

Characterization of Boron Carbide (B_4C) Particle Reinforced Aluminium Metal Matrix Composites Fabricated by Powder Metallurgy

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Abstract

Composite materials are in trend in research and industrial fields due to its superior mechanical properties and easy processing techniques. While there are different processing techniques to fabricate the composite materials, powder metallurgy finds unique place in fabrication of composite materials. To enhance the properties of composite materials added reinforcements have to share loads while applying loads, due to high exceptional properties of added reinforcements composite able to withstand high stress values this load transferring mechanisms happens at interface regions of Al- B_4C system, to understand the interface chemistry and mechanisms it is must to investigate the interface phenomenon at different conditions. In this paper authors reviewed some of the major important works done on Al- B_4C composites fabricated by powder metallurgy techniques.

Keywords: Composite materials Sintering Ball milling Intermetallic compounds Mechanical properties

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1. Introduction

Composite materials are one of the best demanding materials in the present industrial field having high strength to weight ratio, high stiffness, high corrosion resistance etc. there are different matrix materials in the composite materials [8,32,36,39], depending upon the type of application and need matrix material can be chosen. Majorly used matrix materials are Aluminium and Magnesium. Different processing techniques are there to fabricate a composite material those are mentioned in Fig. 1. Among them majorly used technique was powder metallurgy, major researchers choose powder metallurgy as fabricating technique because of its advantages those are low processing conditions [9,10], easily availability of raw materials, low chances of formation of intermetallic compounds etc. step by step process in powder metallurgy are represented in Fig. 2. Through conventional techniques like stir casting, compo casting, squeeze casting wetting problem occurs between matrix and reinforcement materials to achieve that wetting between matrix and reinforcements high temperatures are required [11,12,35], while achieving good wetting phenomenon through high temperatures there is a high

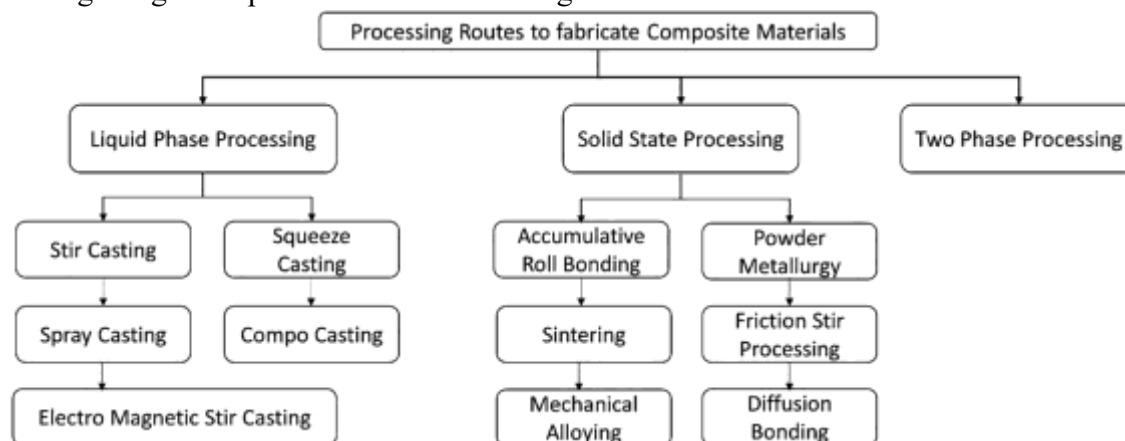


Fig. 1. Different Processing routes to fabricate the composite materials.

