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# Experimental Investigation on Mechanical Properties of an Al6061 Hybrid Metal Matrix Composite

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**Abstract:** The demand for aluminum hybrid metal matrix composites has increased in recent times due to their enhanced mechanical properties for satisfying the requirements of advanced engineering applications. The performance of these materials is greatly influenced by the selection of an appropriate combination of reinforcement materials. The reinforcement materials include carbides, nitrides, and oxides. The ceramic particles, such as silicon carbide and aluminum oxide, are the most widely used reinforcement materials for preparing these composites. In this paper, an attempt has been made to prepare an Al6061 hybrid metal matrix composite (HAMMC) reinforced with particulates with different weight fractions of SiC and $Al_2O_3$ and a constant weight fraction (5%) of fly ash by a stir-casting process. The experimental study has been carried out on the prepared composite to investigate the mechanical properties due to the addition of multiple reinforcement materials. The density and mechanical properties, such as ultimate tensile strength, yield strength, impact strength, and the hardness and wear characteristics of the proposed composite, are compared with those of unreinforced Al6061. The experimental investigation is also aimed at observing the variation of properties with a varying weight percentage of the reinforcement materials SiC and $Al_2O_3$ simultaneously with the fly ash content maintained constant. The outcome of the experimental investigation revealed that the proposed hybrid composite with 20% of total reinforcement material exhibits high hardness, high yield strength, and low wear rate but no considerable improvement in impact strength.

**Keywords:** Al6061; hybrid metal matrix composite; multiple reinforcement materials; stir casting

## 1. Introduction

Metal matrix composites (MMCs) with two or more reinforcement materials, called hybrid metal matrix composites, have received considerable attention in the field of materials research as they are characterized by having lighter weight, higher strength, more wear resistance, and greater fatigue and dimensional stability than conventional composites. Specifically, the Al6061-based hybrid metal matrix composites (HAMMCs) are better substitutes for conventional aluminum alloys because of their increased strength, hardness, and strength to weight ratio and their better wear resistance. The characteristics of HAMMCs primarily depend on the type and the amount of reinforcement materials. HAMMCs can usually be reinforced with various oxides, carbides, nitrides, and borides in particulate, whisker, or fiber form [1]. It is observed from the literature that silicon carbide (SiC), alumina ($Al_2O_3$), graphite (Gr), silica ($SiO_2$), E-glass fiber, boron carbide ($B_4C$), tungsten carbide (WC), granite dust, and fly ash are reported as reinforcement materials for Al6061-based hybrid metal matrix composites. However, silicon carbide (SiC) and alumina ($Al_2O_3$) are the most commonly employed reinforcement particulates for HAMMCs compared to other synthetic reinforcing materials [2,3].

The density of SiC is slightly greater than that of Al6061. However, it is chemically compatible with aluminium and it also exhibits adequate bonding with the matrix material without developing an inter-metallic phase. It is a low-cost material with good thermal conductivity and workability as compared to other reinforcement materials [4]. Kumar et al. [5] studied the influence of SiC on the hardness of an Al6061–SiC composite. They found that the increase of SiC from 0 to 6 wt % leads to an improvement in the hardness of the composite by an amount of 67%. This improvement can be attributed to the reason that the SiC possesses higher hardness. The presence of SiC in the composite provides an improvement in its hardness. Some attempts have been made on preparing HAMMCs with SiC and other reinforcement materials. Mahdavi and Akhlaghi [6] employed an in situ Powder Metallurgy technique for preparing an Al6061/SiC/Gr hybrid composite. They conducted various tests to study its hardness, compaction behaviour, tribological behaviour, etc., and their results show that the SiC particles decrease the compressibility of the hybrid powders and improve the hardness of the composite. The best wear resistance was achieved in the hybrid composite containing 20 vol % SiC particles. Velmurugan et al. [7] investigated the friction and wear behavior of an Al6061 hybrid composite reinforced with 8% SiC and a varying percentage of graphite content (1%, 3%, and 5%). They stated that the hardness of the composite increased with a decreasing weight percentage of graphite particles and an increase in graphite content leads to an increase in wear resistance of the composite. Uvaraja and Natarajan [8] made an attempt to study the tribological characteristics of a stir-cast Al6061 alloy reinforced with varying percentages of SiC and a constant percentage of $B_4C$ particulates. They identified that the hybrid composite sample with 10 wt % SiC and 3 wt % $B_4C$ composition has better tribological properties. Selvam et al. [9] fabricated an Al6061 composite reinforced with various weight percentages of SiC particulates and a constant weight percentage of fly ash by a modified stir-casting route. The mechanical properties, such as hardness and tensile strength, were improved with the increase in weight percentage of SiC particulates with a constant weight percentage of fly ash in the aluminum matrix. Naveed and Khan [10] have successfully produced Al6061–SiC–Graphite hybrid composites by the vortex method with up to 4 wt % graphite and constant 7 wt % SiC. They observed from their experimental study that the ultimate tensile strength of Al6061 increases with the addition of 7 wt % SiC. However, the ultimate tensile strength of Al6061 decreases with an increase in graphite content. Reddy et al. [11] conducted an experimental study to explore mechanical properties of an Al6061 alloy reinforced with various compositions of boron carbide and silicon carbide produced by a stir-casting technique. Tensile, flexural, hardness, and impact tests were performed and it was found that the hybrid composites had better properties than pure aluminum.

