Effect of hardness and tensile behaviour of Al-2024/TiB_2 coated B_4C particles synthesized by stir casting route

G. N. Lokesh[1*], S. Shivakumar[2], B. G. Rohit[3], T. R. Preetham[3]

[1] *Presidency University, Itgalpura, Rajanukunte, Bengaluru, India*
[2] *Sir M.V. Institute of Technology, Bengaluru, India*
[3] *Desmaco Engineering Services Pvt. Ltd, Bengaluru, India*

ABSTRACT

KEYWORDS

Al-2024,
Hardness,
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Tensile,
Tensile Fracture.

Nowadays the production of light weight, low cost and high performance aluminium based composites has undergone significant evolution. In this work, Boron Carbide (B_4C) were introduced into Al-2024 alloy produced by stir casting method. The B_4C particles is coated with TiB_2 via sol-gel process and reinforced in Al-2024 alloy by stir casting process to produce composite. Stir casting technique is gaining importance due to its easy setup, low cost, uniform dispersion of reinforcement compare to other techniques. Metal Matrix Composite is stir casted by incorporation of B_4C reinforcements by varying 2%, 4%,6%, 8% and 10 wt% to investigate mechanical properties. Hardness, porosity and tensile behavior of alloy and composites were evaluated and found that both hardness and tensile strength increases with increases in percentage of reinforcement. On the other hand a slight increasing amount of porosity is observed with increasing the B4C particles of the composites. Microstructure of tensile fractured surface of Al-2024/B_4Cp composites indicates that the presence of intact reinforcement B_4C particles on the fracture surface and bonding between boron carbide and aluminum was superior indicating that deformation caused due to ductile behavior.

1. Introduction

Conventional monolithic materials have limitations in attaining good combination of strength, toughness, stiffness and density. To overcome these deficiencies and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest (Lokesh et al., 2013; Auradi et al., 2014; Dasgupta, 2012; Nie et al., 2007). Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys (Lokesh et al., 2018; Sanjay et al., 2017; Vijaya Kumar Raju et al., 2018; Manjunatha, 2015). The often used reinforcement materials for Aluminium MMCs are SiC and Al_2O_3. Due to the higher cost of B_4C powder relative to SiC and Al_2O_3, limited research has been conducted on B_4C reinforced MMCs (Mazahery, 2012). The B_4C have excellent physical and mechanical properties, such as a high melting point, hardness good abrasion resistance, high impact resistance and excellent resistance to chemical agents and as a good ceramic material, B_4C has wide variety of applications (Ashok Kumar et al., 2018; Pozdniakov et al., 2017; Gudipudi et al., 2020). On the other hand, based on the type of reinforcements the MMCs are fabricated by stir casting, squeeze casting, spray deposition, plasma spraying, powder metallurgy and more (Kalaiselvan et al., 2011; Mohammed Sharifi et al., 2011; Dhanashekar and Senthil Kumar, 2014; Sarikaya et al., 2007; Chen et al., 2018; Tariq et al., 2018). As compared with other process, stir casting offers low cost processing, better matrix particle bonding and uniform dispersion of reinforcements (Mahesh Kumar and Venkatesh, 2018; Mahendra and Radhakrishna, 2007; Ravi et al., 2015). In the present investigation Al-2024/B_4C composite is synthesized by stir casting route with 2, 4, 6, 8 and 10wt% were reinforced in base matrix. The composites fabricated by stir casting were tested for porosity level, hardness and tensile strength. The microstructure using SEM of tensile specimen was studied to know the dispersion of reinforcement and matrix interface.

*Corresponding author,
E-mail: lokeshgn32@gmail.com

Table 1
The chemical composition of the matrix alloy (wt.%).

Cu	Mg	Mn	Si	Fe	Zn	Ti	Cr	Pb	Ni	Al
4.69	1.3	0.55	0.35	0.41	0.19	0.09	0.06	0.03	0.06	Balance

2. Experimental Details

A stir casting setup which consists of a resistance furnace and a separate stirrer assembly was used to synthesize the composite. Commercially available Al-2024 alloy was used as base matrix and its chemical composition is shown in Table 1. B_4C is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. For commercial use B_4C powders usually need to be milled and purified to remove metallic impurities.

