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Research article

Production and microstructure of AA2024 – B_4C metal matrix composites by mechanical alloying method

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Abstract

In this study, effect of mechanical alloying method on the production and properties of metal matrix composites was investigated. Al2024 powders as matrix material and B_4C particles (5 wt.%) as reinforcement material were used. Initially, composite powders were produced by milling the as-received powders in a high energy ball milling at different milling time. Green compacts were fabricated by composite powders pressed with an uniaxial press at different pressures. Then, green samples were sintered under an atmosphere of argon. Microstructure of the Al2024-B_4C composites was investigated by scanning electron microscope (SEM). In addition, the change of composite hardness with milling time and consolidation pressure was investigated. The SEM micrographs demonstrated a uniform distribution of B_4C particles in Al2024 matrix with increasing milling time. The composite hardness increased with increasing milling time and consolidation pressure. As a result, the homogeneous distribution of reinforcement particles not be obtained with liquid phase methods provided by mechanical alloying method that significantly improved the composite properties.

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Keywords: *Metal-matrix composites (MMCs), mechanical alloying, microstructure*

1. Introduction

Scientific studies on metal matrix composites (MMCs) promising as a high-performance building materials led to better understanding of the physical and mechanical properties and their use more widely throughout the world. However, metal matrix composites are used less and less well-known in our country. The most important properties of MMCs, mechanical, physical and thermal properties for industrial applications are adjusted to desired values. In addition, metal matrix composites have advantages such as high modulus of elasticity, high hardness and tensile strength, low thermal conductivity, high abrasion wear resistance, high creep resistance [1]. Metal matrix composites automotive, aerospace industry and nuclear power equipment, gas turbines can be used efficiently due to the above-mentioned advantages. Aluminum-based metal matrix composites have provided superior compared to traditional materials due to high specific strength, high toughness/intensity rates, ease of fabrication, high wear and corrosion resistance, high fatigue life, high strength and the high temperatures in aerospace and automotive sectors [2-4]. Besides these features, a low thermal expansion and thermal conductivity of aluminum matrix composites, advantageously makes use of this materials. Toyota Company has manufactured diesel engine piston using fiber-reinforced aluminum matrix

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composites in the automotive sector. 25% SiC particle reinforced 6061 aluminum alloy matrix composite used in aircraft industry [1]. As can be seen from the studies above, there are numerous studies on MMCs.

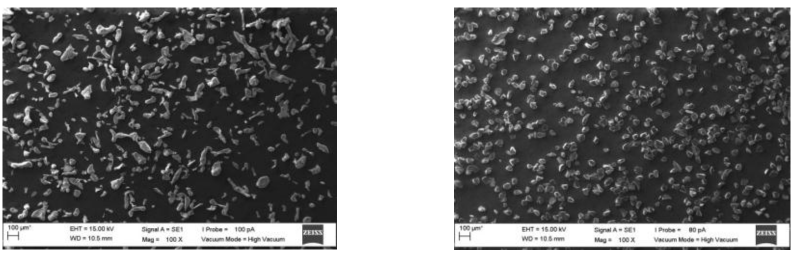
The properties of composite can be improved with control of reinforcement type, content and distribution. The coefficient of thermal expansion rate was reduced to 400% by increasing of volume fraction of ceramic particles for composites reinforced with ceramic particulate [5]. 5% saving in fuel consumption is provided by vehicles produced with MMCs has been reduced by 10% weights [6]. SiC, Al_2O_3, B_4C, TiC, SiO_2 and other reinforcement material can increase the rigidity or improve thermo-physical properties of engine parts. Typical examples of MMCs used in engineering the transmission shafts, brake drums and military armor. In addition, B_4C particle reinforced composites are used as armor material nuclear reactor materials, abrasive spray nozzles, applications that require high abrasion wear resistance and production of abrasive cutting discs.

