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Effect of Graphite and Titanium Dioxide on Mechanical Properties and Wear Behavior of Al Based HMMCs

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Abstract

Aluminium Metal Matrix Composites (MMC) is beneficial in a diversity of applications of engineering, particularly due to their strength while being lightweight. The intention of this paper is to develop a Hybrid Metal Matrix Composite (HMMC) using base metal aluminium alloy which is reinforced with different wt% of Graphite and Titanium Dioxide and then study the different mechanical properties like microstructure analysis, tensile strength, hardness, and wear behavior of HMMC developed experimentally. We need to calculate how much base metal and reinforcements material is required. Stir casting is used for producing new hybrid composite material in the present investigation. Preheating of reinforcement materials needs to be done before doing the casting. After fabricating the hybrid composites, Specimens for the various tests were prepared as per ASTM Standards. Microstructure analysis, tensile test, hardness, and wear tests were performed for the base metal as well as the four combinations of second phase particle composites. We achieved ultimate tensile strength about 123.3 N/mm^2 and hardness value of 103.3. BHN for the combination LM12+6% Gr+ 6% TiO_2 of was obtained due to proper stirring process and mixing of the reinforcement material with base metal. It was observed that with same combination the wear rate goes on varying with load and speed, wear rate decreases up to almost 30 to 40% compared with only base metal.

Keywords: Aluminium alloy, Composite, Titanium Dioxide, Microstructure, Tensile strength, Hardness.

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INTRODUCTION

Hybrid composites are the one composite that have a combination of two or more reinforcement fibers. Hybrid composite materials (HCM) are used in lots application due to its lightweight, low price, ease of shape growth, and high strength. It might be very strong as well as weight-less than other common engineering materials and toughness is greater too, it is possible to accomplish the combo of properties unattainable with any other materials. The idea of big development of hybrid composites has been initiated by researchers and scientists around 1970–80. Hybrid metallic matrix composites (HMMCs) are engineering substances bolstered with or more exceptional forms of reinforcement to be able to take advantage of them which offer a good flexibility in material design. Usually, HMMC showcase precise advanced residences along with excessive specific stiffness, low density, energy, more advantageous fatigue resistance, controlled coefficient of thermal expansion and better dimensional stability at high temperature. HMMC have exceptional features that could be applied in diverse systems and/or important additives without negotiating their performance and durability.

The modern advancement of science and technology demands the construction of materials for various fields like aerospace, transportation, industry, automobile and military applications. Only the development and production of HMMC based on aluminium alloys will be able to meet these needs. Aluminium, after steel, is the mostly used metal because of its flexibility and pure form is ductile, smooth, resistant to corrosion and has a high electric conductivity low melting temperature, The density of the aluminium alloy is 2.68 g/cm^3. It is mainly used in conductor cables and foil, however, to give the greater strengths required for various applications, combining with other elements is required. With strength to weight ratio that is superior to steel, it is used to its useful features, including strength, lightweight, corrosion resistance, recyclability etc. This selection of goods includes everything from thick packaging foils to structural materials. This metal is utilised in a wide range of industries, including delivery, food preparation, power technology, packaging, construction, and electric transmission packages. Aluminium can be used in place of several materials depending on the application.

