Experimental studies on the wear and mechanical properties of Al7075-B₄C-Al₂O₃ composite

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Abstract: In order to deal with the demands of current requirements, traditional metals require changes in some properties. The high strength and light weight application of aluminium is well known. In certain instances, its ductility prevents its application in some environments. In the existing research, Al 7075 is reinforced with materials such as boron carbide (B₄C) and aluminum oxide (Al₂O₃) to achieve low mass, low weight, high power, superior malleability, easy machining and excellent corrosion resistance. Thus, hybrid MMC production is being carried out to enhance these mechanical properties. In this study, Al 7075 is cut into small pieces with 90% wt in the form of a bar and placed in a SiC graphite crucible and the metal matrix is formed by melting it and stirring casting metal to add the reinforcement particles. The quantity of B₄C & Al₂O₃ combined to form the new material was taken at 5% each. The samples were prepared according to ASTM specifications and eventually tested for tensile, compression, hardness, wear and effect measurements, and the findings were compared with those of pure aluminium Al 7075. The test results showed improved properties of Al MMC, which is more efficient than Al 7075.

Keywords: Hybrid aluminium metal matrix composite, Tensile strength, Compression strength, Shear resistance, Impact resistance, Wear properties.

1. Introduction

Composites are materials Consists of more than two components with different properties and known boundaries between the components. Good mechanical performance relies heavily on a non-heterogeneous reinforcement distribution in the end product, and micrographs show no porosity or defects in either the Al-7075 matrix alloy or the composite Al-7075/B₄C alloy.[1]. The B₄C particles is found to be distributed evenly, homogeneously and randomly in the matrix at 2.5 and 7.5 wt. percent B₄C; however in some regions B₄C ascends up to 12.5 wt. percent generates aggregates. For Current applications materials with wide range of properties such as more strong with less weight and less expensive, which can be achieved by developing MMCs.[2]

In MMCs aluminium is most widely used matrix material which extensively finds application in the field of aerospace, automobile and various other fields. Aluminium matrix can be reinforced with various particles like boron carbide, magnesium oxide, titanium oxide, graphite, flyash .etc. [3]Ceramic reinforcements which are used in preparation are commonly less than 30% volume fraction for applications which require high wear resistance and structural applications. In electronic packaging
solutions it require more than 70% volume fractions.[4,5] In stir casting process, the reinforcement material is introduced in a continuously stirred molten matrix and then cast by sand, permanent mold, or pressure die casting. if the stirring is done uniformly the $B_4C$ particles are equally distributed, which gives a uniform strength throughout the material. Non heterogenous distribution of the reinforcement leads to good performance of the material in terms of mechanical aspects.[6] Similarly increase in the volume of content of the additive particles in the matrix increases the strength of the newly formed material.

2. Materials and Methods
In this Study, AL7075 is used as a base material which is reinforced with Boron Carbide ($B_4C$) sized 90µm and Aluminium oxide ($Al_2O_3$) sized 5µm. The Chemical Composition of AL7075 is given in the table 1. Stir Casting was used to fabricate the specimen AL7075-$B_4C-Al_2O_3$. The Base material is taken with 90% in weight in bar form which is cut in to small pieces. Sic Graphite crucible was used to condition the base material. Muffle furnace is used to heat to a temperature of 850 degree celsius. Process parameters for making the specimen is shown in the table 2. With the assistance of a stirrer, the melt was stirred to create a fine vortex. 3 grammes of cover flux (solid hexa chloro ethane) and slag was extracted from the molten metal. $B_4C$ micro powder(90µm) is heated to 250 degrees Celsius temperature to extract moisture, in another crucible with 5 percent wt Aluminium oxide micro powder(50µm) with 5 percent weight is sieved for second reinforcement during the melting of Aluminium. Then the particulates was mixed into the molten metal. A degassing agent and flux were used to cover the molten metal in order to improve the casting consistency and increase the casting speed of Aluminium 7075.