Mechanical alloying method which used in the production of composites and nano-composite material is a powder metallurgy process and this method allows the preparation of powder mixtures and homogeneous materials [7]. The biggest problem in the production of MMCs by liquid-phase method is not enough wettability of reinforced particles with matrix materials and is not used more than 30% of volume fraction of reinforced particles [8]. The desired amounts of reinforcement material can be used in powder metallurgy that is solid phase process. One of the most important advantages of mechanical alloying is provided homogeneous distribution of reinforcing particles within the metal matrix [9, 10]. In addition, the production of nano-crystalline and nano-sized particles, check the availability of the production process is counted among the most important features of mechanical alloying method.

According to literature, in the study with the production of MMCs by mechanical alloying method are used Al_2O_3 and SiC particles [11, 12]. The purpose of this study is to produce of B_4C particle reinforced AA2024 matrix composites by mechanical alloying method and is to investigate the effect of production parameters on composite properties.

2. Experimental

The as-atomized Al2024 alloy powders (Gündoğdu Exotherm Company, Turkey) with an average particle size of 75µm, B_4C powders (99,9% purity, Alfa Aesar, Germany) with an average particle size of 49µm and the density of 2.52 g/cm^3 are used as raw materials. The chemical composition of the as-atomized Al2024 alloy (in wt.%) is 92.114 Al, 4.850 Cu, 1.78 Mg, 0.385 Si, 0.374 Fe, 0.312 Mn, 0.138 Zn, 0.042 Cr, 0,005 Ti and Al (balance). Fig. 1(a) and (b) shows the morphologies of the as received Al2024 alloy matrix powder and B_4C particles. Al2024 powders have an irregular morphology while B_4C particle have an angular or polygonal morphology (Fig. 1).



(a) (b)

Fig. 1 Morphology of as-received powders: (a) Al2024 powders and (b) B_4C particles

Al2024 and Al2024-5 wt.% B_4C powders were milled by ball milling for 0.5h, 1h, 2h, 5h, 7h and 10h. The milling process was carried out in a planetary ball-mill (Fritshc Gmbh, model 'Pulverisette Premium Line 7') at room temperature using tungsten carbide bowl and high argon atmosphere. The milling medium was tungsten carbide balls, 10 mm in diameter. The ball-to-powder weight ratio (BPR) and rotational speed were 10:1 and 400 rpm, respectively. A total of 2wt.% of methanol (Merck) was added to the ball-mill as process control agent (PCA). Gradual process control agent technique [13] was used during milling process and 0.25 wt.% per hour the methanol was added into the vial. The milling atmosphere was argon which was purged into the bowl before milling. To prevent overheating, ball milling experiments were stopped (every 1 h) and then resumed (for 15 min) when the temperature of the bowl decreased to the room temperature. The as-received Al alloy powder, the conventionally mixed (CM) and the mechanically alloyed powders were uniaxially cold pressed in a cylindrical die at 300 and 500MPa, with graphite as the die lubricant. The dimensions of the samples were 20×20×5mm. The green compacts were sintered 600 ^{o}C for 3h under high argon atmosphere. The sintered compacts were cooled to room temperature in the sintering furnace.

The size distribution of as-received and milled powders was quantified by a laser particle size analyzer (Malvern, model 'Mastersizer Hydro 2000'). The morphology and microstructure of raw and milled powders were investigated by scanning electron microscopy (SEM) using Zeiss LS10. Hardness was measured in the Brinnel scale with an indenter of 2.5 mm diameter and a 32.5 Kgf force.

The porosity of the composite produced according to the following formula is calculated.

$$\text{Porosity (\%)} = [(\delta_t - \delta_d) / \delta_t] \times 100$$

Where, δ_t is theoretical density calculated according to the rule of mixtures, δd is experimental density.

