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Mechanical and metallurgical characterization of AA7075 matrix composite reinforced with Zirconium Boride (ZrB_2) synthesized by stir casting route

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Abstract

In this study AA7075 alloy matrix reinforced with Zirconium boride (ZrB_2) ceramic particle reinforced composite was made by electric stir casting furnace and two different weight percentage (such as 10 and 20) of ZrB_2. EDAX analysis, optical microstructure and scanning electron microscope image was used to analyse the metallurgical characterization of the produced composites andmacrohardness, microhardness and ultimate tensile test (UTS) were carried out for the mechanical characterization of the composites. AA7075 alloy matrix were casted and the results of composites were compared with AA7075 alloy to find out the impact of inclusion of ZrB_2 in AA7075 matrix alloy. Uniform distribution of ZrB_2 particles in the matrix was confirmed by optical and SEM images. Macrohardness and microhardness of the AA7075/20 wt.% ZrB_2 composite were 76% and 85% higher than that of AA7075 matrix alloy. Similarly, UTS of AA7075/20 wt.% ZrB_2 composite was 99% higher than that of AA7075 alloy. But percentage of elongation of the composite was reduced by the addition of ZrB_2 ceramic particles.

Keywords: aluminium matrix composite, electric stir casting furnace, SEM, ultimate tensile strength.

1. Introduction

Aluminium alloys widely used in various engineering applications due to its light weight, higher stiffness and moderate tensile strength. Its mechanical properties are enhanced by the inclusion of hard ceramic elements in the aluminium and the obtained product is called aluminium matrix composites (AMCs). Variety of methods are followed to develop the AMCs such as powder metallurgy [1], in situ reaction [2], powder injection moulding [3], squeeze moulding [4], pressure infiltration of liquid aluminium [5] and stir casting route [6]. Stir casting method is widely employed to fabricate AMCs as the developed AMCs by stir casting process have near net shape, complicated shapes can be produced, the process is flexible, simple, economical and appropriate for mass production. Mohanavel et.al. [7] studied the mechanical and metallurgical characterization of AA7570/TiB_2 composite fabricated by stir casting process. Hardness of AA7075/15 weight % of TiB_2 was 78 BHN which is 17 % greater than that of its matrix alloy. Dinesh Kumar et.al. [8] analysed the impact of zirconium boride particles on corrosion, mechanical and microstructural analysis of AA7178 alloy matrix composites. The composite was prepared by stir casting process. Harness, yield strength, tensile strength and flexural strength of AA7178 reinforced upto 10 weight % of ZrB_2 were increased and then decreased for further addition of ZrB_2 in the matrix alloy. Composite containing 15 weight % of ZrB_2 possessing better corrosion resistance. Ashok Kumar [6] synthesized the AA6061 matrix composite reinforced with aluminium nitride of 5, 10, 15 and 20 by weight %. Mechanical and metallurgical characterization were made. UTS of AA6061/20 weight % of AlN composite was 46.95% higher than that of its AA6061 matrix alloy and microhardness of this composite was 106% higher than that of matrix alloy.

In this study AA7075 matrix composite reinforced with ZrB_2 ceramics particles are synthesized by stir casting route and its mechanical and metallurgical characterization was analysed.

