 https://doi.org/10.1051/e3sconf/202458803016

Sustainable Nanotechnology in Stir-Cast Al Composites: Mechanical Performance in Energy Applications

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Abstract. The integration of sustainable nanotechnology into aluminum composites offers significant potential for enhancing mechanical and tribological properties, particularly in energy-related applications. Aluminium alloys are extensively utilised in the aerospace and automotive industries. Due to its low density, superior mechanical characteristics, improved resistance to corrosion and wear, and lower thermal coefficient of expansion as compared to other metals and alloys, From a scientific and technological point of view, these materials are highly interesting applicants for a range of applications due to their good mechanical qualities and relatively low cost of manufacturing. Combining the advantageous qualities of metals and ceramics is the goal of producing metal matrix composite materials. The current research focuses on examining the behaviour of an aluminum cast alloy with a composite made of molybdenum disulphate using the stir casting method. Specimen obtained by the stir casting method were subjected to wear tests and hardness tests. The resultant composites demonstrated improved hardness and wear behavior, making them highly suitable for applications in energy sectors. This research emphasizes the role of sustainable nanotechnology in advancing aluminum-based materials for energy applications, contributing to both performance efficiency and environmental sustainability.

Keywords: Aluminium alloy, Hardness, Wear and Tribological properties, stir casting and Sustainable Nano technology

1. Introduction

Composite first appeared when people began building homes as a means of subsistence in the prehistoric era. In the past, men built their homes by mixing mud and straw in certain amounts. This resulted in the creation of plywood. It is clear from looking at the tree rings that their periphery has different characteristics. Thus, a stream of composite materials is created when different components are combined to create the desired product that meets all requirements. The general specifications for composite materials state that the fibre must not come into direct touch with the particle or fibre and must be uniformly dispersed throughout the homogenous element[1][2]. At high temperatures, the components in the composite mixture shouldn't react with one another because this could cause the composite material to fail too soon. Both the matrix's and the reinforcement member's coefficient of linear expansion will typically be near to one another. Commercial applications involve the use of aluminum, magnesium, and titanium alloys as metal matrices reinforced with fibers made of aluminum oxide or molybdenum di-sulphate [3][4]. In most cases, coating is applied to the reinforcement parts to stop a chemical reaction with the matrix. The reinforcement components of Metal Matrix Composites (MMC) ought to possess exceptional mechanical and chemical compatibility, along with strong thermal stability. Applications involving automobiles use MMC[5][6] .

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The AMCs are reinforced with whiskers, parti Mos2 lates, or continuous or discontinuous fibres, with a volume fraction ranging from a few to seventy percent. One benefit of AMCs is that they may be made to have diverse properties by adjusting the ways in which the matrix, reinforcement members, and blending processes are combined. Short fiber-reinforced composite materials outperform discontinuously reinforced partiMos2 late aluminium composites in terms of performance. Many researchers have examined matrix metal in relation to silicon carbide whiskers, boron- and graphite-reinforced aluminium composites, and the impact of sneaky impurities from diverse sources. When the matrix and reinforcement whiskers, or partiMos2lates, are as chemically and physically compatible as feasible, the composite system can achieve its optimum features. To maximise the performance of some metallic composites, specific whisker coatings and specialised matrix alloy compositions have been developed [7][8][9].

One of the crucial steps in the creation of new products for a range of engineering uses is material selection. For automotive applications, we need materials that are both strong and lightweight. However, these conditions are not met by the traditional metal elements. This prompted scientists to investigate the field of composite materials [10][11][12]. When we refer to composites, we imply specially designed goods that are produced to meet specifications without sacrificing functionality. Composites are made up of a matrix and another element for reinforcement. To investigate its qualities, we have selected the Mos2 reinforced AMCs material. Optimizing the mechanical and wear characteristics of the Mos2-reinforced AMCs is the main goal of this work. Many studies on composite materials and the wear behaviour of aluminium alloy 6061 reinforced with Mos2 generated by stir casting process have been conducted prior to these investigations.Different casting parameters were controlled in order to carry out the study.Variations in the volume percentages of Mos2-reinforced AMC at 3%, 6%, and 9% weight percentage.Since aluminium alloy (6061) is a material with good strength, low weight, resistance to corrosion, and ability to withstand thermal shocks, it is chosen for the investigation.