The other commonly used reinforcement material in HAMMCs is $Al_2O_3$. It exhibits good oxidation resistance. The $Al_2O_3$ particulates are much more inert in an aluminum matrix as compared to SiC particulates. It can be used as an effective ceramic reinforcement material for HAMMCs due to the fact that it has high inter-atomic bonding that provides appropriate material characteristics. $Al_2O_3$ is found to be more appropriate for high-temperature fabrication techniques and applications [3]. Pitchayyapillai et al. [12] made an attempt to develop an HAMMC reinforced with $Al_2O_3$ and $MoS_2$ using a stir-casting method. After their investigation on the mechanical characterization of their HAMMC, they concluded that the incorporation of $Al_2O_3$ in an HAMMC increases the wear resistance of the composite and also they noticed that the addition of $MoS_2$ leads to the further enhancement of the wear resistance of the composite. It is observed from the literature that most of the researchers developed HAMMCs using the particulates of SiC, $Al_2O_3$, and other reinforcement materials. Devaraju et al. [13] made an attempt to investigate the wear and mechanical properties of HAMMCs reinforced with SiC, $Al_2O_3$, and graphite, which were fabricated by a friction stir-casting process. Their experimental study disclosed that the micro hardness increases due to the presence and pining effect of hard SiC and $Al_2O_3$ particles. Saravanan et al. [14] prepared a hybrid metal matrix composite using an Al6061 alloy as a matrix and SiC, $Al_2O_3$, and E-glass fibers as reinforcement materials with the help of a stir-casting process. They conducted sliding wear tests on the prepared composite and their test results show that 10 wt % of $Al_2O_3$, 6 wt % of SiC, and 4 wt % of E-glass fibers possess minimum wear as compared with the Al6061 alloy. Basithrahman and Arravind [15] carried out an experimental investigation for determining the mechanical properties of a hybrid Al6061 alloy with the addition of three reinforcement materials, namely SiC (5%), $Al_2O_3$ (3% to 12%), and $B_4C$ (5%). They observed that the composite with the composition of 12% $Al_2O_3$ with 5% of SiC and $B_4C$ exhibits more hardness and they concluded that the hardness of the composite increases with an increase in $Al_2O_3$ content. James et al. [16] developed an HAMMC with SiC, $Al_2O_3$, and $TiB_2$ as reinforcement materials with compositions of 5%, 3%, and 2%, respectively, using a stir-casting, bottom-pouring technique. They conducted various tests to examine its mechanical characterization and observed that there was a significant improvement in the hardness and wear of the HAMMC.

The addition of $Al_2O_3$ to the aluminium matrix may cause a poor wettability problem when processed by a stir-casting technique [3]. The incorporation of fly ash not only causes a decrease in the density of the composite but may compensate for the problem of wettability to some extent. From the meticulous literature survey, no comprehensive work has been reported for investigating the mechanical characterization of an Al6061 alloy with the addition of the reinforcement materials SiC, $Al_2O_3$, and fly ash (FA). In this paper, an attempt has been made to prepare an Al6061 hybrid composite reinforced with SiC, $Al_2O_3$ (each in three steps i.e., 5 wt %, 7.5 wt %, and 10 wt %), and FA (constant 5 wt %) using a stir-casting technique. In order to explore the mechanical properties of the prepared composite, experiments have been conducted as per American Society for Testing and Materials (ASTM) standards. The materials selection for and fabrication of the proposed hybrid composite, experimentation, and mechanical characterization are discussed in the following sections.

