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# Fabrication and Mechanical Characterization of Al 7075 Hybrid Metal Matrix Composite Reinforced with B4C and Coconut Shell Fly Ash via Powder Metallurgy

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**Abstract:**

This study presents the fabrication and mechanical property evaluation of hybrid aluminum matrix composites (HAMC) using aluminum 7075 (Al7075) alloy reinforced with boron carbide (B4C) and coconut shell fly ash (CSFA). Al7075, widely used in aerospace applications due to its high strength-to-weight ratio, superior hardness, and excellent wear and corrosion resistance, requires further property enhancement to broaden its applicability. The HAMCs were fabricated via the powder metallurgy method, incorporating varying weight percentages of B4C (0%, 3%, 6%, 9%, and 12%) and a fixed 3% CSFA. Mechanical property analysis revealed that hardness increased by 33% with 12% B4C and 3% CSFA reinforcements. Tensile strength improved by 66% with 9% B4C and 3% CSFA but decreased with further reinforcement addition. Elongation showed a decline as reinforcement content increased. Impact energy peaked at 2.3 J with 9% B4C and 3% CSFA, reducing with higher reinforcement levels. Optical micrographs confirmed the homogeneous distribution of B4C and CSFA particles in the Al7075 matrix, contributing significantly to the enhancement of hardness, tensile strength, and impact strength. This study demonstrates the potential of hybrid reinforcements in improving the mechanical properties of Al7075 composites for advanced applications.

**Keywords:** Aluminum 7075 (Al7075), Hybrid aluminum matrix composites (HAMC), Boron carbide (B4C), Coconut shell fly ash (CSFA), Powder metallurgy.

## 1. Introduction

Emerging technologies require materials with specialized properties, which conventional materials cannot meet. Hybrid metal matrix composites (HMMCs) are gaining importance across various engineering fields such as mechanical, electrical, aerospace, and marine due to their superior properties like high strength-to-weight ratio. Aluminum and Magnesium Metal Matrix Composites are particularly valuable for reducing weight in automotive and aerospace applications, thus improving efficiency.

Composite materials are engineered by combining two or more chemically distinct substances to create materials with improved properties. These composites are classified based on their components, including the matrix material, which acts as the base (such as polymers, metals, or ceramics), and the reinforcement material, which enhances mechanical, thermal, or electrical properties.

There are various types of composites, each with unique characteristics and applications. Metal Matrix Composites (MMCs) utilize metals like aluminium alloys, steels, or titanium alloys as the matrix, with ceramic reinforcements like silicon carbide, offering high strength and wear resistance. Polymer Matrix Composites (PMCs) consist of glass or carbon Fibers embedded in epoxy resins, commonly used in sporting goods and automotive parts. Ceramic Matrix Composites (CMCs) are known for their exceptional high-temperature resistance and chemical inertness, making them suitable for aerospace and industrial applications. Additionally, Carbon-Carbon Composites (CCCs) are recognized for their high strength and temperature resistance, often employed in spacecraft components and aircraft brakes.

The properties of composites vary depending on their design. Particle-reinforced MMCs offer isotropic properties, wear resistance, and low density, with volume fractions ranging from 5% to 85%. Fiber-reinforced MMCs are anisotropic, exhibiting a high elastic modulus and improved strength, with volume fractions between 20% and 80%. Hybrid composites combine the benefits of multiple reinforcements, providing high specific strength, corrosion resistance, and durability.

Composite design involves careful selection of both the matrix and reinforcement materials. Matrix materials are chosen based on properties like strength, thermal stability, machinability, chemical resistance, cost-effectiveness, and recyclability. Reinforcement materials are selected considering factors such as strength, stiffness, orientation, and compatibility with the matrix. By combining the unique properties of these materials, composites address modern engineering challenges and continue to drive innovation in industries such as aerospace, automotive, and electronics.

## 2. Methodology

The fabrication process involves transforming raw materials into useful products using techniques such as casting, powder metallurgy, and welding. However, conventional methods often face challenges such as wetting issues and poor interface bonding between reinforcement and matrix materials. Powder metallurgy overcomes these defects, improves mechanical properties, and ensures uniform distribution of reinforcements, making it a preferred technique.