2. Experimental setup

The stir casting method is used to create the Mos2 reinforced AMC. A gearbox, a mild stirrer, a coupling motor, and an oil-fired furnace for melting the alloy are among the tools used in the stir casting process[2]. Aluminum scraps were preheated for three to four hours at 450°C, while Mos2 particles were preheated for one to three hours at 1100 °C. To fully melt the alloy scrap, the furnace temperature is kept above the liquids; the slurry is then kept in a semi-solid form by cooling down below the liquids. Following a 10-minute immersion in a 10% sodium hydroxide solution at 95–100°C, the aluminum ingot pieces were sliced and cleaned with methanol. After being fully dried in the air, a weighted quantity of aluminum specimens was melted in a crucible [13][14]. A mild steel stirrer and a motor with gearbox were combined to create the stirring system. In an oil-fired furnace, a graphite crucible was used for all melting operations[15]. Before melting, the aluminum scraps were heated to 450 degrees Celsius for three to four hours. To oxidize the surfaces of the powdered Mos2 and Micro-Mos2 particles, They spent between one and three hours being warmed at 1100°C. Clean aluminium alloys have been melted beyond the super heating temperature, or around 800 °C, in graphite crucibles covered in a flux layer utilising an electrical resistance furnace, as illustrated in Fig. 1.

The melt was then vented at 800 °C using a solid dry hexa-chloroethane degasser. After that, the preheated Mos2partiMos2lates were mixed to the molten metal and constantly agitated at impeller speed of 700 rpm for approximately fifteen minutes. An electronic scale was used to weigh the aluminum matrix and Mos2particles (AcMos2racy 0.0001 g). To make the Mos2particles more wettable, 1% by weight of magnesium was added during stirring [16]. By using gravity casting, the reinforced melt was poured into permanent, cylindrical metallic molds that measured 120 mm in length and 14 mm in diameter. After the melt had cooled to room temperature and solidified in the molds for roughly three minutes, it was removed. Base alloy samples were also cast under comparable processing circumstances for the purpose of comparison.

Fig. 1. Stir Casting setup

Fig. 2. Al 6061 casting samples with different %wt reinforcement

Fig. 3. Hardness tester

2.1 Hardness test

In order to prevent abrasive wear, erosion, and thermal deformation, it is imperative to identify the sample with the highest hardness feasible. The hardness of each of the test samples in Table 1 is measured using a Wilson Wolpert Small hardness tester. Four tests were conducted on each sample, applying a 0.5 kg weight & a 10-second dwell time to each test specimen.

 https://doi.org/10.1051/e3sconf/202458803016

Table 1. Hardness result

Locations	H.V. @ 0.5 Kg load. (avg)
Sample A (1,2,3)	35.1
Sample B (1,2,3)	37.8
Sample C (1,2,3)	41.6

2.2 Dry sliding wear test

The dry sliding wear parameters of specimens made of aluminium composite reinforced with Mos2 were examined using the DUCOM pin-on-disc test device. The ASTM G99 guidelines were followed when conducting dry sliding wear tests. Cast samples were machined into wear specimens with an 8 mm diameter and 32 mm length, which were subsequently polished metallographically. Cleansed pins made of unreinforced metallic alloys and composites were set against a rotating EN32 steel disc of 165 mm in diameter and 8 mm in thickness, as shown in Figure 3. For ten minutes, the weight was applied at the ambient temperature. The test specimens were all ground using 600-a grid emery paper to give them a uniform, standard surface polish. The disc's roughness on the surface was measured at 1.6μm RA.