![Fabricated metal matrix composite of Al7075-B_4C-Al_2O_3](image)

**Figure 1.** Fabricated metal matrix composite of Al7075-$B_4C-Al_2O_3$

Mechanical Stirrer is used to stir the mixture at a speed of 60rpm for 5-10 min. Temperature of 850°C was maintained in the Furnace constantly during the addition of reinforcement particles. Then the prepared Aluminium matrix was poured in the preheated die for which the specimen was prepared according to ASTM Standard. Figure 1 shows the fabricated MMC using reinforced particles.
Table 1. Chemical composition of Al7075

| Al Alloy | Al(%) | Si(%) | Fe(%) | Cu(%) | Mn(%) | Mg(%) | Cr(%) | Zn(%) | Ti(%) | others(%) |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----------|
| 7075    | 87.1  | Max   | 1.2   | Max   | 2.1   | 0.18- | 5.1-  | Max   | Max   |
|         | -91.4 | 0.40  | 0.50  | -2.0  | 0.30  | -2.9  | 0.28  | 6.1   | 0.20  | 0.15      |

Table 2. Process parameter used for stir casting

| S.NO   | PARAMETER                                    | UNIT | VALUE |
|--------|----------------------------------------------|------|-------|
| 1.     | Temperature of the melt                       | °C   | 850   |
| 2.     | Preheated temperature of B<sub>4</sub>C Particle | °C   | 250   |
| 3.     | Spindle speed                                 | Rpm  | 60    |
| 4.     | Stirring time                                 | Min  | 10-15 |
| 5.     | Powder feed rate                              | g/s  | 0.8-2 |

3. Results and discussion

Tensile, compression, hardness, wear and impact tests were performed for the prepared specimens in the current study and the values were compared with that of pure aluminum specimens.

3.1 Tensile Test

This test is conducted to find tensile strength of MMC. Among the standard testing, ASTM E8-16a is chosen based on its significance and uses. To perform this test, an electro-mechanical or hydraulic universal testing machine equipped with the appropriate sample grips, an extensometer which is shown in Figure 2 and software capable of strain rate control and stress recording-strain information is necessary. The Standards for specimen testing is shown in figure 3.

Both ultimate strength and yield strength of AL 7075 MMC was found to be increased when compared with AL7075 by 20% and 33% , which is due to the high strength and stiffness[7] provided by the Al<sub>2</sub>O<sub>3</sub> which is blended with Al7075.the particles have bonding capability which bonds with the base material. The values of Tensile strength of the specimen is mentioned in table 3.

![Figure 2. ASTM E8-16a Testing Machine](image)

![Figure 3. Specimen for Tenstile Test](image)
INPUT DATA
- Mode of Test: Tension
- Sample Type: Round
- Diameter: 12.56 mm
- Area: 123.93 mm²
- Gauge Length: 50.00 mm
- Final Gauge Length: 51.430 mm.

Table 3. Comparison of Tensile Strength

| Composition              | Ultimate strength (N/mm²) | $F_{MAX}$ (KN) | Yield Strength (N/mm²) | Elongation (%) |
|--------------------------|---------------------------|----------------|------------------------|----------------|
| 100% AL 7075            | 50.887                     | 5.220          | 40.709                 | 1.9            |
| 90% Al                  | 63.49                      | 7.87           | 54.21                  | 2.86           |
| 7075+5%B₄C+5%Al₂O₃     |                           |                |                        |                |

3.2 Compressive test

A compression test is any test in which a sample encounters competing forces pressing from opposite sides upward on the specimen or otherwise compressed, "squashed," crushed, or flattened. The standard test method for compression testing of metals at room temperature is carried out by using ASTM E9.

INPUT DATA:
- Mode of Test: Compression
- Sample Type: Round
- Diameter: 17.52 mm
- Area: 241.08 mm²
- Gauge Length: 36.68 mm

Figure 4. Compression Test Graph
Compressive load $F_{\text{max}} = 111.83$KN. Figure 4 depicts the variation of compression strength. From the graph we can see that the compressive strength is increased with the addition of reinforcement particle due to the high compressive strength of Al$_2$O$_3$ particles. Al$_2$O$_3$ particles are well known for their good mechanical properties such as good compressive strength and good mechanical strength[8].

3.3 Hardness test

Hardness is a physical property which resists the scratches and indentations on the surfaces. The hardness test is carried out by basic hardness testing apparatus called Brinell hardness tester. In this a hardened ball indentor of 10mm dia is pressed against one surface of sample made with a load of 1000kgf.