3. Results and Discussion

3.1. Particle Size

The particle size of Al2024 alloy powders and Al2024-5% B_4C composite powders were decreased with increasing milling time (Fig. 2). The average particle size of the Al2024-B_4C composite powders (ductile-brittle system) was lower than that of the Al2024 alloy powders (ductile-ductile system) it was reduced by increasing the reinforcement content. Indeed, the presence of the ceramic phase accelerates the rate at which the milling process reaches completion. The presence of B_4C particles increases local deformation which improves the particle welding process. Beside this, the higher local deformation imposed by reinforcement particles increases the deformation hardening, which helps the fracture process. The small hard brittle particles in the matrix act as small milling agents, and thus the steady state the milling time is reduced [14]. The steady state for particle size was reached at the end of 7h of milling. It wasn't observed a significant change for particle size up to 10h of milling.

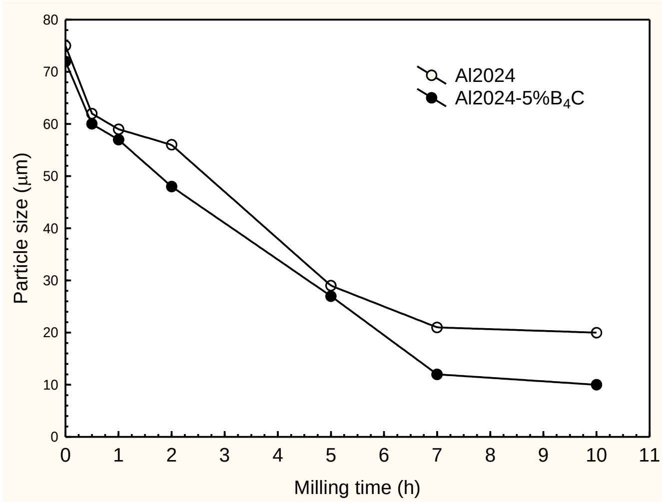
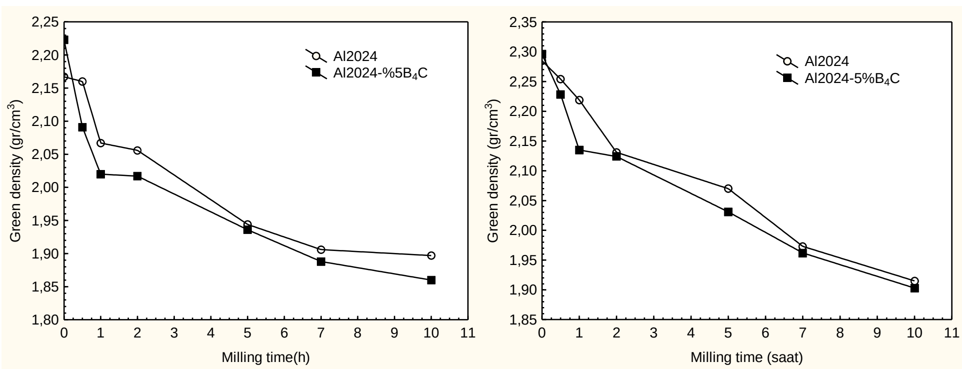