A weight loading mechanism applies load to press the pin against the disc. The disc rotates while the specimen stays fixed for the duration of the experiment. A wear test was conducted using standard load=20 N at sliding velocities =2 m/sec, 3 m/sec, and 4 m/sec. In this investigation, wear rate was determined following a ten-minute interval. The test specimen is consistently cleaned using woollen cloth to prevent worn debris from being trapped and to provide a consistent experimental method. Acetone solution was used to clean the disc following each test. The wear testing apparatus is managed by a microprocessor, enabling simultaneous monitoring of the frictional force and height loss using a PC-based data logging system. The results were shown and data was acquired using WinDucom software. Test results were viewed and compared using the CompariView programme in order to assess them. A load cell was used to quantify the frictional force, and a linear variable differential transducer (LVDT) was used to measure the height loss of the pin specimen. Every test was conducted three times based on selection of wear parameters is depicted in Table.2, and the average results were used to determine the composite material's wear rate and coefficient of friction.

3.Result and discussion

3.1 Effect of micro sized MOS2 percentage on hardness

Table 2. lists the hardness of composite specimens with varying volume fractions of micro-sized Mos2 particles (2 and 4%). Hardness is a characteristic that distinguishes composite materials from unreinforced aluminium alloy. The composite specimens' Brinell hardness values show that as the number of micro-sized Mos2 particles increases, so does the specimens' hardness. The hardness of the composites exhibited a nearly linear relationship with the increase in micro-sized Mos2 content. The composites' hardness increased as the size of the Mos2 particles developed. The hardness of the composite is enhanced by an increase in the volume fraction of this ceramic phase (Mos2) since it is brittle and hard. The pure aluminium matrix's hardness value was 32.4 HV. The lowest hardness value (35.1 HV) is displayed by composites reinforced with micro-sized Mos2 particles at 3% volume fraction, while the highest hardness (41.6 HV) is displayed by composites reinforced with particles at 10% weight percentage. When comparing composites to unreinforced aluminium alloy, the largest improvement in hardness that was observed was 26.%. Because the hard micro-sized Mos2particles are more resistant to indentation and function as a barrier to dislocation movement within the matrix, an increase in hardness has been reported. Moreover, it was clear that the hardness rose in tandem with an increase in particle size. As the volume percentage of Mos2 increases, porosity likewise decreases. Since the dispersion of Mos2 in Al-6061 is noticeable and more uniform and the hardness qualities are transmitted from Mos2 to Al matrix, a galloping increase in hardness is noticed between 6% and 9% volume fraction.

Fig. 4. Wear tester

Table 2. Wear Test parameters and Machine setting

Test parameters				Machine setting			
Expt. No.	Applied Load (N)	Sliding velocity (m/sec)	Sliding Distance (m)	Sliding dia in mm	r.p.m	Time in secs	Time in min:secs
1	20	3	1000	30	1911	333.33	5.5547
2	20	3	1000	46	1246	333.33	5.5547
3	20	3	1000	46	1246	333.33	5.5547

3.2 Effect of micro sized MOS2 percentage on wear

It is clearly noticeable that, from all of the Al-Mos2 composites, the coefficient of friction increases within the first 240 seconds of the wear test. The POD (Figure 4) is used to perform the wear test. This results from the hard disk's contact sticking to the Al composites' surface. When comparing Al / Mos2 with base aluminium to Al / Mos2 with 3wt% and 4wt%, a critical analysis of the graphical plots reveals that the latter have a less wear tendency. This suggests that the material's strength is strong in volume fractions three and six because of the magnesium and Mos2 particles present. Magnesium improves the composite material by acting as a lubricant and carrying load.

The Mos2 reinforced Aluminium Matrix Composite material's wear resistance qualities can be exacerbated and the frictional load can be tolerated because the reinforcement is thermally stable. It is also observed that each Mos2 composite's friction rate reaches its peak saturation after 40 minutes. The combination of composites that demonstrate the wear interaction on grain boundaries lends credence to this hypothesis. On the other hand, matrix composites containing 6wt% and 9wt% of Mos2 had the highest wear rates, indicating a poor link between the boundary layers of the Mos2 composite and the MMC grains. The wear rate (μm) of Al/Mos2 composites is shown graphically in Figure 5 as a function of time.