Casting, one of the oldest fabrication processes, has evolved significantly since its initial use for making objects like arrowheads. The process involves pouring molten metal into molds to create objects such as engine blocks, turbine blades, and gear wheels. Casting methods include sand casting, permanent mold casting, investment casting, die casting, and centrifugal casting. Each method has unique advantages, disadvantages, and applications, as shown in Table 2.1. Additionally, stir casting, a widely accepted manufacturing process for metal matrix composites, is highlighted for its simplicity, cost-effectiveness, and suitability for large-scale production.

Conventional powder metallurgy processing follows a systematic approach, including atomization of powders, blending and mixing, compaction, sintering, and, in some cases, liquid phase sintering. Atomization provides control over powder characteristics, while blending and mixing ensure homogeneity in composition. Compaction techniques such as die compaction and cold isostatic pressing enhance density and mechanical strength. Sintering further densifies and strengthens the compacted powders, while liquid phase sintering accelerates diffusion and enhances densification. Despite its advantages, conventional methods face certain challenges, such as uniformity and material limitations. Non-conventional powder metallurgy techniques like Spark Plasma Sintering (SPS) offer innovative solutions. SPS employs high current and pressure to achieve rapid heating rates and full densification within a shorter cycle time. It provides numerous advantages, including the ability to retain refined microstructures, process exotic chemistries, and improve bonding by disrupting oxide layers, making it particularly useful in aerospace applications. Composite preparation involves using Al7075 as the matrix material, reinforced with boron carbide (B4C) and coconut shell fly ash (CSFA). The process includes compaction and sintering to fabricate specimens with varying reinforcement compositions, as shown in Table 2.2. Mechanical properties, such as tensile strength and hardness, are critical for evaluating the performance of fabricated composites. Tensile testing determines parameters like ultimate tensile strength and yield point, while hardness testing assesses a material's resistance to deformation using methods like Rockwell, Brinell, and Vickers tests. Together, these methodologies ensure the development of high-performance composites with desirable mechanical characteristics.

Table 2.1. Comparison of various casting processes

| CASTING PROCESS | LIMITATIONS | EXAMPLES | ADVANTAGES |
|---|---|---|---|
| Sand casting | Harsh finish<br>Dimensional accuracy is not good<br>Finishing required | Engine Blocks<br>Cylinder Heads | Almost of all types of metals can be cast easily<br>No bounds for size and shape |
| Permanent mold casting | Exclusive pattern and mold<br>Appropriate for low meting- point metals | Gears<br>Gear housings | Worthy surface finish<br>Easy to produce at near to net shape<br>More Productivity |
| Investment casting | Constraint on part proportions<br>Exclusive pattern and mold | Jewelry | Almost of all types of metals can be cast easily<br>Worthy surface finish |
| Die casting | Constraint on part proportions<br>Die cost is exclusive<br>Casting of non-ferrous metals | Gears<br>Camera bodies<br>Car wheels | Easy to produce at near to net shape<br>More Productivity |

Table 2.2. Varying wt.% of Al 7075-$B_4C$ with constant CSFA

| **Specimen No** | **Matrix** | **Reinforcement -1** | **Reinforcement -2** |
|---|---|---|---|
| | **Al 7075(wt. %)** | **$B_4C$ (wt. %)** | **CSFA (wt. %)** |
| 1 | 100 | 0 | 0 |
| 2 | 97 | 0 | 3 |
| 3 | 94 | 3 | 3 |
| 4 | 91 | 6 | 3 |
| 5 | 88 | 9 | 3 |
| 6 | 85 | 12 | 3 |

## 3. Results and Discussions

### Testing of Composite

Hence fabricated the specimens of Al 7075 alloy composite reinforced with boron carbide and coconut shell fly ash with different wt.% of B4C and CSFA and tested the mechanical properties of the composite like tensile strength, hardness, impact strength

