite	108	1.92	4.6	1.9

2 displays the characteristics of the current matrix and reinforcing materials.

2.2 Methodology

The Pressurized Air Infiltration (PAI) method was used to prepare Metal Matrix Composite capsule. The interior of the capsule was coated with a pre-weighted graphite materials and alcoholic mixture, which is dried in the muffle furnace. After baking, temperature reaches at 600°C in a furnace, SiC powders are placed inside the shell, and it shows Figure 1(a). It was covered with a layer of the Al 6061 alloy.

Baked SiC particles are used to ensure even mixing with the matrix material because it makes the mixture more wet table. The location of the capsule and kept inside the furnace shown in the Figure 1(b). Temperature of the furnace was heated to 720°C before the air valve was pressurized. Opened for ten seconds to force the melt through the after which the air valve was shut.

The atmosphere air is kept up at 0.71MPa of pressure. The billets fabricated were made to determine SiC particle volume percentage. In the second step, an electric resistance furnace heated to 660°C was used to dissolve a pre-weighed alloy into stainless steel vessel. The temperature inside the crucible was controlled and recorded using a set of chromel–alumel thermocouples. AMC billet made using the PAI technique was simultaneously heated in a separate electrical furnace to 660°C, dipped into the molten alloy, and mixed for 3 min at rotations of 50rpm. These billets are shown in Figure 1(c). Additionally, the speed was raised to 1000rpm and kept there to maintain the required vortex. After being poured into a steel mould, the mixture was allowed to cool at room temperature[14-15].

3. Characterizations

3.1 Tensile Strength

Aluminium matrix composites specimens were prepared

Figure 1. a) SiC particles b) muffle furnace, c) AMC billets.

as per standard ASTM E08-8. Figure 2(b) displays the five tensile test specimens with various composition. These samples were examined using an MTS machine Figure 2(a) at room temperature. Three specimens in total are tested using tensometer, and the average value is considered for every specimen.

3.2 Hardness

The manufactured composites were assessed using the Vickers hardness test machine, which is model VM 50. These testers strictly abide by ISO 6507-2 and IS 1754. Hardness specimens were prepared with reference to the ASTM E10 standard shown in Figure 2(c). A load of 30 N was used in the Vickers hardness measurement. The average of the six reading was taken and analyzing the data.

3.3 Wear Characterization

The Pin-on-Disc wear testing machine is used for wear test experimentation. The test specimens and machine are shown in Figure 3. It consists of a motor with variable speed and a horizontal steel disc that rotates. The test specimens were positioned in the specimen holder, which was firmly fastened to the loading lever's rough surface. Through the use of two sheets fastened to strain gauges, the friction coefficient can be measured. The disc speed, load, machine and material factors all affect rate of wear.

Wear test specimens were tested at various loads (10N to 40N) and a constant speed of 600rpm. Complete interaction between abrasive disc and the specimen was guaranteed to obtain reliable wear data. The pin specimen was produced in according to ASTM G99-95 standards and had dimensions of diameter 8mm and length

