Materials Science and Engineering A 505 (2009) 70–78

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Superplastic behavior of micro-regions in two-pass friction stir processed 7075Al alloy

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ARTICLE INFO

Article history:
Received 25 August 2008
Received in revised form 29 October 2008
Accepted 14 November 2008

Keywords:
Superplasticity
Friction stir processing
Aluminum alloy
Overlapping

ABSTRACT

Effect of overlapping passes on the microstructure and superplastic behavior of friction stir processed (FSP) 7075Al was subjected to a detailed investigation. Overlapping passes exerted no obvious effect on the size of recrystallized grains. Both single and two-pass FSP 7075Al exhibited similar grain sizes of 5.4–5.7 μm. Compared to single-pass FSP, two-pass FSP resulted in an enhancement in superplastic elongation and a change in superplastic response. A shift to higher optimum temperature was observed in the two-pass FSP 7075Al. Furthermore, overlapping passes led to a shift to higher optimum strain rate in the center region of second pass in the two-pass FSP 7075Al. Maximum superplastic elongation of 1220% was achieved at 480 °C and an initial strain rate of $1 \times 10^{-2}\ s^{-1}$ in the center region of second pass in the two-pass FSP 7075Al. Analyses of superplastic data indicated that grain boundary sliding is the main superplastic deformation mechanism for both single and two-pass FSP 7075Al.
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1. Introduction

Friction stir processing (FSP), developed based on friction stir welding (FSW) [1,2], is a new solid-state processing technique for microstructural modification [3,4]. During the FSP, the material in the processed zone undergoes intense plastic deformation, mixing, and thermal exposure, resulting in the generation of fine and equiaxed recrystallized grains with predominant high-angle boundaries [4,5]. The microstructure in the FSP aluminum alloys is typical microstructure amenable to superplastic deformation. This has attracted a considerable research interest in the superplastic behavior of FSP aluminum alloys. In the past few years, a number of aluminum alloys, such as 7075Al, 7050Al, 2024Al, 5083Al, A356, Al–Mg–Zr, have been subjected to FSP and superplasticity investigations [3–14]. High-strain rate/low-temperature superplasticity (HSRS/LTSP) has been obtained in several FSP aluminum alloys, such as 7075Al, 2024Al, Al–Mg–Zr [3–8,10,11].

Single-pass FSP with a pin diameter of 8 mm usually produces a processed zone 10–14 mm wide. Such a narrow processed zone is not suitable for practical engineering applications. Therefore, it is necessary to overlap FSP passes to produce large-sized fine-grained aluminum plates. In this case, it is important to understand the microstructural evolution during multiple-pass FSP and its effect on the superplastic behavior of FSP material. Some previous studies indicated that for 7050Al, overlapping FSP passes reduced overall ductility due to reduced microstructural stability [11], and for 7475Al, no superplasticity was achieved due to abnormal grain growth under both single and multiple-pass FSP conditions [13]. This indicates that the resultant microstructure and superplastic properties of the FSP aluminum alloys are intimately associated with the alloy chemistries and FSP parameters [5,6,8–14,15].

Recently, Johannes and Mishra [16] investigated the effect of multiple pass FSP on the superplasticity of 7075Al rolled plate. In their study, mini tensile specimens were cut from the center of each stir zone (SZ) on the staggered pass samples. It was reported that good superplastic ductility was achieved in each SZ of the multiple pass FSP 7075Al samples. This indicated that overlapping FSP passes is a feasible method to create a large-sized fine-grained aluminum alloy plate. However, it should be pointed out that for engineering applications, not only the center of each SZ, but also the transition zone of the multiple pass FSP samples are subjected to superplastic deformation. In this case, an understanding on the superplastic behavior of the transition zone in the multiple pass FSP samples becomes of practical importance. Therefore, further investigations on the correlation between the intrinsic superplastic properties and the local microstructure are necessary for both engineering application and scientific analysis.

In this paper, we reported the microstructure and superplasticity of various zones in a two-pass FSP 7075Al sample and a single-pass FSP sample, and the microstructural evolution of various samples during superplastic deformation. Furthermore, the superplastic data of various samples were analyzed based on the constitutive equation for superplasticity of fine-grained aluminum

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doi:10.1016/j.msea.2008.11.016

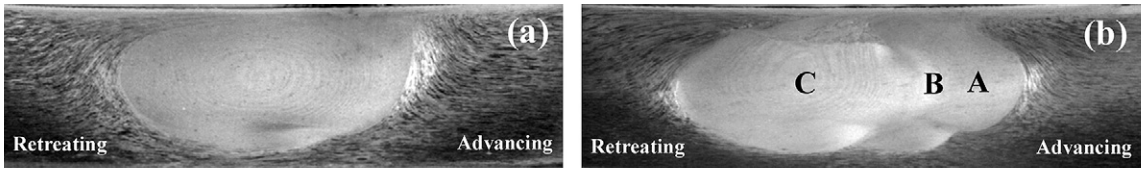

Fig. 1. Macrographs showing stir zone in as-FSP 7075Al: (a) single-pass and (b) two-pass.

alloys. The aim is to understand superplastic behavior and deformation mechanism of various zones in the multiple pass FSP aluminum alloys and to establish the relationship between the intrinsic superplastic properties and the local microstructure.

