

Fabrication, Microstructure and Mechanical Properties of Boron Carbide (B_4C_p) Reinforced Aluminum Metal Matrix Composite - A Review

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Abstract: This review paper surmised the work on Al/ B_4C composite, different methods of processing, microstructure and mechanical properties of different size and quantity of B_4C with different grade of aluminum alloy. Since B_4C_p have high hardness, good chemical resistance, good nuclear properties and low density it is widely used by the researcher among all other reinforcements like TiC, SiC, Al_2O_3 in MMC. Stir casting method is simple and economical with some disadvantages like porosity, agglomeration and inter-metallic compounds. However these are minimized in powder metallurgy methods of fabrication of MMC.

1. Introduction

The origination of metal matrix composite is the addition of hard, high strength, high modulus ceramic reinforcements to a softer metals (matrix) to produce a material whose mechanical properties are between the matrix alloy and ceramic reinforcement. Generally Aluminum, Magnesium, Copper, Zinc, Lead, Iron, and Nickel are used as matrix materials and SiC, TiC, Al_2O_3 , B_4C are used as reinforcement. As boron carbide is one of the hardest material (3700 Hv), Boron carbide exhibits high degree of chemical stability, very good thermal properties, low density (2.52 g cm^{-3}) even lower than Al_2O_3 (3.20 g cm^{-3}) and SiC (3.96 g cm^{-3}) with an high elastic modulus of 427 GPa [1, 2 and 3]. Another distinguished characteristic of boron carbide is its ability to absorb neutron in a nuclear reaction which makes it suitable for nuclear shielding applications[4]. A detailed review of Al/ B_4C metal matrix composite considering all the various aspects such as possible fabrication methods, their microstructure and mechanical properties have been explored.

2. Fabrication of Al- B_4C Metal Matrix Composite

Al- B_4C composites can be fabricated by many different methods but two methods are mostly used such as: molten method (such as stir casting), solid state method (such as powder metallurgy).

2.1 Stir Casting

A stir casting technique is a liquid metallurgical route of casting metal matrix composite. In stir casting Technique the MMC can be proceeded through both in-situ and ex-situ methods. In Ex-situ methods, reinforcements are added externally into molten matrix followed by proper stirring and then poured into the molds of desired shape. The major challenges confronted in the fabricating the MMCs by stir casting



methods are to obtain a homogeneous distribution of reinforcements, its wettability into matrix, porosity and unwanted chemical reactions. Non uniform distribution of particles generally leads to three type of defects namely clustering, agglomeration and segregation [3,4]. Incorporation of B_4C particles into the aluminum matrix melt is very challenging below $1100^\circ C$. There are several methods have been suggested by many authors to improve wettability of B_4C_p into the moltain matrix. Fluxes such as K_2TiF_6 , $KCl-KF$, etc are added to enhance wettability of particle into moltain matrix. The use of K_2TiF_6 have duel benefit as Ti acts as a grain refiner and makes a strong bond with aluminum metal and potassium and fluoride prevents the gas entrapment in to the melt[6,7]. Apart from fluxs Mg, Ti, Zr and Sc, can also be used together or individually to improve wettability of B_4C into the moltain matrix[8,9 and 16].

Figure 1 shows the typical stir casting setup, in this casting technique the optimum process parameters choosen by various authors are as melt temperature $800-920^\circ C$, stirring speed 250-500 rpm, mould preheat $400-500^\circ C$ under innert atmosphere by providing argon gas into the melt or the use of hexacloroethane to remove the hydrogen gas from the melt[5,6,7,12 and 19].