The B_4C is coated with TiB_2 using sol-gel precursor. The titanium isopropoxide is a chemical compound with the formula Ti{OCH(CH3)2}4 is selected and the precursor was initially diluted with ethanol. For coating, the titanium oxide, boron carbide powders were dispersed in ethanol, stirred well, and Ti{OCH(CH3)2}4 and distilled water were added to the stirred suspension. The processing was conducted at room temperature at a PH solution of 7. The solution was then aged for 3 hours at room temperature with steady stirring. After the sol-gel process, the powders were dried out at 110°C and heat treatment cycle is continues with argon atmosphere to eliminate the adsorbed water and to achieve a TiB_2 coating. The powders were heat treated in a graphite crucible and under argon atmosphere and heat treatment is continued to eliminate the moisture to achieve TiB_2 coating. The Al-2024 alloy was loaded in the graphite crucible and melted to 760°C in the resistance furnace of stir casting setup. The degassing hexachloroethane tablets were added to remove slag. Also 0.5% Mg is added to increase the wettability between matrix and reinforcements. The stirrer was then lowered vertically up to 15 cm from the top of the crucible. The speed of the stirrer was gradually raised to 400rpm and the TiB_2 coated B_4C particles were added with a spoon at the rate of 10-20g/min into the melt. The speed controller maintained a constant speed, as the stirrer speed may get reduced due to the increase in viscosity of the melt when particulates were added into the melt. The melt was kept in the crucible for 20 seconds in stationary condition and it was then top poured in small metal moulds successively. The stirring and pouring of molten mixture is shown in Fig 1 & 2.

Fig. 1. Stirring of Al-4.5%Cu alloy.

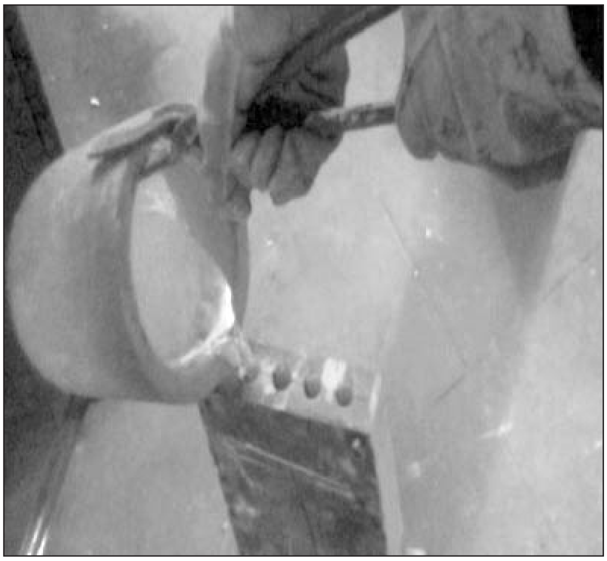

Fig. 2. Pouring of Al-4.5%Cu/B_4C molten into die.

The experimental density of the composites was obtained by the Archimedean principle, while the theoretical density was calculated using rule of mixture according to the weight fraction of the B_4C particles. The porosities of the composites were assessed from the deference between the experimental and the theoretical density of each sample. Hardness measurements were performed using a Brinell hardness tester with a load of 10kgf. Hardness values were averaged over five measurements taken at different points on the cross-section. Tensile tests were carried out using samples prepared according to ASTMD3479-1982 standard.Microphotographs were taken by SEM after tensile fracture wear to know the distribution and fracture of reinforcements.

3. Results and Discussion

3.1 Hardness

Hardness of MMCs is increased gradually with increased weight percentage of B_4C particle. From Fig.3 it was found that the hardness of Al-alloy for 10% wt B_4C increased about 42% when compared to base alloy. This may be due to the harder ceramic particle of B_4C which acts as load barrier due to obstacles to the motion of dislocation. The reinforcement of B_4C particle enhances the hardness as Al matrix is softer and B_4C particle is harder, due to which the composite render their inherent properties of the soft matrix. The strengthening of the composite can be owed to dispersion strengthening as well as due to hard particle reinforcement. Thus, B_4C as filler in Al casting decreases density and increase hardness which are needed in various industries like automotive applications.