2. Experimental

6.35 mm thick commercial 7075Al rolled plates with nominal composition of 5.6Zn–2.5Mg–1.6Cu–0.23Cr–bal Al (in wt. pct) were used for FSP and superplastic evaluation. Single-pass FSP and two-pass FSP with 50% overlap (the overlap between passes was one-half of the pin diameter) were performed, respectively, at a tool rotation rate of 600 rpm and a traverse speed of 102 mm/min. For the two-pass FSP, the second pass FSP was located on the retreating side of the first pass FSP. A H13 steel tool with a shoulder diameter of 24 mm and a threaded cylindrical pin of 8 mm diameter and 6 mm length was used. The thread depth and pitch of the pin are 0.8 and 1 mm, respectively.

As-FSP samples were cut in the transverse direction, mounted, and mechanically polished. Keller's reagent was used to reveal the microstructures in these samples. Metallographic examination was conducted by using optical microscopy (OM). Grain sizes were estimated by the linear intercept method. The microstructure of the FSP samples was examined by a transmission electron microscope (TEM). Thin foils for TEM were prepared by the jet polishing technique. Jet polishing was conducted at −25 °C using a solution 20%HNO_3 + 80%methanol (in vol.).

Mini tensile specimens with 1.3 mm gage length were electro-discharge machined from the FSP region in the transverse direction, ground and polished to a final thickness of ~0.5 mm. For the single-pass FSP sample, the gage length of the tensile specimens was located at the center of the SZ. For the two-pass FSP alloy, the gage length of the tensile specimens was located at the transitional zone between two FSP passes (zone B) and the central zone of second pass (zone C), respectively, as shown in Fig. 1. Constant crosshead speed tensile tests were conducted using a computer-controlled, custom-built mini tensile tester. Each sample was held at the testing temperature for about 15 min in order to reach thermal equilibrium. The surfaces of deformed specimens were examined by scanning electron microscope (SEM). Further, deformed tensile specimens were polished to a 0.25-μm finish and used for static and dynamic grain growth evaluation.

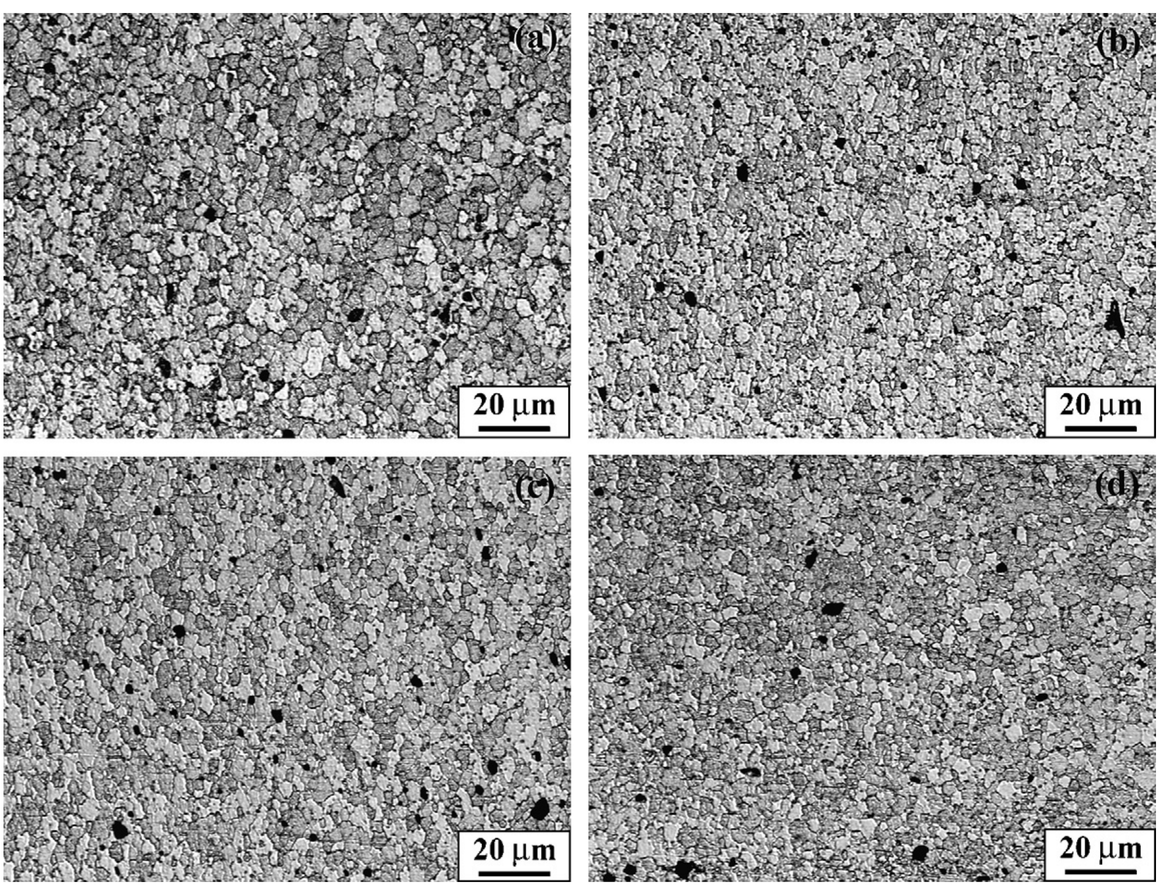

Fig. 2. Optical micrographs showing grain structure of FSP 7075Al: (a) single-pass sample, (b) remnant zone of first pass in two-pass sample (zone A in Fig. 1), (c) transitional zone between two passes in two-pass sample (zone B in Fig. 1) and (d) central zone of second pass in two-pass sample (zone C in Fig. 1).

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