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Original Research Paper

Preparation of super-high strength nanostructured B_4C reinforced Al-2Cu aluminum alloy matrix composites by mechanical milling and hot press method: Microstructural, mechanical and tribological characterization

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ABSTRACT

In this research, super-high strength nanostructured B_4C reinforced Al-2Cu aluminum alloy matrix composites produced by mechanical milling and hot press method. Nanostructured Al-2Cu powder containing 4, 6 and 10 wt.% B_4C reinforcement particles synthesized using a high-energy attritor under argon atmosphere. Results showed that with increasing the content of B_4C particles the matrix grain size decreased. Since the compressibility of mechanically milled powders is very low, hot press processing used for consolidation of nanostructured Al-2Cu/B_4C powders. The hot pressed Al-2Cu/10 wt.%B_4C nanocomposite, when tested in compression, exhibited extremely high strength (1.1 GPa) which is 735 MPa higher than that of coarse grain Al-2Cu sample. Moreover, the hardening capacity (H_c) of hot pressed nanocomposites decreased with the increase in the content of B_4C particles. According to Orowan strengthening mechanism, since B_4C particles act as a barrier to the dislocations movement, the increase of B_4C particles leads to the increase of barriers and as a result, $\Delta\sigma_{Orowan}$ increases. Therefore, the strength of composite increases but work hardening capacity (H_c) decreases. The results of wear test indicated that wear rate and friction coefficient declined gradually as the B_4C particles fraction increased. Based on this result, hot-pressed sample containing 10 wt.% B_4C showed the lowest wear rate and friction coefficient (1.9×10^{-5} mm^3/m and 0.48 respectively).

1. Introduction

In the past 20 years, metal matrix composites (MMCs) have progressed from primarily a laboratory enterprise with only narrow commercial significance to a diverse and robust class of materials with numerous important applications across a number of commercial markets [1]. For this reason, there is a growing tendency in industries for development of metal based composites as the structural materials. Among composite materials, aluminum matrix composites (AMCs) have a great deal of importance for their low density, high strength, excellent wear resistance and low coefficient of thermal expansion compared to common metals and alloys. These unique properties make AMCs very interesting for a wide range of applications in industries specially aerospace and automotive industries [2]. The embedment of ceramic particles in the soft aluminum matrix enhances many properties especially mechanical strength and wear resistance. B_4C-reinforced aluminum matrix composites (Al-B_4C MMCs) have attracted much attention over the past decade [3]. Stir casting [2] and mechanical milling [4] are the common methods for production of Al-B_4C MMCs.

To obtain the high strength and wear resistance of Al-B_4C MMCs by adding the B_4C particles, it is essential to control distribution of the B_4C reinforcements in the aluminum matrix. However, it is difficult to achieve a homogeneous microstructure by stir casting method because clusters/agglomerates are easily formed through aggregation of the B_4C reinforcement particles. The clusters/agglomerates act as stress concentration sites which promote generation of cracks. The propagation of this cracks can decreases the mechanical properties of Al-B_4C MMCs. In addition, the clusters/agglomerates and propagated crack cause high rate of delamination under wear condition and thus increase wear rate.

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Mechanical milling method is usually used to produce particle reinforced composites with high mechanical properties, because these methods provide a uniform distribution of secondary phase particles in the matrix [5]. In addition, Mechanical milling is one of the several techniques to synthesize nanostructured and ultrafine-grained (UFG) Al-B_4C MMCs. In the past few decades, these materials have drawn attention due to the improved mechanical properties and the unusual grain structures [4,6].

Wear behavior of aluminum matrix composites depends on interface strength of the matrix and the reinforcement particles. If the interface between the matrix and reinforcement material is not strong enough, debonding of reinforcement particles occurs and leads to considerable degradation. Since the interface between particles and matrix in mechanically milled Al-B_4C MMCs has a good metallurgical quality debonding between particle and matrix in these composites rarely occurs [7]. On the other hand, the effect of reinforcing particles size on wear behavior of composite is related to powder preparation method. In composites produced by mechanical milling, reinforcement particles are distributed well and hence with more fine particles, the wear resistance improves [8].

It is well known that the Cu-containing Al alloys (2xxx series aluminum alloys especially AA2024) are high strength aluminum alloys. This indicate that the addition of Cu to Al improves its mechanical properties. For this reason in many researches, AA2024 powder (prealloyed powder) was used as a matrix, which has relatively high cost. In the mechanical milling process the raw powders can be elemental or prealloyed. Using elemental powders is not only more economical, but also brings an extra advantage to modify the matrix composition easily. Thus, in present research Cu and Al elemental powders were used for production of matrix of composite.

The present investigation has been concerned with a more detailed investigation of the tribological, mechanical and microstructural changes in the mechanically milled Al based composites containing different amounts of B_4C reinforcement phase. Since the compressibility of mechanically milled powders is very low, in this research hot press processing used for consolidation of Al-2Cu/B_4C powders.