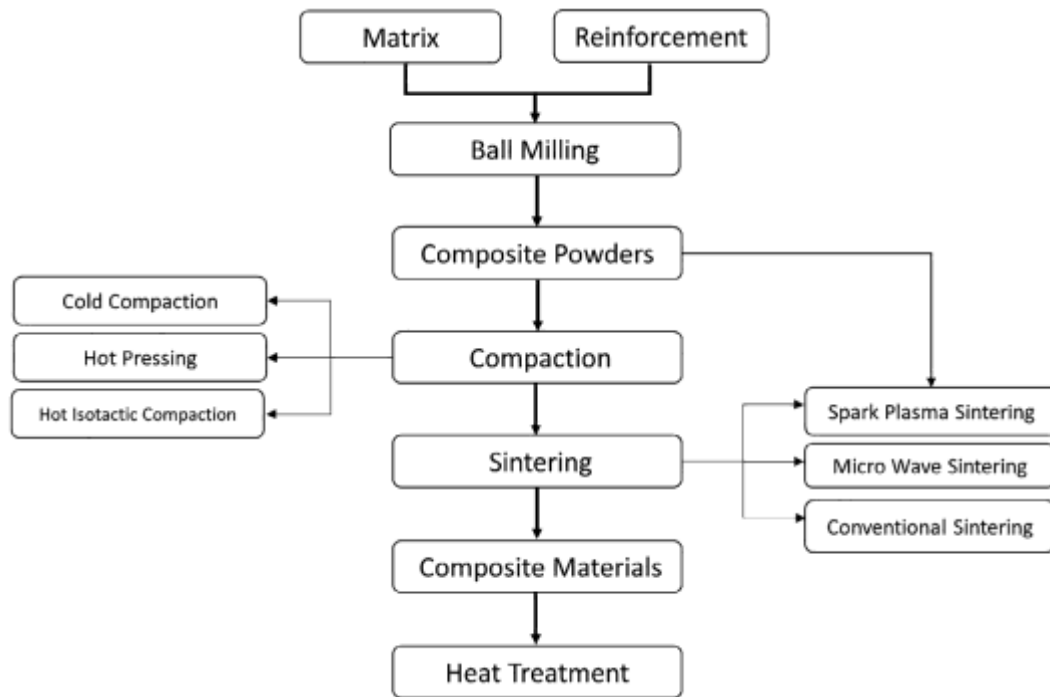


Fig. 2. Powder metallurgy processing routes.

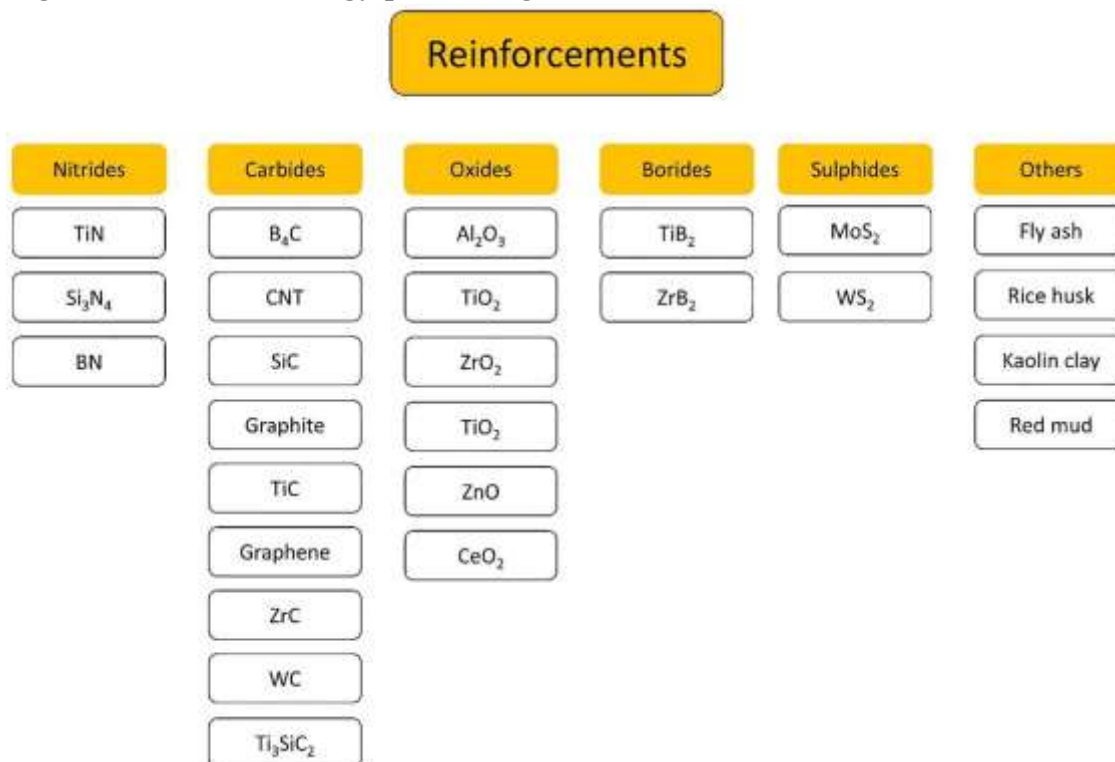


Fig. 3. Classification of reinforcement particles

2 Some reported research works on B₄C composites

2.1 Microstructural and mechanical properties analysis

Reinforcing nano sized B₄C particles of volume fractions 5,10,15 percentages (%) in pure Al shows superior enhancement in terms of hardness, wear and compressive strengths because of hot pressing used in this technique. Fig. 4 shows the SEM images of raw alu-minium particles and Nano B₄C particles used. It is

