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Fabrication of Nano-composite Al-B_4C Foam via Powder Metallurgy-Space Holder Technique

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Abstract

Nanocomposite Al-B_4C foams were manufactured using five different volume percent of 0.5, 1, 1.5, 2 and 2.5 from B_4C, through powder metallurgy-space holder method. Carbamidewas used as space-holder material in this study. Microstructure and compressive behaviour of nanocomposite Al-B_4C foams were studied. The results show that the mechanical properties were affected by foam porosity size and reinforcing volume percent. The compressive strength increased by nano-B_4C reinforcing volume up to 2 vol.%. It is also found that densification strain of composite Al-B_4C foam decreases with increasing reinforcing volume percent. The maximum yield strength and energy absorption capacity of produced foams of this study were achieved via utilizing 2 vol.% nano-B_4C, which were 23.9 MPa and 11.47 MJ/m^3, respectively.

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*Keywords:*Nanocomposite; Foams; Space-holder; Nano B_4C reinforcement.

1. Introduction

The use of metal foam in aerospace industry, automobile manufacturing, military and other industries is in progress in industrialized countries due to the unique properties of this material, Banhart (2001), Ashby et al. (2000), Moloodi and Raiszadeh (2011). Some of these features include: high energy absorption capability, low relative density, appropriate sound and heat insulation, Ashby et al. (2000), Moloodi and Raiszadeh

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(2011), Sarajan et al. (2011), Taoet al. (2009). To achieve some mechanical and physical properties particularly higher strength in metal foam it is needed to be produced in composite materials. Therefore, many researchers manufacture composite metal foam with reinforcing particles such as SiC, Ugur et al. (2011), Mondal et al.(2014), Al2O3, Alizadeh and Mirzaei (2012), Jingyuan et al. (2008), short fiber, Jiaan et al. (2008) and study their properties.B4C is a ceramic material used as a reinforcing particle in composites due to the unique properties such as high neutron absorption capability (~ 600 bapn), ultra-high hardness (~ 30 GPa), low density (2.52 g cm-3), high melting point (2427 ◦C), as well as high strength and wear resistance with wide use in nuclear industries, military, tool making, turning, etc., Suriet et al. (2010), Yin et al. (2013), Abdollahi and Mashhadi (2014). The use of powder metallurgy techniques in the production of advanced materials is one of the conventional methods. Foam production using powder metallurgy method by space-holder material is a relatively easy and controllable method in the production of metal foam and composite metal foam. In general, the process steps are: 1) mixing metal powder (in composite metal foam with reinforcing particles) with space-holder material, 2) compression of mixtures prepared, 3) removal of space-holder material from the sample, and 4) sintered solid state and liquid state, Banhart (2001). Among the different methods of producing composite metal foam, using powder metallurgy method by carbamide space-holder material is conventional and significant, Jiang et al. (2005). According to the researchers conducted, Bafti and Habibolahzadeh (2010), using this method results in open-cell foam porosity up to 80% simultaneous with acceptable mechanical and structural results. The study deals with production of composite metal foam with B4C reinforcing nanoparticles at different volume percentages using carbamide space-holder material. The powder metallurgy method and mechanical properties of the foam produced including compression test, determination of the yield strength and energy absorption capability have been investigated. The pore structure morphology of the composite foam has also been evaluated using macroscopic and microscopic images.

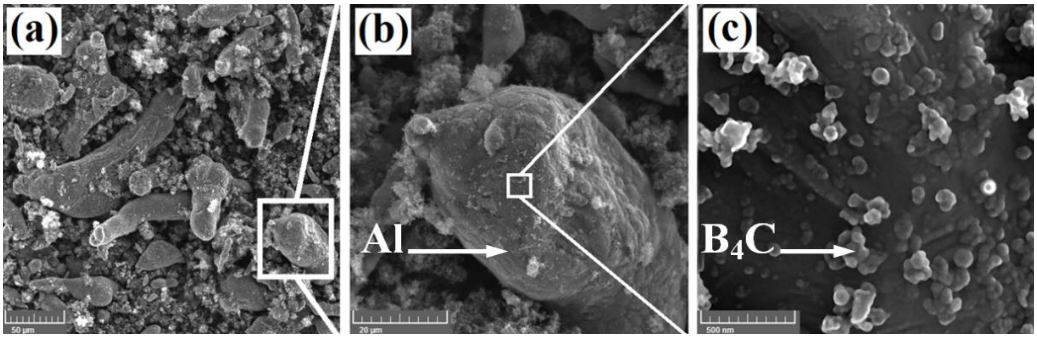

Fig. 1. The FESEM image of: (a) mixture of aluminum powder and B_4C nano particles; (b) an aluminum powder in higher magnification; (c) B_4C nano particles on an aluminum powder.