## 2. Materials for Preparing the Hybrid Metal Matrix Composite

### 2.1. Matrix Material

In the present work, Al6061 has been chosen as the matrix material for preparing the hybrid metal matrix composite as it finds enormous application in the construction, automotive, marine, etc. industries due to characteristics such as moderate strength, good corrosion resistance, and toughness compared to other aluminum alloys.

### 2.2. Reinforcement Materials

In this work, three ceramic particulates, namely SiC, $Al_2O_3$, and fly ash (FA) have been employed as reinforcement materials to make the proposed hybrid MMC.

#### 2.2.1. Silicon Carbide (SiC)

SiC is very hard as compared to aluminum metals. The density of SiC is 3.2 $g/cm^3$, which is close to the density of aluminum, and it has advantages over other reinforcement materials, such as its thermal conductivity, strength, and corrosion resistance. It has excellent resistance to erosion and to chemical attacks in reducing environments [17]. The tensile and flexural strength of aluminum alloys can be improved by reinforcing them with SiC (up to 10 wt % of SiC) [18].

#### 2.2.2. Alumina ($Al_2O_3$)

In order to improve the properties more, there is a need for a further reinforcement matrix alloy. Alumina ($Al_2O_3$) and fly ash (FA) are used in this work to enhance the mechanical properties of the composite. $Al_2O_3$ is a hard ceramic material that exhibits moderate density (3.97 $g/cm^3$) and a high coefficient of thermal expansion. $Al_2O_3$ particles also act as load-bearing elements in the hybrid composites [12].

#### 2.2.3. Fly Ash (FA)

Fly ash is an inexpensive, low-density material available as a solid waste by-product of coal-fired thermal power plants. It has been incorporated into metal matrix composites for the last few decades to reduce their weight and manufacturing cost and enhance selected properties. The addition of FA particles prevents the dissolution of SiC and the formation of unwanted $Al_4C_3$ [19]. To prepare the hybrid composite, fly ash (Siliceous fly ash) was procured from the thermal power plant located in Visakhapatnam. The average particle size of the fly ash is about 13 µm and the density of the fly ash is 2.1 g/cm$^3$. The fly ash is characterized by a relatively higher concentration of $SiO_2$ and $Al_2O_3$ and lower contents of $Fe_2O_3$. To synthesize the hybrid metal matrix composite, the stir-casting method has been employed as it is a simple and the most economical method of fabricating particulate-reinforced composites. Al6061 alloy is made to a molten state in the furnace and then preheated reinforcement particles are added. The material composition for preparing the specimens of the proposed hybrid composite in the present study is shown in Table 1. One kilogram of Al6061 alloy is melted in a ceramic crucible in a resistance-heated muffle furnace. The temperature of the molten metal is raised to 720 °C and after complete melting and degassing of the aluminum alloy by nitrogen, a mechanically operated stainless steel stirrer coated with alumina is introduced into the melt and stirring is carried out. The alumina coating on the blades of the stirrer prevents the migration of ferrous ions from the stirrer into the molten metal.

**Table 1.** Composition of proposed hybrid metal matrix composite (MMC) for different specimens.

| Specimen | Composition (wt %) | | | |
|---|---|---|---|---|
| | **Al 6061** | **SiC** | **$Al_2O_3$** | **FA** |
| *A* | 85 | 5 | 5 | 5 |
| *B* | 80 | 7.5 | 7.5 | 5 |
| *C* | 75 | 10 | 10 | 5 |

The particles of SiC, $Al_2O_3$, and fly ash are preheated to 600 °C with a view to removing gases and to avoid a temperature drop during casting. Equal proportions (each 5 wt %) of these preheated particles are introduced into the molten metal for preparing the first set of three specimens which are coded as *A*. With the addition of all the reinforcement materials, the liquid composite is poured into the steel mould, which is preheated to 250 °C to avoid the chance of capturing moisture from the atmosphere. The liquid metal is allowed to cool in the atmosphere until solidification. The solidified composite is removed from the mold. The same procedure with the reinforcement materials of different proportions shown in Table 1 has been carried out to prepare the other two sets of specimens, each set coded as *B* and *C*. The density of the specimens *A*, *B*, and *C* was computed using the Archimedes principle [20]. Now, the hybrid Al6061 composite specimens *A*, *B*, and *C* are ready for testing to study their mechanical characteristics.