3.2 Porosity

Figure 4 shows the variation of porosity with the B_4C content. It indicates that a slight increasing amount of porosity is observed with increasing the B_4C particles of the composites.

The porosity level increased, since the contact surface area was increased. It is also reported by the early works (Chen et al., 2018; Tariq et al., 2018). This is attributed to increasing surface gas layers surrounding particles, increasing effective viscosity of suspension resulting in a higher gas hold up as well as improper filling of the gaps between adjacent particles and increasing sites for heterogeneous pore nucleation.

3.3 Tensile strength

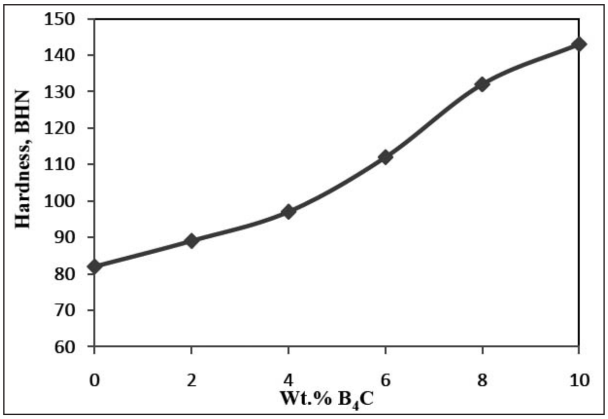

Fig. 3. Variations of hardness of the stir cast composites as a function of coated B_4C content.

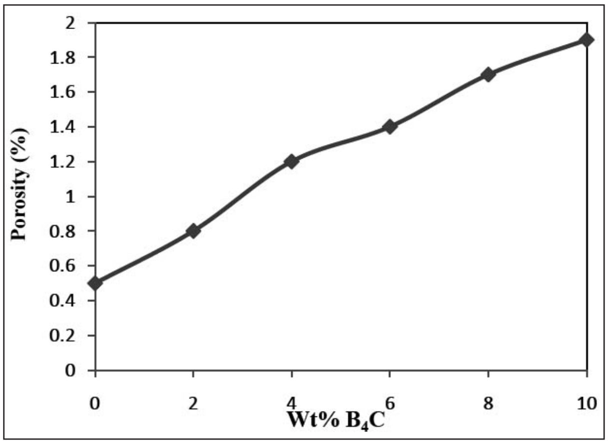

Fig. 4. Variations of porosity of the stir cast composites as a function of coated B_4C content.

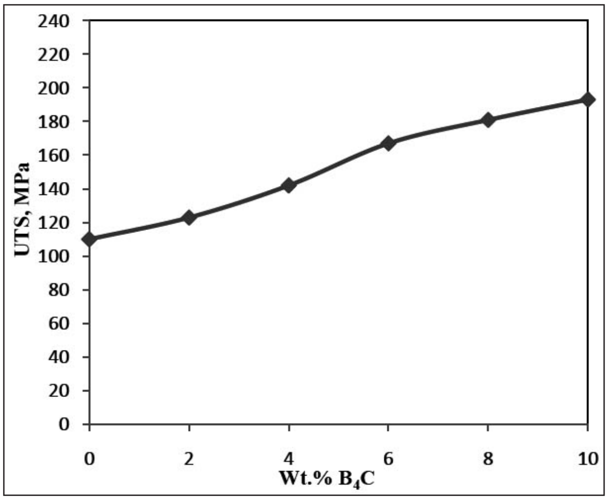

Fig. 5. Variations of UTS of the stir cast composites as a function of coated B_4C content.

