Effect of high energy ball milling on compressibility of nanostructured composite powder

H. Abdoli*[1], H. R. Farnoush[1], H. Asgharzadeh[2] and S. K. Sadrnezhaad[1]

Compressibility of a nanostructured Al–5AlN composite powder synthesised via high energy ball milling for various times was studied by means of a modified Heckel equation. Since workhardening and morphological changes take place by milling evolution, the compressibility was consequently affected. Strengthening of composite compacts was influenced by milling and compaction processes, i.e. strength of compacts increased at longer milling times and higher compaction pressures. It was found that, at the initial stages of milling and higher compaction pressures, the strengthening was mostly affected from compaction process, whereas the milling strengthening fraction was near to unity at lower compaction pressures as well as prolonged milling. Nevertheless, a sharp increase in milling strengthening fraction of unreinforced Al occurred at intermediate milling times. The rate of strengthening induced by milling raised at higher compaction pressures.

Keywords: Nanostructure, High energy ball milling, Compressibility, Yield strength, Workhardening

Introduction

Nanocrystalline materials have been taken into consideration significantly because of their enhanced mechanical, magnetic, elevated temperature, optical and excellent catalytic properties.[1] Different routes have been developed to produce these materials, including mechanical milling, shot peening, equal channel angular extrusion, high pressure torsion and multipass coin-forge.[2] Among these, mechanical milling has been widely used to produce nanocrystalline materials because of its simplicity and ability of refining the grains for most of metals, alloys, intermetallics and metal matrix composites.[3] During high energy ball milling, the powder particles are trapped between the colliding balls and undergo repeated welding–fracturing–welding, depending on the mechanical behaviour of the powder components.[4]

Cold compaction is widely used in powder technology as the initial step for consolidation of powder particles with different geometries at low cost and with high productivity.[5] Cold pressed powders are then subjected to final consolidation by sintering or hot extrusion. Generally, most of the densification occurs in the cold compaction step.[6] The results of different investigations reveal that, although the densification of composite powders is similar to that of unreinforced metals, they exhibit lower densification rate due to stress partitioning effect.[7] Compressibility of mechanically milled metal matrix composites was infrequently studied. Hesabi *et al.*[8] studied the effect of mechanical alloying on the compressibility of Al reinforced with 5 vol.-%Al_2O_3 nanoparticles. They showed that mechanically milled composite powders have lower compressibility in comparison to mixture of powders produced by conventional blending. Fogagnolo *et al.*[5] studied the effect of milling time on the compressibility of Al6061 matrix composites reinforced with 5 and 15 wt-%AlN particles. They found that plastic deformation capacity of powders degraded by increasing the milling time. Similar results was recently reported for Cu–30 vol.-%SiC composite system.[9]

Many compaction equations have been suggested to describe the extent of densification via applied pressure of powders, e.g. Panelli and Filho,[10] Heckel[11] and Ge.[12] In the authors' previous work,[13] the effects of reinforcement content on compressibility of Al–AlN composite powders synthesised by high energy ball milling were studied. The results showed that compressibility behaviour was best fitted to a modified Heckel equation. The modified form of Heckel equation by considering that yield stress of the powder is pressure dependent can be shown as follows[14]

$$\ln\left(\frac{1}{1-D}\right)=\ln\left(\frac{1}{1-D_0}\right)+\frac{1}{3k_1}\ln\left(1+\frac{k_1P}{\sigma_0}\right) \qquad (1)$$

where D and D_0 are the relative densities at compaction pressure of P and zero respectively. The term σ_0 is the yield strength of material at zero pressure. The term k_1 is constant. According to the modified Heckel equation,

[1]Materials and Energy Research Center, PO Box 14155-4777, Tehran, Iran
[2]Department of Materials Science and Engineering, Sharif University of Technology, PO Box 11365-9466, Tehran, Iran

*Corresponding author, email habdoli@alum.sharif.edu

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