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"Investigation on Mechanical Behaviour of Aluminium Metal Matrix Al6061 Reinforced with Varying Wt. % Aluminium Oxide (Al_2O_3) And 5% Molybdenum Di-Sulphide (Mos_2) Micron Particles"

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Abstract

The study focused on the mechanical characteristics of hybrid metal matrix composites made of Al 6061 alloy reinforced with Molybdenum Di-sulphide (MoS_2), and Aluminium Oxide (Al_2O_3) in micron form. The composites were made by employing the stir casting technique to reinforce the Al6061 base metal with different weight fractions of aluminium oxide (Al_2O_3), ranging from 5 to 20%, while maintaining a constant weight of molybdenum disulphide (MoS_2) 5%. Samples were machined in accordance with ASTM standards E8 & E10 and put to the test under standard testing settings utilizing a universal testing machine and a Brinell hardness testing machine in order to assess the mechanical properties of the manufactured hybrid composite like Ultimate Tensile Strength and Brinells Hardness. The study findings may shed light on the possible usage of metal matrix hybrid composites in fields including aerospace, automotive,--etc. that call for great mechanical strength.

Key Words: *Hybrid Metal Matrix Composites (HMMC), Molybdenum Di-sulphide (MoS_2), Aluminium Oxide (Al_2O_3), Ultimate Tensile Strength and Brinell hardness.*

1. Introduction

Due to the constraints of standard monolithic materials in terms of obtaining good strength, toughness, hardness, density, and strength-to-weight ratio, etc., the demand for low-cost, high-performance materials has increased exponentially in recent years. This has resulted in the creation of new sophisticated materials. A composite material is one that is composed of two or more distinct materials, each with its own set of physical and chemical properties. Metal matrix composite is a material made up of a metallic matrix and reinforcements. Aluminium, magnesium, copper, zinc, and titanium are the most commonly utilized matrix materials. SiC, alumina, boron, graphite, and fly ash are the most often used reinforcements[1]-[2].

The reinforced aluminium matrix is a matrix material that is extensively utilized in aerospace and aeronautical applications. Aluminium is extremely strong. When utilized as a low-density matrix, the principal reinforcements used to improve mechanical qualities are ceramics such as SiC, Al_2O_3, TiC, and Boron carbide. Mechanical qualities and operating difficulties of B_4C particles reinforced composites, which are already used in industrial applications, can be greatly improved by adding aluminium as a matrix[3].

Stir casting, powder metallurgy, spray forming, liquid infiltration, ball milling, diffusion bonding, and other composite manufacturing processes are available. However, stir casting and powder metallurgy are the most often utilized processes because they are less expensive than other approaches[4]. The ultrasonic liquid stir casting process was utilized in this work due of its simplicity, cost-effectiveness, and ability to build complicated shapes[5]. To achieve homogeneous dispersion of the alloy, B_4C was added in phases, ideally two (or more) [6]. Aluminium was heated to above melting point temperature to soften it, and the melt was continually swirled for suitable time duration while reinforcement was added in stages.The microstructure of the prepared specimens was studied using a SEM, an X-ray diffractometer (XRD), tensile tests with a UTM to assess material behaviour, and hardness and wear tests. The amalgamates density is also examined and compared to the base matrix alloy[7]. Many researchers employed micron particles as reinforcements in the aluminium matrix and discovered improved mechanical properties when compared to unreinforced and single-reinforced aluminium alloy composites [8].

For applications where it is necessary to withstand high temperatures, great hardness, and strength, Al6061alloys are frequently employed. Si, Mg, Zn, and Fe serve as the Al6061's primary reinforcing components. In order to create the hybrid composites, micron particles of alumina , graphene , TiC , SiC , and also combinations of numerous reinforcements are added to the Al6061matrix[9]. The micron-particle reinforcements were also used to make the composite materials B_4C-Al_2O_3, B_4C-SiC, TiC-SiC, and graphene-Beryl. Researchers also utilized micro B4C particles in an Al6061 matrix and found that, in contrast to monolithic aluminium, which loses ductility, adding reinforcement boosts composite strength with relatively small weight increases[10][11][12].