The influence of B_4C particles content on the Ultimate tensile strength (UTS) of the MMC is shown in Figure 5. It was noted that the UTS increases with the addition of B_4C particles. The UTS shows the peak value of 198MPa for 10wt% B_4C and shows an increase of strength to 44% when compared to base alloy. This is due to the hard B_4C, which act as barriers to the movement of dislocation and refines the structure of matrix. The size ranges of the B_4C indicate that the composite prepared can be considered as dispersion strengthened as well as particle reinforced composite (Lokesh & Karunakara, 2020). This may be due to segregation of particles and finer grain structure of the castings. Thus the strengthening of composite can be due to dispersion strengthening as well as due to particle reinforcement. Dispersion strengthening is due to the incorporation of very hard B_4C particles which help to restrict the dislocations, whereas in particle strengthening, load sharing is the mechanism.

3.4 Tensile elongation

The percentage elongation for stir cast composites is shown in Fig.6. Ductile material show larger deformation before fracture and it is observed clearly in elongation curve. The lesser remained

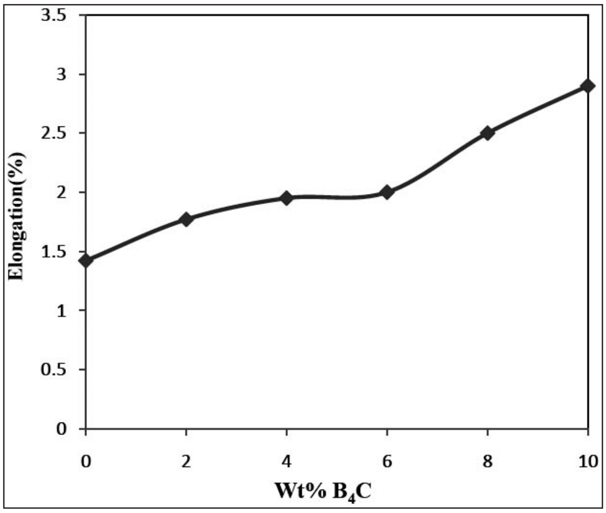

Fig. 6. Variations of elongation of the stir cast composites as a function of coated B_4C content.