2. Experimental Procedure

Required quantity of AA7075 alloy (Zn-5.6, Mg-2.6, Cu-1.6, Si-0.3, Fe-0.30, Mn-0.2, Ti-0.2 Ni,-0.02 and Al- Balance by wt.%) of diameter 25 mm and 150 mm length rods were heated in the electric stir casting furnaces facilitated with bottom pouring. Fig. 1 shows the electric stir casting furnace. Once the aluminium changed in to liquid state, the molten alloy was started to stirred by the stirrer in 400 rpm and then the required amount of ZrB_2 particles were added. Argon gas was continuously supplied into the furnace @ 2 litres per minute right from the aluminium alloy reached the temperature of 500 ºC to till the slurry was poured into the mould to avoid the chemical reaction between the materials involved in the casting with atmosphere [15]. Proper stirring speed in essential as the lesser stirring results accumulation of ceramic particles and on the other hand higher stirring speed causes entrapment of gases into the slurry and leads to porosity. The slurry was stirred for 600 s and then poured into the mould cavity of size 50 mm x100 mm x 70 mm. Before pour the slurry, the mould was preheated in an electric heater to avoid the sudden cooling of molten slurry in the mould. The electric heater used to preheat the permanent mould is shown in Fig. 2. In this way the composite containing 20 weight percentage of ZrB_2 composite and AA7075 alloy were fabricated [14]. The specimens for the various analysis were cut from the AA7075/10 and 20 weight % of ZrB_2 cast composites and AA7075 cast alloy by wire cut electrical discharge machining process. For EDAX, optical microscopy and SEM images specimen of size 25 mm x 25 mm x 6 mm were prepared and those specimens were polished from various grades of SiC emery sheets from 180 grit SiC to 1200 grit. Thereafter polished specimens were further polished by disc polishing machine with diamond paste of size 6, 3 and 0.5 microns. The polished specimens were etched by an etchant containing 1-2 g ammonium bifluoride, 5 ml HCl (35%) and 2-3 g sodium molybdate in 100 ml distilled water [9]. Then the polished specimens were washed by acetone and EDAX analysis and SEM images were captured by using a scanning electron microscope integrated with energy dispersive spectroscope (JEOLJSM-6390) andoptical microstructure were captured by optical microscope - OLYMPUS-BX51M.

A microhardness tester (MITUTOYO-MVK-H1) was employed to measure the microhardness. At twenty different locations a load of five hundred grams was applied for fifteen seconds. Mean values of microhardness was used to draw a graph. A Brillnell hardness tester was used to measure the macrohardness of the specimens where five hundred kg load was applied for fifteen seconds at ten different locations and the mean values are used to draw the graph. As per ASTM E8 M-11 standard, three specimens for tensile test were cut from the each AA7075/ZrB_2 composite having 10 and 20 weight % of ZrB_2 and AA7075 alloy. Fig. 3 and 4 depict the dimensions of the tensile specimen and prepared tensile specimen as per ASTM E8 M-11 respectively. The prepared tensile specimens are also shown in Fig. 4. A Computerized Universal Testing Machine (UTM) -HITECH TUE-C-1000 was employed to calculate the UTS and elongation percentage of the specimens. Average values are used to calculate the UTS and elongation percentage of composites and matrix alloy.

Fig. 1 Electric stir casting furnace employed to fabricate AA7075/ZrB_2 composites

Fig. 2 Preheater of permanent mould

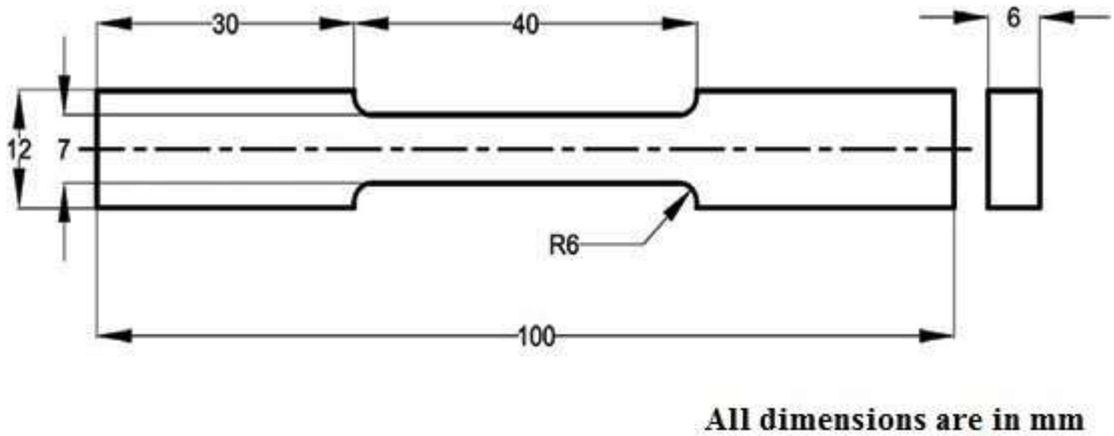

Fig. 3 Dimensions of the tensile test sample according to ASTM E8/E8 M-11 standard.