The mechanical behaviour of composites comprised of different micron-sized particles and an aluminium matrix has been extensively discussed in scientific literature. It is now possible to research the mechanical properties of hybrid aluminium composites that contain Al_2O_3 and MoS_2 micron particles. This work aims to investigate the effects of Al_2O_3 and MoS_2 micron particles on the tensile behaviour and microstructure of hybrid Al6061-Al_2O_3/MoS_2 composites.

2. Materials and Preparations

2.1. Materials

In this study, the Al6061 (aluminium alloy) is employed as the matrix, while Al_2O_3 and MoS_2 Micron-particles are used as reinforcements to reinforce the structure (Fig. 1(a-b)). The main justification for adopting these materials is that their densities are almost equal, with Al6061 having a density of 2.71g/cc, aluminium oxide having a density of 3.87g/cc, and molybdenum di sulphide having a density of 5.06g/cc. The distribution of reinforcements in the matrix will therefore become almost homogenous if the composite is produced using the liquid metallurgical process. In addition, pure Al6061 has unusually low yield and tensile strengths, with yield strength measuring 70 MPa and tensile strength ranging from 70 to 120 MPa.Al_2O_3 and MoS_2 in particular, whose melting temperatures are higher than those of other ceramics, are utilized in high-temperature applications. Consequently, creating hybrid composites using aluminium oxide (Al_2O_3) and molybdenum di sulphide (MoS_2) boosts their hardness and tensile strength while lowering their elongation. Both reinforcements have melting points ranging from 2500^0 to 3200 °C. Additionally, they are used in circumstances when great temperature resistance is necessary.

The most crucial factor in defining the composites' material properties is the particle size of the reinforcement. The microstructure of the composites will be significantly impacted by the particle size of the reinforcement, among many other factors. The reinforcements utilized in this experiment have the following particle sizes: MoS_2 has a diameter of 20 microns, whereas Al_2O_3 is 20 microns in size. The stir casting method (Fig. 1(c)), which is more cost-effective, easier to use, and ensures equal dispersion of the reinforcements throughout the matrix, is preferred for manufacturing the aforementioned composite due to its many benefits.

(a) (b) (c)

(d) (e) (f)

Figure 1. (a) Al6061 blocks; (b) Al_2O_3 and MoS_2 particles; (c) stir casting setup used in the fabrication of MMC; (d) casted composites; (e) Tensile specimens and (f) Hardness specimens

2.2. Processing

Al6061 was added to the graphite crucible, and it was then heated to 800ºC. A C2Cl6 degassing tablet was used to reduce the amount of gas in the aluminium melt while maintaining the temperature near 800°C for an hour. When stirring molten liquid, Mg particles with higher grain sizes were utilized as a flux to increase the wettability of reinforcements. A version of the stir casting technique was used to disseminate the micron particles throughout the liquid.

To ensure compatibility with the liquid metal and to prevent organic contaminants and moisture, vertex formation speed at 370 to 420 rpm was used to introduce and agitate the liquid metal pool with preheated aluminium oxide (Al_2O_3) and molybdenum di sulphide (MoS_2) micron-particles.

For the next 20 minutes, the process will be continued. Between each stage, the formation of a semisolid state was preceded by a 10-minute stirring phase. The viscosity of the aluminium alloy melt was automatically raised by the addition of micron-sized particles. To ensure the efficiency of the procedure, a higher melting temperature of 800^0C was maintained inside the crucible while improving the flow ability of micron particles in a liquid substance to reduce viscosity.

The liquid metal was mechanically agitated for five minutes to break up any blasted clusters and agglomerations. After the sonication process, the liquid metal was mechanically agitated for five minutes to break up any blasted clusters and agglomerations. The molten substance was then instantly placed into a graphite mold that had been heated to 500°C and allowed to spontaneously cool for 24 hours at room temperature.

