Assessment of Tensile Behavior of Boron Carbide/AA2024 Alloy Metal Matrix Composites

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Abstract: The present work was intended to assess the influence of boron carbide particle loading on the tensile behavior of B_4C/AA2024 alloy metal matrix composites. The results obtained by the finite element analysis through RVE models were compared with those of tensile specimens fabricated by the stir casting process. The adhesive bond was broken between the boron carbide particle and AA2024 alloy matrix in the composite when the stress exceeded the tensile strength (345 MPa) of the matrix. The stiffness of B_4C/AA2024 alloy metal matrix composites increased with increased content of B_4C.

Keywords: AA2024 alloy, boron carbide, RVE model, finite element analysis, stir casting process.

1. INTRODUCTION

Metal matrix composites (MMCs) open up unlimited possibilities for advanced material science and development; the characteristics of MMCs can be designed into the material, custom-made, dependent on the application. Reinforcement materials for metal matrix composites have numerous requirements, which is determined by production and processing and by the matrix system of the composite material. Melt stirring is used for the production of particle-strengthened aluminum alloys [1]. Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface [2]. The finite element procedure and analytical methods have been exceptionally effective in determining the mechanical properties of non-homogeneous materials like composites. Currently, the use of a representative volume element (RVE) or a unit cell [3] of the composite microstructure, in conjunction with a finite element (FE) analysis tool is well established for examining the effective material properties and understanding the micromechanics of the composite materials. Boron carbide is (B_4C) is an extremely hard boron–carbon ceramic, and Ionic material used in tank armor, bullet proof vests and engine sabotage powders.

The objective the present paper is to investigate the effects of particle size and volume fraction of boron carbide as a reinforcement material in AA2024 alloy matrix. Finite element analysis (FEA) of B_4C/AA2024 alloy metal matrix composites was carried out through RVE models. The results obtained from the FEA were verified with those obtained from experimentation. B_4C/AA2024 alloy metal matrix composites were fabricated using stir casting process.

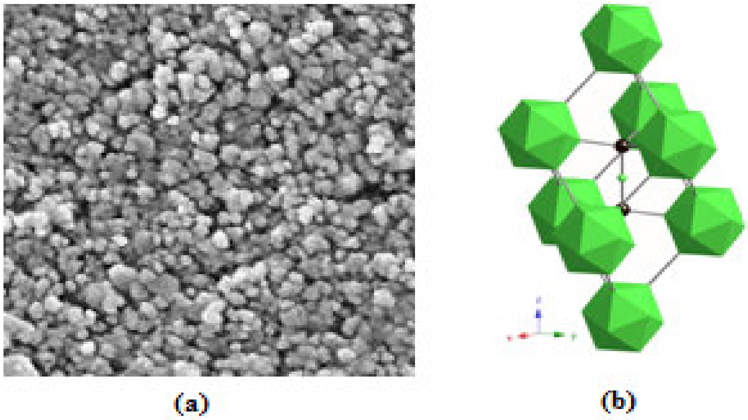
(a) (b)

Figure 1: Boron carbide powder (a); a unit cell of B_4C (b).

2. MATERIALS AND METHODS

The matrix material was AA2024 alloy. The reinforcement material was boron carbide (B_4C) particles of average size 200 nm. The morphology of boron carbide particles is shown in figure 1. The green sphere and icosahedra consist of boron atoms, and black spheres are carbon atoms. Boron carbide has a complex crystal structure typical of icosahedron-based borides.

2.1 Preparation of Composite Specimens

The matrix alloys and composites were prepared by the stir casting and low-pressure die casting process. The volume fractions of boron carbide reinforcement were 10%, 20%, and 30%. AA2024 matrix alloy was melted in a resistance furnace. The crucibles were made of graphite. The charge was fluxed with coverall to prevent dressing. The molten alloy was degasified by tetrachlorethane (in solid form). The crucible was taken away from the furnace and treated with sodium modifier. Then the liquid melt was allowed to cool down just below the liquidus temperature to get the melt semi solid state. At this stage, the preheated (500^0C for 1 hour) reinforcement particles were added to the liquid melt. The molten alloy and reinforcement particles are thoroughly stirred manually for 15 minutes. After manual steering, the semi-solid, liquid melt was reheated, to a full liquid state in the resistance furnace followed by an automatic mechanical stirring using a mixer to make the melt homogenous for about 10 minutes at 200 rpm. The temperature of melted metal was measured using a dip type thermocouple. The preheated cast iron die was filled with dross-removed melt by the compressed (3.0 bar) argon gas. All the samples were set for T4 heat treatment prior to the machining of composite samples for tensile testing.

2.2 Tensile Tests

The heat-treated samples were machined to get flat-rectangular specimens (figure 2a) for the tensile tests. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) at a specified grip separation and pulled until failure. The test speed was 2 mm/min (as for ASTM D3039). A strain gauge was used to determine elongation as shown in figure 2b.