## 3. Measurement of Mechanical Properties

In order to explore the mechanical characterization of the developed Al6061 hybrid metal matrix composite, various mechanical tests have been conducted and are discussed below.

### *3.1. Tensile Test*

The materials used for engineering applications are usually selected on the basis of their properties, such as ultimate tensile strength, yield strength, and modulus of elasticity. The tensile test is the most common method for determining these mechanical properties. In the present work, a tensile test was conducted on a universal testing machine (UTM) and the developed hybrid composite specimens *A*, *B*, and *C* were prepared as per ASTM standards. The stress-strain curve was plotted as shown in Figure 1 for determining the ultimate tensile strength.

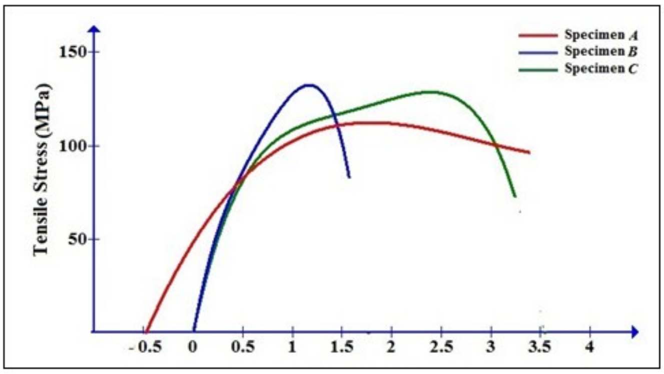



**Figure 1.** Stress-strain curve for specimens *A*, *B*, and *C*.

The average values of ultimate tensile strength and ultimate yield strength found for specimens *A*, *B*, and *C* were 117 MPa, 126 MPa, and 129 MPa, respectively.

### 3.2. Hardness Test

In the present work, a Brinell hardness tester with an indenter diameter of 5 mm was used to determine the hardness of the specimens *A*, *B*, and *C* of the hybrid composite. A load of 5 kN was applied for 30 seconds on each specimen. The Brinell hardness number (BHN) was calculated by dividing the load applied by the surface area of the indentation. The BHN values obtained for the specimens *A*, *B*, and *C* were 53.03, 63.66, and 44.54 respectively.

### 3.3. Impact Strength Test

The ability of a material to absorb energy before an actual fracture occurs is known as its impact strength. The impact strength of the specimens *A*, *B*, and *C* of the hybrid composite was tested using a standard impact testing machine. The Izod test is carried out by a pendulum-type testing machine which employs a cantilever specimen of 75 mm long and a 10 mm $\times$ 10 mm cross-section having a standard 45° notch 2 mm deep. The impact strength obtained for the specimens *A*, *B*, and *C* was 1.73 J/mm$^2$, 1.75 J/mm$^2$, and 1.70 J/mm$^2$, respectively.