After solidifying, the cylindrical work pieces (Fig. 1(d)) were removed from the mold and machined in accordance with ASTM requirements for various testing (Fig. 1(e-f)). Similar to this, aluminium matrix hybrid composites with varying amounts of Al_2O_3 from 0 to 20 weight percent and MoS_2 5% weight percent were created. The specimens for the tensile and Brinell hardness tests were made in accordance with ASTM guidelines.

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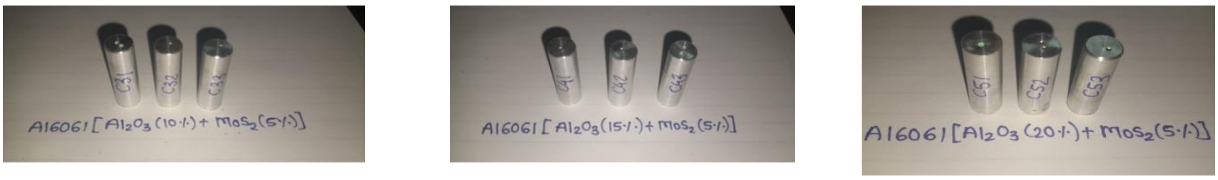
3. Experimentation

As per ASTM E8, tensile testing were conducted using UTM equipment, and hardness tests were conducted using a Brinell hardness machine. The distribution of ceramic particle reinforcement in the composites was examined using SEM. An energy-dispersive spectroscopy (EDS) record was used to identify the different elements that were present in the sample's distinct components. According toASTM E8 standard, the circular rod of the aforementioned hybrid composites is tested to determine the ultimate tensile strength. Fine grit grinding mesh paper was used to brighten and lessen the impact of surface area defects on the specimen. A computerized universal testing machine (UTM) with a 50 kN load was used to conduct the tensile test. The load and displacement data were noted.

A BHN unit is used to conduct the Brinell hardness test. In this test technique, a tungsten carbide ball with a specified diameter (D) is subjected to a predetermined force of 100 kgf(F) for aluminium composites, held for a predetermined amount of time, and then released. The test metal piece receives an impression (permanent deformation) from the spherical indenter. To get the indentation diameter (d), this indentation is measured over two or more diameters and then averaged. The Brinell Hardness Number (BHN) is determined using a chart or computed using the Brinell hardness test formula using this indentation size (d).

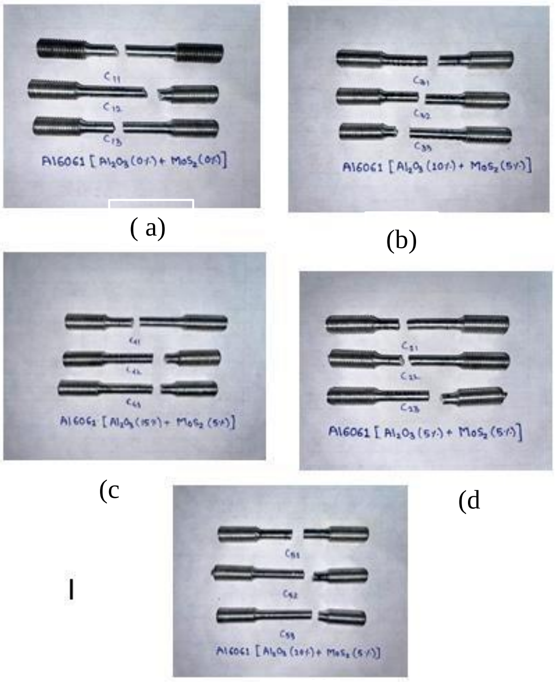
Figure 2. (a) Al6061-Al_2O_3/MoS_2 Metal matrix composites Tensile specimens machining with varying composition,(b)C1Pure Al6061,(c)Al6061/5% Al_2O_3-5%MoS_2, ,(d)Al6061/10% Al_2O_3-5%MoS_2, ,(e)Al6061/15% Al_2O_3-5%MoS_2, ,(f)Al6061/20% Al_2O_3-5%MoS_2