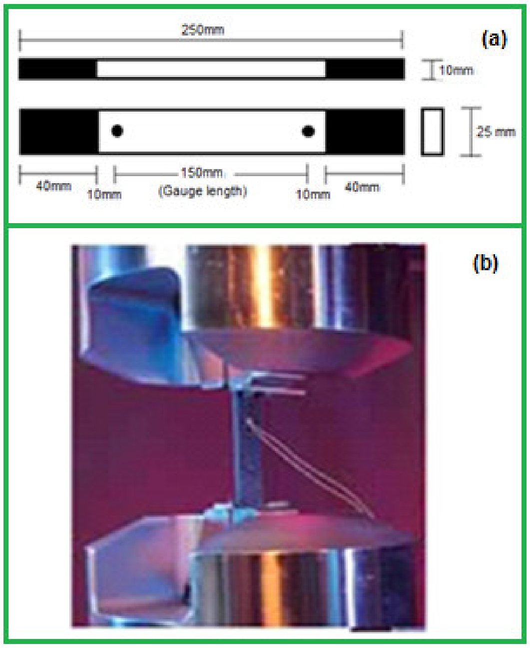

Figure 2: Shape and dimensions of tensile specimen; (b) tensile testing.

2.3 RVE Modeling using Finite Element Analysis

In this research, a cubical RVE was implemented to analyze the tensile behavior of boron carbide as shown in figure 3. B_4C/AA2024 alloy metal matrix composites (figure 4). The volume fraction of the nanoparticles in the composite (vp) was chosen to be 0.10, 0.20 and 0.30; the nanoparticle radius (r) was taken to be 200 nm. The RVE scheme with adhesion (without interphase) was applied between the matrix and the filler. The PLANE183 element was used for the matrix and the nanoparticle. In order to model the adhesion between the matrix and the particle, a COMBIN14 spring-damper element was used. The stiffness of this element was chosen to be unity, which determines the interfacial strength for the interface region. To converge an exact nonlinear solution, it is also important to set the strain rates of the FEM models based on the experimental tensile tests' setups. In this respect, the ratio of the tensile test speed to the gauge length of the specimens should be equal to the corresponding ratio in the RVE displacement model.

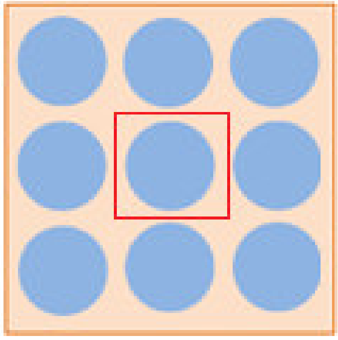

Figure 3: The RVE model.

3. RESULTS AND DISCUSSION

Figure 4 describes the tensile properties of B_4C/AA2024 alloy metal matrix composites obtained by FEA and experimental procedure. The tensile properties, in general, increased with an increase of boron carbide content in the composites. For composites having 20% B_4C, the tensile strains were decreased very marginally (figure 4a). The elastic modulus was unchanged for change of B_4C content in the composites from 20% to 30% (figure 4c). The results obtained by the finite element analysis (FEA) were higher than the experimental values. This was due to ignoring of the agglomeration of B_4C particles and porosity due to stir casting process during finite element modeling. As seen from figure 5, the AA2024 matrix material had experienced larger strains than B_4C reinforcing particles.

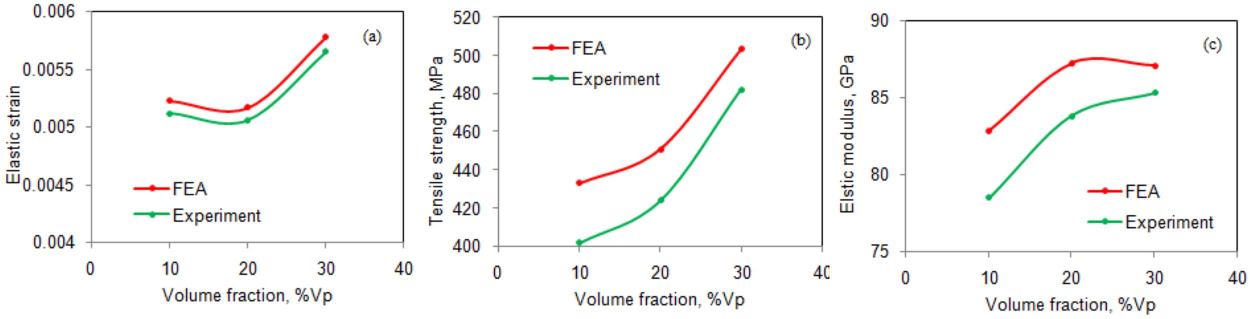

Figure 4: Effect of volume fraction on tensile strength.