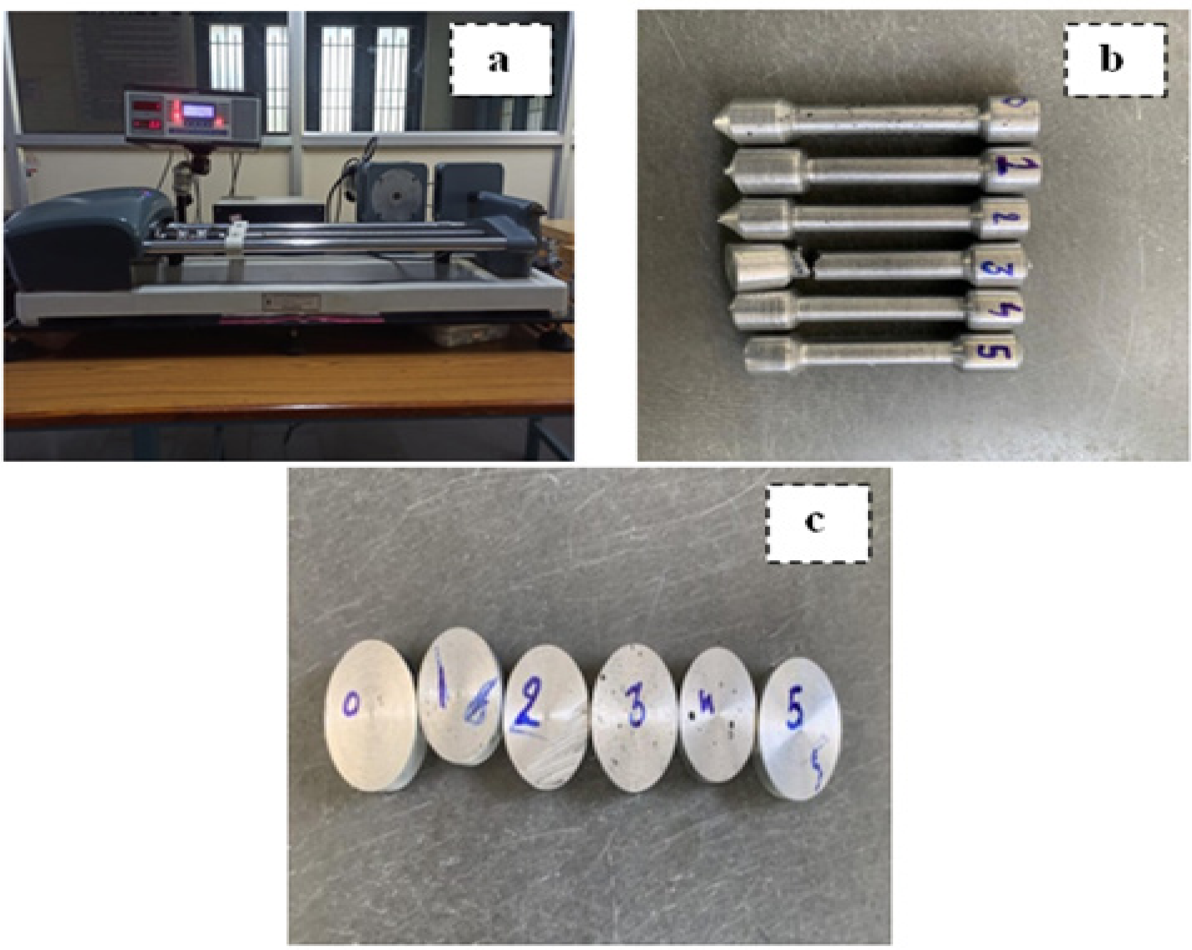

Figure 2. a) Tensometer tensile test machine, b) Tensile test specimens and c) Hardness test samples.

50mm. Steel disc EN-31 with a hardness of 60HRC was used.

4.0 Result and Discussion

4.1 Tensile Results

From the Figure 4, characterization of the stress–strain curve of the Aluminium matrix composite with various reinforcement fractions. It means that compared to the Al 6061 alloy, the SiC/Gr reinforced has better tensile strength. In comparison to Al 6061 with reinforcement of 6% vol. of SiC + 5% vol. of Gr, the tensile values of the hybrid Al 6061 (12% volume fraction of SiC + 5% volume fraction of Gr) composite is greater. Among all fabricated composites, AMC with 12% vol. of SiC particles and 5% vol. of Gr was found to be the strongest. With an increase in the reinforcement fraction, the composites' tensile strength increased.

The tensile value of AMC with 12% volume fraction of SiC + 5% volume fraction of Grrein forcement was 50 percent higher than that of the base material. Due to addition of Gr & SiC shows good bonding with Al 6061 alloy, which allows them to withstand more load than Al 6061 alloy, this is the case. Grain refinement, an increase in dislocation density near the matrix boundary, and the transfer of tensile force to the firmly bound SiC & Gr particles in aluminium are all responsible for the increase in tensile strength in AMCs[16]. The improvement in tensile strength may be due to the reinforcement being packed tightly during the matrix phase. The solidification time between aluminium matrix and Gr & SiC reinforcements during the specimen preparation process also significantly affects the interfacial properties, which in turn have an impact on the performance of AMCs[17]. A boost in the composites' tensile strength is supported by a solid bond between the matrix and reinforcements[18].