### 3.4. Wear Test

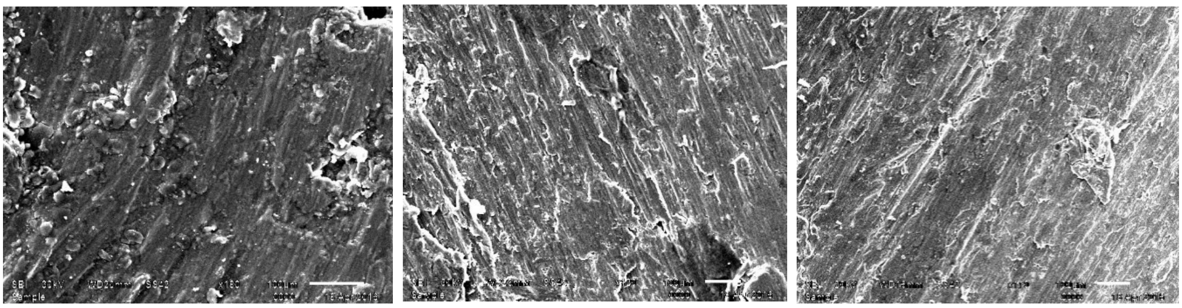
Wear is a process of removal of material from one or both of two solid surfaces when their surfaces are in solid contact during sliding or rolling under a load. In order to make the best choice of material for a specific application, it is necessary to know the wear resistance of the material because wear is the main cause of material wastage. In the present work, the developed hybrid composite specimens were subjected to a dry sliding wear test under dry conditions using a horizontal pin-on-disc wear tester. All of the test specimens were in the form of cylindrical pins of length 35 mm and diameter 6 mm, and the rotating disc counterpart was made of EN 31steel (wt % C-1.08, Si-0.25, Mn-0.53, S-0.015, P-0.022, Ni-0.33, Cr-1.46, Mo-0.06) having a hardness of 60 HRC. The tangential friction force and wear were monitored with the help of electronic sensors. These two parameters were measured as a function of load and sliding distance. For each specimen, tests were conducted at different loads, speeds, and amounts of reinforcement material. The sliding distance (1000 m) was maintained constant during the wear test on all of the specimens. The tests were carried out at room temperature without lubrication. The photoelectric balance with an accuracy of $\pm$0.1 mg was used to find the mass of the specimens before and after the experiments. The wear rates for the specimens *A*, *B*, and *C* under different operating conditions (load and speed) were observed and are presented in the Table 2. The average wear rates for the specimens *A*, *B*, and *C* were 87.4 mm$^3$/m, 33.6 mm$^3$/m, and 131.8 mm$^3$/m, respectively.

**Table 2.** Wear rates of the proposed hybrid MMC for different specimens.

| Serial No. | Specimen | Load (kg) | Speed (m/s) | Wear Rate ($mm^3/s$) |
|---|---|---|---|---|
| 1 | *A* | 2 | 1.5 | 23.104 |
| 2 | *A* | 4 | 1.5 | 15.403 |
| 3 | *A* | 2 | 3.5 | 5.7760 |
| 4 | *A* | 4 | 3.5 | 123.46 |
| 5 | *A* | 3 | 2.5 | 69.313 |
| 6 | *B* | 2 | 2.5 | 7.5600 |
| 7 | *B* | 4 | 2.5 | 39.620 |
| 8 | *B* | 3 | 1.5 | 18.900 |
| 9 | *B* | 3 | 3.5 | 20.466 |
| 10 | *B* | 3 | 2.5 | 11.340 |
| 11 | *C* | 2 | 1.5 | 19.549 |
| 12 | *C* | 4 | 1.5 | 84.062 |
| 13 | *C* | 3.5 | 3.5 | 62.558 |
| 14 | *C* | 3.5 | 3.5 | 198.81 |
| 15 | *C* | 2.5 | 2.5 | 93.837 |

### *3.5. Microscopic Examination*

The scanning electron microscopy (SEM) micrographs of the hybrid composite specimens *A*, *B*, and *C* are depicted in Figure 2a–c, respectively. From Figure 2a, the grooves and holes are clearly visible. The large grooves and holes indicate that specimen *A* has a greater wear rate. Figure 2b,c revealed that the groves are fine in specimens *B* and *C* as compared to specimen *A*. Though the images are similar for specimens *B* and *C* with respect to holes, the wear rate is high for specimen *C* because of the greater amount of reinforcement material.



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

**Figure 2.** (**a**) Scanning electron microscopy (SEM) micrograph of specimen *A* (**b**) SEM micrograph of specimen *B* (**c**) SEM micrograph of specimen *C*.

## 4. Results and Discussion

The values of densities and mechanical properties of the Al6061 hybrid MMC obtained through the experimentation are summarized in Table 3.