3.3 Variation of wear rate with Temperature

The Al6061's rate of wear studied the effects of temperature variations on reinforced with micro-sized titanium boride composites at 50, 100, 150, 200, 250, and 300°C, respectively, under a 20N applied stress. A graph illustrating the results is shown in Figure 5. The results demonstrated that while the wear rate is increased for volume proportions of 3%, 6%, and 9% of Mos2, it is relatively low for these volume fractions due to the lack or irregularity of the grain border. The lack of multidirectional thermal resistance and grain refinement results in greater wear at higher temperatures. The composite materials with 3wt, 6wt, and 9wt%Mos2 have a low wear rate.

3.4 COF behavior of the 6061 Al / Mos2 composites

The primary cause of kinetic friction in Al/Mos2 composites is the specimen's surface roughness when it encounters the disc. Fig. 6. shows that the friction rate rose quickly in a brief amount of time. Instantaneous

 https://doi.org/10.1051/e3sconf/202458803016

thermal energy is produced at the specimen and disc point of contact. The composites' hardness is lowered and their friction rate is raised by this heat source. After a while, the specimen and disk's thermal energy contribution steadily dropped as the friction rate gradually decreased. The composites containing 3wt% and 6wt% Mos2 exhibit increased rates of friction. The hardness of the samples tends to diminish as the Mos2 content rises above 9wt%, as revealed by an excessive rate of friction. The reduction in the rate of friction was ascribed to the enhanced wear resistance provided by hard Mos2 particles inside a soft ductile matrix. It demonstrates how the uniformly distributed Mos2 particle strengthens the composite. Another explanation is that the concentration of Mos2 improved wear resistance by filling in the dislocation voids.

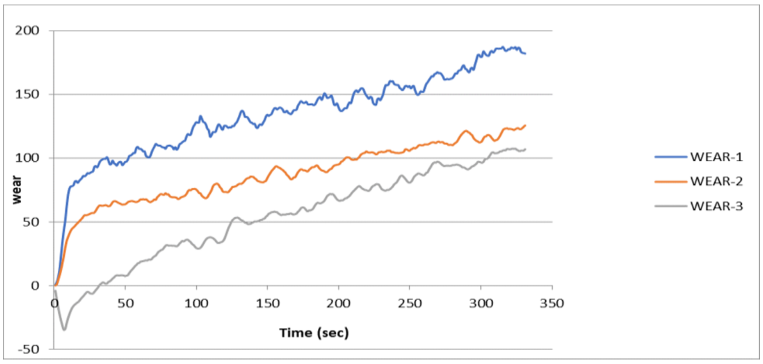

Fig. 5. Wear rate with respect to the time

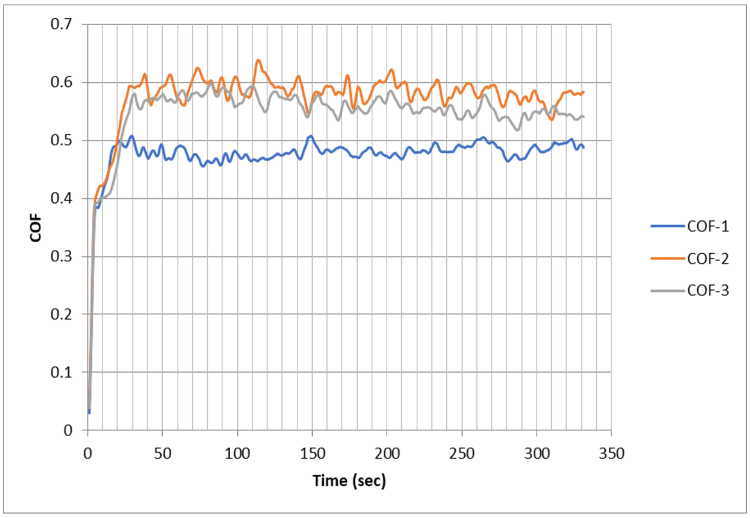

Fig. 6. COF with respect to the time

3.5 SEM

The grain size and porosity of the material affect how tough it is. Fracture and cratering result from decreased toughness. We conduct a microscopic test on the samples to ascertain their grain size and porosity scanning electron microscope (SEM) is used to test the samples. We can find out the samples' porosity thanks to this test. Two conditions are used for this test: polished and etched, respectively, at two different sites. The specimens undergo examination at magnifications of 100X and 200X. The Effect of different weight % of Micro sized Mos2 with Al6061 on wear are shown in Fig.7-9.

