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Hot deformation behavior of friction-stir processed strip-cast 5083 aluminum alloys with different Mn contents

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ABSTRACT

Fine grained 5083 aluminum alloy is the most common Al–Mg alloy for superplastic forming (SPF) of lightweight sheet metal parts in the automotive and aerospace industries. The fine grained sheet is industrially produced by massive cold rolling of conventionally rolled sheet stock at high cost. Friction stir processing (FSP) as a thermomechanical process is very effective in refining the microstructure of as-cast alloys such as that produced by continuous strip casting (CC). In this work, the effect of friction stir processing on the superplastic properties of three CC 5083 aluminum alloys, with different Mn content, has been investigated. The three alloys were friction stir processed. Very fine microstructures with grain sizes less than 3 μm were obtained. Tensile tests revealed elongations of over 600% at a high strain rate of 10^{-1} s^{-1} in all 3 alloys. The maximum tensile elongation of 800% was achieved in the alloy with the lowest Mn content at 490 °C and strain rate of 3×10^{-2} s^{-1}. The stability of the microstructure was an important concern above 500 °C.

1. Introduction

The use of aluminum in vehicle body structures is of great interest for the purpose of reducing mass and thereby improving the fuel efficiency of automobiles. In this context, Al–Mg alloys have been widely investigated because of their attractive combination of properties such as moderate strength, good corrosion resistance, good weldability and competitive price. Since traditional stamping of aluminum alloys is limited by their lower formability relative to drawing-quality steels, superplastic forming (SPF) of aluminum sheet has attracted considerable attention. The commercial 5083 aluminum alloys (Al–4.7Mg–0.35Mn) has been extensively investigated because of its high potential for superplasticity [1–7]. The superplastic-grade sheet is produced from conventionally processed sheet, by imparting additional multi-pass reductions in a cold rolling mill, which increases the sheet cost. Continuous strip casting (CC) process has the potential to reduce sheet cost, but would require a suitable process to impart substantial cold work, without thickness reduction, to produce the required fine grain size in the sheet. Several severe plastic deformation methods, such as equal channel angular pressing (ECAP), accumulative roll bonding (ARB), high pressure torsion (HTP), cyclic channel die compression (CCDC) and friction stir processing (FSP) [8–12], are known to reduce the grain size of 5083 aluminum below 5 μm. Among these, FSP has a unique industrial potential because it can be applied to sheets selectively in areas requiring high formability, thereby allowing selective superplastic forming (SSPF) [13]. Combining the CC sheet process with selective FSP can produce highly formable sheet at low cost [14,15]. In addition to grain refinement, FSP has been shown to break down and homogenize the size and distribution of large second-phase particles [16,17]. Depending upon size, these particles can either act as efficient nuclei for recrystallization [18–20], or suppress the discontinuous recrystallization process altogether by stabilizing grain boundaries against migration at superplastic temperatures [21,22]. Among the common second phase formers in aluminum alloys, viz. Cr, Mn, Zr and Sc, manganese has been shown to be more effective at inhibiting grain growth than Sc or Zr under certain conditions of thermal treatments [23]. Since it is believed that FSP materials are exposed to similar thermal conditions, the goal of the present investigation was to examine the effect of three different Mn contents on the high temperature deformation behavior of friction stir processed continuous cast AA5083 alloy.

2. Experimental

5083 Aluminum alloy plates produced by the CC process were received in the as-cast condition. The chemical compositions of

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Table 1
Compositions of the alloys in weight percent (balance Al).

Alloy	Mg	Mn	Cr	Fe	Si
1	4.72	0.49	0.19	0.16	0.09
2	4.73	0.74	0.17	0.15	0.09
3	4.72	1.00	0.17	0.15	0.09

the alloys are shown in Table 1. Mn and Cr dispersoid formers are added to the alloy for grain refinement while Fe and Si are impurity elements. The plates were friction stir processed using a tool of MP159 alloy at 400 rpm rotation rate and 0.42 mm/s (1 ipm) traverse speed since these conditions gave good thermal stability to the microstructure during superplastic tests [17]. The tool had a featureless shoulder with a diameter of 16 mm, a conical threaded pin with a bottom diameter of 7 mm, a minor diameter of 4.8 mm and a height of 5 mm. The pin was right-handed screw type. The tool tilt angle and plunge depth were 2.5° and 5.4 mm, respectively. The microstructure was observed by optical, scanning and transmission electron microscopes on the transverse cross-section of the FSP zone. The samples for optical analysis were mechanically polished then etched using Keller's reagent to reveal grain boundaries (a heat treatment at 150 °C for 20 h was applied to the samples to decorate the grain boundaries with precipitates). Grain size was measured by the linear intercept method. Large second-phase particles were examined in a Hitachi S-570 scanning electron microscope in backscattered electron mode from as-polished samples. TEM samples were ground and polished, and then thinned by twin-jet electro-polishing at 12 V in a solution of 80% methanol + 20% nitric acid at −30 °C. The samples were examined using a Jeol JEM-2000-FX II transmission electron microscope at 200 kV. Because of the narrow path of the FSP zone, mini-tensile specimens, with the gage length within this stirred zone, were used for tensile testing. The specimens having a gage length of 1.3 mm, a width of 1.0 mm and a thickness of 0.55 mm were machined from the transverse cross section of the FSP zone while maintaining the gage length in the nugget region having the finest grain size. Elongation-to-failure tests were performed with a custom-built, computer-controlled tensile tester at constant crosshead speeds. It took about 23 min for stabilizing the temperature before tensile tests. The elongation-to-failure tests were carried out at 490 and 510 °C and initial strain rates of 3×10^{-3}, 1×10^{-2}, 3×10^{-2} and 1×10^{-1} s^{-1}.