(a) (b) **(c)**



(d) (e) (f)

Figure 3. (a) Brinell Hardness specimens of Al6061-Al_2O_3/MoS_2 Metal matrix composites with varying composition,(b)C1Pure Al6061,(c)Al6061/5% Al_2O_3-5%MoS_2, ,(d)Al6061/10% Al_2O_3-5%MoS_2, ,(e)Al6061/15% Al_2O_3-5%MoS_2, ,(f)Al6061/20% Al_2O_3-5%MoS_2



(a) (b)

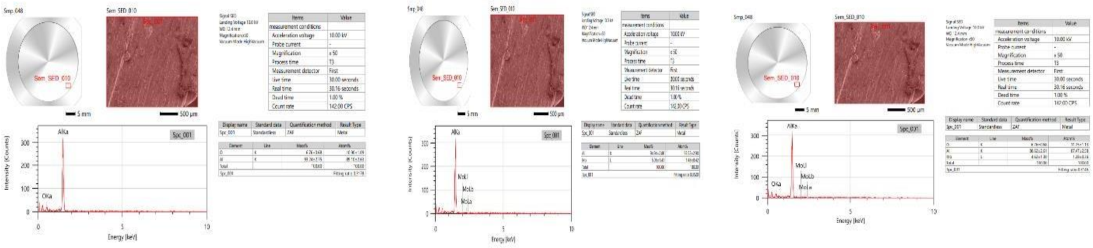
(c (d

(e)

Figure 4.Images of fractured tensile speci ith varying composition after tensile testing in Universal Testing Machine

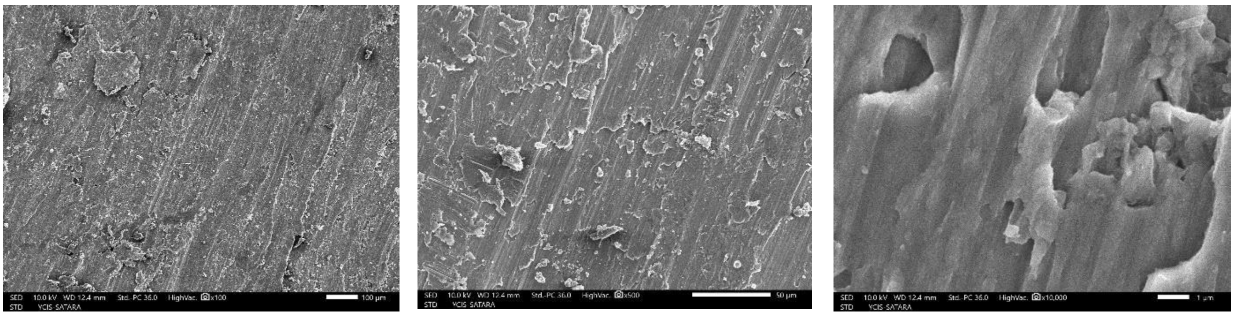
4. Results and Discussions

4.1 Microstructure



(a) (b) (c)

Figure 5. EDS Images and Spectrum of Al6061-Aluminium Oxide (Al2O3)-Molybdenum Di Sulphide (MoS_2) Composites.



(a) (b) (c)

Figure6. SEM micrographs: Al6061-20 %Aluminium Oxide (Al2O3)-5%Molybdenum Di Sulphide (MoS_2) Composites with varying Magnification (a)100X,(b)500X,(C)10,000X