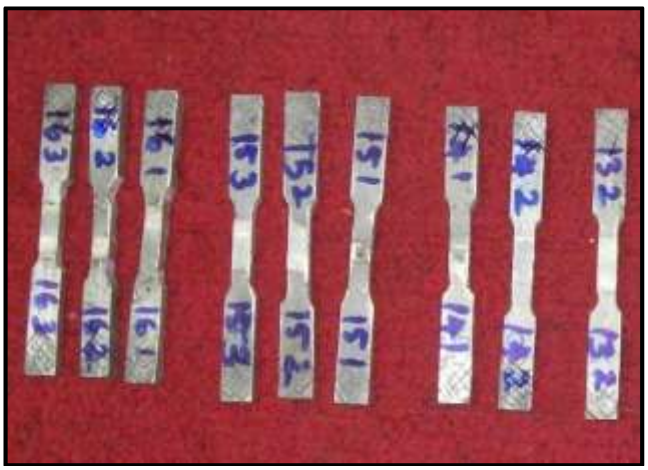

Fig. 4 Fabricated tensile test samples according to ASTM E8/E8 M-11 standard.

3. Results and Discussions

The stir casting approach with optimal process parameters was used to successfully make AA7075 alloy matrix reinforced with 10 and 20 weight percent ZrB_2composites. The next sections detail the metallurgical and mechanical characterisation studies of the fabricated AA7075/ZrB_2composites.

Fig. 5 depicts the EDAX analysis of AA7075/10 weight % of ZrB_2 composites which confirms the existence of ZrB_2 particles in the matrix. This ensures that no chemical reactions were taken place between the AA7075 matrix and ZrB_2 particles during the casting. Figure 6 shows the optical microstructures of AA7075 alloy and AA7075 alloy matrix composites reinforced with 10 and 20 weight % ZrB_2. Figure 6a shows the optical microstructure of cast AA7075 alloy. The microstructure revealed alpha-aluminum dendritic network formations. The quick cooling of the AA7075 alloy during solidification is responsible for the formation of alpha-aluminium dendritic. Precipitation of the inorganic compound magnesium silicate (Mg_2Si) can be seen in the microstructure. Micrographs of AA7075/10 and 20 wt. percent ZrB_2 composites are shown in Fig. 6b. In these micrographs, the ZrB_2 reinforcement particles are more evenly dispersed in the matrix, and there is no sign of porosity or other casting defects. This implies that the composites were cast using proper casting procedures. The reasons for alpha-aluminium grain refining are as follows: i) ZrB_2 particles are pushed in the direction of refined alpha-aluminium grains during the solidification of the AA7075 / ZrB_2 composite. ii) Alpha-aluminium grains cling to ZrB_2 particles, which serve as a nucleus [10]. The precipitation of Mg_2Si in the matrix is depicted in Figure 6a. The main elements of the AA7075 alloy are Si and Mg is the reason for the formation of Magnesium silicide. The microstructure of composites revealed no oxide layer inclusions or intermetallic complexes. It could be owing to the crucible's constant supply of inert argon gas. The SEM picture of AA7075 / 10 and 20 wt. percent ZrB_2 composites is shown in Fig. 7. The dispersion of ZrB_2 reinforcement particles in the matrix alloy is more homogeneous, as seen in SEM micrographs.