2. Experimental

Al–2Cu powder atomized by Argon gas with particle size of 20 µm was used for matrix. As represented in Fig. 1a, the particles are spheres with broad size distribution. Boron carbide (B_4C) particles with mean size of 1 µm were used as the reinforcement phase. The morphology of the B_4C particles is depicted in Fig. 1b.

Nanocrystalline Al-2Cu powder containing 4, 6 and 10 wt.% B_4C reinforcement particles was synthesized using a high-energy attritor equipped with a water cooling system in argon atmosphere. Attrition mill setup made at Malek Ashtar University of Technology (MUT). Ball-to-powder weight ratio and the rotational speed were defined to be 10:1 and 350 rpm respectively. To prevent cold welding during milling, 1 wt.% stearic acid was used as process control agent (PCA). The mixture was milled for 20 h to reach to a steady state.

For study the effect of B_4C fraction on grain size of the aluminum matrix, Williamson-Hall equation [9] was used and Changes in matrix grain size vs. B_4C weight percent was plotted. Microstructure of powders after 20 h milling was studied by transmission electron microscopy (Philips-FEGC200) and scanning electron microscopy (Camscan MV2300 SEM) to determine the grain size, morphology and reinforcement particles distribution within the aluminum matrix. Particle size analysis of as-milled powders was done in a Malvern particle size analyzer (PSA). Microhardness data for the powders were obtained on a microhardness setup using a load of 10 g. Powders were cold mounted and hand polished and microhardness was measured according to ASTM E384 standard. About 10 measurements were made on each sample.

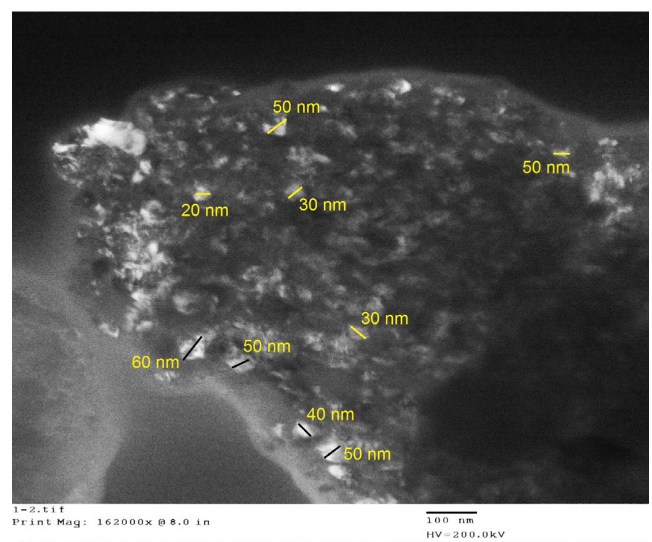

Fig. 2. Dark-field TEM image of Al-2Cu/B_4C powder after 20 h mechanical milling.

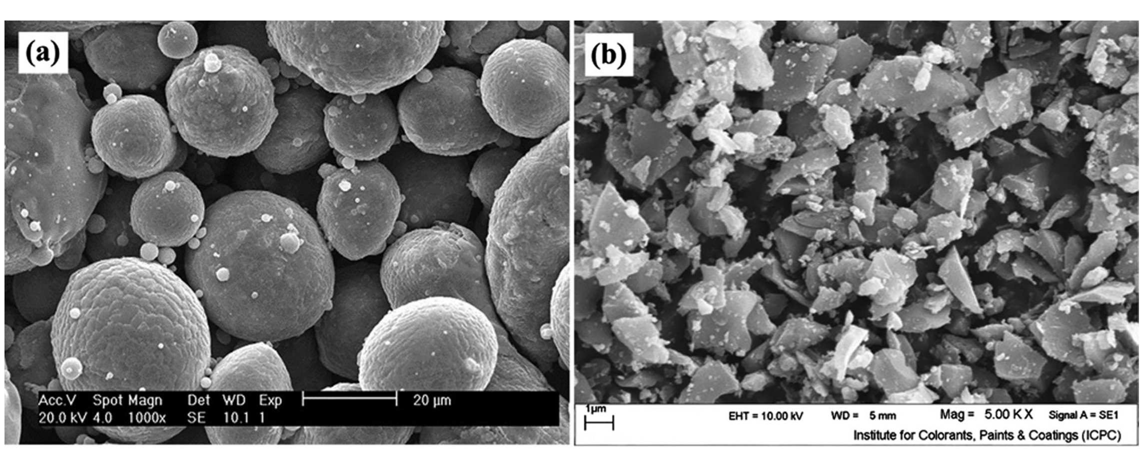

Fig. 1. SEM micrograph of raw materials used in this research: (a) Al-2Cu and (b) B_4C powders.

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