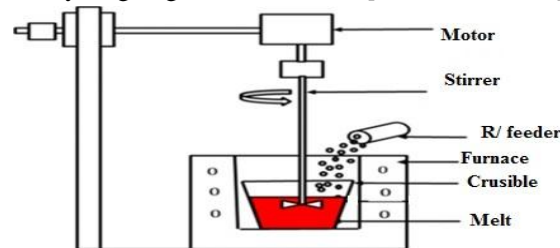


Figure 1. Stir Casting set up [9]

2.2 Powder Metallurgy

Powder Metallurgy is solid state methods of producing Aluminium metal matrix composite. Powder Metallurgy composites having very high mechanical properties, because in these methods reinforced particles are uniform distributed in the matrix. Therefore, Al/B_4C composites produced by these methods are generally isotropic. Another important fact about powder metallurgy process is that the unwanted interfacial compounds between the matrix material and reinforcement particles are less and minimum segregation of reinforcement particles. The unwanted interfacial compounds usually decorate the mechanical properties. Matrix and reinforced particles need to be pretreated, some of the researchers have reported that the matrix particles are atomized by water, argon gas and stearic acid while mixing whereas the boron carbide particles are pre-oxidized to get B_2O_3 oxide film for proper interfacial bonding. It has also been reported that in powder metallurgy method, high volume up to 20-30 % of boron can be incorporated significantly into the matrix material. The average size of matrix particles are between $10-100\mu m$ for good mixing and average size of boron carbide particles are between $2-23\mu m$ have been reported for proper bonding between matrix and reinforcements. Since mixing is required in this method, different mixers are used such as turbula mixer , shaker mixture and planetary ball , and it is dry milled with ZrO_2 ball with diameter 4-8 mm and Chromium steel ball with diameter 6 mm. The compacting pressure generally reported is between 300-600 MPa. Since the powder metallurgical composites under goes secondary processing such as cold pressed, hot pressed, die pressed, sometime both cold and hot

press are used respectively to get desired properties at different pressure and temperature. Due to secondary processing the void contents are very less and the composite attains the relative density up to 99.9% [8, 10, 11, 22 and 23].

3. Microstructures Al-B₄C Composite Produced By Various Techniques

Microstructures of any composite reveal its physical properties. Microstructures of different processing methods are discussed in following sections.

3.1 Stir Casting Process

Microstructure of aluminum metal matrix composite fabricated by stir casting method are characterized by XRD, Optical Microscope, SEM, FESEM etc., Microstructure of composite give a clear description about distribution of particle, bonding between matrix and B₄C, inter-metallic phases. Among all these, solidification mechanism of the melt composite also plays significant role in describing its microstructures. Due to particle pushing phenomena B₄C particles are rejected by solid front and trapped in inter-dendrite zone and leaving the dendrite branches as particle-free regions in the materials [12 and 13]. Other factors also influences the microstructures are size of reinforcement particles and its quantity. It has been observed that the reinforcements having size more than 20 μm shows uniform dispersion as shown in figure 2, whereas particles less than 10 μm lead to agglomerations [6,7].

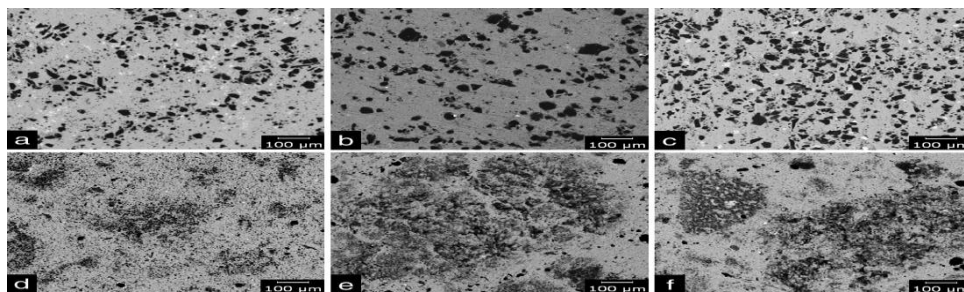


Figure 2, bigger B₄C particulates (a, b, c,) and agglomeration of smaller B₄C particulates (d, e, f) within the matrix [7]