### Tensile test

- Tensile test is performed by using ASTM E8/E8M-2009 method.
- Tensile tests are used to determine the tensile properties of a material, including the tensile strength. The tensile strength of a material is the maximum tensile stress that can be developed in the material.
- In order to conduct a tensile test, the proper specimen must be obtained. This specimen should conform to ASTM standards for size and features. Prior to the test, the cross-sectional area may be calculated and a pre-determined gage length marked.
- The specimen is then loaded into a machine set up for tensile loads and placed in the proper grippers. Once loaded, the machine can then be used to apply a steady, continuous tensile load.
- Data is collected at pre-determined points or increments during the test. Depending on the material and specimen being tested, data points may be more or less frequent. Data include the applied load and change in gage length. The load is generally read from the machine panel in pounds or kilograms.
- The change in gage length is determined using an extensometer. An extensometer is firmly fixed to the machine or specimen and relates the amount of deformation or deflection over the gage length during a test.
- While paying close attention to the readings, data points are collected until the material starts to yield significantly. This can be seen when deformation continues without having to increase the applied load. Once this begins, the extensometer is removed and loading continued until failure. Ultimate tensile strength and rupture strength can be calculated from this latter loading.

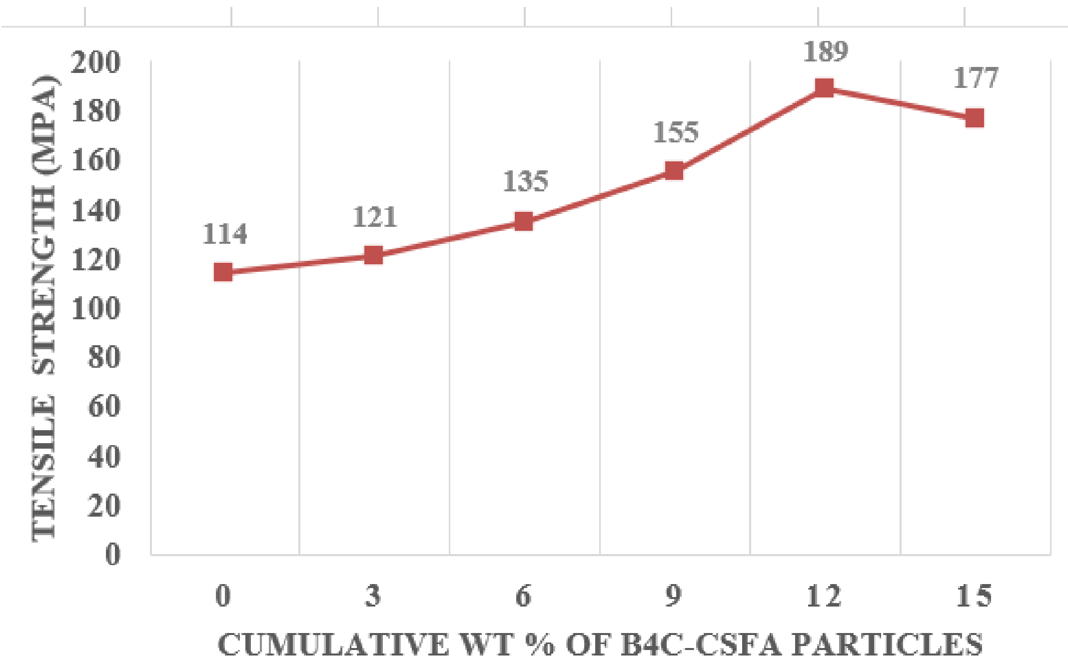


Fig. 3.1. Variation of tensile strength of hybrid composite

**Tensile strength characteristics of composite**

- Boron carbide wt. % is increased from 0 to 12 %
- Coconut shell fly ash wt. % is maintained constant.
- From the result we can observe that tensile strength increases with increasing the wt. % of B4C and CSFA.
- The maximum tensile strength (189 MPa) is observed at 9 wt. % of B4C and 3 wt.% of CSFA as shown in Fig. 3.1.
- After that further addition of B4C and CSFA particles into Al 7075 alloy matrix phase decreases the tensile strength.

**Brinell hardness test**

The Brinell scale characterizes the indentation Hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in material science. The typical test uses a 5 millimeters diameter steel ball as an indenter with standard load of 250Kg..Brinell hardness is determined by forcing a hard steel or carbide sphere of a specified diameter under a specified load into the surface of a material and measuring the diameter of the indentation left after the test. The Brinell hardness number, or simply the Brinell number, is obtained by dividing the load used, in kilograms, by the actual surface area of the indentation, in square millimeters. The result is a pressure measurement, but the units are rarely stated.