Umanath et al. made an investigation on preparing Al6061-SiC-Al_2O_3 HMMC by stir casting and the strengh of the Al/SiC was enhanced with the combination of SiC up to 30wt. % and then reduces after this % of reinforcement [1]. K. Paul and M. Sijo conducted a study on the impact of stirrer parameter on stir-casting-formed SiC MMC reinforced with aluminium alloy (LM6). Results showed that four-blade stirrers are superior to two- and five-blade stirrers in terms of composite characteristics [2]. Hashim et al. made an investigation on difficulties connected with the stir casting used in the making of SiC and Al alloy MMCs. Due to particle cracking and existence of shrinkage cavities, Mechanical properties of these MMCs were not greatly improved. Although unreinforced alloy 6061 has great toughness and, as a result, crack arrest capabilities when it is rolled [3]. Yar made an investigation on aluminum matrix composite-added in proportion 1.5, 2.5, and 5 vol. % nanoparticles MgO through cast by stirring with many temperatures, viz. 800, 850 and 950°C and identified the composites with 1.5 Vol. added particles made at 850 have a good microstructure and better mechanical properties [4]. Nair and Joshi made an investigation on (AMMC) using technique of stir casting, where Al 6061 and SiC used to produce good-quality AMMC [5]. A. Anis, M. Nagarajan et al. made an investigation on MMC Al-10%MoO_3 by stir casting. Their results showed that the formulated composite has better properties than the only aluminium, [6]. Baradeswaran, A. Elayaperumal made an investigation on the "mechanical and tribological behaviour" of AA7075/Al_2O_3/graphite hybrid composite. A stir casting was used to fabricate 7075 aluminium alloy and Al_2O_3/graphite. For the hybrid. composites the graphite particles were separately pre-heated to about 750°C. The melted charge was added with Al_2O_3 and the charge was stirred at about 500 rpm for 5 min approximately and the pre-heated graphite was added to vortex when the same the stirrer was rotating at the same speed with the same furnace temperature. From the tests conducted above they concluded that AA7075– Al_2O_3 (p) exhibits higher "mechanical and tribological properties" than that of AA 7075 and Hybrid composites [7]. Anthony, M. Vamsi Krishnaa. M. Xaviorb investigated hybrid composites made of Al6061-SiC and Al6061-SiC/Graphite. The reinforcement was added in increments of 5wt, ranging from 5–15%. Microstructure characterization was explored experimentally by employing an inverted metallurgical microscope to guarantee the spreading of the reinforcement in the matrix. According to the outcomes of the testing, metal reinforced with SiC and Gr performed better mechanically than composites reinforced only with SiC. It is clear from studies of microstructure that reinforcing particles are distributed uniformly [8]. Abraham et al., made a study of microstructural characterization and they used Titanium dioxide (TiO_2) as the reinforcement of the AMMC. The method used by them was friction stir processing. TiO_2 particle was seen to be dispersed equally in the developed composite. The TiO_2 particles clusters were noticed at a larger content of