observed that 15% volume fraction of Nano B₄C shows optimum results with increase in hardness from 33HV to 164HV along with compressive strength from 130 MPa to 485 MPa [2]. Changing the matrix phase from Al to AlCuMg same Nano B₄C reinforced composites ball milled for different durations of 0.5, 1, 3, 6, 10, 15, 20, 25 h hot pressed at 560 °C at 300 MPa, composites shows low density levels which are milled for 25 h, hardness was increased when compared to base alloy, composites with 10% volume fraction of B₄C and milled for 6 h shows superior tensile strength of 332 MPa [1]. While ball milling operations presence of hard ceramic B₄C reinforcements in Al matrix phase helps in effective milling operation, strain hardening of Al particles and fracture takes place efficiently results in reduce in particle size at a very faster rate [40]. To improve the strength of the composite and to make composite stronger after sintering process quality of the green compact should be necessary, while studying the compressibility of the composite powders results shows that as the increase in the volume fraction of the reinforcements decreases compressibility nature of composite powders [15]. Ductility nature is also important property for a material to be used in application field but adding brittle hard ceramic reinforcements makes composite materials brittle and formed interfaces with matrix materials acts as obstacles for dislocation movements that makes material less deform and another factor that effects the ductility nature was difference

in coefficient of thermal expansion between matrix and reinforcements, while sintering process these coefficient of thermal expansion differences raises dislocation densities at interface regions which makes adjacent Al grains difficult to grow that leads to dislocation strengthening mechanism. Distribution of reinforcement particles play an important role in strength of the composite material generally ball milled was used to evenly distribute the reinforcement in matrix phase, some researchers tried blended powder semisolid forming process which has the benefits of both semi solid forming and powder metallurgy and also effect of reinforcement particle sizes, volume fraction and compaction pressures were analysed, results show that uniform distribution was achieved in case of reinforcement particle size is more than matrix phase, above 10% volume fractioned composites shows high porosity levels [14].

homogeneous composites were prepared by vacuum hot pressing sintering process at 680 °C for 90 min with a sintering pressure of 30 MPa and to analyse the in situ phase transformations XRD analysis were carried out, results shows that optimum results were obtained for lamellar one with Vickers hardness 116Hv, bending strength 780 MPa and fracture toughness 12.21 Mpa.m^{-1/2} [12]. B₄C Particle size of 10 mm reinforced in 100 mm particle size AA6061 matrix alloy with a volume fractions of 5, 10, 15, 20 wt% shows decrease in fracture toughness and increase in hardness with increased volume fractions, composites with 5% B₄C content shows best tensile and transverse rupture strength and 10% B₄C content shows best fracture toughness [3].

Micro wave sintering of Al/B₄C composites with volume fractions of 10, 15, 20% shows enhanced hardness values and best for 20% reinforced one sintered at 850 °C, variation in sintering temperatures at different temperatures of 650, 750, 850 and 950 °C shows best bending and compressive strengths of 238 MPa and 330 MPa for composites sintered at 950 and 750 °C [5]. B₄C reinforced AA6061 composites was used in neutron shielding due to high strength to weight ratio and neutron absorption capability, 30% volume fractioned composite extruded and rolled to investigate changes in it, it was observed that increased deformation by rolling leads to increase in dynamic recrystallization, B₄C particles excite dynamic recrystallization process that hinders grain growth that makes composite material having low strain to fracture values [6].