4.2 Macro Hardness

The main parameter which affects the wear rate of AMC composite specimens was surface hardness. With addition of SiC & Gr particles in the AMC composites the hardness values increased as shown in Figure 4 which depicts the effect of reinforcement. In comparison to the Al 6061 alloy, the SiC & Gr matrix composites were discovered to be tougher. In comparison to Al 6061 with 6% volume fraction of SiC + 5% volume fraction of Gr reinforcement, the hybrid reinforced composite of Al 6061 with 12% volume fraction of SiC + 5% volume fraction of Gr shows higher hardness values. AMC with 12% SiC and 5% Gr particles shows better hardness values when compared with other composites studied in the experiment. The yield stress is well known to be the

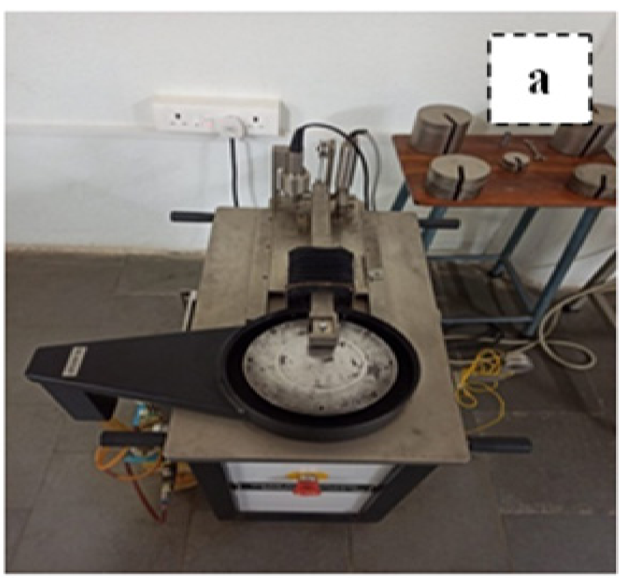

Figure 3. a) Pin on disc wear test equipment b) Wear test specimens.

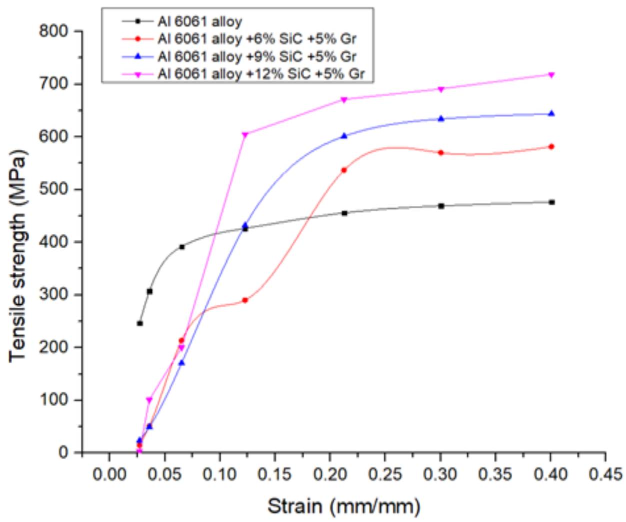

Figure 4. Al 6061 alloy stress–strain curve at various volume fractions of particles.

lowest stress necessary to cause dislocations to move. The inclusion of extremely brittle SiC Gr in aluminium causes obstacles for development of dislocations[19].

4.3 Wear Properties

Cylindrical pin specimens were tested for wear against a turning steel disc. In order to track the tangential friction force and wear rate, electronic transducers were used. The applied load, sliding velocity were used to compute the rate of wear. As shown in Figure 5, the wear characteristics were studied with nominal loads of 10N, 20N, 30N, and 40N rotating at a speed of 600 rpm. It was found that as the load is increased, the rate of wear as fit. The same linear trend was also found by Idrisi *et al.*[20]. Additionally, it was found that as the load is increased, the unreinforced alloy have lower wear resistance than the AMC. In comparison to Al 6061 with 6% volume fraction of SiC + 5% volume fraction of Gr, Al 6061 with 12% volume fraction of SiC + 5% volume fraction of Gr hybrid reinforced composite had higher wear resistance. From all fabricated components, AMC with 12% volume fraction of SiC and 5% volume fraction of Gr particles was establish to achieve highest wear strength. In comparison to the alloy of unrein forcing, the rate of wear was decreased by 62.52% at an applied load of 10N and decreased by 55% at an applied load of 40N for the AMC (12% volume fraction of SiC and 5% volume fraction of Gr). Wear rate with respect to applied load was shown in Figure 5(a).

