Evaluation of Mechanical Properties of Ceramic Reinforced Aluminium-7029 Hybrid Composite

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Abstract. Composites are often chosen for structural applications because they have tailored material properties. The production of hybrid metal matrix composites has become a major research area in materials science. With this interest, present paper deals with fabrication of aluminium alloy (Al-7029), boron carbide (B$_4$C) and graphite (Gr) hybrid composite using conventional stir casting is investigated. Evaluation of mechanical properties such as tensile hardness and impact strength of base alloy with reinforcement [B$_4$C (2%, 4%, 6%, 8%) with constant 2% Gr] was performed on the samples. After solidification, the samples are prepared according to ASTM standards and tested to find the various mechanical properties like tensile, hardness and impact. It was observed that the hybrid composite tensile strength was increased, with decrease in elongation rate of unreinforced aluminium alloy. The impact strength and hardness property for a hybrid composite was increased compared to base alloy. The composite's microstructure was studied using a Scanning Electron Microscope (SEM).

Keywords: Metal matrix composites; Boron carbide; graphite; Hardness; Impact test; Tensile strength.

1. Introduction

Over the past few years, industries have focused on materials with multiple applications, which are lightweight, durable, and cost effective. Hybrid composites are more popular recently, and they cover multiple material properties. We have a broad range of aluminium alloys to choose from when developing material for automotive applications. Mechanical properties of the aluminium based composite can be enhanced with the addition of reinforcement, when compared to the base alloy. Addition of ceramic reinforcements to aluminium metal matrix composites (AMMCs) exhibit superior strength and rigidity, resistance to creep and wear. Addition of boron carbide (B$_4$C) improve tensile strength, impact strength, toughness and show stronger interface bonding with the aluminium matrix. Addition of graphite reduces the wear rate of the composite due to its self-lubricating property [1]. The properties of AMC can be tailored to the requirements of various industrial applications by appropriate combinations of matrix, reinforcement, and processing routes [2-4]. The most used industrial method of producing aluminium-based composites is traditional stir casting. Because of its applicability to mass production and cost-efficiency [5]. Ceramic particle reinforced aluminium composites have shown a significant improvement in their mechanical properties [6]. Al6061 and Al7015 alloy with TiB$_2$ particulates reinforced composite produced by hot extrusion were studied to evaluate the mechanical properties. Tests were done for room and high temperature condition (500 °C) for both the composites. Al7015+ TiB$_2$ composites show the better result with hardness up to 148HV and UTS till 400 MPa at room temperature [7]. Mechanical behaviour of B$_4$C reinforced with Al-7075 matrix composite were studied. It was found that the ultimate tensile strength, compressive strength, and the hardness of the composite increased linearly with increase in volume percentage of B$_4$C. Also, the wear effect found minimum in the composite with 10 % B$_4$C [8]. Keeping 3% weight fraction of Gr and by varying the weight percentage (3-12 %) of B$_4$C Aluminium alloy (LM25) composites were characterised for wear and hardness test. Vicker’s hardness value increased with increase in B$_4$C reinforcement. Aluminium alloy with 12% B$_4$C+3%Gr found with better characteristics [9]. Dry sliding friction behaviour Al-SiC-Gr particles was studied. Concluded that the load is the most important factor affecting the friction coefficient of the hybrid composite followed by
sliding speed. The coefficient of friction increased with increase in load and sliding distance. The author also revealed that the average friction coefficient of the hybrid composite is quite low compared to pure alloy [10]. It was found that wear behaviour of Al 7075/Bagasse ash/Gr hybrid composite the percentage of ceramic phase weight increased and finally suggested wear behaviour of hybrid composites containing graphite showed superior wear resistance [11].

In the present paper, fabrication of aluminium alloy (Al-7029), boron carbide (B,C) and graphite (Gr) hybrid composite using conventional stir casting is carried. The prepared composites were subjected to mechanical properties such as tensile hardness and impact strength of base alloy with reinforcement [B,C (2%, 4%, 6%, 8%)] with constant 2% Gr]. The composite's micro structure was studied using a Scanning Electron Microscope (SEM).

