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Grain Refinement of Zn–22Al Superplastic Alloy Using Friction Stir Processing

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In this study, we demonstrate that friction stir processing can be used to increase the fineness of the grain structures of Zn–22Al superplastic alloy. The average grain size of 0.7 μm of the base metal was reduced to 0.3 μm within the stir zone. In addition, the results of the microstructural observations, hardness tests, and average grain size measurements are presented.

INTRODUCTION

Friction Stir Welding (FSW) is a solid-state joining process that uses friction heat. This method was invented by The Welding Institute (TWI) in Cambridge, England and was patented by Thomas (1991). Because friction stir welding is particularly appropriate for aluminum alloys, which often cannot be easily joined through the use of standard welding, initial research efforts were concentrated on these materials.

In addition, FSW has generated interest because of its association with Friction Stir Processing (FSP), a new technique that employs FSW tools. FSP is currently being explored as a thermomechanical processing tool that can be used to transform a heterogeneous microstructure into a more homogenous microstructure. Mahoney et al. (2001) have emphasized that FSP can be selectively applied to a location within a conventional aluminum alloy sample to tailor its microstructure and achieve increased superplasticity. Mahoney and Lynch (2006) have reported some practical applications of FSP, including the application of FSP to Al-, Cu-, Fe-, and Ni-based alloys to improve their material properties. Some of the demonstrated beneficial effects of FSP include the doubling of the strength of cast Ni–Al–bronze, the five-fold increase in the ductility of Al alloy A356, the increased fatigue life of fusion welds, the increased corrosion resistance of a Cu–Mn alloy, and the bending of a 25-mm-thick Al alloy 2519 plate to an angle of 85° at room temperature without surface cracking (Mahoney and Lynch, 2006).

Furthermore, FSP is believed to affect the grain size of the stirred material. Nishihara (2004) has reported initial results for the FSW of superplastic Zn–22Al eutectoid alloy, which demonstrate that FSW produces a fine grain structure within the joint part.

Zn–22Al is a well-known superplastic material that has been widely used in different fields of studies. Zn–22Al can be obtained as sheet for thermal forming and is often useful in low-volume applications where tooling costs must be kept low. It is also used for electronic enclosures, cabinets and panels, business machine parts, and medical and other laboratory instruments and tools (Barnhurst, 1990). However, few trials of FSP on this alloy have been conducted. Studies of controlling and improving the mechanical properties of this alloy have been conducted in our laboratory. It has been reported in a previous study that the tensile strength increases after FSP. Additionally, in friction stir-processed Zn–22Al, a high strain rate sensitivity exponent m of 0.59 was observed on the high strain rate side at 250°C, and the possibility of grain refinement by FSP has been indicated (Mofidi and Nishihara, 2013). For a superplastic metal that is tensile tested under proper temperature conditions, the observed ductility varies substantially with the strain rate. There are significant losses in the ductility as the strain rate is increased or decreased from the value at which the ductility is maximized. It is well known that the primary factor related to this behavior is the rate of change of the flow stress with respect to the strain rate, which is usually measured and reported as m. Higher values of m correspond to greater superplasticity (Hamilton and Ghosh, 1988).

As is well known, one of the basic requirements for superplasticity is having a very fine grain (Hamilton and Ghosh, 1988). It is expected that the grain refinement of Zn–22Al can be achieved through the use of FSP, which could be of great significance in superplasticity studies. The focus of this study is the effect of FSP on the microstructure of superplastic Zn–22Al. In particular, the effect of varying different tool process parameters of FSP on the grain size of superplastic Zn–22Al is discussed on the basis of microstructural observation and hardness test results. The results of the present study also open a new channel for discussing different possible new applications and challenges of FSW and FSP, such as applying FSP to the improvement and development of fine grain structures for increased superplasticity or other purposes.

As is known, in general metallic materials, the yield stress σ_y is related to the grain size d through the Hall–Petch equation as (Hall, 1951; Petch, 1953)

$$\sigma_y = \sigma_0 + k_y d^{-1/2} \tag{1}$$

where σ_0 is the friction stress and k_y is a positive constant of yielding associated with the stress required to extend dislocation activity into adjacent unyielded grains. This relationship demonstrates that the yield stress increases with the decreasing grain size. In the absence of appreciable work hardening, the Vickers Hardness (HV) of the material is proportional to the yield stress as $\mathrm{HV} = 3\sigma_y$ (Ashby and Jones, 1980). Equation 1 can therefore be rewritten in terms of the hardness as (Sato et al., 2003)

$$\mathrm{HV} = H_0 + k_H d^{-1/2} \tag{2}$$

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