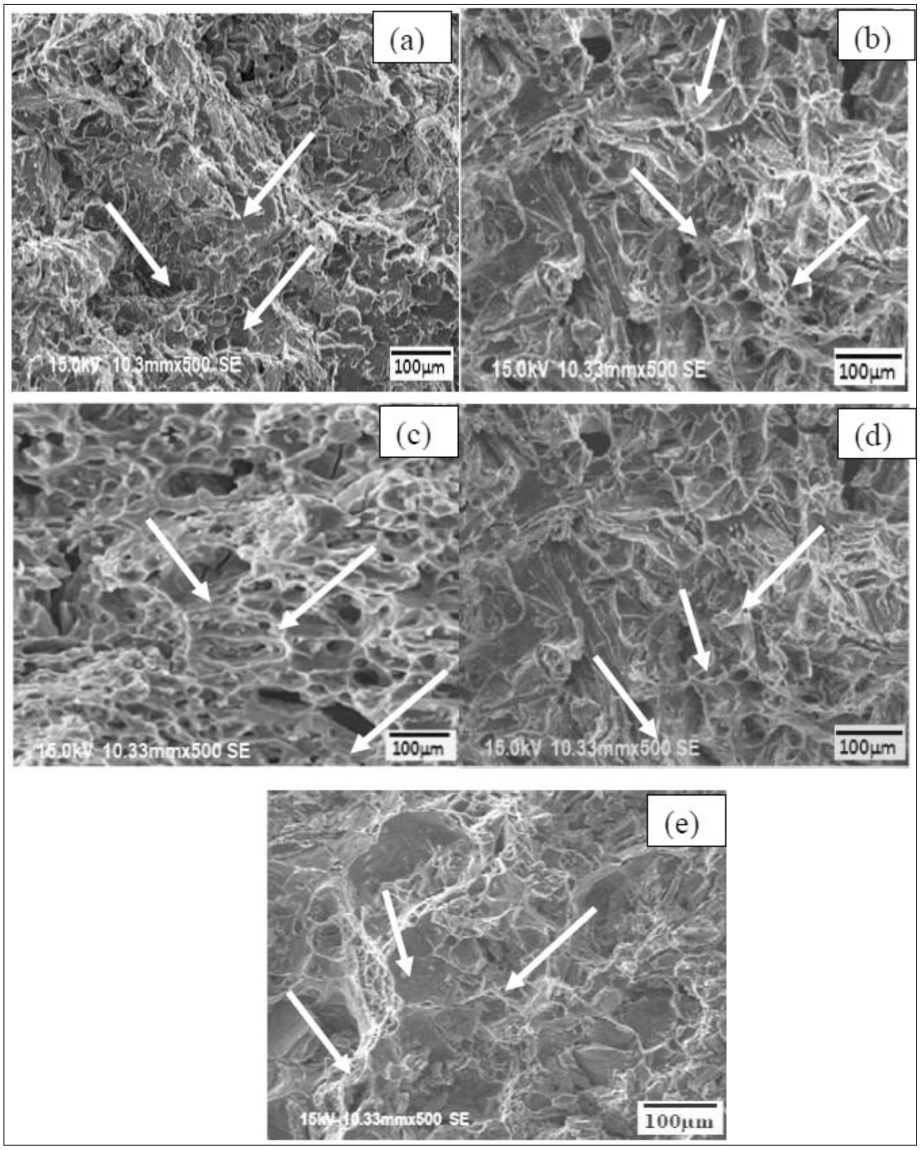

Fig. 7. SEM of Fractured Tensile Specimen: (a) Al-2024/2wt%B_4Cp, (b) Al-2024/4wt%B_4Cp, (c) Al-2024/6wt%B_4Cp, (d) Al-2024/8wt%B_4Cp and (e) Al-2024/10wt%B_4Cp.

porosity can be an important reason for higher strength and ductility for B_4C reinforced samples. The reinforcement distribution may have great effect on ductility and so, the better the distribution of hard particles the greater the ductility (Mazaheri et al., 2013). As deformation continues, the stress increases on account of strain hardening until it reaches the ultimate tensile stress. Until this point, the cross-sectional area decreases uniformly because of Poisson contractions. Then it starts necking and finally fractures. The appearance of necking in ductile materials is associated with geometrical instability in the system. Due to the natural in homogeneity of the material, it is common to find some regions with small inclusions or porosity within it or surface, where strain will concentrate, leading to a locally smaller area than other regions. For strain less than the ultimate tensile strain, the increase of work-hardening rate in this region will be greater than the area reduction rate, thereby make this region harder to be further deform than others, so that the instability will be removed, i.e. the materials have abilities to weaken the in homogeneity before reaching ultimate strain. However, as the strain become larger, the work hardening rate will decreases, so that for now the region with smaller area is weaker than other region, therefore reduction in area will concentrate in this region and the neck becomes more and more pronounced until fracture. After the neck has formed in the materials, further plastic deformation is concentrated in the neck while the remainder of the material undergoes elastic contraction owing to the decrease in tensile force.

3.5 Tensile fracture

Figure 7 shows the tensile fractured surface examination of Al-2024/B4Cp composites. The presence of intact reinforcement particles (marked with inserted arrow) on the fracture surface indicated that bonding between boron carbide and aluminum was good. Dimples presented on the fracture surface indicating that based alloy deformed with a ductile manner in microscopic view. Addition of Mg during melting of the Al-alloy matrix improved the wettability resulting in certain bonding at the particulate-matrix interface (Lokesh et al., 2014). It should be noted that other factors such as the grain refinement and strain hardening by dislocations may also contribute to increasing the strength by correct mixing the molten metal. The two regions are visible on the surface where a flat surface located around B_4C particles and on area in the matrix including fine dimples. All B_4C particles were broken by brittle mechanism and it is the combination of soft mechanism in matrix due to which formation of dimples and a cleavage mechanism around and inside of B_4C precipitates. There are still some cracks visible inside the B_4C fracture and this proved that, during tensile test, more than one crack is formed in the bulk of B_4C particle and finally one of them leads to breakdown of B_4C particles. The fracture surfaces consist of numerous dimples on the matrix shown in arrows and decohesion of the B_4C particles from the matrix. The dimples should be a result of the void nucleation and subsequent coalescence by strong shear deformation and fracture process on the shear plane, while the decohesion of the B_4C particles can be explained by "pull-out" of the ceramic phases caused by high stress concentration during tensile and it is in par with literature (Wang et al., 2011).