18vol%. Since TiO_2 is natural in minerals so that is used in friction stir casting process to get smooth result. In the final dictating the TiO_2 doesn't play any role in the composite. The aluminum cast would respond to this massive strain by efficiently deforming. Thus, the mechanical properties will boost up the average distance improving the much interaction between the particles. The average size of the grain is 30 µm, since the base materials with grain are shown which has an elongation in it. Since TiO_2 pieces cannot undergo deformation at the like rate of container cast, the disruptions are created to adapt the characteristic strain rate. Thus, they summarized that Submicron level TiO_2 atoms (0, 6, 12 and 18 vol%) were completely organized into the AA6063 to make the composite [9]. Amira H. Nassar etal has investigated that composite was processed with aluminum by using the reinforcement particle. After adding titanium dioxide and silicon carbide, changes observed in microstructure. The external layer is completely thick with equivalent microstructure while the inner layer is equally accompanying relatively spongy microstructure.. The reinforcement was equally distributed in the matrix [10]. Cocen et al. conducted research on Al/SiCp composite samples under cast conditions with increasing SiCp content, followed by decreasing SiCp content. For extruded materials, these values improved by 40%, and they grew steadily as reinforcement volume fraction rose [11]. Veeresh et al. conducted research on strength of Al 6063-SiC and Al 7075-Al_2O_3 with SiC reinforcement increasing from 5 to 15 weight percent, the strength of the AA 7075/SiC composite climbed by 12.74%. Increasing the weight percent of SiCp from 5 to 30 is stated to have enhanced the indirect strength of Al-SiCp, which was affected by a raise in the material's elastic limit and modulus of elasticity [12]. Alaneme made investigation on Al-Mg-Si alloy with SiC and bamboo leaf ash addition of silica, which gives less hardness and strength values compare to SiC observed. Adding to the Al 2024 alloy with SiC and fly ash increases its strength in terms of yield and tensile, which reduces its ductility [13]. Muruganandan carried out study on aluminium 7075 with fly ash and TiC, Ultimate Tensile Strength and elongation by varying speeds. Better TS was obtained because of less reaction with interface [14]. J. Jeykrishnan et al. made an investigation of aluminium alloy was reinforced with 5%,10%,15% of silicon carbide respectively. The outcome demonstrates that higher silicon carbide weight percentages produce better hardness values. The reason for this is that silicon carbide acts as obstruction for crack multiplication and likewise says that there is reliable connection between aluminium and the Silicon carbide [15]. R. Ashok Kumar et al. made a study on hardness of aluminium HMMC's reinforced by titanium carbide (TiC) and graphite with different % of weight of titanium carbide varying from 1%-4%. The forging of Al7075-TiCAl7075–TiC Graphite is processed by utilizing a Stir Casting technique. The findings show that titanium carbide increases the hardness of aluminium alloy. It is because there is an increase in wt% (1–4%) of titanium carbide and 5% of graphite we can see the improvement in hardness [16]. Shreyas P S et al. has made a study on aluminium reinforced with copper and silicon carbide. Aluminium alloy Al6061 has been reinforced with 0.75%, 1.5%, 2.5% of SiC and 5% of copper respectively. The outcome demonstrates that, in comparison to other examples, the aluminium reinforced with 1.5% SiC and 5% copper gives greater hardness. The reason behind this is, higher the % of SiC, specimen become brittle. Hence the specimen with reinforcements of 1.5% of SiC and 5% of Cu gave better hardness values compared to the other two hybrid composites [17]. Sri Ram Murthy and Y. Seetha has made a study on aluminium reinforced with SiC, Aluminium oxide, and Boron Carbide and used stir casting where base metal was reinforced with aluminium oxide (2%, 3%, 0%, 0%), boron carbide (2%, 0%, 6%, 0%) and silicon carbide (2%,3%,0%,0%) respectively. The results showed that aluminium reinforced with 2 % of aluminium oxide, SiC and B_4C had higher hardness followed by aluminium reinforced by 6% of boron carbide. As the hardness is extreme the HMMC sample has more strength to bear weighty loads [18]. A.M. Rajesha, M.K. Kaleemullab, S. Doddamanic made an investigation of alluminium reinforced with diverse weight % of varying weight fractions of SiC and Al-fly ash (5–30 %) by stir For every single condition of wear test, three samples were tested, and standard deviation is calculated. The wear rate was uniform at medium loads and at higher loads, 6 kg (58.86 N), the contact resistance was low, leads to severe wear in heat treated Al7075-10%SiC-10%Al_2O_3 HAMMCs the particulate acts to restrain the change to a severe wear rate in 15 wt.% of reinforcement, it is observed that decrease of wear rate [19].

Alloy Al6061 grade reinforced with SiC and Al_2O_3 formed HMMC by casting through stirring with a weight percentage of 2.5% to 12.5%, according to research by Umanath et al. From the test, it is observed that the HMMCs' wear area is coarser than the base metal and presence of hard particulates on the HMMCs' wear area is reason for this. In HMMCs, the resistance for wear is additional because the particles prevent the development of delamination [20]. V. Ramakoteswara et al. did an investigation on AA7075 matrix reinforced within the range of 2–10 weight % of TiC particles. Stir casting was used to solidify the composites under investigation in this study. The pin-on-disc machine was utilised to conduct the wear test and determine the wear behaviour. It is evident that at wt% 8 TiC exhibits improved mechanical properties than other good hardness and wear resistance increases with increased contents of TiC. However, the resistance for wear is not significantly enhanced by the addition of 10% TiC [21].

Lunat Faiyaz et al., did an investigation on homogenized (2%, 4%, and 6%) alumina & (3%,6, and 9%) by weight of graphite by using stir casting method. The results showed that increase reinforcement led to decrease in wear rate [22]. S. Johny et al. made an investigation on HMMC using $SiC/Al_2O_3/TiB_2$. Conducted Wear test to get wear resistant of composite, the values of COF and FF which is 0.668, 33.483N respectively. Substitution of adding materials like SiC, Al_2O_3, raises wear resistance. The rigid addition of corroboration particles, exclusively TiB2 with more wear resistant avoid the aluminium matrix since wear [23].

