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Enhanced mechanical properties of pure aluminium fabricated by powder metallurgy process

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1. Introduction

Bulk nanostructure and ultrafine-grained materials produce by a combination of mechanical milling (MM) and spark plasma sintering (SPS) processes have attracted significant attention as they offer significant potential for exhibiting enhanced mechanical properties compared to their microstructured equivalent. MM is a type of solid state powder processing, typically using highly energetic ball milling, in which elemental powder particles are mechanically mixed in order to introduce high number density of defects with controlled microstructures.

A number of consolidation processes have been applied to fabricate bulk nanostructured materials from MMed powders, e.g. a combination of cold pressing and hot extrusion, hot pressing, hot isostatic pressing and more recently spark plasma sintering or synthesis (SPS). The SPS method is a novel technique developed for sintering advanced ceramics and composite materials. The major advantage of the SPS process is that it allows fabrication of bulk nanostructured materials from MMed powders using relatively short sintering times at nominally low temperatures. Therefore, coarsening of both ultrafine-grains and nano-sized particles in the MMed powders can be avoided.

Mechanical properties of nanostructured pure aluminium produced by MM and SPS have been investigated. This work showed that the SPS materials fabricated from 8 h MMed aluminium powders exhibited compressive 0.2% proof stresses of 440 MPa at room temperature. These results clearly implied that the combination of MM and SPS processes can produce nanostructured materials with enhanced mechanical properties compared to those produced by conventional powder metallurgy routes. However, there is limited microstructural characterisation of SPS consolidated materials, particularly at the grain scale level, making it difficult to elucidate the underlying sources of the improved properties.

The aim of the present work thus was to characterise a nanostructured pure aluminium material produced by MM of pure aluminium powder followed by consolidation via SPS. Characterisation of microstructure for the SPS material was primarily conducted using the electron backscatter diffraction (EBSD) technique in the scanning electron microscope.

粉末冶金法による高強度化された純アルミニウムの創製

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2. Experimental Procedures

The starting material was air-atomised 99.9% pure aluminium powder with an average diameter of 100 μm. Stainless steel balls of 7 mm in diameter together with 10 g of the pure aluminium powder and stearic acid were sealed in a hardened steel vial using a glove box filled with argon. MM was performed at room temperature using an SPEX8000 mixer/mill with processing time varied from 4 h or 8 h. The average Vickers microhardness of the MMed powders was determined with a microhardness tester.

The MMed powders were consolidated by an SPS apparatus. Seven grams of the MMed powder was placed in a graphite die of 20 mm in diameter and 40 mm in height, and heated under vacuum with an applied pressure of 49 MPa at 873 K for 1 h. The Vickers hardness of the SPS materials was measured with a Vickers hardness tester.

Investigation of the aluminium matrix grain orientations was undertaken for the 8 h SPS specimen in its compression plane, using high-resolution EBSD. The specimen was mechanically ground, pre-polished using 3 and 1 μm diamond pastes and finally polished using a 0.5 μm colloidal silica suspension. Acquisition of EBSD data was done using an FEI Sirion field-emission gun scanning electron microscope equipped with a fully automatic HKL Technology EBSD attachment, and operated at 10 kV. Orientation mapping was performed on a rectangular grid with a step size of 0.04 μm covering an area of 22 × 13 μm^2. The corresponding data processing was then carried out using the HKL Channel 5 software.

3. Experimental Results

An EBSD orientation image map (OIM) obtained from the aluminium matrix of the 8 h MMed plus SPS processed material clearly exhibits that the grain distribution has a bimodal character, being composed of nanostructured grains with diameters of approximately 300 nm and contiguous microstructured grains having diameters between 2 and 5 μm. Corresponding {001} pole figures clearly exhibited the coarse and fine grains. As expected the texture of the coarse grain appears on first viewing to be very strong due to the limited number of grains analysed; however, it is of interest to note that whilst these grains are contiguous there does not appear to be any orientation relationship between them suggesting the texture of the coarse grains is random. For the fine grains the texture is random with a maximum intensity of 1.6 times random. Analysis of boundary misorientation in the OIM shows that the vast majority to be of high angle (> 15°) for both coarse and fine grains.

4. Conclusions

The combination of MM and SPS processes has been used successfully to fabricate bulk, fully dense nanostructured pure aluminium. The microstructure of the SPS materials fabricated from the 8 h MMed powders possessed a mixture of fine, typically ~ 300 nm grains and contiguous coarse 2-5 μm grains. This bimodal structure possessed virtually all high angle grain boundaries together with no preferred grain orientation which leads to higher strengths via Hall-Petch type strengthening mechanisms.