Fig. 2 The change of particle size with increasing milling time

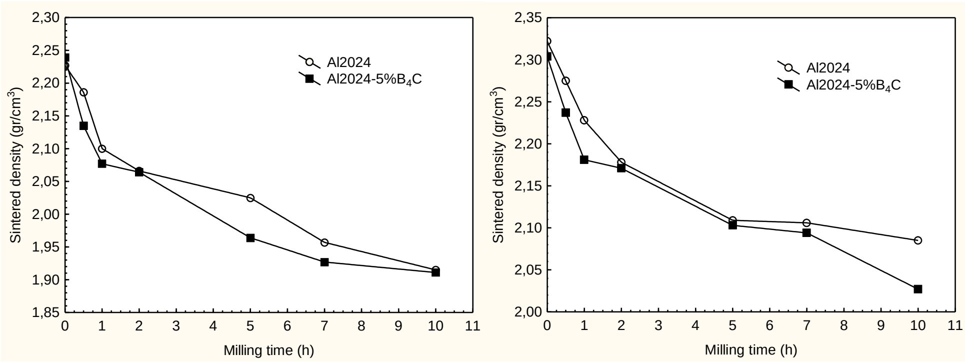
3.2. Green and Sintered Density

The consolidation ability of milled powders was reduced due to deformation hardening mechanism and the so density of produced materials decreased. The density of materials increased with increasing consolidation pressure (Fig. 3 and 4). Moreover, the density of materials decreased due to brittle particles (B_4C particles). It is known that the compaction mechanism of powders in a rigid die is usually considered in three stages including; (I) sliding and rearrangement of the particles; (II) elastic deformation of ductile powders and fragmentation of brittle solids and (III) plastic deformation of bulk compacted powders. At the first stage of the compaction process, particle sliding and rearrangement of the powders are the dominant mechanisms of consolidation [15].



(a) (b)

Fig. 3 The change of green density of Al2024 alloy and Al2024-5%B_4C composite, (a) 300 MPa, (b) 400 MPa

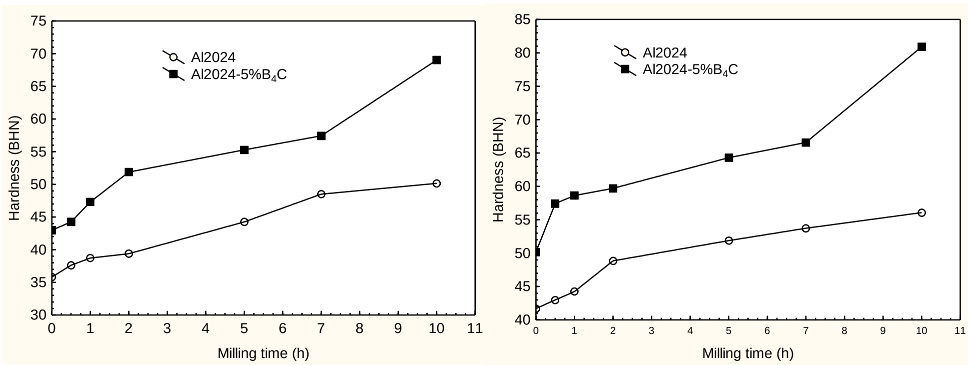


(a) (b)

Fig. 4 The change of sintered density of Al2024 alloy and Al2024-5%B_4C composite, (a) 300 MPa, (b) 400 MPa

3.3. Hardness

The hardness of sintered samples versus milling time was given in Fig. 5. It was seen that the hardness values increased with increasing milling time and addition of B_4C particles. The hardness of mechanically alloyed Al2024 alloy and Al2024-B_4C composites are affected by two factors: the first factor is the work hardening of matrix alloy due to the milling and second is the effect of B_4C particles as reinforcement.