The focus of the Nikil et al. investigation is on the influences of increasing weight percentages of nano-TiO_2-1%, 2%, and 3% with AA7178 formed by stir casting. Observed that the mechanical and tribological behaviour of the alloy matrix improved in comparison to the base alloy as the weight % of TiO_2 nanoparticles increased. At 2 wt% of nano-TiO_2, the best mechanical and tribological properties were attained [24]. Abeens et al., Al 8011 with different TiO_2 and Gr compositions and casting is done using stir method. Evaluations were made of the microstructure, wear, and hardness. It has been observed that the findings are affected by TiO_2 and Gr particle to Al 8011 [25].

In the present research, we have identified composition of distinctive alloy grade with two types of reinforcements to meet the various choices of benefits in various industries. The goal of the current study is to study the “mechanical and wear” properties of an aluminium reinforced with various weight percentages of graphite and titanium dioxide. To determine the quality of the generated material, results must be compared to a base metal.

METHODOLOGY

Material Selection

Alluminium Alloy is used as base metal is shown in Figure 1 and Table 1 shows the chemical composition of LM-12. Titanium Dioxide and Graphite are used as reinforcements Material which is depicted in Figure 2 (a) and (b).

Figure 1. Aluminium Alloy LM-12.

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Table1. Chemical composition.

Copper	Titanium	Manganese	Iron	Zinc	Lead	Tin	Nickel	Magnesium	Aluminium
9.0–11.0	2.5	0.6	1.0	0.8	0.1	0.05	0.5	0.2–0.4	Remainder

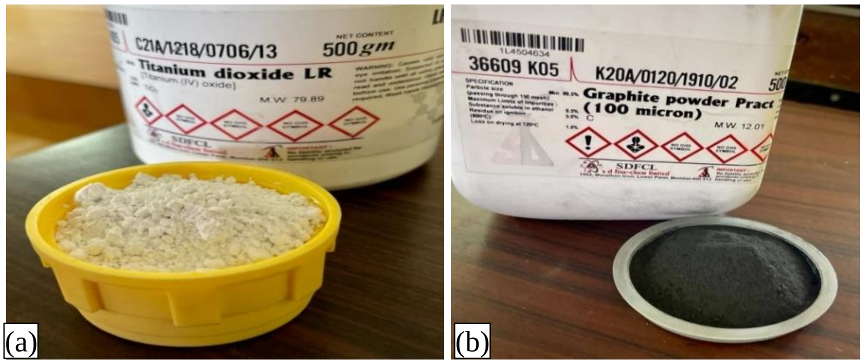


Figure 2. (a) Titanium dioxide (b) Graphite.

Titanium dioxide, also identified as titanium oxide or titania is the inorganic with the chemical formula TiO_2 and it is it is a cheap, readily available, biocompatible semiconductor with unique optoelectronic characteristics, it is normally used along with aluminium or iron because of its low density it is used in parts of aircraft, missiles, rockets because of its high resistance to high temperature, numerous tests were conducted by addition of titanium dioxide to a base metal. This is having outstanding corrosion resistance and also superior strength-to-weight ratios, high heat transfer capability, very good oxidation capabilities.

Graphite is a natural form of carbon. Addition of graphite with aluminium helps to reduce friction during compaction and it induces lubricating properties it also has high resistant to corrosion.

Sand Mold Preparation

First place the mold pattern of dimensions 150 mm*100 mm*60 mm in the cope box. Add green sand to the cope box containing the pattern. Ram the sand until it is hardened. Then create a gating system to add the molten metal and then remove the mold pattern.

Stir Casting

It is a type of casting process at which point a mechanical stirrer is introduced to create a whirlpool to mix reinforcement with base metal. It is an acceptable process for the result of MMC on account of its cost-effectiveness, applicability to volume production, integrity, almost net forming, and smooth control of the composite building. In this process, aluminium alloy LM-12 is kept in the furnace for melting at 650°C. Simultaneously, reinforcements are preheated in a different furnace at a temperature of 1000°C to remove moisture and impurities for 30 minutes. After melting the aluminium alloy, the mechanical stirrer is turned on and set at a speed of around 500 rpm to form a whirlpool. Then the reinforcement i.e., 2 wt.% of titanium dioxide and graphite is added using the feeder at a constant feed rate, then the stirring process is continued for 30 minutes. Figure 3 shows pouring the molten metal into the sand mold.