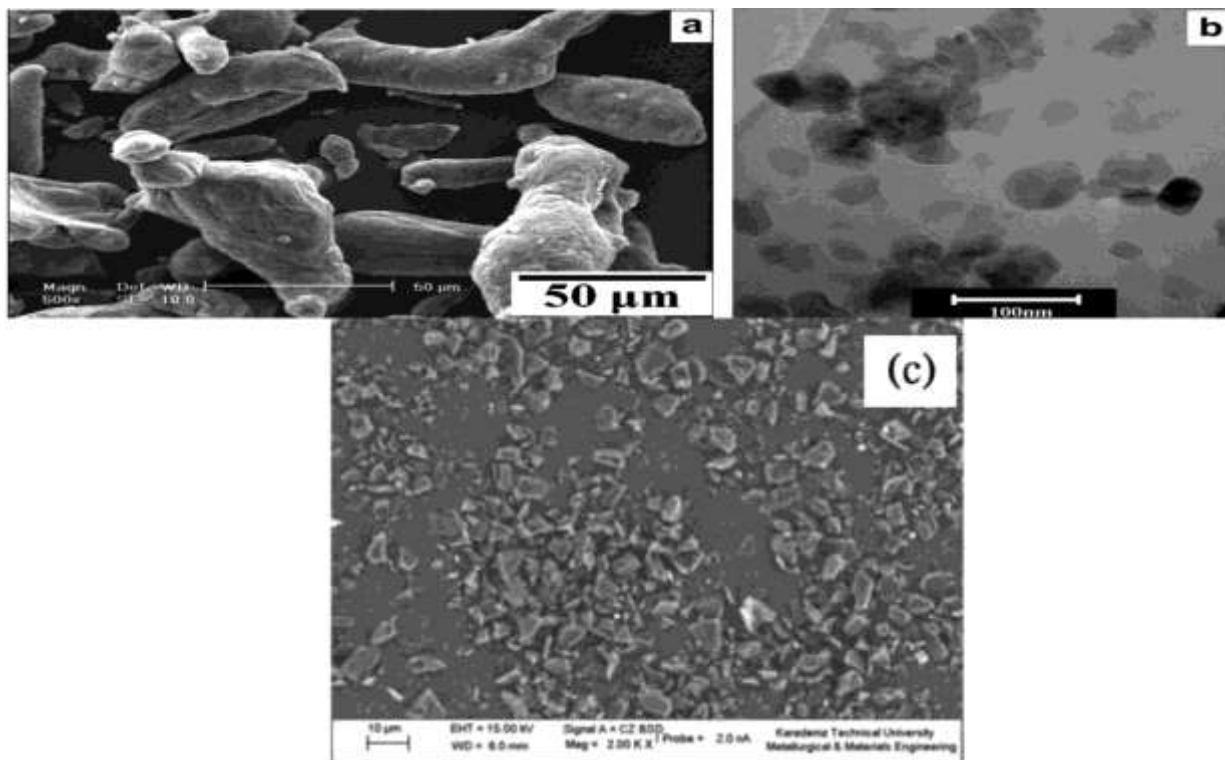


Fig. 4 SEM images of (a) Aluminium particles (b) Nano Boron Carbide Particles (c) Micro Boron carbide particles [1,2].

2.2 Intermetallic compounds analysis

To find out the phase transformations while sintering mechanisms in situ XRD analysis were carried out on Al/B₄C composite powders that are shown in Fig. 5, results shows that elemental dif-

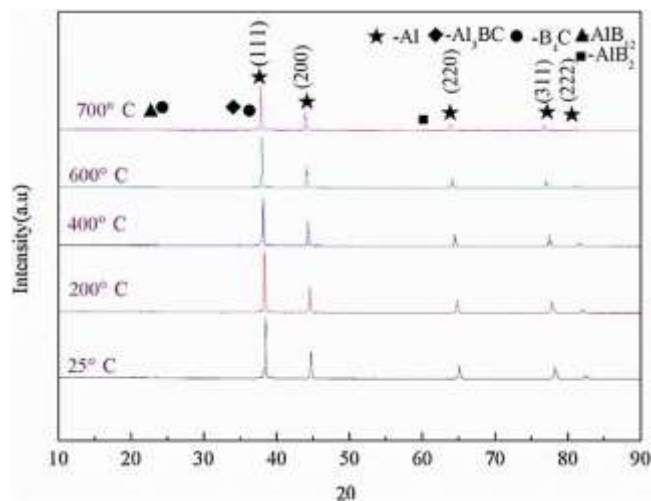


Fig. 5. In situ XRD of 25 vol% B₄C/Al powders.

fusion takes place along with possible formation of intermetallic compounds happen temperatures above 600 °C, possible reactions are stated in Eqs. (1) & (2) [16].



