

Production and Characterization of an Aluminum Based Nanocomposite Reinforced With Particles from the Al-Zr System by Means of Mechanical Alloying Process

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1- Introduction

In recent years, much attention has been paid to the production and application of aluminum based composites reinforced with ceramic particles due to their high strength to weight ratio, excellent wear resistance, and suitable stability at high temperatures. Zirconia is a heat resistant material with a melting temperature of 2680 °C. Zirconia has appealing properties such as high resistivity against thermal shocks, high melting point as well as thermodynamic stability; however, its main problem is its allotropic changes at different temperatures. Zirconia is stable up to 1700 °C with a monoclinic structure.

2- Experimental procedure

Aluminum and zirconium oxide powders were used for the mechanical alloying experiments.

Table. 1 The size and shape of the aluminum powder

Material	Particles size (µm)	Particles shape
Aluminum	<100	Extended and irregular

To evaluate the production of in-situ zirconium and aluminum intermetallic oxides in an aluminum matrix, a mixture of aluminum and zirconium powders were subjected to milling and subsequent heat treatment in an argon atmosphere. X-ray diffraction is a main method for grain size measurements in nanostructured materials. X-ray diffraction patterns were obtained for sample after 15 and 50 hours of milling. Aluminum and zirconium oxide peaks are observed in the sample milled for 15 hours. By increasing the milling time, the intensity of the aluminum and zirconium oxide peaks decreased gradually while the width increased; this is due to grain size refinement down to a nanoscale as well as an increase in the internal elastic strains.

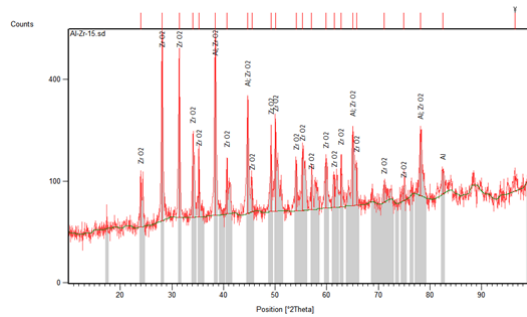


Fig. 1 The X-ray diffraction pattern for Al-ZrO₂ powder mixture obtained after milling for 15 h

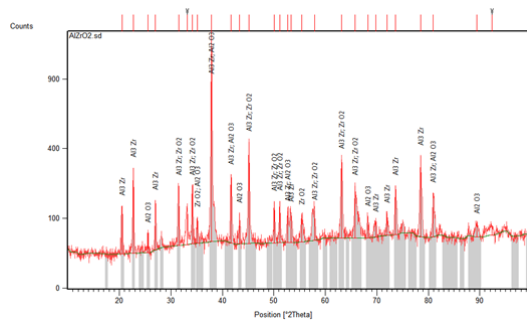


Fig. 2 X-ray diffraction pattern for Al-ZrO₂ powder mixture, after milling for 15 h and subsequent heat treating for 1 h at 700°C

After 50 hours of milling, some peaks in the diffraction pattern have disappeared. This phenomenon can be attributed to the dissolution in the aluminum lattice or breakdown of the structure into nanoparticles and distribution in the matrix or a transformation into an amorphous state. However, the important point deduced from Fig. 1 is that no reaction occurred between the Al-ZrO₂ powder components and no evidence for the formation of new phases was found during milling. The reason intermetallic phases did not form in the Al-Zr system during milling is due to the lack of the required activation energy for the formation of these phases. On the other hand, these phases possess a complicated structure with covalent bonds causing the milling process to become difficult. In order to evaluate the possibility of the formation of intermetallic compounds during the subsequent heat treatment process in air, the milled powder mixture was subjected to heat treatment at 700 °C for 60 minutes. The diffraction pattern for this powder is shown in Fig. 2. This pattern consists of aluminum oxide, zirconium oxide as well as Al₃Zr peaks. The formation of these phases can be due to their negative Gibbs free energy at the heat treatment temperature.

It is well known that during the milling process, the energy provided by the collision of the balls reduces the required activation energy for the

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reactions. During the milling process, due to the repetitive breakage and joining of powders, the reactant particle surface area increases. This increase in surface area facilitates the reaction because there is no longer any need for long distance diffusion. As shown from the X-ray diffraction patterns, after 50 hours of milling, the height of aluminum and zirconium oxide peaks is reduced while the width of these peaks is increased; this indicates that the grain size is reduced while the internal elastic strains are increased as a result of the milling process. Reducing the grain size to a nanometer scale and increasing the density of crystalline defects can lead to the acceleration of the reaction kinetics. Fig. 3 shows the changes in the hardness of the nanocomposite samples in comparison to pure aluminum. As can be seen from this figure, the formation of the reinforced particles, i.e. Al_3Zr and Al_2O_3 intermetallic phases, is the reason for the observed increase in the hardness values. This increase in hardness is due to the presence of small particles, i.e. nanometer scale. It can be concluded that producing nanocomposites and the formation of reinforcing particles using the milling process causes a reduction in the friction coefficient.

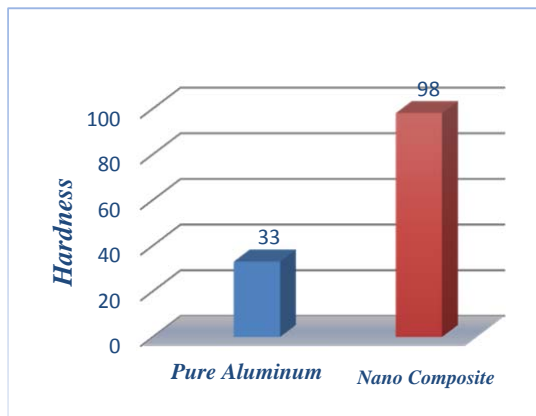


Fig. 3 The hardness values of the nanocomposite samples and pure aluminum

The weight loss in the surface composite sample is considerably lower than pure aluminum. Moreover, it can be seen that the wear behavior in the coated sample is stable. In fact, the greater load handling capability of the particles and their influence on the plastic flow arrest and adhesion of the base metal are the reasons for the observed decrease in wear rate and the complete elimination of the primary wear. This explanation can be justified considering the higher hardness value of the coated sample relative to the base metal.

3- Conclusions

The diffraction pattern for the milled powder mixture after heat treatment consists of peaks of aluminum oxide, zirconium oxide, and Al_3Zr intermetallic phase. The formation of reinforcing particles, i.e. Al_3Zr and Al_2O_3 intermetallic phases, caused the hardness of the nanocomposite sample to reach 98 Vickers which is three times greater than the hardness of pure aluminum (33 HV). The wear rate of the base metal and the nanocomposite sample were measured to be 0.0696 and 0.0108 mg/m, respectively. In fact, the ceramic reinforcing particles act as a load carrier and due to their high hardness, a significant decrease in the direct force between the steel pin and the aluminum matrix is observed and so, the wear resistance is significantly improved.