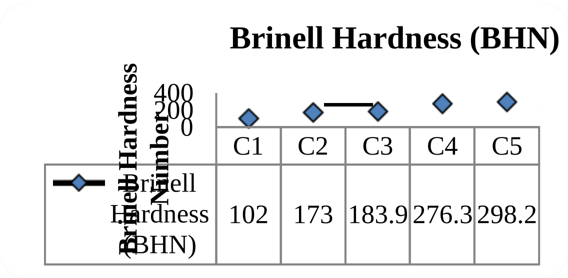
The above EDS graph shows alloying elements with contents more than 10% by weight. The Al6061 EDS spectra also reveal a little oxygen peak, aluminium, and molybdenum sulphide. The EDS analysis of the hybrid composites was carried out (Fig. 5(a-c)) to confirm that they comprised an Al-6061 matrix, 5 to 20 wt% Aluminium Oxide (Al_2O_3) reinforcements, and 5 wt. % Molybdenum di sulphiude (MoS_2). It should be noted that the presence of Al6061, Aluminium Oxide (Al_2O_3), and Molybdenum Di Sulphide (MoS_2) in the casted hybrid composite samples is confirmed by the spectra of the Al, Al2O_3, MoS_2, and C peaks.

4.2 Brinell-Hardness

In Al6061-Al2O3/MoS2 hybrid composites, Brinell hardness values and various Al_2O_3 concentrations were measured. The results are summarized in Fig. 7.(a) and (b) As the percentage of Al_2O_3 micron particles in the composites rises, so does their hardness. The brinell hardness of a sample of Al6061 alloy is 101.96 BHN. The brinell hardness of Al6061-Al_2O_3/MoS_2 hybrid composites is increased from 101.96 BHN to 298.16 BHN for same testing conditions, which is a twofold increase over the unreinforced Al6061. This outcome is the result of the combination of Al_2O_3 and MoS_2 micron-sized particles, which can pin grain boundaries in an aluminium matrix to restrict grain growth, producing an aluminium alloy with finer grains. Finer grain forms may lead to higher hardness levels.

Table 1.Mechanical properties of the Al6061-Al_2O_3/MoS_2 composite

Sl. No	Composition(Weight Percentage)	Brinell Hardness (BHN)	Tensile Strength (Mpa)
1	C1-Pure Aluminum 6061	101.96	118.93
2	C2-Al6061+5%Al_2O_3+5 % MoS_2	173.01	121.92
3	C3- Al6061+10%Al_2O_3+5 % MoS_2	183.85	113.87
4	C4- Al6061+15%Al_2O_3+5 % MoS_2	276.25	99.37
5	C5- Al6061+20%Al_2O_3+5 % MoS_2	298.16	122.94



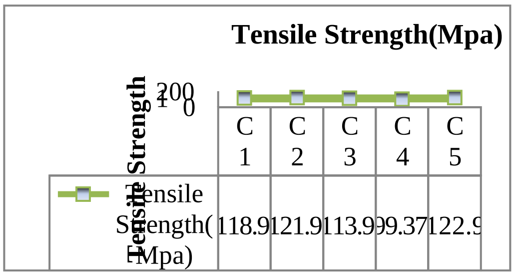
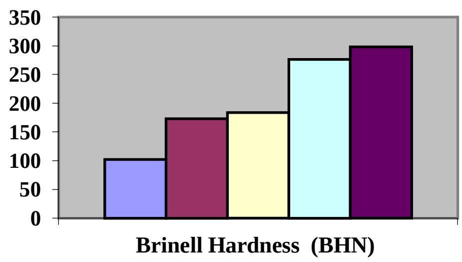