2. Experimentation

2.1 Material selection

Aluminum-7029 alloy, containing zinc and magnesium as its main alloy elements, selected as the base material due to its good mechanical properties, such as high corrosion resistance, re-crystallization capability and the most economical thermal aluminium alloy. Table 1 and 2 shows the chemical composition of the Al7029 alloy and material composition used for this study.

Table 1. Chemical composition of Al7029 alloy (mass fraction%) [3]

| Si  | Fe   | Cu  | Mn   | Mg   | Zn         | Ti   | V   | Al       |
|-----|------|-----|------|------|------------|------|-----|----------|
| 0.10| 0.12 | 0.5-0.9 | 0.03 | 1.3-2.0 | 4.2-5.2    | 0.05 | 0.05 | Remaining |

Table 2. Material composition in percentage

| Sample | Al7029 | Boron carbide | Graphite |
|--------|--------|---------------|----------|
| A      | 100    | 0             | 0        |
| B      | 96     | 2             | 2        |
| C      | 94     | 4             | 2        |
| D      | 92     | 6             | 2        |
| E      | 90     | 8             | 2        |

Commercially available boron carbide (partial size average 50 μm [1]) and graphite reinforcements were used for preparing the composites with Al7029 matrix material. The chemical composition of master alloys used in the present study is reported in Table 1. Al7029 alloys was procured from M/s Fen fee Metallurgical, Bangalore, India. Boron carbide was procured from Parshwamani metals, Mumbai, India, and graphite was procured from Graphite India, Bangalore, India.

2.2 Material preparation

Hybrid Al7029-B,C-Gr composites were fabricated by stir casting technique using electrical furnace of 5 kW capacity. Figure.1a and figure.1c shows photograph of casting furnace and cast specimen used in the present study. Graphite crucible is used because Al7029 matrix material melt was held for 9 minutes at a temperature between 600 and 700 °C, at this temperature graphite crucible does not react with Al7029. Magnesium (3%) was added to the molten metal as the Al7029 ingot material reached a liquid condition to enable the dispersion of particles inside the molten metal. 2% boron carbide has been preheated at temperature of 500 °C to remove moisture or any other gases. Boron carbide fine-reinforcing particles (50μm) has been applied to a molten metal, which can have heterogeneous nuclei. Stirring is carried for 15-20 minutes at 150 rpm to acquire consistent distribution of B,C particulate in Al7029. Graphite (2%) was pre-heated and poured into the premixed molten metal (Al7029 with B,C). Stirring is further carried up to 10-15 minutes to ensure proper mixing of Gr with molten metal. Degasification agent hexa-chloroethane (C2Cl6) is used to eliminate porosity, voids, and casting defects. Progressive solidification will begin when hot molten metal has been poured into the pre-heated die. The molten pool is then allowed to solidify and are extracted at room temperature [1].
2.3 Test procedure

Cast samples are machined as per ASTM standards accordingly. Tensile behaviour of the sample is conducted as per ASTM E8 standard. As per ASTM E10 standard, Brinell hardness test was carried out by applying load of 50 g for a period of 10 seconds. Readings were taken at five various places on the sample and an average value was used for study. Charpy impact test was carried to measure the samples’ ability to resist high rate loading and samples were prepared according to the ASTM E23 standard. Metallographic investigation was carried out through scanning electron microscope (SEM). Etching was done using 10% NaOH solution on the surface of polished sample.