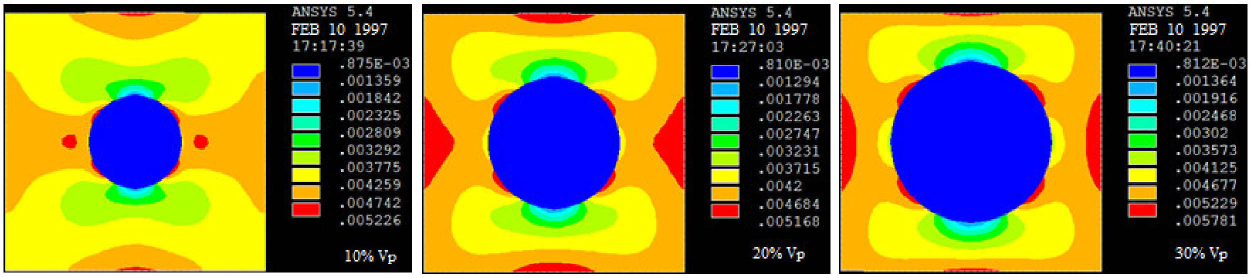

Figure 5: Elastic strain developed in B_4C/AA2024 alloy metal matrix composites.

The tensile strengths of AA2024 alloy and B4C particles, are, respectively, 345 MPa and 417 MPa. For composites comprising low volume fraction (10% Vp) of B_4C, the reinforcing particle had undergone severe stress due to failure of AA2024 matrix material and subsequent load transfer from the matrix to the reinforcing particle. For composites comprising high volume fraction (30% Vp) of B_4C, the interface and near-interface of reinforcing particle had undergone severe stress.

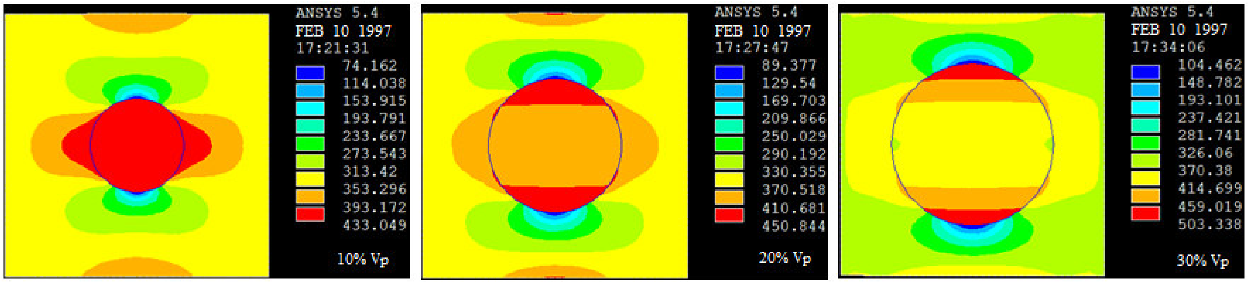

Figure 6: Tensile stress induced in B_4C/AA2024 alloy metal matrix composites.

Figure 7 shows the variation of von Mises stress in B_4C/AA2024 alloy metal matrix composites. The von Mises stress increased with an increase of boron carbide content. It is observed that the interfacial debonding was high between the particle and the matrix because the local stress concentration around the B_4C particle increased with an increase in the volume fraction.

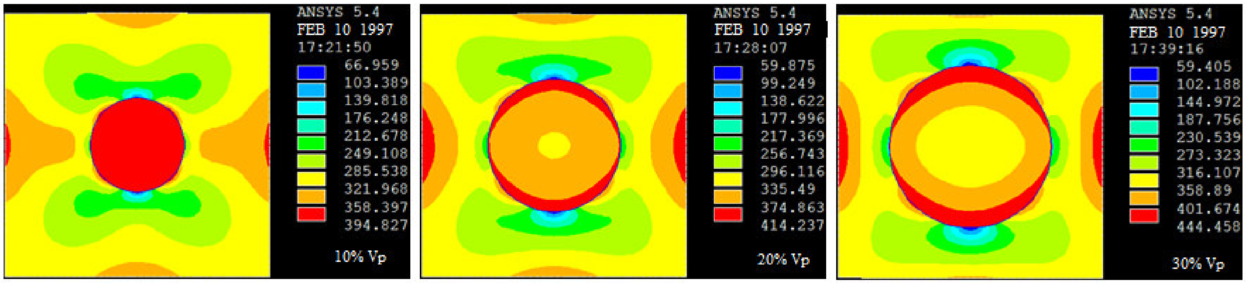

Figure 7: von Mises stress induced in B_4C/AA2024 alloy metal matrix composites.

4. CONCLUSION

The tensile strength increased with an increase of boron carbide content. The adhesive bond was broken between the boron carbide particle and AA2024 alloy matrix in the composite when the stress exceeded the tensile strength (345 MPa) of the matrix. The stiffness of B_4C/AA2024 alloy metal matrix composites increased with increased content of B_4C.

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