Figure7(a). Brinell hardness of preparedFigure 8(a). Ultimate Tensile

Composites of prepared composites



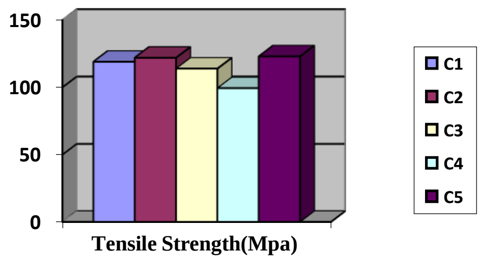


Figure 7(b). Brinell hardness of preparedFigure 8(b). Ultimate Tensile

Composites of prepared composites

4.3 Tensile Strength

Fig. 8(a) and (b) displays the tensile strength data for the hybrid Al6061 metal matrix composites reinforced with Al_2O_3 and MoS_2. In terms of tensile strength, Al6061 hybrid composites perform better than the base alloy. The strengthening effect of composites is caused by the presence of hard reinforcing particles. The homogenous ceramic particle distribution in the aluminium alloy composite (Al_2O_3 and MoS_2) does not operate as a stopgap against the matrix alloy's dislocation motion, enhancing breakage. The inclusion of ceramic particles principally increases the brittleness fracture by decreasing the stress transfer from the ductile surfaces of the aluminium matrix to the brittle surfaces of the reinforced particles. As a result, a dislocation can create a large fracture all the way around a particle. As a result, the hardness rises while the tensile strength falls. Al6061+20wt% Al_2O_3+5wt% MoS_2 exhibits a maximum strength of 122.94 MPa, which is an increase of around 125 MPa (or 5%) when compared to the basic alloy. The accumulation of stress at the nucleation point will lead to fracture.

Fig.4 displays the fracture formation of the 6061 hybrid MMC. The figure of aluminium alloy composites with a higher reinforcing content illustrates a degree of material displacement and matrix cracks close to the MoS_2 and Al_2O_3 particles. The hybrid Al6061-Al_2O_3/MoS_2 composite broke tensile specimens in the current work, as depicted in the figure. Using a fractography investigation, the failure processes of the materials were investigated.

In above figure shows shallow dimples and ductile started brittle cracks in Al6061 prepared composites. Hard, extremely brittle Al_2O_3 and MoS_2 micron particles are present, and they offer the transgranular fracture surface. The Al_2O_3 and MoS_2 particles show plastic deformation perpendicular to the applied tensile force. Furthermore, it has been observed that as the Al_2O_3 content rises, the formation of dimples diminishes, which results in a reduction in ductility. MoS_2 particles were drawn out and dragged off when tensile tension was applied because the higher Al_2O3 composition induces brittle fracture. As a result, less external stress was transferred from Al6061 to the hard Al_2O_3 and MOS_2 particles, resulting in a decrease in strength, as seen in Fig.4.

5. Conclusion

- From this experimental work, it has been investigated how adding Al_2O_3 and MoS_2 micro particles to an Al6061-Al_2O_3/MoS_2 hybrid composite affects its tensile strength and hardness. Stir casting is used to create the Al6061-Al_2O_3/MoS_2 micron-particulate hybrid composite, as shown in fig. 1 (a-f).

- It is confirmed by the EDX analysis, as shown in Figs.5 and 6, that Al6061contains reinforcing elements Al_2O_3 and MoS_2suggests that the cast hybrid composites. The random and uniform distribution of reinforcements in the aluminum matrix is confirmed by EDS elemental mapping analysis. When an "O" is present, it means that distinct oxides have formed during casting and machining. The Al6061 matrix contains reinforcement nanoparticles that are uniformly distributed without clumping, according to SEM examination.

- The Brinell hardness of the Al6061-Al_2O_3/MoS_2hybrid composites increases with an increase in wt. % of Al_2O_3 as shown in fig.7. This increment is due to the pinning of matrix grain boundaries by the reinforcements which results in the finer grains of aluminum. The maximum Brinell-hardness that is obtained is 291.86 BHN for 20wt% of Al_2O_3, which is 2 times higher than the unreinforced Al6061.

- The Al6061 matrix contains evenly distributed reinforcing particles that operate as a block-off for the matrix alloy's dislocation motion and boost the strength of the composites, as seen in fig. 6(a), (b), and (c) with changing magnification. Additionally, the addition of ceramic reinforcements reduces the load on the matrix material, increasing the hardness and decreasing the tensile strength of Al6061-Al2O3/MoS2 hybrid composites by a modest amount.

- Above results from fig.5&6, fig.7, and fig.8 shows that addition of Al_2O_3/MoS_2 micron particles in Al6061-Al_2O_3/MoS_2hybrid composite, the hardness of the composite increases. However, this growth is gained with the loss of ductility, which is evident from the results showing the brittle fracture.

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