Reaction products observed are AlB_2 , AlB_{12} , Al_3BC . Al and B_4C reactants are reacted while sintering processes forms initial products of AlB_{12} and Al_3BC further AlB_{12} reacts with Al matrix phase AlB_2 phase generated [12,16,35]. Addition of Titanium in the molten melt along with B_4C particles enhances the wetting ability between Al matrix and B_4C particles by forming TiB or TiC thin layers around the B_4C reinforcement particles. Some researchers observed that addition of transition elements to Al alloys helps in formation of precipitates that shows decreased tendency of alloy sensitivity towards recrystallization, majorly observed elements in this category was Zirconium and Scandium [4,34], formation of precipitates that are cathodic in nature also leads to dissolution of matrix phase [41,33].

While studying about the chemical reactivity of Al- B_4C interface, researchers found that Al- B_4C samples heated for 160 h at 900 K shows no reactive zones at interface regions but small traces of AlB_2 crystals were found and are as shown in Fig. 6a, increasing the temperature to 950 K just above the melting point of Al shows formation of Al_3BC and AlB_2 those are shown in Fig. 6b by consuming half of the Al and B_4C reactants further heating of the samples from 950 to 1100 K shows mainly phases consisting of Al_3BC , AlB_2 and B_4C at this temperatures Al was consumed more than the B_4C those are shown in Fig. 6c raising the temperatures in the range of 1150 K to 1273 K shows B_4C was totally consumed and decomposed into Al_3BC and $\text{Al}_3\text{B}_{48}\text{C}_2$ as shown in Fig. 6d [7].

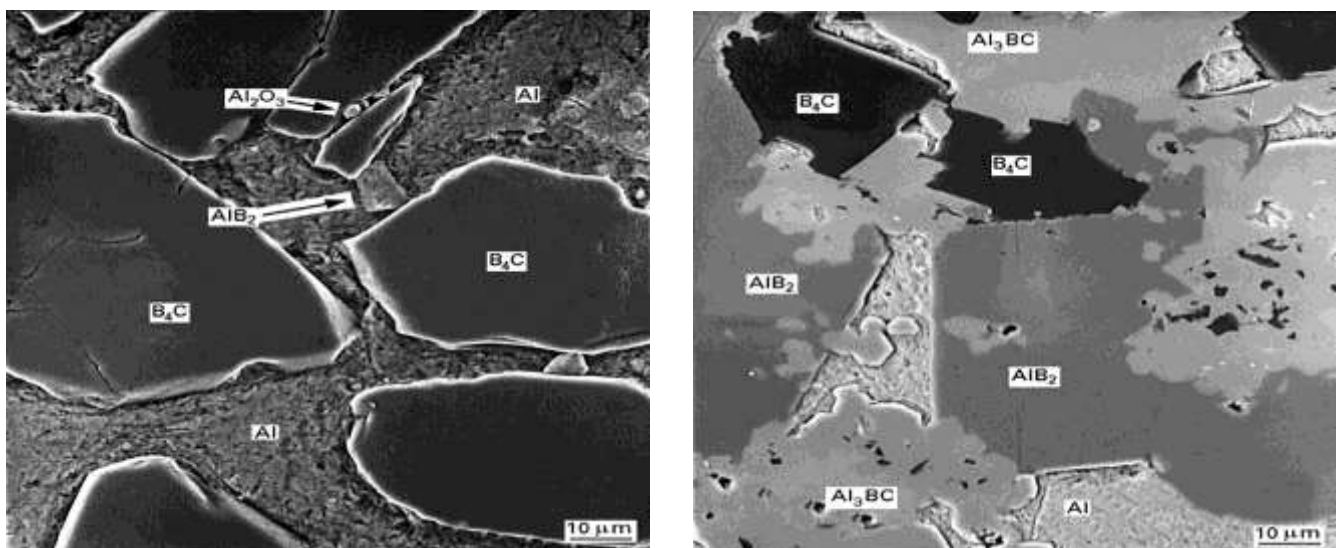


Fig. 6a. Heating at 900 K for 160 h.

