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Dependency of physical and mechanical properties of mechanical alloyed Al–Al_2O_3 composite on milling time

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Abstract

In this work aluminum–alumina composite material was first produced by mechanical alloying method and then physical and mechanical properties of the products were investigated. For this purpose the aluminum and alumina powders were charged in horizontal ball mill and milled at different times. In order to investigate the physical and mechanical properties of the processed powders, powder metallurgy samples were produced by single action compaction of the powders. The compacted green samples were sintered by an inert atmosphere furnace. Mechanical tests such as compression, microhardness, wear resistance besides physical tests such as dimensional stability and electrical resistivity were done on the milled composites. The results show that mechanical and physical properties of the milled aluminum base composites depend strongly on milling time so that increasing milling time causes to change the values of the mentioned properties. But in steady-state stage increasing milling time has not significant effect on the properties.

Keywords: Composite; Alumina; Aluminum; Mechanical alloying; Physical and mechanical properties

1. Introduction

Metal matrix composites (MMCs) are under attention for many applications in aerospace, defense, and automobile industries. These materials have been considered for using in automobile brake rotors and various components in internal combustion engines because of its high strength/weight ratio [1–5]. Among MMCs aluminum metal matrix composites (Al MMCs) are being considered as a group of new advanced materials for its light weight, high strength, high specific modulus, low coefficient of thermal expansion and good wear resistance properties [1–5].

The most commonly used types of Al MMCs are Al–graphite, Al–SiC and Al–Al_2O_3 which present good behavior up to 450 °C. Al–Al_2O_3 composites are a special class of these advanced materials because of their recent applicability in the automotive industry. Their mechanical properties recommend this type of material for auto components that are working at high temperatures (200–300 °C) or in aggressive atmospheres (except water) [6–10].

Nowadays, the use of Al–Al_2O_3 has been limited in very specific applications such as aerospace and military weapon due to high processing cost. On the other hand, application of Al–Al_2O_3 composites has been limited compared to its potential because of fabrication method. Although, Al matrix composites can be used for the automobile products such as engine piston, cylinder liner and brake disc/drum [2].

In fact, there are several fabrication techniques available to manufacture Al–Al_2O_3 composite. The fabrication methods can be divided into three types. These are solid phase processes, liquid phase process and semi-solid fabrication process. Solid state processes (mechanical milling of a mixture of metal powder and ceramic powder) are generally used to obtain the best mechanical properties in Al–Al_2O_3 [9–14]. This is because segregation effects and intermetallic phase formations are less in the processes, when compared with liquid state processes. Although there are a lot of problems concerning the distribution of the

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reinforcement in the composite matrix under these conditions, there is necessary to use certain blending procedures in order to reach a homogeneous distribution of the Al_2O_3 particles in the Al matrix. The optimal mixing procedure of the two components of the composite is the aim of mechanical alloying process [9–14].

It has been reported in our earlier works [15–17] that Al–Al_2O_3 composites can be made using mechanical alloying method. Also it has been shown that microstructure of Al–Al_2O_3 composites depends strongly on milling parameters, such as ball sizes, number of balls and milling time [15–17]. This paper follows a series of papers issued on mechanical alloying and reports the results of a study on role of milling time on physical and mechanical properties of Al–Al_2O_3 composite made by mechanical milling and powder metallurgy methods.

2. Experimental methods

2.1. Materials

To produce Al–Al_2O_3 composite, commercial aluminum powders with particle size smaller than 90 μm and alumina powder with 99.5 purity and average size of about 165 μm have been provided from Zamin Tavana (Iran, Tehran) Company. Details of the material properties have been mentioned elsewhere [17].

2.2. Milling and sample preparation

Horizontal ball mill with 135 mm in diameter and steel balls with different diameters (15.8–24.4 mm) were employed. Round per minute of the mill was kept about 85. The aluminum and alumina powders with 20/1 weight ratio were added to the ball mill and milled for different times, i.e. 20, 30, 75, 150, 270, 330, 450, 600 and 900 min. Then cylindrical samples were produced using powder metallurgy method. For sintering, the compressed powders were kept at 585–600 °C for 0.5 h under inert gas control.

2.3. Microhardness test

To obtain hardness of milled powders microhardness test was performed. Since the main goal of this test was to understand the role of both work hardening and alumina particles on microhardness, thus the milled powders at different times were tested before sintering process to avoid omitting plastic deformation effect.

2.4. Compression test

To find out the role of milling time on compression properties of Al–5 wt% Al_2O_3 composite compression test was done. To decrease friction effect Cook and Lark [18] method was followed. In fact, by using this method the stress–strain curves of Al–5 wt% Al_2O_3 composites which are milled for different milling time have been obtained at frictionless condition. Compression test was done according to ASTM B 331 using an 1115 Instron tensile frame at a cross-head speed of 5 mm/min. At each condition three samples were tested at room temperature.

2.5. Room temperature hardness test after holding the samples at high temperature

For doing this test firstly some series of mixed Al–5 wt% Al_2O_3 samples at different milling times were produced and sintered. The samples were put in an oven for 1 h at different temperatures i.e. 100, 200, 300, 400, 500 and 550 °C. To avoid oxidation of aluminum, particularly at high temperature, all samples were protected using argon gas during heating. Then hardness of the materials has been measured using Rockwell B method.

2.6. Wear resistance test

To obtain wear resistance of milled Al–5 wt% Al_2O_3 samples, the weight change before and after wear test can be a criterion for wear resistance. For this purpose the following conditions were followed.

The samples weighted before testing.
The samples placed on the rotary grinding paper with grid size 600.
The applied load 5 kg was chosen.
Since the performance of grinding paper decreases gradually the paper changed after 2 min.
The sample weight was measured at different abrasion times, i.e. 10, 20, 30, 40 and 50 min.

2.7. Dilatometry test

Dilatometry is one of the oldest methods for measuring the volume change due to phase transformation and even temperature changes. To find out the role of milling time on thermal expansion of Al–5 wt% Al_2O_3 composite the dilatometry test was done. The length of the used samples, varied between 22 and 25 mm. The temperature range examined was from room temperature to 500 °C. The rate of increasing temperature was selected 3 °C/min.

2.8. Specific resistivity measurement

To understand the difference between electrical resistivity of milled and un-milled Al/5 wt% Al_2O_3 measurement was done according to ASTM B715-96 (2001) standard. The milled composite samples at different times were tested. Specific resistivity was obtained using the relation $R = \rho\frac{L}{A}$, where R, ρ are resistance, specific resistivity and L and A are geometrical dimensions of the samples, respectively.

3. Results and discussion

Fig. 1 shows variation of micro hardness of powders versus milling time. As it can be seen increasing milling time causes a raise in micro hardness of powders. At the beginning of milling time the rate of increasing of micro hardness is so much. But the rate decreases as milling time increases gradually and finally leads toward zero. For the material studied in this research if the milling time raises more than 210 min the slope reduced drastically and finally after 15 h the rate became almost constant. Looking at in more details in Fig. 1 shows that the system approaches to the steady state condition after 210 min milling and increasing milling time, even more than 15 h, has not any significant effect on micro hardness. Increasing micro hardness can be referred to both alumina particles and work hardening of aluminum powders. In fact, as it was shown in our earlier work [17] at initial milling time, the particle distribution was not uniform and the distance between alumina particles was so high. But, increasing milling time causes to break the big and brittle alumina powders and to indent them into the ductile aluminum powders. Also, with increasing milling time the distance between alumina