Break open the mold and remove the prepared metal casting. Repeat the above steps for Aluminium with no reinforcement, 4wt.%, 6wt.% and 8wt.% respectively. Figure 4 shows casting of HMMCs.

RESULTS AND DISCUSSIONS

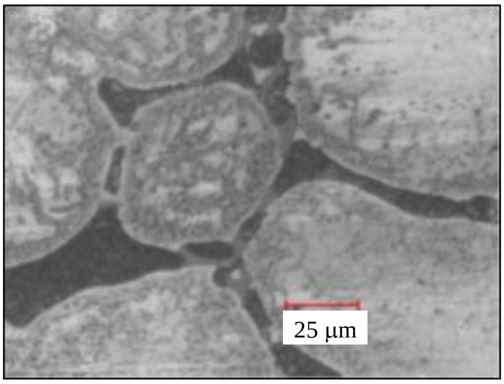
From fabricated HMMCs we made five samples, Sample (1) Only Base metal without any reinforcements, Sample (2) Base metal with 2wt% of Gr and 2wt% TiO_2, Sample (3) Base metal with 4wt% of Gr and 4wt% TiO_2, Sample (4) Base metal with 6wt% of Gr and 6wt% TiO_2, Sample (5) Base metal with 8wt% of Gr and 8wt% TiO_2.

Microstructure Analysis

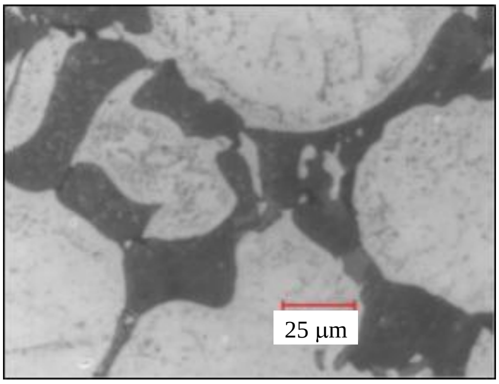
Figure 5 reveals that the spreading of reinforcing elements was quite homogenous, TiO_2 acted more effective than graphite to obtain fine microstructure. Figure 5a shows the grain structure clearly in the diagram for only base metal with 0% of reinforcement. Figure 5(b), 5(c), 5(d) and 5(e) shows, the grain boundary is obtained in 2%, 4%, 6%, and 8% because the reinforcement is mixed up with the aluminium. The microscopic analysis predicts that the distribution of the graphite and tio2 particle is all over the specimen and also reveals that the mixing of reinforcement was proper. The microstructures consist of fine particles and inter particle and metallic compounds dispersed along the grain boundary in the matrix of aluminum solid solution.

Figure 3. Pouring molten metal to the sand mold.

Figure 4. Metal casting.