2. Experimental procedure

Metal used in this research was pure (99.5%) aluminum powder (median diameter 45 μm) and B_4C nanoparticles (median diameter <50 nm) as reinforcing particles in vol.% 0.5, 1, 1.5, 2, and 2.5 and carbamide spherical particles ($(NH_2)_2CO$) as a space-holder material with particle sizes between 2 - 2.3 mm (density equal to 1.33 g/cm^3 and melting point 133 °C and solubility in 20 °C water) in 50 wt.% . Fig. 1 shows different FESEM images of aluminum powder mixture with B_4C nanoparticles.

First, aluminum powder and B4C were mixed with 1 wt.% Sn(<10 μ m) and 1wt.% Mg (<5 μ m) powders via rotary mixer for 3 hours. Afterward mixed powders wasblended with carbamide particles with 2 vol.% of ethanol for 30 minutes to enhance the uniformity of carbamide distribution and create adhesion between particles of the mixture. The mixed material was finally compressed within a steel tube with a diameter of 25mm with 300 to 430 MPa. Remarkably, the amount of mixed raw material was considered in such a way that the ratio of height to diameter $[H/D]$ in the samples prepared is at least 1.5, Bafti and Habibolahzadeh (2010), Hassani et al. (2012).

After pressing the samples in order to dissolve carbamide from the green sample, it was placed in the water container with ambient temperature for 5 h after the operation, samples should be at a temperature of 60 °C for 6 h in the electric furnace to be completely dry, Bafti and Habibolahzadeh (2010), Alizadeh and Mirzaei (2012). The precursor has been finally placed in the furnace with shielding gas at 650 °C for 3h for sintering.Density was measured by Archimedes method. The pressure test was performed by Santam pressure universal testing machine according to standard ASTM E9-09 up to 60% engineering strain with the rate of 1 mm/min on samples with dimensions of length and diameter 25 and 38mm, respectively. Lubricant was used to avoid three-dimensional stress between the gage and samples, Bazzazbonabi et al. (2014). The energy absorption capability which is equal to the area under of stress-strain curve of the compression test was calculated according to equation 1.

$$W = \int_0^{\varepsilon_d} \sigma(\varepsilon) d\varepsilon \quad (\frac{joule}{m3}) \tag{1}$$

Where (ε_d) and (σ) are densification strain and compressive stress, respectively.

3. Results and discussion

3.1. Pore morphology

Figure 2 shows themacrostructure image of composite metal foam. Fig. 2(a and b) show the composite sample of foam produced in the state before and after machining. Fig. 2(c and d) show the composite foam structure of cells (pores) and the cell wall with nearly uniform distribution of cell sizes of 2 – 2.3 mm and different dimensions of the cell wall. By the pore distribution being more uniform, strength properties improve due to a more uniform distribution in the structure of the foam, Kahanikhabushan et al. (2014).

The density of the foam produced was calculated 1.3 g/cm^3 that the relative density of which equals 0.48. In the porous material, cell wall plays a very important role and pore distribution and wall produced between the two cells and the wall between the spheres are highly effective on the physical and mechanical properties of the foam, Bafti and Habibolahzadeh (2010), Kahanikhabushan et al. (2014).

Basically, composites enjoy higher strength properties than monolithic which is due to the proper role and distribution of reinforcing particle material in the matrix, Mondal et al. (2014), Jingyuan et al. (2008). In the composite foam, reinforcing particle distribution in the matrix (cell wall) increases strength. The cell wall intact and perfect with uniform dimensions plays the main role in strength and physical properties, Sirong et al. (2008), Bazzazbonabi et al. (2014). Bansiddhi et al., Bansiddhi and Dunand (2007) produced Ni-Ti alloy metal foam with the use of space-holder materials and investigated its mechanical properties.The main reason for reducing the mechanical properties of the foam produced is non-uniform distribution of the pores in the structure of the piece and being closer to each other in parts of the sample. This led to fracture cell walls and a sharp reduction in the strength and energy absorption capability.

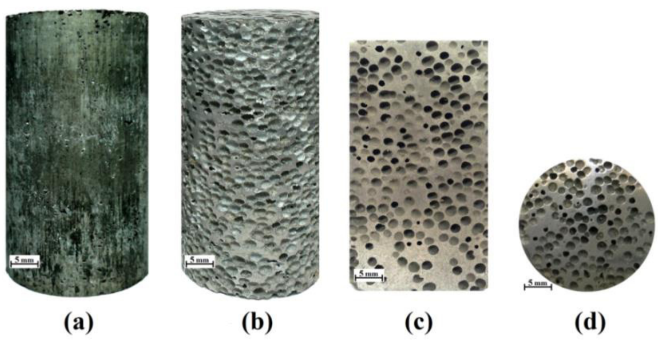

Fig. 2. Cell structures and cell walls in composite metal foam: (a) normal sample; (b) surface machined sample; (c) Vertical sectionsd; (d) Cross-section.