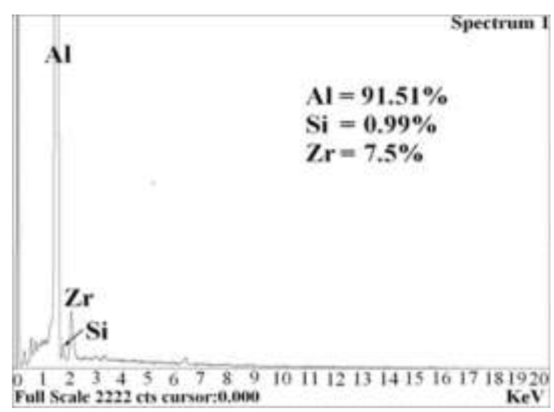

Fig. 5 EDAX Analysis of AA7075/10 weight % ZrB_2 Composite

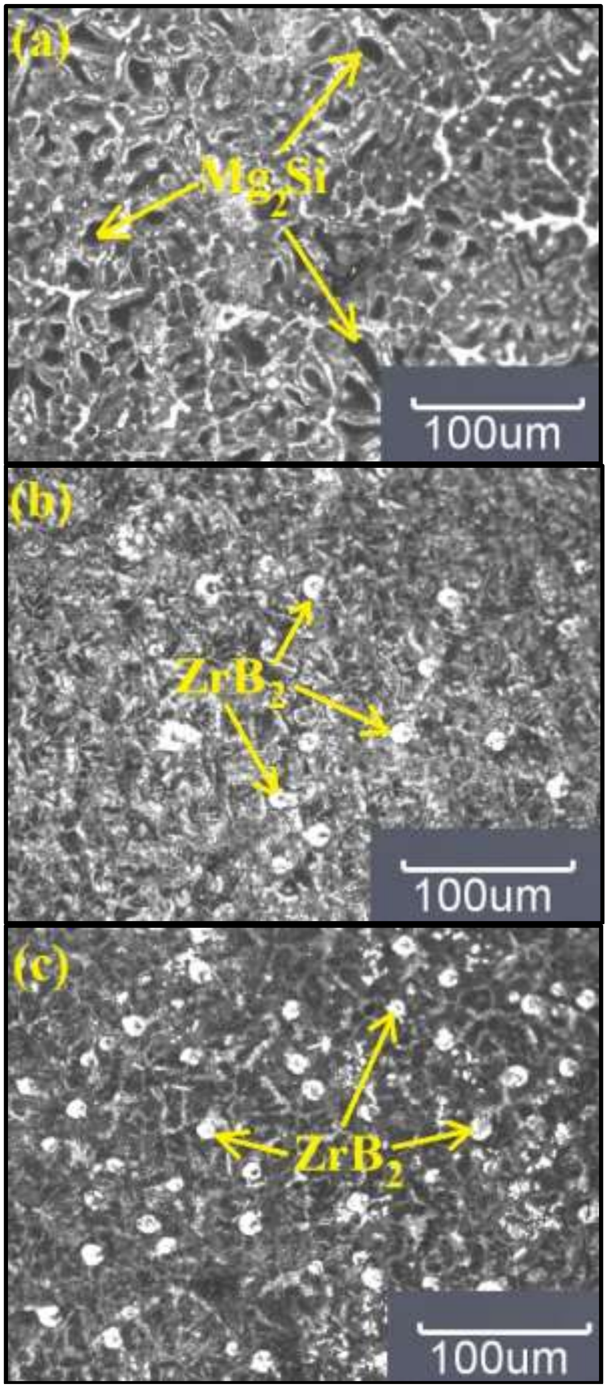

Fig. 6 optical microstructure of AA7075 matrix composite containing a) 0 weight % of ZrB_2 b) 10 weight % of ZrB_2 and c) 20 weight % of ZrB_2