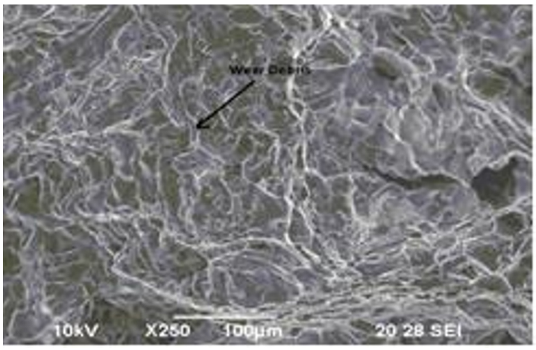

Fig.7. 3% Mos2 reinforced Al6061

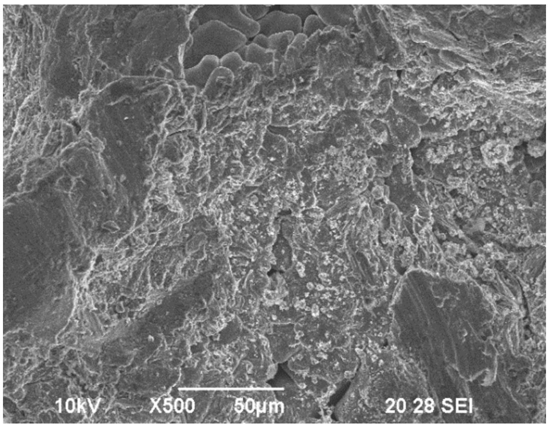

Fig. 8. 6% Mos2 reinforced AMC

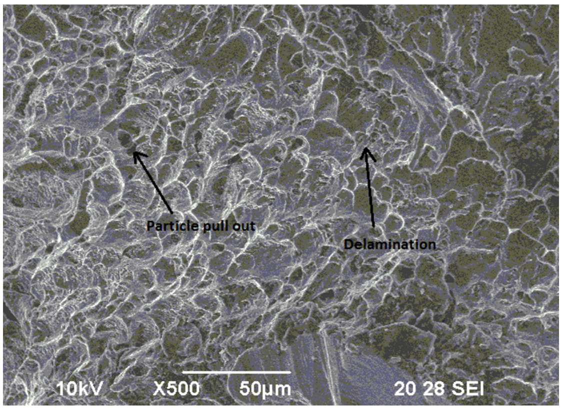

Fig. 9. 9% Mos2 reinforced AMC

5.Conclusion

The study's findings indicate that increased wear strength, normalized displacement, and hardness have all been linked to increased composite of Mos2. Comparing the reinforced aluminium alloy to the unreinforced version, a maximum increase in hardness of 28.47% and a wear strength of approximately 27 to 44% were noted. In samples made without using a stirring process, with manual stirring, and using a two-step stir casting approach, there is an increasing trend in the homogenous dispersion of Mos2 particles in the Al matrix. When compared to Nano Mos2 with an even higher weight percentage of aluminium, wear testing on 3% of the material likewise revealed a low wear rate. Three is the sample with the highest hardness compared to the other two. This research underscores the critical role of sustainable nanotechnology in the development of advanced aluminum-based materials tailored for energy applications. By integrating reinforcements like MOS2 and TiB2, the study not only boosts the mechanical performance of aluminum alloys but also contributes to energy efficiency by minimizing material losses due to wear and friction. Furthermore, the environmentally conscious approach to material optimization aligns with global sustainability goals, reducing the carbon footprint associated with energy production and material processing.

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