Several research confirm that the optimum quantity of reinforcement should up to 10% either by wt. or by vol%, less quantity of boron carbide leads to several particle free region where as higher quantity leads to Porosity and increasing sites for heterogeneous pore nucleation i.e. the particles are surrounded by surface gas layers and the hindered liquid metal flow due to more particle clustering [20]. It is also evident that Ti compound reaction layer is found around B₄C reinforcement when adding K₂TiF₆ flux to the melt. The number of particles transferred to the melt depends upon the level of Ti present in the flux, a higher Ti level resulting in increased particle transfer. Incorporation is facilitated by exothermic reaction between the B₄C particles and Ti Present in the flux to produce Ti compound around boron carbide particles which intern prevent B₄C particle to decompose into matrix, hence increase mechanical properties [5, 17].

3.2 Powder Metallurgy

In powder Metallurgy process during extrusion many structural changes occurs, namely change in grain structure, particle orientation along the direction of extrusion. In the parallel direction of extrusion microstructure shows anisotropic property as particle have tendency to rotate and align along the extrusion Direction shown in figure 3. Al-B₄C cryomilled followed by hot pressing produces clean and strong interface between Al and B₄C. Various phases are identified by XRD analysis, apart from Al and boron carbide small amount of AlB₂, Al₃BC and Al₄C₃ phases are present with the Al and B₄C [11].

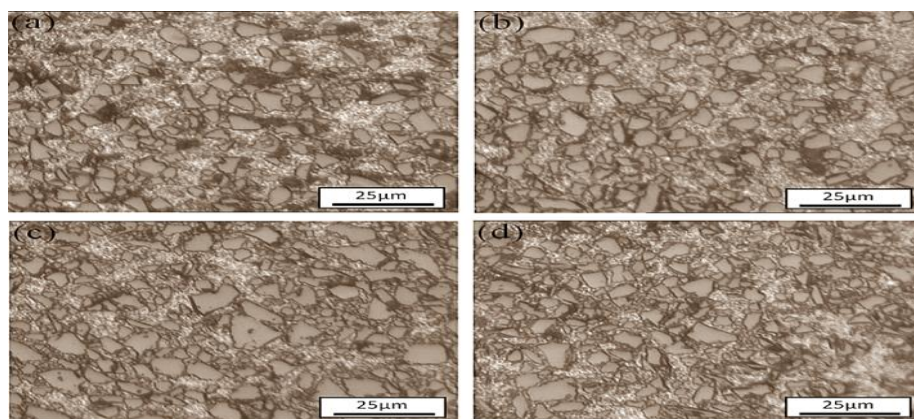


Figure 3 OM micrographs of the B₄C/6061Al with different contents of (a) 10%, (b) 20%, (c) 30% and (d) 40% [11]

4. Mechanical Properties of Al-B₄C Composite Produced By Various Techniques

Reinforcement particles are the load bearing elements in the composite material hence homogeneous distribution leads to higher mechanical properties.

4.1 Stir Casting

The Mechanical properties of the Al-B₄C composites like hardness, tensile strength, compressive strength and wear behavior mainly depend upon the distribution of reinforcement particles in the matrix, proper incorporation of reinforcements in the matrix and amount of Reinforcements (wt% or vol %) actually dispersed into the matrix. Reinforcement particles are the load bearing elements in the composite materials, hence for higher tensile strength of composite materials the reinforcements should be uniformly distributed and properly incorporated. The tensile strength also increases with increase weight percentage of reinforcements as it offers strength to matrix alloy by offering more resistance to induced tensile stresses. Since the variation in coefficient of thermal expansion between the matrix and the boron carbide particle is very high, this causes higher dislocation density in the matrix and load bearing capacity of the hard particles increases hence the strength of composite increases. The hard B₄C particles prevents the crack to propagate, rather it acts as barrier for crack propagation. Also the compressive strength of The Al-B₄C composite as B₄C particles offers more restriction to the plastic flow during deformation [5, 20]. The

yield stress increases with decreasing inter-particle distance. It has been recommended from researcher that the inter-particle distances (λ) values should be within 10 μm . Boron carbide and aluminum reaction forms several inter-metallic phases at higher temperature like AlB_2 , Al_3BC , Al_4C_3 . These phase increases the flow stress in the composite consequently decreases the ductility of composite. Therefore fabrication of composite at higher temperature leads to the formation of more brittleness phases [19].

