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나노결정 알루미늄의 기계적 거동 (I) : 실험

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Mechanical Behavior of Nanocrystalline Aluminum (I) : Experiments

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Abstract

The responses of nanocrystalline aluminum powder of different grain sizes, prepared by ball milling and consolidated into bulk specimens by hot pressing, were determined under quasi-static and dynamic compression. The experiments demonstrated that the reduction in grain size resulted in several-fold increase in hardness and strength; the responses of nanocrystalline aluminum was found to be strain-rate dependent.

Key Words : Nanocrystalline Aluminum, Ball Milling, Hot Pressing, Dynamic response, Split-Hopkinson Bar

1. Introduction

Nanocrystalline materials are single- or multi-phase polycrystals with grain sizes in the nanometer region (typically less than 100 nm in at least one dimension). Owing to the extremely small dimensions, nanocrystalline materials are structurally characterized by a large volume fraction of grain boundaries that may significantly alter a variety of physical, mechanical, and chemical properties with respect to the conventional coarse-grained polycrystalline materials. Although comprehensive studies and modeling over wide range of strain rates and temperatures are quite frequent for metals and polymers, especially at high strain rates, such extensive studies have been generally lacking for nanocrystalline solids. Especially, little research has been done on the bulk mechanical properties of commercially pure nanocrystalline aluminum, due to the difficulties associated with milling pure aluminum powder and producing samples large enough for mechanical tests. Bonetti *et al.* [1] have performed uniaxial tensile tests with nanocrystalline aluminum prepared by mechanical attrition and cold consolidation with average grain size in the 20~40 nm ranges, where they observed an enhanced tensile strength and reduced ductility with respect to coarse-grained aluminum. Sun *et al.* [2] sintered nanocrystalline aluminum and rolled at room temperature to make sheet samples with 99 % relative density. They observed that the yield strength and tensile strength are 12 to 16 and 5 to 6 times those of annealed coarse-

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grained aluminum, respectively. However, none of these studies include materials with a gradually decreasing grain size and subjected to loading over a wide range of strain rates. The present investigation is expected to fill this void.

2. Experimental Procedures

As is generally known for mechanical alloying, the particle size of the metal powder decreases with increasing milling time. However, after a critical milling duration, the particle size remains constant, or increases if milling is continued. The changes in particle size during milling depend on the type of milling material and the milling energy. Milling of aluminum powder mixtures presents various problems, including welding of the material to balls and the container. In order to avoid it, a small quantity of stearic acid was added as a lubricant. The milling speed was controlled in order to avoid the increase of the temperature inside vial.

Powders were compacted in a die in an argon-atmosphere glove box. The first step was to produce a compacted powder. The raw shape specimen, with some porosity (approximately 3 %) after the cold compaction, was then reloaded and sintered. Another sintering, under no pressure or load, was performed. Finally the specimen was annealed after taking it out of the die.

The grain size was analyzed through X-ray diffraction. Vickers microhardness measurements were carried out.

The quasi-static compression tests at strain rates of 0.0001 s^{-1} and 1 s^{-1} were performed. Strain gages were used for the strain measurement. A dynamic compression test for a strain rate of 1210 s^{-1} was carried out using Split Hopkinson Pressure Bar.

3. Results and Discussion

The grain sizes up to 40 nm were obtained by ball milling. The grain size decreased rapidly during the first 10 hours of milling. Mechanical properties were obtained for different grain size with constant strain rate of 0.0001 s^{-1}. The compression test results are shown at the presentation. The Young's Modulus was determined from the initial slope of the stress-strain plot and was found to be 71.7 GPa, which indicate that almost fully dense high-density nanocrystalline materials have approximately the same elastic moduli as fully dense coarse-grained materials. Vickers microhardness under 0.5 kgf loads ($VH_{0.5}$) and yield stress (0.2 % offset) increase as the grain size is reduced.

Quasi-static and dynamic test results with various strain rates and grain sizes are shown at the presentation. The yield stress increased with the increase of the strain rate in both quasi-static and dynamic cases.

4. Conclusions

The responses of nanocrystalline aluminum obtained by consolidating powders of different grain sizes were observed under quasi-static and dynamic compression.

At a constant stain rate, it was found that both the yield stress and the microhardness increased with the decrease of grain sizes. The nanocrystalline aluminum was found to be strain-rate sensitive.

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