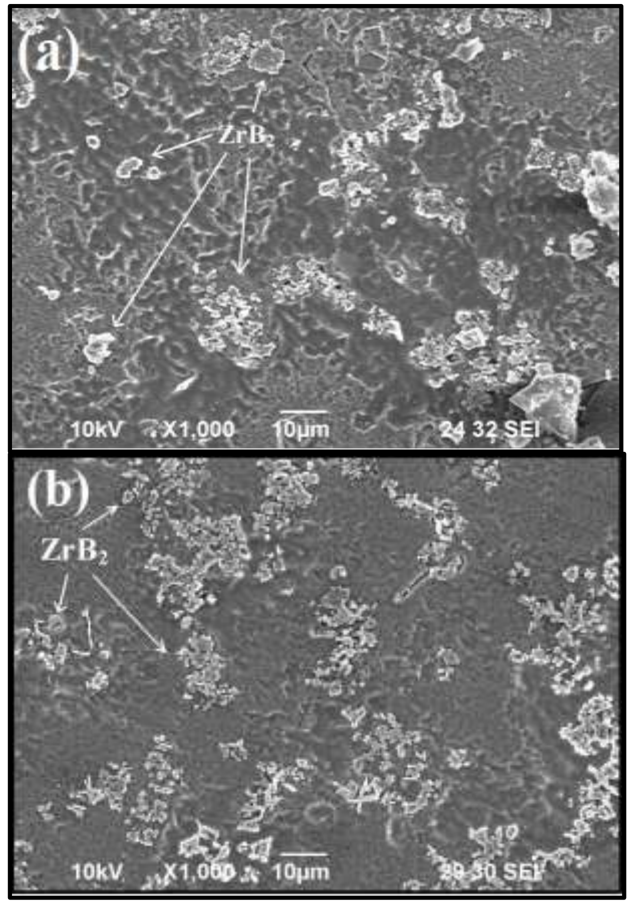

Fig. 7. SEM image of AA7075 composite reinforced with a) 10 weight % of ZrB_2 and b) 20 weight % of ZrB_2

Figure 8 shows the microhardness values of AA7075 alloy and AA7075 / 10 and 20 wt. percent ZrB_2composites. Both the hardness of the AMCs are increased when inclusion of ZrB_2 elements in the AA7075 alloy matrix increase linearly. AA7075 / 10 and 20 wt. percent ZrB_2composites have microhardness of 79 VHN and 102 VHN, respectively, which are 36.2 percent and 75.86 percent higher than the AA7075 matrix alloy. The AA7075 alloy has a microhardness of 58 VHN. Similarly, the macrohardness of the AA7075 /10 and 20 wt. percent ZrB_2composites is 74 BHN and 96 BHN, respectively, which is 42.30 percent and 84.61 percent higher than the AA7075 matrix alloy. The AA7075 alloy has a macrohardness of 52 BHN. Figure 9 shows the average UTS and elongation percentage of AA7075 matrix and AA7075 matrix composites with 10 and 20 wt.% ZrB_2 reinforcement particles. The UTS of the AA7075 /10 and 20 wt% ZrB_2 samples were 288.66 and 369.48 MPa, respectively. The addition of ZrB_2partices (which have a lower thermal strain of 6.6 x 10^{-6}/K) to an aluminium alloy (which has a greater thermal strain of 23.6 x 10^{-6}/K) affects the microstructural alterations in the matrix, improving the composites strength. The grain size and substructure of an aluminium matrix alloy are reduced as the amount of ZrB_2ceramic particles in the alloy grows, but the dislocation density surrounding the ZrB_2particles increases during solidification. [11].

Hard ceramic ZrB_2particles in the molten aluminium alloy give extra heterogeneous nucleating sites during solidification. As a result, the grain size of the AA7075 matrix alloy has shrunk even more. Under the operation of a far-field stress, all of these microstructural modifications increase the resistive force against macroscopic and microscopic level dislocations [12]. As a result, increasing the amount of ZrB_2 in the matrix enhances the composites' hardness and UTS. Figure 9b shows the effect of ZrB_2 reinforcement on the composite's percent elongation (PE). The ductility of the aluminium matrix is reduced as a result of: (i) an increase in the quantity of hard ZrB_2in the AA7075 matrix, which minimize plastic flow of matrix alloy; (ii) increment of grain boundaries per unit area caused by the refinement of grains as the number of turns of the dislocation path increases as reinforcement particles are incorporated; and (iii) an increase in the weight percentage of ZrB_2reinforcement particles in the matrix [13].