4.2 Powder Metallurgy

Tensile strength of Aluminium boroncarbide composite fabricated by powder metallurgy process increases with increasing B_4C but at higher content of B_4C tensile strength decrease. Also the tensile strength increases with increasing secondary processing temperature (Hot rolling). The strengthening mechanism of Al- B_4C attributed to the following factors: (a) grain refinement and dislocation strengthening mechanism, Dislocation strengthening can play an important role. When The composites are prepared through two stages: Primary Processing (vacuum hot pressing) and secondary processing (hot rolling) the thermal mismatch is developed due to difference in coefficient of thermal expansion between B_4C and Aluminium alloy this thermal mismatch lead to the dislocation density and it increases around the B_4C particles. (b) Load transfer effect that is the presence of B_4C particles can transfer load from matrix to the B_4C Particles (c) Orowan strengthening. [23,24] . Bie B et al; [22] reported that the higher particle content leads to a higher yield strength but lower ductility, he has reported that 15- $\text{B}_4\text{C}/\text{Al}$ composite indicating plasticity and ductile fracture whereas 30- $\text{B}_4\text{C}/\text{Al}$ is reported of brittle fracture as shown in figure 4. Q shen et al; [25] have fabricated Al-7075/ B_4C composite fabricated through plasma activated sintering and he has observed that hardness, bending strength and compressive strength increases with increasing B_4C content but at higher B_4C content the these properties decreases due to algomeration of B_4C particle . The Mechanical properties like compressive fracture and yeild strength increases by about 18% on increasing the sintering temperature from 450 C to 530 C.

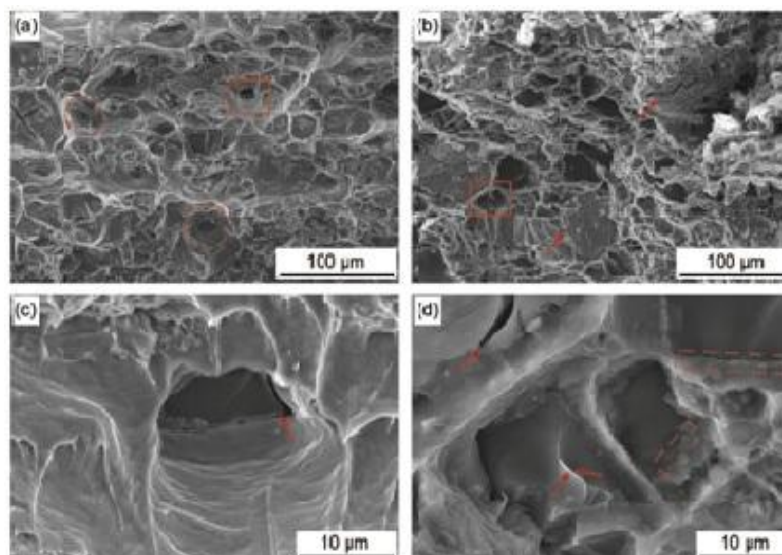


Figure 4. SEM micrographs of fracture surfaces of the recovered samples: 15% - $\text{B}_4\text{C}/\text{Al}$ (a) and (c) 30- $\text{B}_4\text{C}/\text{Al}$ (b) and (d) [22]

5 Conclusions

This review paper discussed the various fabrication techniques, microstructures and mechanical properties of Al/B₄C composite. As per the available literature, among the various fabrication techniques, Liquid metallurgical route are the most suitable to fabrication of Al/B₄C composite due to its simplicity, low cost of production and its flexibility. It has been noticed that wettability of B₄C below 1100 °C is difficult, this has been overcome by the use of flux in the melt. However Al/B₄C composite produced by powder metallurgy have less porosity and intermetallic compounds. Microstructure study shows that in stir casted Al/B₄C Composite have uniform distribution of reinforcement in the matrix. Also bonding between matrix and B₄C are strong. However small size of reinforcement particle and higher quantity of reinforcement particles leads to agglomeration in the composite materials. Similarly, the microstructure study of Al/B₄C produced by powder metallurgy shows that particles are properly incorporated in the matrix due to the application of pressure. The mechanical properties of such as tensile, compressive, flexural strength and Hardness increases with the application of boron carbide particles in both the processing techniques.