3. Results

Fig. 1 shows the grain structure of the FSP alloys. The FSP zone exhibited a recrystallized and heterogeneous grain structure. A fine microstructure is found in the central and lower FSP regions while a coarser microstructure is found near the surface. The average grain sizes obtained with the different FSP parameters were in the range 1.5–2.2 μm in the finest region. Although there is not a clear trend in the grain size over the Mn range investigated, it is possible to say that the grain size did significantly reduce going from the initial 0.49% content to the elevated levels of 0.74 and 1.0%. Parent microstructures, which have been published earlier [17], had a cast grain size of approximately 70 μm. Table 2 compiles the data of average grain sizes and mechanical properties at room temperature for all alloys. The results reveal an increase in yield strength and ultimate tensile strength as Mn content is increased, which can be explained by the increase in the second-phase particle fraction at higher Mn, e.g. alloy 3. Ductility is approximately the same in the three alloys.

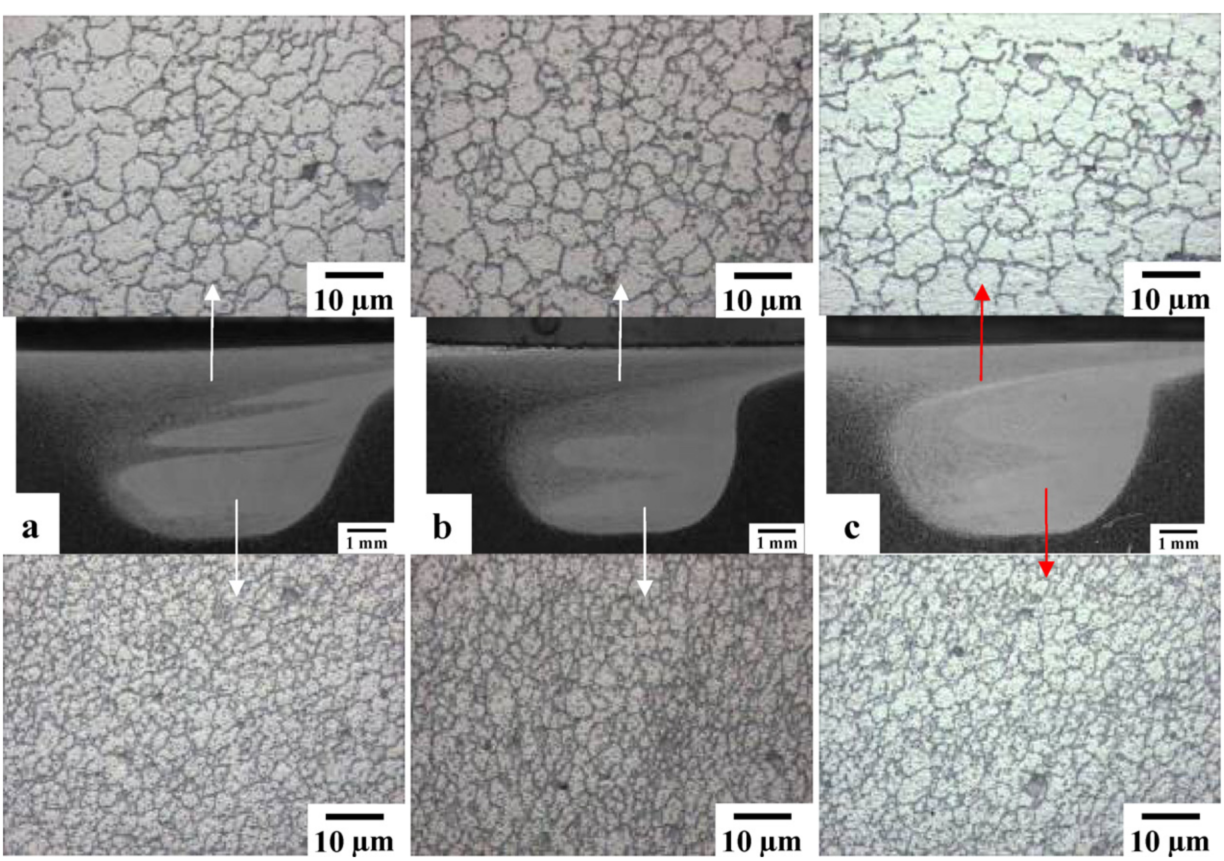

Fig. 1. Optical micrographs showing the transverse cross-sectional of the FSP zone and grain structure of alloys (a) 1, (b) 2, and (c) 3. Top micrographs exhibit the coarse structure near surface while the bottom micrographs exhibit the fine structure in the center/lower region of the FSP zone.