(a) Base Metal



(b) Base Meatl+2 wt% Graphite+ 2wt% TiO_2

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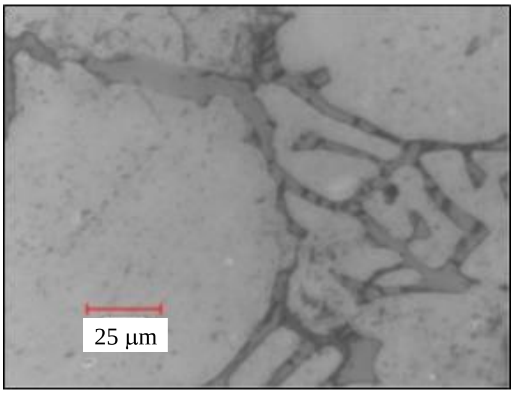
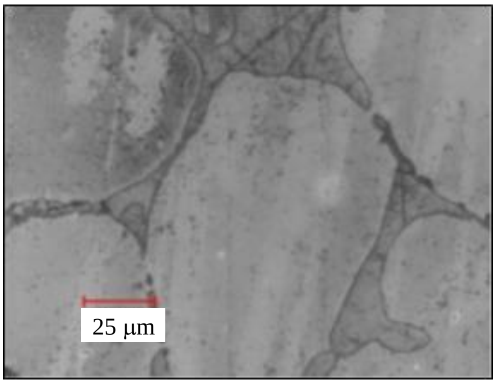
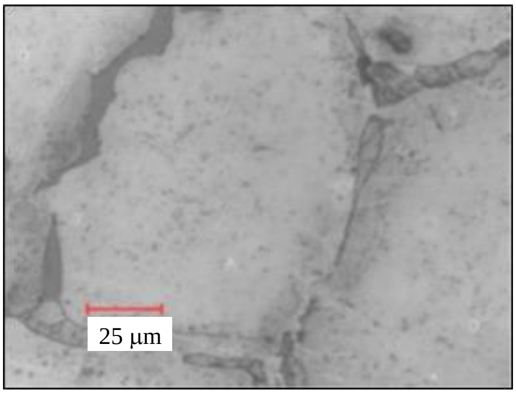


(c) Base Meatl+4 wt% Graphite+ 4wt% TiO_2



(d) Base Meatl+6 wt% Graphite+ 6 wt% TiO_2



(e) Base Meatl+8 wt% Graphite+ 8 wt% TiO_2

Figure 5. Microstructure analysis.

Figure 6. Shows broken specimens after tensile test.

Mechanical Properties

Tensile Test: This test conducted as per the "ASTM standard ASTM E8-M04" and broken specimens are indicated in Figure 6 under tensile test. Tensile strength of the base metal and composites with different Gr/TiO_2 ratios represented in the graph by Figure 7. However, in HMMCs, the base materials with reinforcements are fabricated to get favorable "mechanical properties" from the combined material. Tensile tests is executed to measure the increase or decrease of tensile strength caused by the addition of reinforcements in different weight percentages by increasing in Gr/TiO_2 ratio from 2 to 6 is due to rise in volume fraction of graphite.

To evaluate the tensile power of the newly made HMMC, a tensile test was performed and result of that is illustrated in below chart for the 5 samples. The obtained result shows that the hike in the reinforcement graphite and titanium dioxide shows increase in the UTS of the composite significantly.

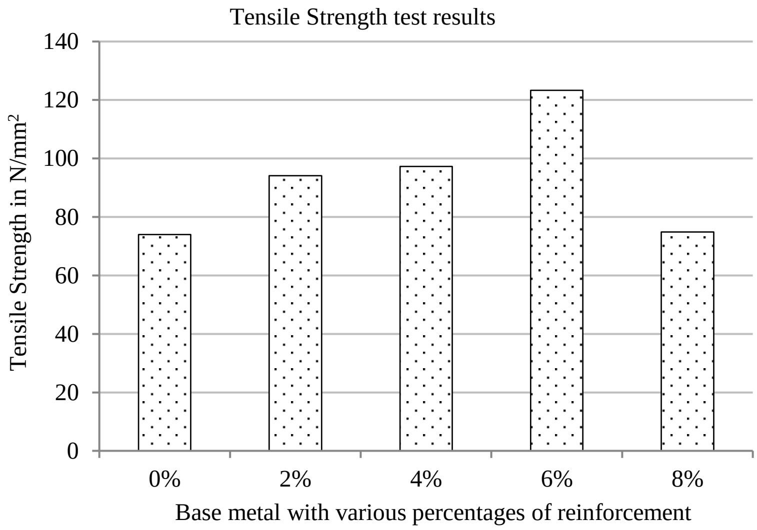


Figure 7. Tensile Strength of Al-MMC.

Figure 8. Specimen After Conducting Hardness Test.

The composition containing LM12 base metal has given a UTS value of 74 N/mm^2, where the steady growths of reinforcement in the composition have shown enhancements in the tensile strength. The sample-4 with the composition (LM12+6% Gr+ 6% TiO_2) has shown the best results with 123.3 N/mm^2. The hard nature of the graphite and the Titanium dioxide particles is the cause of the increment in strength. Also seen that, there is a sudden drop in the tensile strength in sample no.5 (LM12+8% Gr+ 8% TiO_2) with a strength of 74.9 N/mm^2 because of improper mixing and bonding of reinforcements with base metal more wt% of addition.