From all these conclusion it is concluded that Boron carbide is most promising reinforcement and it can be used for superior mechanical properties of the composite.

6 References

- [1]. Mazahery A and M.O. Shabani 2012 Journal of Materials: Design and Applications **226**,159
- [2]. Mazahery A and M.O. Shabani 2012 Journal of materials engineering and performance **21**,247
- [3]. Hashim J, L. Looney and M. Hashmi 2002 Journal of Materials Processing Technology **123** 251.
- [4]. Hashim J, L Looney and M Hashmi Journal of Materials Processing Technology **123**, 258.
- [5]. Kalaiselvan K, N Murugan and S Parameswaran 2011 Materials & Design **32** 4004.
- [6]. Canakci A, F. Arslan, I. Yasar 2007 Journal of Materials Science **42** 9536.
- [7]. Isil Kerti and Fatih Toptan 2008 Materials Letters **62**, 1215.
- [8]. Q Hu, H Zhao, and F Li 2016 Materials and Manufacturing Processes **31** 1292
- [9]. Thandalam S K, S Ramanathan and S Sundarrajan Journal of Materials Research and Technology **4** 333.
- [10]. Yu LI Li, Qiu-lin Dong, Wei, LIU Shu, Guo-gang 2016 Transaction of nonferrous metal Society of China **26** 2304.
- [11]. H.S.Chen, W.X.Wang, Y.L.Li, P.Zhang, H.H.Nie and Q.C.Wu, 2015, Journal of Alloy And Compounds, **632**, 29.
- [12]. K Rajkumar 2014 Procedia Engineering **86** 34.
- [13]. Ibrahim M 2015 Composites Part B Engineering **79** 83.

- [14] F Toptan, A Kilicarslan, A Karaaslan, M Cigdem, I Kerti 2010 Materials & Design **31** 87.
- [15] Ahmad R, D T Gethin and R W Lewis 2012 Applied Mathematical Modelling **36**, 4760.
- [16] Raj R and D G Thakur 2016 Archives of Civil and Mechanical Engineering **16** 949.
- [17] Zhang Z, X.-G. Chen and A. Charette 2009 Journal of Materials Science, **44**. 492
- [18] Marianna Kouzeli, Christopher San Marchi and Andreas Mortensen 2002 Materials Science and Engineering: A **337**(1) 264
- [19] Ranjith, R. and P. Giridharan, 2015, High Temperature Material Processes: An International Quarterly of High-Technology Plasma Processes. **19**, 3.
- [20] Baradeswaran, A. and A.E. Perumal, 2013, Composites Part B: Engineering, **54**, 146.
- [21] BX Bie, JY Huang, B Su, L Lu, D Fan, T Sun, 2016, Materials Science and Engineering: A, 664, 86
- [22] Oñoro J , M.D. Salvador, and L.E.G. Cambronero, 2009, Materials Science and Engineering: A, **499**, 421.
- [23] Ozkan Sarikaya ,Selahaddin Anik, Erdal Celik ,S. Cem Okumus, Salim Aslanlar, 2007, Materials and Design, 28, 2177.
- [24] Qiang Shen, Chuandong Wu, Guoqiang Luo ,Pan Fang, Chenzhang Li, Yiyu Wang, Lianmeng Zhang, 2014, Journal of Alloys and Compounds, 588, 265.
- [25] Zhuoqiang Mo, Yunzhong Liu ,Jiangjiang Geng, Teng Wang, 2016, Materials Science & Engineering A 652, 305.