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High-temperature deformation and enhanced ductility of friction stir processed-7010 Aluminum Alloy

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ABSTRACT

In the present study the microstructural and high-temperature mechanical properties of 7010 Aluminum Alloy (AA) resulting from friction stir processing (FSP) were analyzed and compared to unprocessed material. The sheets were processed perpendicularly to the rolling direction that resulted into fine-grained microstructure having the size of about 7 μm. The high-temperature deformation characteristics and mechanical properties of the processed material were studied using hot tensile tests at temperatures of 703, 723 and 753 K and at different strain rates in the range of 1×10^{-2}–$1 \times 10^{-4}\ s^{-1}$. Correlation between the flow stress σ and strain rate $\dot{\varepsilon}$ and temperature, T gave an apparent stress exponent n_a of 5 and apparent activation energy Q_a of 260 kJ/mol. The high value of Q_a was attributed to the presence of threshold stress under the present experimental conditions.

1. Introduction

Friction stir processing (FSP) is a new solid state technique which uses the principles of friction stir welding (FSW) to produce materials with fine-grained microstructures as produced by Cavaliere et al. [1]. In FSP, a tool consisting of a shoulder and a concentric pin, which is slightly shorter than the material thickness, is forced into the material being processed until the shoulder comes in contact with its surface. Once the pin has fully penetrated, the tool is allowed to rotate whereas the material linearly moves past the tool. This provides localized frictional heating and mechanical mixing in the area covered by the tool. McNelley et al. [2] have concluded that the severe plastic deformation achieved by the tool stirring action results into large processing strain leading to dynamic recrystallization and consequently microstructural refinement and homogenization. The FSP creates a region called the “stir zone” SZ or “nugget”, where the microstructural refinement occurs having an equiaxed-fine grains with high angle grain boundaries. The characteristics of FSP have led to several applications for microstructural modification in metallic materials, including the production of ultrafine-grained (UFG) microstructures amenable to low temperature-high strain rate superplasticity [3–6], dispersing powders into Aluminum matrix to produce high microhardness by the promotion of grain refinement within the nano-scale [7]. Another application of FSP is incorporating nano-sized alumina particles into Aluminum matrix to form particulate composite surface layer [8]. Several researches have succeeded in refining the microstructure of cast Aluminum Alloy such that achieved in the work published [9–11].

Cavalierea and Squillace [12] have studied the high-temperature deformation of FSP-ed 7075 AA using hot tensile tests at different temperatures and different strain rates. This was done in order to analyze the mechanical properties of the recrystallized material and to observe the differences from the parent material as a function of the grain refinement due to the FSP. They found that the strength and ductility of the material increased in the nugget zone with respect to the base material due to the uniform and very fine structure resulting from FSP. In addition, the true stress–true strain response has shown that the flow stress at high temperatures decreases with increasing temperature and also the strain to fracture increases with increasing temperature. However, there is no steady state exhibited by the curves for all the temperatures and strain rates investigated which was in the range of 150–500 °C and 10^{-2}–$10^{-4}\ s^{-1}$ respectively. It was also reported that the strain rate sensitivity variation obtained at strain = 1 increases upon increasing the strain rate from 10^{-4} to 10^{-3} and then decreases for higher strain rates indicating that FSP-ed material possesses superplastic properties.

The superplastic deformation of FSP-ed 7075 AA has been studied by Ma et al. [13]. In this work two grain size 3.8 and 7.5 μm have been obtained by using different processing parameters. In order to evaluate the microstructural stability the as-processed Aluminum plates were heat treated at 490 °C for 1 h. This treatment revealed that the fine-grained microstructure was stable during hot tensile tests. Superplastic investigations in the temperature range of 420–530 °C and strain rate of 1×10^{-3}–$1 \times 10^{-4}\ s^{-1}$ demonstrated that a decrease in grain size from 7.5 to 3.8 μm

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