**Table 3.** Mechanical properties of the proposed hybrid MMC for different specimens.

| Material | Density (g/cc) | Tensile Strength (MPa) | Yield Strength (MPa) | Hardness (BHN) |
|---|---|---|---|---|
| Al6061 | 2.67 | 115 | 48 | 30 |
| Specimen *A*: | 2.48 | 117 | 79 | 53 |
| Specimen *B*: | 2.56 | 126 | 108 | 64 |
| Specimen *C*: | 2.44 | 129 | 99 | 45 |

BHN, Brinell hardness number.

### 4.1. Density

Figure 3a shows the variation in densities with a percentage increase of reinforcement material. The densities of hybrid composite specimens are lower as compared to those of the unreinforced Al6061.

### 4.2. Tensile Strength

The ultimate tensile strength of a hybrid composite material depends on the amount of reinforcement materials, which is shown in Figure 3b. The values of the ultimate tensile strength for the specimens *A*, *B*, and *C* shown in Table 3 indicate that there is a remarkable increase in the ultimate tensile strength in specimen *B* and specimen *C* when compared to the base material. The ultimate tensile strength of specimens *A*, *B*, and *C* is increased to an amount of 1.5%, 9.8%, and 12%, respectively, when compared to the base material. The lowest improvement in strength for specimen *A* may be attributed to the reason of an insufficient adhesive bond between the reinforcement particles and the matrix compared to that of the other two specimens of the composite.

### 4.3. Hardness

The hardness of specimens *A* and *C* increased by 73% and 48%, respectively, as compared to the non-reinforced metal matrix (base metal). However, for specimen *B*, there was a drastic improvement in hardness, by an amount of 112%, as compared to the non-reinforced metal matrix. Figure 3c illustrates that the BHN value for the hybrid composite material is higher when 20% of reinforcement material is employed and also indicates that a further increase in reinforcement material leads to a decrease of the BHN value.

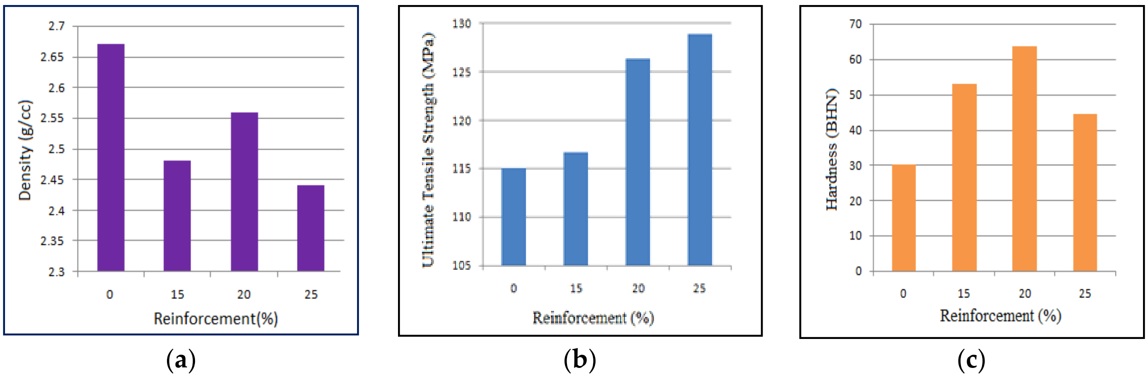



**Figure 3.** (**a**) Variation of density with reinforcement (**b**) Variation of tensile strength with reinforcement (**c**) Variation of hardness with reinforcement.

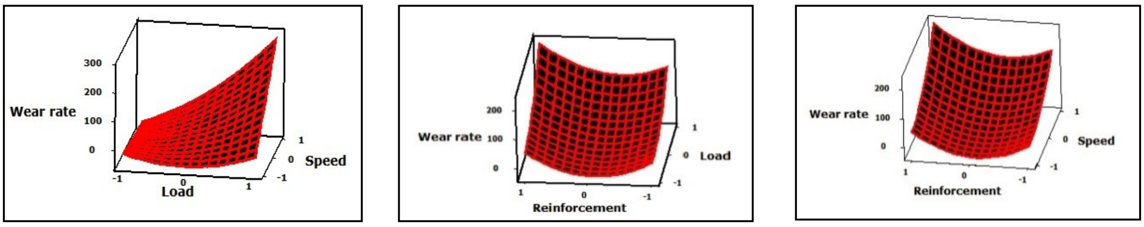
### 4.4. Wear Rate

For the wear analysis, an experiment has been conducted on a horizontal pin-on-disc wear tester. The input experimental data is shown in Table 4. By using the input experimental data with the help of the response surface method, 15 experiments had been carried out and the results are shown in Table 4.