Zhao et al. (2009) produced Ni-Ti metal foam using space-holder materials, too. The biggest problem of foam produced by them was small pore sizes less than 5 µm in the cell wall, which is unwanted porosity reducing the strength of the foam. Wang et al. (2010) produced copper foam with the use of space-holder material. Foam produced by them had fine pores in the cell walls and close to the cavity due to the crunch of space-holder materials during the press as reported. On the other hand, reported by Jiang et al. (2007) who examined the mechanical properties of foams produced with the use of carbamide space-holder both spherical and angular. It is determined that the foam produced using the spherical carbamide has much more favorable mechanical properties than the angular carbamide. Fig. 3 shows SEM images of the cell walls, pores and fracture surface produced after the pressure test. Fig. 3a displays the healthy cell wall of the composite foam produced. If the pressure amount is low in production it leads to a lack of proper bonding between the components; conversely, if the pressure is too much it can fracture and crunch the carbamide as well as the conversion of spherical pores to semi-spherical causing much influence on the physical and mechanical properties. In addition to the composite foam healthy cell walls which increase mechanical properties, uniform distribution of reinforcing particles in matrix (cell wall) also plays an important role in improving the mechanical properties.

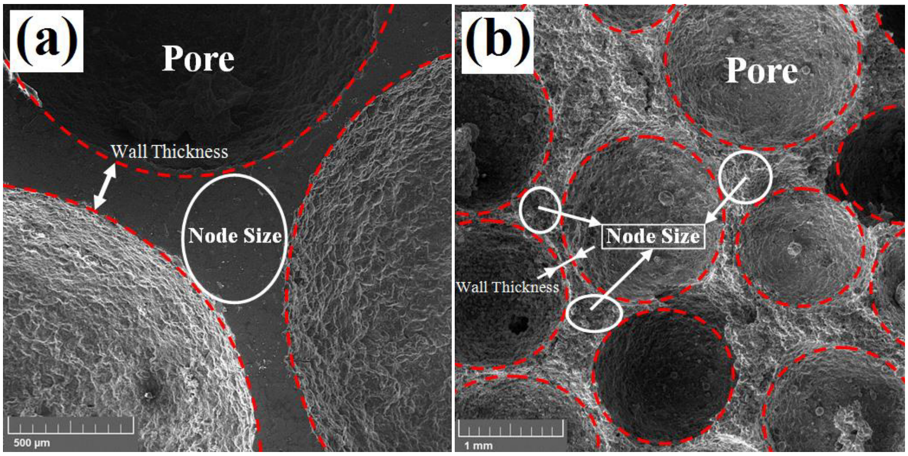

Fig. 3. SEM image of: (a) pore and cell wall; (b) fracture surface of composite metal foam.

Basically, in the composite materials produced by powder metallurgy method, reinforcing particles are accumulated at the grain boundaries, Alizadeh et al. (2011). These factors improve properties such as elastic modulus, yield strength and energy absorption capability. The more the cell wall is strong and has more uniform dimensions, the more mechanical properties of the sample increases, Bazzazbonabi et al. (2014).

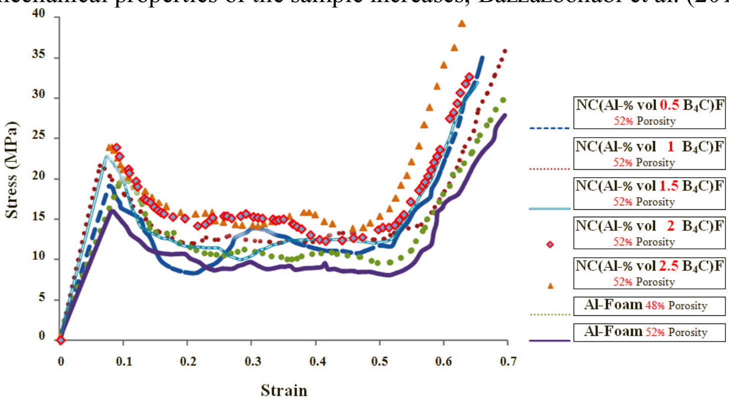

Fig. 4. Stress - Strain curve of samples with different Vol.% of nano B_4C.