Table 4. Brinell Hardness Table

| Composition         | Specimen | Trial 1 | Trial 2 | Trial 3 | Average |
|---------------------|----------|---------|---------|---------|---------|
| 100%Al 7075         | A        | 88.1    | 87.8    | 87      | 87.63   |
| 90%Al 7075+5%B$_4$C+| B        | 95      | 95      | 93      | 94.34   |
| 5%Al$_2$O$_3$       |          |         |         |         |         |

Figure 5. Brinell Hardness Test Comparison

The Comparison of Hardness between the specimens is shown in Figure 5. From the above graph it can be seen that the brinell hardness is increased by 8% for the reinforcement when compared with aluminium Al7075. Hardness value of various trials are shown in table 4. This concludes that the incorporation of boron carbide and aluminium oxide as a particle of reinforcement contributes to an improvement in hardness. Al$_2$O$_3$ has high corrosion resistance and high temperature tolerance, low thermal expansion and a desirable stiffness-to-weight ratio that improves the newly formed MMC's hardness. However this property relies entirely on the mixing with the base material of the powdered components, improper mixing leads to uneven MMC hardness.

3.4 Impact test

Impact test is conducted to check amount of energy that can be absorbed by a material during fracture. Charpy testing method is one of the worldwide procedures used to verify the impact intensity as it's easy to plan and execute, and results can be collected easily and cheaply. Figure 6 shows the comparison of impact strength between the two specimens. Boron carbide can be used as ballistic shielding (including body or personal armor) in addition to other components, where the combination of high hardness, high
elastic modulus, and low density allows the material an extremely high basic stopping power to combat high-speed projectiles. The newly developed MMC managed to withstand high impact loads with this B₄C property. [9]. Table 5 shows the variation in energy observed for the two specimens.

**Table 5. Charpy Test specimen observed readings**

| Specimen | Composition | Observed joules(J) |
|----------|-------------|--------------------|
| A        | 100% Al 7075 | 2                  |
| B        | 90%Al 7075+5%B₄C+5%Al₂O₃ | 2.3                |

![Observed value (Joules)](image)

**Figure 6** Charpy Test Comparison

### 3.5 Wear test

The wear behaviour of the composites for different applied loads from the pin-on-disc test is taken. The material loss for the Al7075-B₄C-Al₂O₃ composite is significantly higher compared to pure aluminium from Table, indicating superior wear resistance property of the composite with the wear rate increasing with increase in applied load. This decreased wear rate is due to increased hardness of the composite, wear resistance property of the carbide reinforcements and smaller grain size of the reinforcements.

**Test Parameters:**

- Cylinder Size: ø 150mm and 500mm length
- Coarser abrasive sheet content: 60 grade
- Equivalent revolution: 84 times
- Rotational frequency: 40 ±1 rpm
- Applied Load: 1kg

**Table 6. Wear Test**

| Sample | Initial weight (g) | Final weight (g) | Abrasion loss(g) | Percentage (%) |
|--------|--------------------|------------------|------------------|----------------|
| 1      | 5.0457             | 4.9213           | 0.1241           | 2.46           |

From table 6, the value of abrasion loss shows that the wear is less when the Al 7075 is reinforced with boron carbide and aluminium oxide. So it has high durability and high resistance, obviously it is much reliable than aluminium 7075.
4. Conclusion

- Aluminum metal matrix composite tensile strength, performance strength and compression strength were found to be growing with an improvement in wt percentage of reinforcement percentage.

- The increase of the wt. % of reinforcement of the B₄C and Al₂O₃ in the stir casting method has led to the increase of the microhardness of the AMCs. The hardness of the matrix material is improved by the dispersion of boron carbide and aluminium oxide particles in the aluminium matrix.

- The aluminium metal matrix composite has high wear resistance on addition of reinforcement particle.

- The microstructure shows that the shearing force caused by the stirring in the stir casting method produces a homogeneous distribution of reinforcement in the matrix step..

- The significant process parameters that influence the strength of the MMC are the stirring casting process, stirrer design and location, stirring velocity and time, particle preheating temperature, particle incorporation rate, etc.

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