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- Penetration. Therefore, most hardness tests involve measuring the amount of force required to implant a specified indentation in the surface of a specimen OR the size of the indentation produced from applying a specified load. The indenter used varies with the test selected, but is generally hardened steel or diamond.
- Other types of hardness tests involve the rebound of a dynamic or impact load, such as the scleroscope. The amount of rebound those results is used as an indication of the surface hardness of the specimen.
- Common hardness tests include the Rockwell and Brinell. Other test procedures used include the scleroscope, surface abrasion testing, Vickers, and Tukon-Knoop.

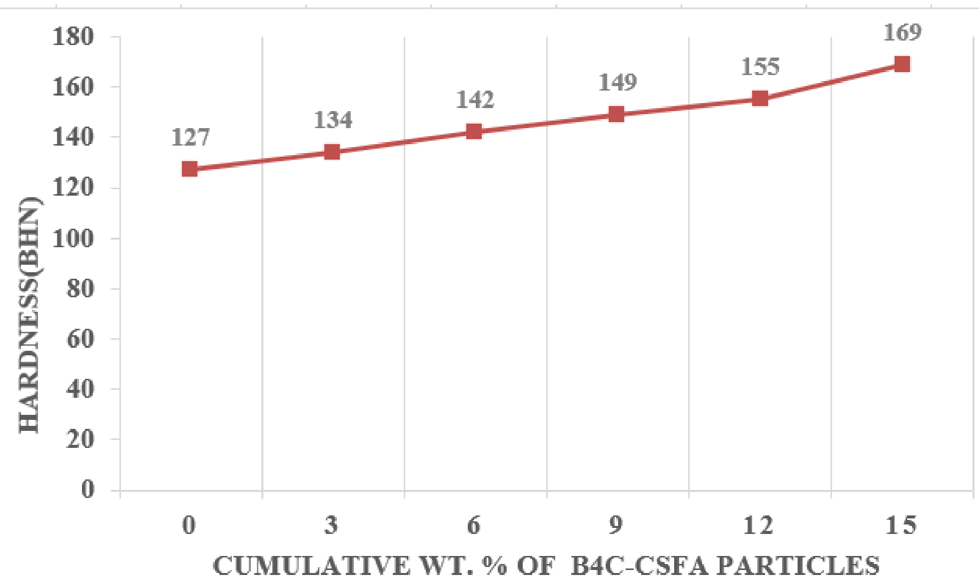


Fig 3.2. Variation of hardness of hybrid composite

**Hardness characteristics of composite**

- Boron carbide wt. % is increased from 0 to 12 %
- Coconut shell fly ash wt. % is maintained constant.
- From the result we can observe that Hardness increases with increasing the wt. % of B4C and CSFA.
- The maximum hardness (169BHN) is observed at 12 wt. % of B4C and 3 wt. % of CSFA.
- Addition of B4C and CSFA particles into Al 7075 alloy matrix phase increases the hardness in a linear way as shown in Fig. 3.2.

**Impact test**

Impact energy is a measure of the work done to fracture a test specimen. When the striker impacts the specimen, the specimen will absorb energy until it yields. At this point, the specimen will begin to undergo plastic deformation at the notch both Charpy and Izod impact testing are popular methods of determining impact strength, or toughness, of a material. In other words, these tests measure the total amount of energy that a material is able to absorb. This energy absorption is directly related to the brittleness of the material. Brittle materials, such as ceramics or glass, tend to have lower absorption rates than ductile materials like copper or aluminum.

- In charpy impact test the specimen is placed horizontally with either u or v shaped notches.
- The striker hitting direction is opposite to notch.
- Charpy test is generally used for metals.
- Load is applied at the middle of the specimen.