Hardness Test: To calculate the hardness of the newly made composites, the Brinell hardness was carried out. Aluminium hardness is increased with the adding of TiO_2 as it continues increasing of 2wt.%,4 wt.%, and 6 wt.% TiO_2 and Graphite respectively, TiO_2 and graphite have increased hardness. The hardness tests were conducted and the specimens after indentation is shown below in the Figure 8.

Measurement of microhardness in Figure 9 also upheld the results acquired from tensile tests. By increasing Gr/TiO_2 ratio from 2wt% to 6 wt%, hardness value increased by around 40 BHN, but dropped by increasing Gr/TiO_2 8 wt%. From the result, it is saw that the hardness of base metal LM-12 is 62.5. Then the hardness increases as there is a growth in weight % of reinforcements. The sample 4 hardness with the composition (LM-12+6% Gr+ 6% TiO_2) has shown the best results with the hardness number 103.3. Then there is a sudden drop in the hardness in sample no.5 (LM-12+8% Gr+ 8% TiO_2) with a harness of 95.2. The graph revealed that increasing by further reinforcement in wt %, which is lower strengths and microhardness values.

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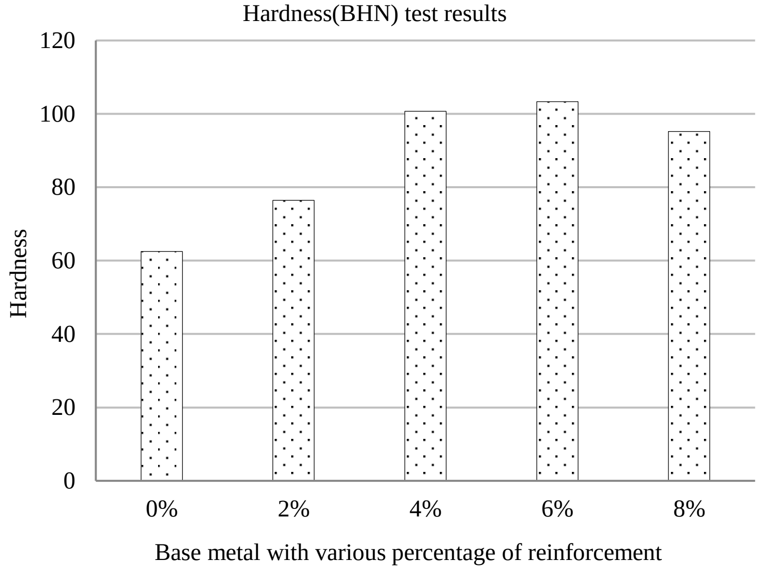

Figure 9. Hardness of Al-MMC.