3.2. Mechanical properties

Compression testing was done on composite samples made with 52% porosity in different percent volumes of reinforcing particles, as well as pure sample with porosity of 48 and 52 percent. Fig. 4 shows the stress-strain curves of the foam composite samples produced. As can be seen the stress-strain curve behaves similar to other metal foam and metal composite that includes 3 regions as follows: elastic region, large plateau region and densification region, Banhart (2001), Bazzazbonabi et al. (2014). It can be said generally that stress-strain curve follows the steps listed in compression testing of foams, but due to metal foams type and their unique properties they can have a different yield strength, modulus, densification strain and plateau stress to each other. Neville and Rabiei (2008) examined foam composite produced by powder metallurgy method and stated that characteristics such as strain rate, relative density and the volume of materials and chemicals can be effective on the slope of the compression stress-strain curve.

Figure 5 shows the image of yield strength-volume percent of reinforcing particles. With the increase in the percent volume of reinforcing particles, yield strength is increased; on the other hand, as shown in fig. 4 it is also observed that by increasing the percent volume of reinforcing particles, compression strain does not change. For composite foam produced with 52% porosity and different vol.% of B_4C reinforcing nanoparticles, yield strength and densification strain are far more than pure compression stress-strain curves with 48 and 52 percent porosity.

As seen in fig. 5, for foam porosity of 48% yield strength is equal to 19.77 MPa, and the densification strain is equal to 49% according to fig. 5. On the other hand, in pure aluminum foam with a porosity of 52% the yield strength is equal to 15.95 and the densification strain is equal to 56%. So it can be said with respect to figs. 5 and 6 that with an increase in porosity, yield strength reduces and densification strain increases. Also notice that according to Fig. 6porosity can increase along with strength increase by composite production. On the other hand, a property that separates the metal foam from the bulk metal is energy absorption capability which can be obtained by calculating the area under the stress-strain curve of a pressure test according to equation 1, Bazzazbonabi et al. (2014).

Figure 6 also shows the energy absorption capability at different percentage volumes of reinforcing B_4C nanoparticles. According to fig. 6, with the increase to 2 vol.% in reinforcing particles, energy absorption capability of foam composite produced has also increased. But the rate of this increasing is not rigid. On the other word, it can be said that the increasing in vol.% of nano B4C did not have a sharp influence on ductility of metal foam.

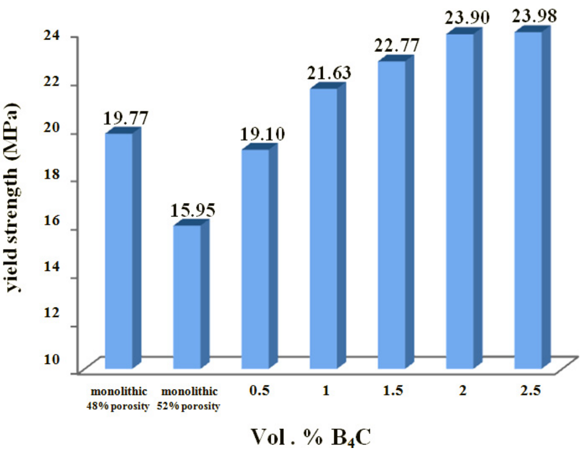

Fig. 5. The relation between yield stress and vol.% B4C andporosity volume percent.

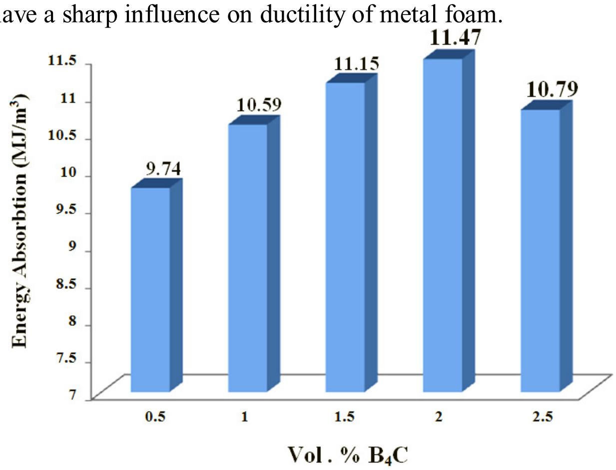

Fig. 6. The relation between vol.% B4C and energy absorption.

4. Conclusions

Metal foam composite was successfully created with carbide particles on 0.5 to 2.5 vol.% with the use of carbamide space-holder materials and powder metallurgy method. Structural and mechanical properties of the foam composite produced are examined. The results show that the uniform dispersions of pores can be achieved by this method.The strength can increase by composite production and the use of nanoparticles up to 2 vol.% B_4C. Also, yield strength increases and densification strain did not change with increasing the volume percentage of reinforcing particles. By composite production in the foam produced along with increasing the porosity, mechanical properties compared to pure foam sample with lower porosity improved.

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