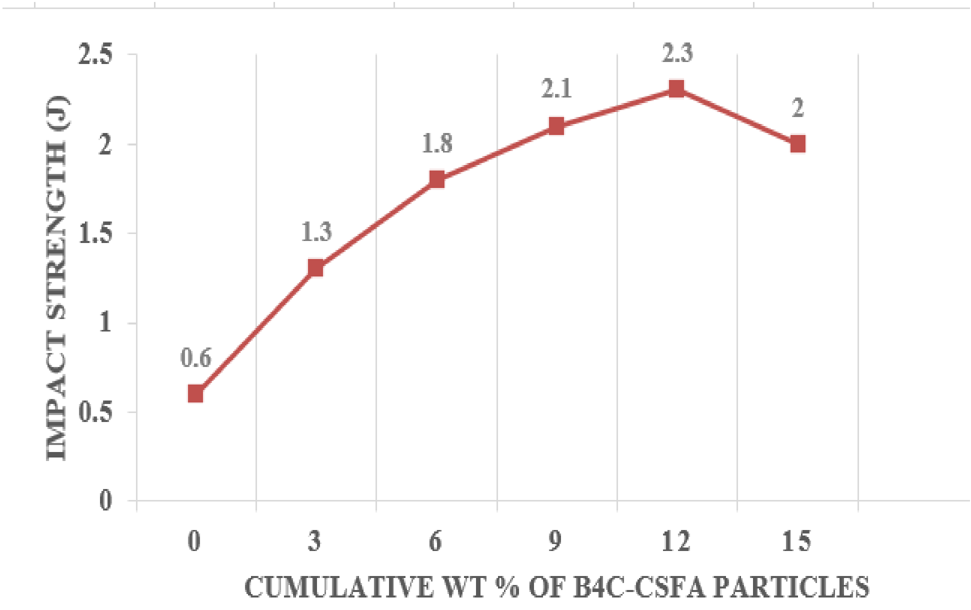


Fig.3.3. Variation of impact strength of hybrid composite

**Impact strength characteristics of composite**

- Boron carbide wt. % is increased from 0 to 12 %
- Coconut shell fly ash wt. % is maintained constant.
- From the result we can observe that impact energy increases with increasing the wt. % of B4C and CSFA.
- The maximum impact energy (2.3 J) is observed at 9 wt. % of B4 and 3 wt. % of CSFA.
- After that further addition of B4C and CSFA particles into Al 7075 alloy matrix phase decreases the tensile impact energy as shown in Fig. 3.3.

**Conclusion**

Hence fabricated the specimens of Al 7075 alloy composite reinforced with boron carbide and coconut shell fly ash with different wt.% of B4C and CSFA and tested the mechanical properties of the composite. Uniform reinforcements and minimum level of porosity in the composites. The manufacturing of low-cost hybrid aluminum matrix composites using coconut shell fly ash as a complementing reinforcement with boron carbide has a great advantage because of its higher mechanical properties. The following are the conclusions from the results obtained by testing.

- Hardness of composites increases with increasing reinforcement content in the matrix. The maximum hardness (169 BHN) of composites is observed for the 12wt.% B4C and 3wt.% CSFA composite.
- Tensile strength of composites increases by the addition of reinforcement particles B4C and CSFA in the aluminium7075. The maximum tensile strength (189 MPa) is obtained for 9wt.% B4C and 3wt.% CSFA composite that increased by 66% compared with the unreinforced aluminium7075. The ductility of the composites decreases with increasing the weight percentage of reinforcement particles.
- Impact energy of composites is increased by increasing the reinforcement content in the matrix. Maximum impact energy of 2.3 J is achieved for 9wt.% B4C and 3wt.% CSFA composite. The impact energy decreases with further addition of reinforcement particles in the matrix due to micro pores, crack initiation in the composites which bring about permanent failure in the composites.
- Addition of B4C and CSFA to Al 7075 alloy metal matrix are limited to 9 wt.% and 3 wt. %. Further increasing the wt. % of reinforcements may decrease the properties like tensile strength, impact energy.

**SCOPE OF FUTURE WORK:**

- The changing the reinforcements we can work on the new composite.
- Currently the use of powder metallurgy aluminium parts are restricted to low stress applications, where the net shaped capability is critical for cost reduction.
- The primary reason for the limited use of aluminium powder metallurgy alloys is that there are limited commercial grade aluminium alloys available. As a result, design engineers find it is difficult to specify aluminium alloys for new applications.
- Further the mechanical properties of existing powder metallurgy alloys, especially wear resistance or elevated temperature property retention, do not meet the needs for an expanded range of applications.

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