**Table 4.** Input data for different specimens.

| Serial No. | Factor | Units | Limits | | |
|---|---|---|---|---|---|
| | | | −1 | 0 | +1 |
| 1 | Load | kg | 2 | 3 | 4 |
| 2 | Speed | m/s | 1.5 | 2.5 | 3.5 |
| 3 | Reinforcement | % | 15 | 20 | 25 |

The wear rates of hybrid composite materials are influenced by three factors: load, speed, and reinforcement. Figure 4a–c represent the variation of wear rate of the hybrid composite with load, speed, and percentage of reinforcement, respectively.




(a) (b) (c)

**Figure 4.** (**a**) Variation of wear rate with speed and load; (**b**) Variation of wear rate with load and reinforcement; (**c**) Variation of wear rate with speed and reinforcement.

The wear rate is at its minimum at medium load and low speed and at its maximum at high load and high speed. It is observed from Figure 4b,c that the wear rate is at its minimum when the reinforcement is medium (20%) under low speed and load conditions. When a lower amount of reinforcement (15%) is employed at high speed and load conditions, the wear rate is at its maximum. However, the wear rate is at its minimum under a 3 kg load. With an increase in speed, the wear rate also increases because of the fact that by increasing the speed the temperature of the surface also increases and it leads to the softening of the surface which promotes wear.

## 5. Conclusions

This experimental study aimed at preparing an Al6061 hybrid metal matrix composite (AHMMC) with the non-metallic ceramic reinforcement materials SiC, $Al_2O_3$, and fly ash using the stir-casting technique and to explore its mechanical characterization. The density of the proposed composite is decreased and the mechanical properties, including hardness, tensile strength, and yield strength, were slightly lowered compared to that of an Al6061 MMC reinforced with a single ceramic reinforcement material. The AHMMC prepared with equal amounts of SiC, $Al_2O_3$, and fly ash (each of 5 wt %) possesses a tensile strength of 117 MPa, a yield strength of 79 MPa, and a hardness of 53 BHN. The present study is confined to observing the variation of mechanical properties with the simultaneous increase of weight percentage of SiC and $Al_2O_3$ in equal amounts in two steps (7.5% each and 10% each) and without any change in fly ash content. The following remarks can be made.

- When the SiC and $Al_2O_3$ content of each increased from 5% to 7.5%, the tensile strength of the composite increased by 8.2%, the yield strength increased by 36.48%, and the hardness increased by 20%.
- The increase of SiC and $Al_2O_3$ content from 5% to 10% leads to an increase of tensile strength and yield strength of the composite by 10.4% and 25%, respectively. However, the hardness of the composite decreased by 16%.
- On comparison with the base metal Al6061, the proposed composite exhibits a good improvement in tensile strength, yield strength, and hardness. However, no significant change is observed in impact strength.

In this work, a study was carried out to observe the mechanical properties of the proposed HAMMC with a change in weight percentage of two reinforcement materials (SiC and $Al_2O_3$) and no change in the amount of the third reinforcement material (fly ash). The present work may be extended to study the variation of mechanical properties by keeping the percentage wt of one reinforcement material other than fly ash constant and varying the percentage wt of the remaining two reinforcement materials.