4. Conclusion

In this study, B_4C particles were coated with TiB_2 and incorporated successfully into Al-2024 matrix via stir casting process. It is observed that porosity level increased slightly with increasing particulate content. These results can be attributed to the increased surface area of the B_4C particles which can in turn increase the porosity levels. The hardness of the MMCs increases with the wt% of B_4C particulates due to the increasing ceramic phases of the matrix alloy. The higher hardness of the composites could be attributed to the fact that B_4C particles act as obstacles to the motion of dislocation. It was noted that UTS of the MMCs was higher than that of the unreinforced Al alloy and increased with increasing of B_4C content. SEM analysis reveals a better interfacial bonding at the particulate-matrix interface.

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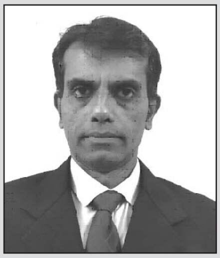
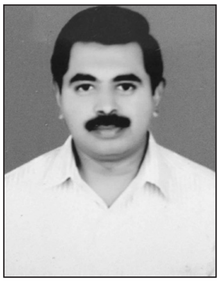


Dr. G.N. Lokesh is presently working as Associate Professor in Mechanical Engineering, at Presidency University, Bangalore. He is a graduate in Mechanical Engineering from Dayananda Sagar College of Engineering, Bangalore and M.Tech. in Production Engineering from UBDT College of Engineering, Davangere. He was awarded Ph.D in the year 2017 by Visvesvaraya Technological University, Belgaum, and having a teaching experience of more than 21 years. He is a BOE/BOS member at VTU and he was also worked in Karnataka State Road Transport Corporation and worked on problem solving in fuel injectors at Divisional workshop in Tumkur Depot. He has published more than 30 technical papers in international journals and conferences. His specialization includes CAD/CAM, TQM, Non Traditional Machining, Non Destructive Testing and Hybrid composites for its secondary process and he is a life member of Indian society for Technical Education.

Shivakumar S. is presently working as Assistant Professor, Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore affiliated to Visvesvaraya Technological University, Belgaum, India. He graduated in 2001 and obtained his post graduation in 2006, He is pursuing his research under the guidance of Dr. G. Balakumar. He has 16 years of teaching experience and published 6 National papers & 3 International papers. His area of interest is Design Engineering. He is having vast experience in teaching Mechanical Engineering subjects such as Mechanics of Materials, Design of Machine elements, Control Engineering, Hydraulics and Pneumatics, Computer Aided Engineering Drawing, Theory of Elasticity, Theory of Plasticity Kinematics of Machines, Robotics and also having vast experience in handling the various Mechanical Engineering laboratories. (E-mail: hkumar.hiremath@gmail.com)



Rohit B. Gonemma Navara is presently working as Junior Design Engineer at Desmaco Engineering Services PVT LTD, Bangalore. He is a B.Tech graduated in Mechanical Engineering from Presidency University, Bengaluru and his interest includes Characterization of Metal Matrix Composites for Automotive applications, Design of Die for extrusion, and rolling. He has having a good experience on software skills and expertize in CATIA, UGNX, FIDES, MATLAB and interested in solving Taguchi Techniques.

Preetham T.R. is presently working as Junior Design Engineer at Desmaco Engineering Services PVT LTD, Bengaluru. He is a B.Tech graduated in Mechanical Engineering from Presidency University, Bengaluru and his interest includes Mechanical Design and Development and known software skills are CATIA, UGNX, FIDES, MATLAB.