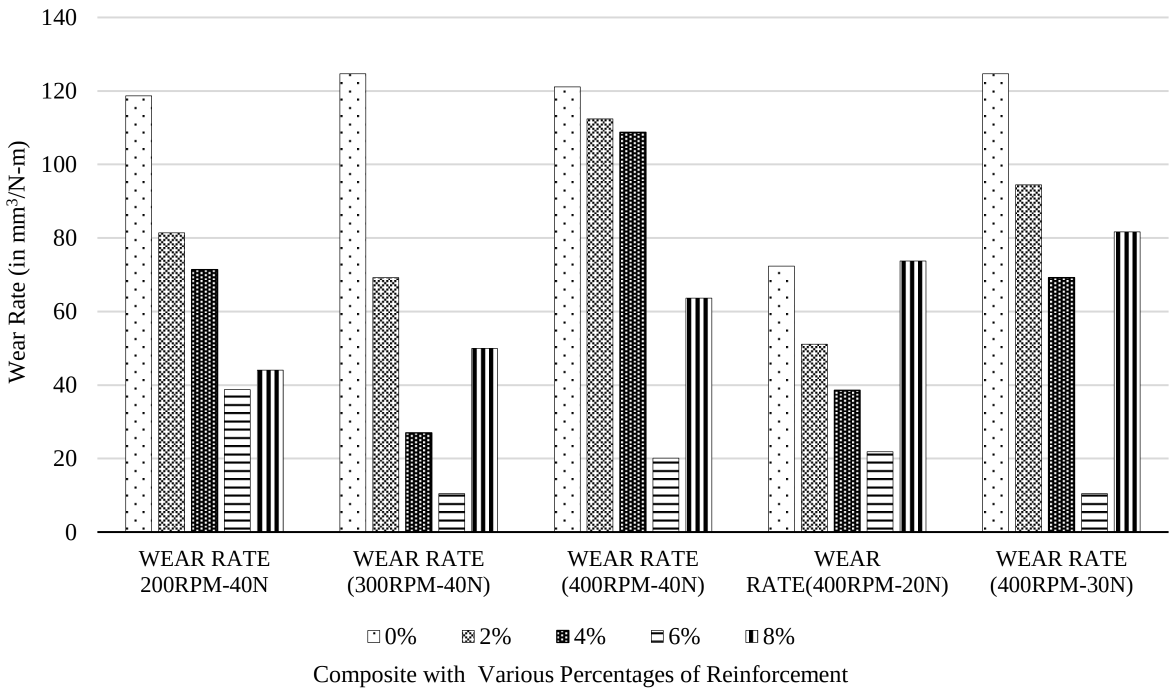

Figure 10. Wear test graph.

Wear Test: Metallic wear tests are done under room temperature on a pin-on-disk method. The pin sample is a flat pin with a "diameter of 8 mm and a length of 30 mm". The metal counter disk has a diameter of 100 mm and a thickness of 10 mm. The pin slides on the disc with a slide radius of 50 mm. The counter washer is made of high-quality, HV256-hardened steel. Abrasion tests of composite samples and non-reinforced aluminum alloys are performed under dry metal-to-metal slip conditions at four different loads (20 N, 30 N, and 40 N), a constant rate of 400 rpm, and a constant time of 5 minutes. The test time is 5 minutes with a stable slide speed. Similarly, tests were run at four different speeds (200 rpm, 300 rpm, and 400 rpm) with a load of 40 N. Wear test result is given in table.

The tests showed that the "base metal" sample without reinforcement showed more wear than the reinforcement sample, and the "base metal" with 0% reinforcement showed a significantly higher wear rate. Graph shows excellent results with a significantly reduced wear rate compared to all other test pieces with increases in the wt % of reinforcements up to 6% of both Gr and TiO_2. This is because the particles of Gr and TiO_2 are crushed to make a work-hardened layer, and the rate of wear reduces as the increment in the reinforcement and further due to improper mixing of reinforcements with base metal. That is in the sample composition (LM-12 + 8% Gr + 8% TiO_2), the wear rate increased sharply, so the composition could only be formed up to 6% reinforcement. Test results show that the proportion of added reinforcement reduces wear rates. The existence of Gr and TiO_2 particles distributed on the exterior of the pin and the formation of a protective layer between the pin and the disc reduces the wear rate. The results are indicated in the figure 10, which shows the wear test results. As the wt% of the graphite increased, wear rate decreased by around 30–40%. The creation of graphite layer and squeezed out graphite particles are responsible for the lower wear rate. This layer acts as solid lubricant and reduces contact between sliding pairs also indicates the establishment of mechanical mixed layer, which can enhance tribological properties.

CONCLUSIONS

The fabrication of aluminum alloy composites with different weight percentages of Graphite and TiO_2 using the Stir Casting method was successful in this research work. A microstructural study was conducted, revealing the uniform distribution of the dispersed particulates in the composites compared to MMCs. It was observed that the tensile strength of the TiO_2 and Graphite-filled LM-12 alloy composites increased by 123.3 N/mm^2 with a 6 wt% increase in reinforcements. The hardness of the TiO_2 & Graphite-filled LM-12 alloy composites also increased by more than 40 BHN when ceramic particulates were added, compared to the base metal. The wear test showed that the wear rate correlated with the load, as an increase in load resulted in a higher wear rate.

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