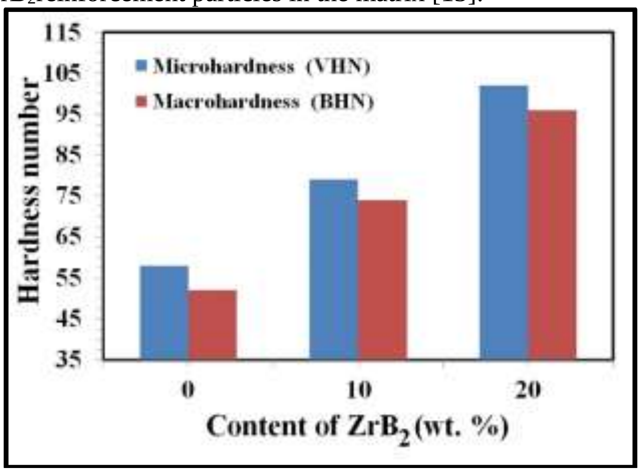

Fig. 8 microhadness and macrohardness of the AA7075/ZrB_2 composites

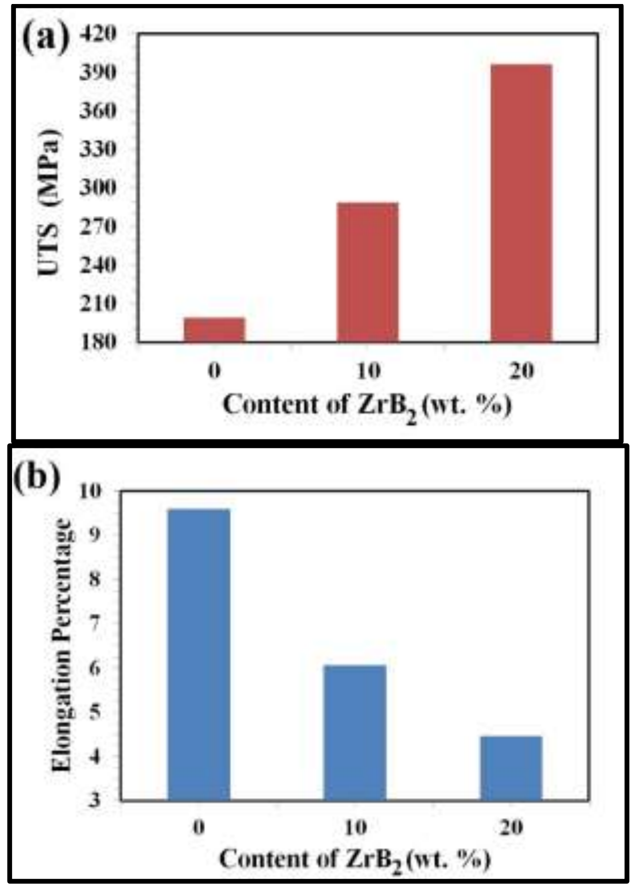

Fig. 9 a) UTS and b) Elongation percentage of AA7075/ZrB_2 Composites

4. Conclusions:

- ➢ AA7075 alloy and AA7075 alloy matrix composites with 10 and 20 weight percent ZrB_2 reinforcement were effectively synthesised using an indigenously built customized stir casting furnace with bottom discharge attachment.
- ➢ In the AA7075 matrix, ZrB_2 reinforcement particles were more evenly disseminated.
- ➢ The inclusion of ZrB_2particles enhanced the hardness and UTS of the AA7075 / ZrB_2composite. The microhardness and macrohardness of the AA7075 /20 wt. ZrB_2composite were 102 VHN and 96 BHN, respectively, which are 76 % and 85 % higher than those of the AA7075 matrix alloy. The UTS of AA7075 was 159.82 MPa, but in the AA7075 /20 wt. percent ZrB_2composite, it was enhanced to 396.48 MPa. However, when the number of particles in the composite increased, the percent elongation of the composite decreased. The AA7075 alloy has a percent elongation of 9.6, which is reduced to 4.46 in the AA7075 /20 wt. ZrB_2 composite.

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