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## References

1. Toptan, F.; Ayfer, K.; Ahmet, K.; Mustafa, C.; Isil, K. Processing and microstructural characterization of AA 1070 and AA 6063 matrix $B_4C_P$ reinforced composites. *Mater. Des.* **2010**, *31*, 87–91. [CrossRef]
2. Bodunrin, M.; Alaneme, K.K.; Chown, L.H. Aluminium matrix hybrid composites: A review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. *J. Mater. Res. Technol.* **2015**, *4*, 434–445. [CrossRef]
3. Ashwath, P.; Xavior, M.A. Processing methods and property evaluation of $Al_2O_3$ and SiC reinforced metal matrix composites based on aluminium 2xxx alloys. *J. Mater. Res.* **2016**, *31*, 1201–1219. [CrossRef]
4. Umanath, K.; PalaniKumar, K.; Selvamani, S.T. Analysis of dry sliding wear behaviour of Al6061/SiC/$Al_2O_3$ hybrid metal matrix composites. *Compos. Part B* **2013**, *53*, 159–168. [CrossRef]
5. Kumar, G.V.; Rao, C.S.P.; Selvaraj, N. Studies on mechanical and dry sliding wear of Al6061–SiC composites. *Compos. Part B Eng.* **2012**, *43*, 1185–1191. [CrossRef]
6. Mahdavi, S.; Akhlaghi, F. Effect of SiC content on the processing, compaction behavior, and properties of Al6061/SiC/Gr hybrid composites. *J. Mater. Sci.* **2011**, *46*, 1502–1511. [CrossRef]
7. Velmurugan, C.; Subramanian, R.; Thirugnanam, S.; Anandavel, B. Investigation of friction and wear behavior of hybrid aluminium composites. *Ind. Lubr. Tribol.* **2012**, *64*, 152–163. [CrossRef]
8. Uvaraja, V.; Natarajan, N. Tribological characterization of stir-cast hybrid composite Aluminium 6061 reinforced with SiC and $B_4C$ particulates. *Eur. J. Sci. Res.* **2012**, *76*, 539–552.
9. Selvam, D.R.J.; Smart, D.R.; Dinaharan, I. Synthesis and Characterization of Al6061-Fly $Ash_p$-$SiC_p$ Composites by Stir Casting and Compocasting Methods. *Energy Procedia* **2013**, *34*, 637–646. [CrossRef]
10. Naveed, M.; Khan, A.R.A. Ultimate Tensile Strength of Heat Treated Hybrid Metal Matrix Composites. *Int. J. Sci. Res.* **2015**, *4*, 146–151.
11. Reddy, P.S.; Kesavan, R.; Vijaya Ramnath, B. Investigation of mechanical properties of aluminum 6061-silicon carbide, boron carbide metal matrix composite. *Silicon* **2017**, *9*, 1–8.
12. Pitchayyapillai, G.; Seenikannan, P.; Raja, K.; Chandrasekaran, K. Al6061 hybrid metal matrix composite reinforced with alumina and molybdenum disulphide. *Adv. Mater. Sci. Eng.* **2016**, *2016*, 6127624. [CrossRef]
13. Devaraju, A.; Kumar, A.; Kumaraswamy, A.; Kotiveerachari, B. Wear and mechanical properties of 6061-T6 aluminum alloy surface hybrid composites [(SiC + Gr) and (SiC + $Al_2O_3$)]. *J. Mater. Res. Technol.* **2013**, *2*, 362–369.
14. Saravanan, V.K.; Tamilarasan, T. Investigation of wear behaviour of Al 6061 alloy reinforced with SiC, $Al_2O_3$ and E glass fiber. *Int. J. Sci. Eng. Appl. Sci.* **2015**, *1*, 430–434.
15. Basithrahman, A. Experimental analysis of mechanical properties of aluminium hybrid metal matrix composites. *Int. J. Eng. Res. Technol.* **2016**, *5*, 132–135. [CrossRef]
16. James, S.; Annamalai, A.; Kuppan, P.; Oyyaravelu, R. Fabrication of hybrid metal matrix composite reinforced with SiC/$Al_2O_3$/$TiB_2$. *Mech. Mater. Sci. Eng.* **2017**, *9*, 301–305.
17. Chawla, K. *Fibrous Materials*, 2nd ed.; Cambridge University Press: Cambridge, UK, 2016.
18. Bansal, S.; Saini, J.S. Mechanical and wear properties of SiC/Graphite reinforced Al359 alloy-based metal matrix composite. *Defence Sci. J.* **2015**, *65*, 330–338. [CrossRef]
19. Dey, A.; Pandey, K.M. Characterization of fly ash and its reinforcement effect on metal matrix composites: A review. *Rev. Adv. Mater. Sci.* **2016**, *44*, 168–181.

20. Gireesh, C.H.; Prasad, K.D.; Ramji, K.; Vinay, P.V. Mechanical characterization of aluminium metal matrix composite reinforced with Aloe vera powder. *Mater. Today Proc.* **2018**, *5*, 3289–3297. [CrossRef]

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