3. Results and Discussions

3.1 Tensile strength

Purpose of this study is to investigate tensile strength of Al7029 and HMMc (Al7029-B4C-Gr). Tensile test is carried out in Universal testing machine. Tensile strength increases progressively with a rise of up to 6% in the composition of B.C. Results of the tensile tests also revealed significant improvement in (2 % wt of B,C & Gr) reinforced hybrid composite. Increase in tensile strength (reinforcement up to 6% B,C & 2%Gr) is also attributed to increase in grain boundary area due to grain refinement and effective propagation of applied tensile load to well-bound reinforcement with a standardized distribution. Strength of ceramic materials lies much higher than metallic materials and higher than that of the matrix alloy. Under the applied stress, grain boundaries serve as an obstruction to the dislocation movement and ultimately results in a dislocation stack on the grain boundaries. Again, multi-directional stress induced during elongation easily starts multi-gliding system under applied stress so that dislocations were found developing and moving in several directions. These multi-glide planes agglomerate with reinforcement particles under the applied stress forms grain boundary ledges. As applied load increases, these ledges act as obstacle to dislocation movement resulting in pile-ups. The cumulative impact of these two barriers enhances the hybrid composite’s strength.
### 3.2 Hardness test
Experiments are done with the constant Gr (2%), changing weight fraction B4C (2%, 4%, 6%, 8%). The graph reveals that Al7029 alloy surface hardness rises steadily, with rise in the weight percentage of strengthening particulates (B4C & constant 2 % Gr). The results of hardness test conducted on unreinforced Al7029 and hybridised Al7029 samples have shown that matrix hardness levels are growing with reinforcement material up to 6% (Figure 3.). Effects of hardness measurements shows that the increase in reinforcement content results in a considerable increase in hardness which can be mainly due to; the existence of hard ceramic B4C & Gr particles scattered in the matrix, the deformation restricted due to their inclusion during indentation and the reduced size of grain due to the chilling phase.

![Hardness bar chart](image)

**Figure 3. Hardness**

### 3.3 Impact test
Figure 4 portrays the variation in the impact strength of the specimen for varying wt. % of reinforcements. Energy observed by the 6 wt. % primary reinforced composite is superior to the other composites. The increase in impact strength is due to the reduction in the porosity. Experiment is carried out on Al7029 Alloy with different weight divisions B4C (0%, 2%, 4%, 6%, 8%) and Gr (2%). At the beginning, the impact strength increases with increase in percentage composition of B4C and Gr. It has been concluded that (Al7029+6%B4C-2%Gr) hybrid composite has the highest impact capacity. It is concluded that highest impact strength is for Al6082 hybrid composite with 8% B4C and 2% Al2O3 reinforcements, this indicates that maximum amount of energy is absorbed during fracture.

![Impact energy bar chart](image)

**Figure 4. Impact energy**
3.4 SEM Analysis

Figure 5. SEM images of cast samples

SEM micrographs of base alloy and hybrid composites is shown in figure 5. The distribution of the B₄C and Gr particles in the Al7029 is noticeably uniform. Micrographs discloses the uniform particles distribution of the cast composites. The uniform particles distribution enhances the mechanical properties of the reinforced Al7029. B₄C particles are observed to be accumulated within the grain boundary regions and geometrical trapping by dendrites is observed [1]. B₄C and Gr particles have located at grain boundary region, so that it increases the bonding between matrix and the reinforcement. Hence there is increase in the grain strength, which results in increase in mechanical properties as revealed from mechanical tests. Also, both the reinforcements act as obstacles to the dislocations, at the boundary region which improves the mechanical properties.

4. Conclusions

1. Mechanical properties of hybrid composites increase with an increase in wt. % of B₄C & Gr. Tensile strength maximization is obtained by 6% B₄C and 2% Gr.
2. From hardness test, the better effects will be seen if the B₄C is used at 6 % with 2 % Gr.
3. It is inferred that for (Al7029+6 % B₄C+2 % Gr) hybrid composite has highest impact strength which indicates that maximum energy is absorbed during fracture.
4. B₄C and Gr were found to be distributed reliably. It was confirmed, the interfacial analysis indicated that the reinforcement particulate is related closely to the matrix strengthening.

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