At various sliding velocities (0.6, 1.2, 1.8, and 2.0 m/s) under a constant load condition of 40 N, At each sliding velocities, the wear rate in Al 6061 alloy was higher than that of developed AMCs. The rate of wear of Al 6061 alloy was found to enhance linearly from 7×10^{-3} mm^3/m to 8 $\times10^{-3}mm^3/s$ at 0.4m/s to 1.2m/s sliding velocities respectively, before increasing steeply to 13x 10^{-3} mm^3/m at 1.6m/s. For the AMCs, a different pattern was seen. From Figure 5(b), at 1.2m/s sliding velocity, the rate of wear improved linearly; however, as the sliding velocity improved, the rate of wear abruptly decreased. For AMC with 6% volume fraction of SiC + 5% volume fraction Gr, the rate of wear improved by 64% from the sliding velocity 0.4m/s to 1.6m/s. For AMC with 12% volume fraction of SiC and 5% volume fraction of Grrein forced particles, that is 5% only. The transformations of the carbon bond arrangements into graphite may be the cause of reduce in rate of wear with rising sliding speed. The genuine contact area, where flash temperatures are elevated, may also experience such a decrease. This modification can speed up the formation of a lubricating oil film and lessen surface wear rate. The existence of Gr percentage in fusion composite materials, a frozen oil that will cause wear rates to decrease at higher sliding velocities, may be the cause of the wear rate decreasing as reinforcement volume fraction increased. Additionally, SiC particles serve as barriers throughout the relative motion of the surfaces and counteract matrix phase abrasion. Figure 5(c) depicts the impact of SiC volume percent on the developed AMCs'

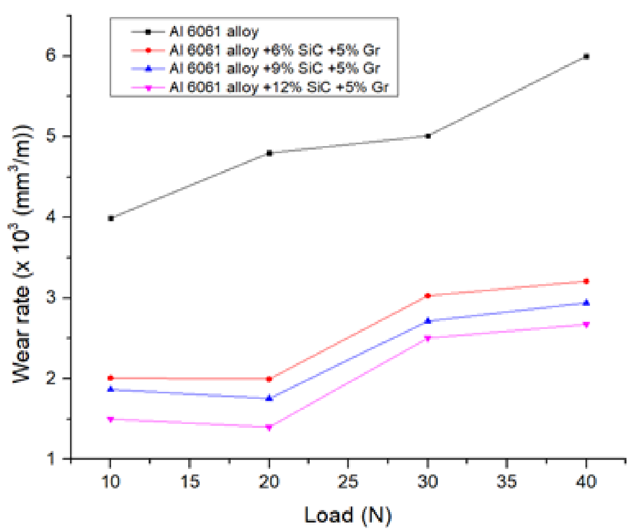

Figure 5. (a) Applied load w.r.t. wear rate.

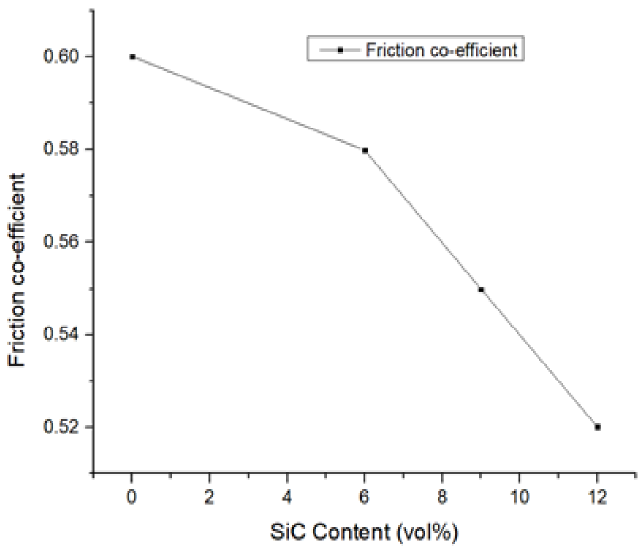

Figure 5. (b) Sliding velocity w.r.t. wear rate.