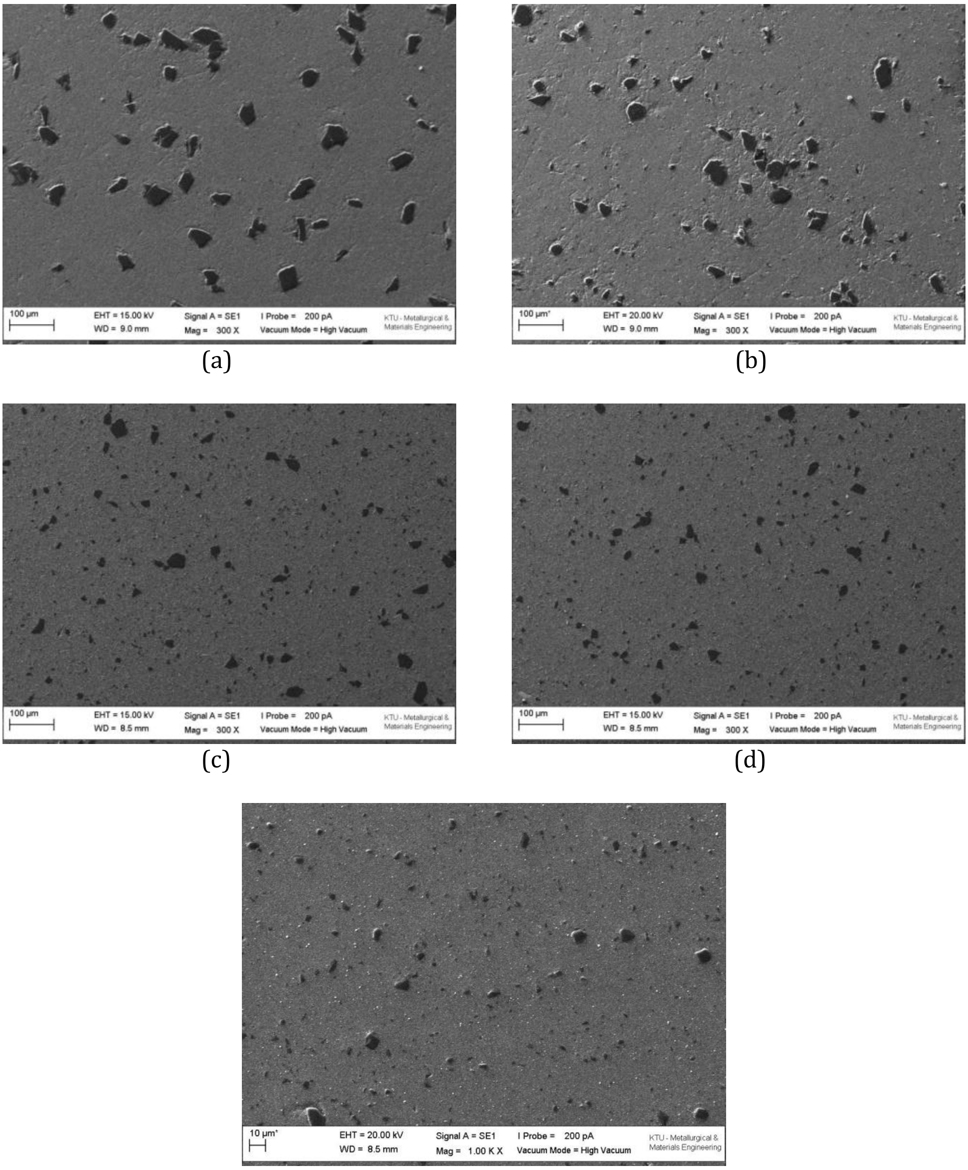


(a) (b)

Fig. 5 The change of hardness of Al2024 alloy and Al2024- 5%B_4C composite, (a) 300 MPa, (b) 400 MPa

3.4. Microstructure

The effect of milling time on the distribution of B_4C particles was examined by SEM (Fig. 6). The reinforcement particle distribution was not uniform at initial milling time (Fig. 6a). It can be seen that the dispersion of reinforcement B_4C particles became more homogeneous and a smaller particle size with increasing milling time (Fig. 6e).



(a) (b) (c) (d) (e)

Fig. 6 SEM images of Al2024-5% B_4C composites, (a) 0h, (b) 0.5h, (c) 2h, (d) 5h, (e) 10h

4. Conclusion

Some important remarks could be listed as below:

- The steady state time is 7h for the particle size of Al2024-5% B_4C composite powders.
- The effectiveness of mechanical alloying was increased by B_4C particles.
- Density of produced materials decreased with increasing milling time. However, the density values increased with increasing consolidation pressure.
- The hardness of produced materials increased with increasing milling time and reinforcement materials (B_4C).
- The distribution of the B_4C powders in the Al2024 alloy matrix reaches homogeneity with increasing milling time.

Acknowledgements

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