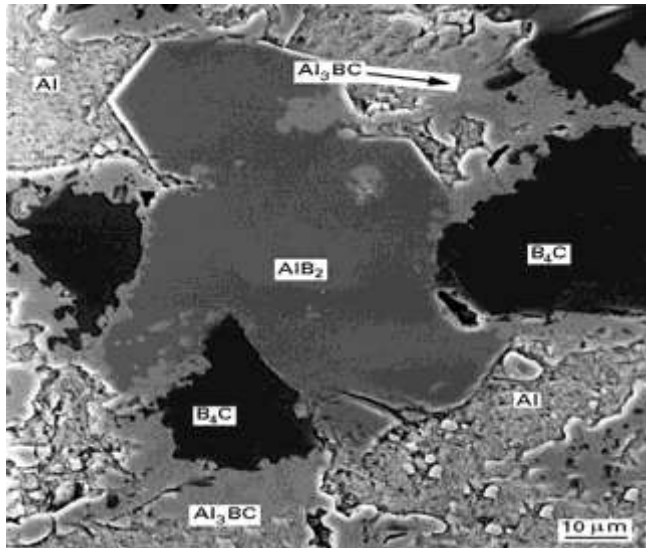


Fig. 6b. Heating at 950 K for 160 h.

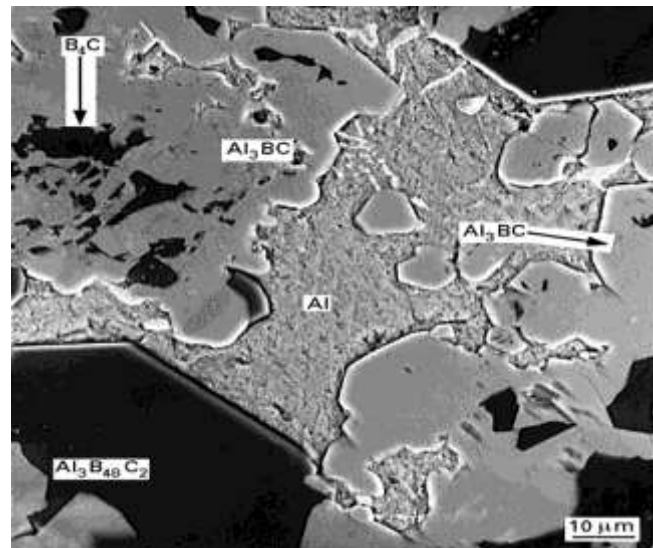


Fig. 6d. Heating at 1273 K for 160 h.

As B_4C finds major applications in industrial fields so, machining of B_4C is also an important factor to make B_4C machinable by using WEDM it has to support electrical conductivity. Machining of spark plasma sintered B_4C was possible because of the presence of electrically conductive phase $B_{13}C_2$ and after sintering process phases like B_8C detected which are responsible for electrical conductivity of B_4C . Results found that SPS process enables enough electrical conductivity nature to machine B_4C . Fracture surface analysis shows that trans granular fracture modes are responsible for failure of the B_4C sample [38].

3 Conclusion

- Aluminium matrix phase was perfectly suitable for major reinforcement particles increasing the properties above its base alloy irrespective of fabrication techniques
- B_4C is one of the best and hardest reinforcement while choosing the reinforcement particles.
- From the studies it is clear that compared to micro Nano level reinforcements give superior results but Nano level reinforcements are more prone towards agglomerations and reactions.
- In Al- B_4C system majorly formed intermetallic compounds are AlB_2 , Al_3BC , $Al_3B_{48}C_2$.
- Compared to conventional sintering techniques modern sintering techniques like microwave sintering and spark plasma sintering shows better results in Al- B_4C system.
- It is clearly observed that increasing the volume fraction of B_4C results in decrease in strain to fracture values, increase in hardness and increase in mechanical strengths up to critical volume fractions.
- B_4C critical volume fractions in matrix phase were varying depending upon the parameters selected those are particle size, volume fractions, compaction pressures, sintering time and temperatures.
- Added B_4C reinforcements help in strengthening of composite by inducing dislocation strengthening mechanisms by obstructing dislocation mobilities at interface

Concluding that B_4C was one of the best ceramic hard reinforcements in Aluminium ductile matrix phase exhibiting superior mechanical properties compared to base alloys, still a lot of research is needed to investigate and understand the interface chemistry of Al- B_4C system so that good interface bonding can be achieved which helps in exceptional composite properties by eliminating

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