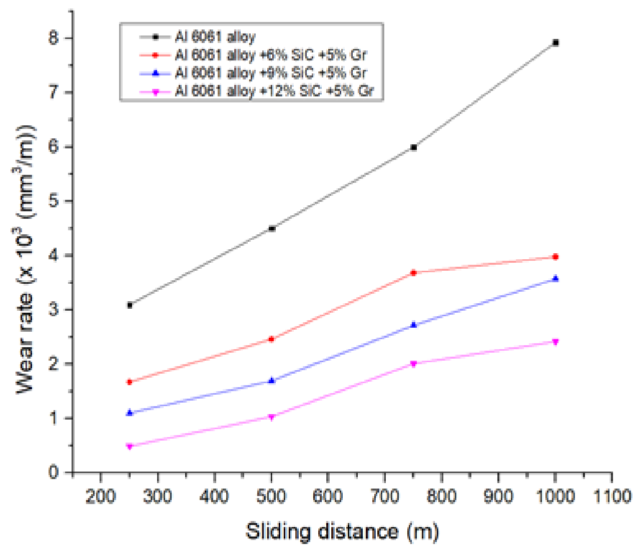

Figure 5. (d) Sliding distance w.r.t. wear rate.

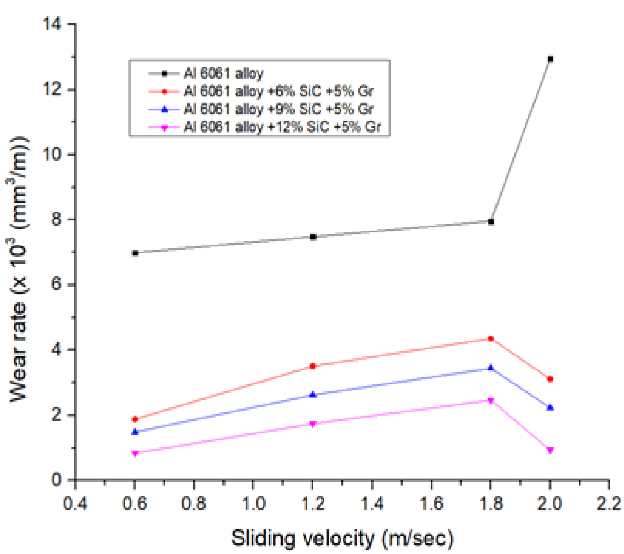

Figure 5. (c) SiC % of volume w.r.t. friction coefficient.

coefficient of friction. It shows that as SiC volume fraction % is increased, the coefficient of friction decreases. For Aluminium 6061 alloy to the AMC with 12% volume fraction of SiC, the coefficient of friction decreased from 0.6 to 0.52. The observed friction coefficients for AMC at 6 and 12 vol. percent were 0.58 and 0.55, respectively. The Figure 5(d) shows the rate of wear variation of Al6061 alloy and Al 6061 alloy at various sliding distance (250m to 1000m). At all sliding distances, the wear resistance in Al 60061 alloy was higher than that of developed AMCs. At sliding distances of 250m to 1000m, it was observed that the Al alloy wear resistance is linearly increased ($3.1\text{x}10^{-3}$ mm^3/m to $7.9\text{x}10^{-3}$ mm^3/s). When compared to Al 6061 alloy, the rate of wear for AMC with 6% volume fraction of SiC + 5 % volume fraction of Gr and ADC with 12% volume fraction of SiC + 5% volume fraction of Gr decreased by 46% and 84% at sliding distance of 250 m and decreased by 50% and 68% at sliding distance of 1000 m respectively. These findings are reliable with the results obtained in the literature[21-26].

5.0 Conclusion

Through the use of stir casting, Aluminium Matrix Composites with SiC and Gr particles have be experimentally studied effectively.

Significant conclusions included the following:

1. When compared to the Aluminium6061 alloy, mechanical properties of AMC (12% volume fraction of SiC + 5% volume fraction of Gr particles) has increased by 50%.
2. The adding of 12% vol. of SiC + 5% vol. of Gr particles in Al 6061 alloy hardness increased from 75 VHN to 88 VHN.
3. SiC and Gr particle addition increased the wear confrontation of developed AMCs.

4. The wear properties of Al 6061 alloy linearly enhanced at 1.2m/s sliding velocity and then it enhanced steeply up to 1.8m/s.

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