The Effects of Tool Rotational Speed on Microstructure and Mechanical Properties of Friction Stir Welded 7075-T6 Aluminum Thin Sheet

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1- Introduction

High strength aluminum alloys, especially 7xxx series, are extensively used in aerospace industry. Due to their poor weldability, it is difficult to utilize conventional welding techniques to join these alloys. Therefore, much attention has been paid to solid state welding, especially friction stir welding (FSW). Many studies have been conducted to optimize the tool and FSW parameters of AA7075-T6 with different thicknesses, ranging from 2.3 to 9 mm. AA7xxx series contain reinforcing precipitates that are quench sensitive. At lower thickness, the effect of the heat input on the microstructural evolutions might be lowered due to the higher cooling rate. There was quite rare comprehensive studies in open literatures on the microstructural evolution of AA7075-T6 thin sheets during FSW. Hence, the aim of the present work was to investigate the effects of welding tool rotational speeds on microstructural evolution and mechanical properties of friction stir welded AA7075-T6 1 mm thin sheet. Tensile properties of the FSW samples were examined using the sub-sized specimens according to ASTM E8M.

2. Experimental

In this study, the commercial AA7075-T6 sheet with 1.1 mm in thickness and the chemical composition of Al, 5.86 Zn, 2.37 Mg, 1.91 Cu, 0.02 Si, 0.03 Fe, and 0.004 Mn (all in wt.%) was used. Three different welding conditions including rotational speeds of 600, 1000, and 1600 rpm at a constant welding speed of 50 mm/min were used. Butt joints were prepared with welding direction perpendicular to the rolling direction (RD) of the sheets. The welding tool was tilted 3° about vertical axis. After FSW, the plates were held about two months at ambient atmosphere to be naturally aged. The FSW tool was made of heat-treated H13 tool steel consisted of a shoulder with 12 mm in diameter and a cylindrical probe with 3 mm in diameter and 1 mm in length. Temperature changes were measured at the welded joint during the process by means of K-type thermocouples which were set 7 mm form the welding center line on the surface of the sheet. The grain structure and orientations were examined using a Hitachi SU 1510 SEM equipped with an electron backscattered diffraction (EBSD) system at the step size of 0.15 µm. The high angle grain boundaries were identified with misorientations greater than 15°. Three millimeters in diameter TEM specimen discs were cut out of the nugget regions, then thinned to 100 μm with sand papers, and finally polished using ion-milling method to obtain a thin foil. The state of precipitates was studied by a Tecnai G200 TEM operating at 200 kV.

3. Results and Discussion

The results shows that there is no meaningful difference between the peak temperatures of different FSW specimens (Fig. 1).

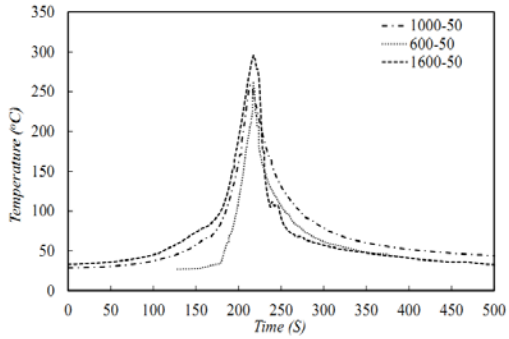

Fig. 1 Temperature-time diagram (thermal cycle) of the welding samples at velocity of 50 mm/min and rotating speed of 600, 1000 and 1600 rpm

Therefore, the heat input is not presumably an effective factor on the microstructure of the stirred zone (SZ). The grains of the specimens with 600, 1000 and 1600 rpm are converted to fine equiaxed grains with an average grain size of 3.8, 2.5 and 5.1 µm, respectively (Fig. 2(b), 2(c) and 2(d), respectively).

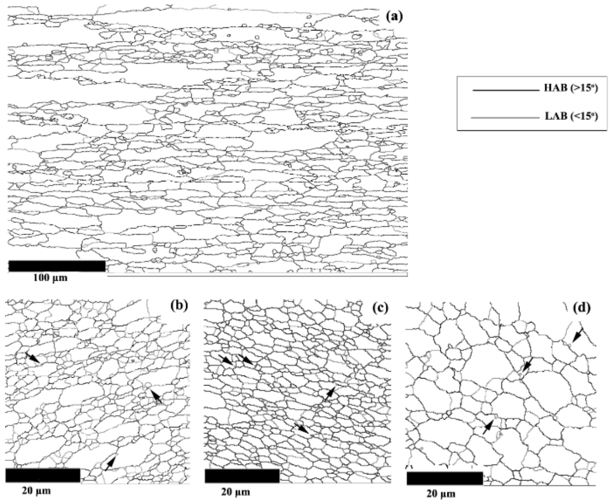

Fig. 2 EBSD grain characteristics of (a) base metal, and naturally aged SZs of (b) 600 rpm, (c) 1000 rpm, and (d) 1600 rpm rotational speed specimens over 15,000 hours. A few bulgings are indicated on the SZ images by black arrows

The conversion of the initial pancaked grains (Fig. 2(a)) into the fine equiaxed grains with a homogeneous distribution points to the dynamic recrystallization (DRX). The numerous low-angle grain boundaries indicated that the continuous dynamic recrystallization (CDRX) is a dominant mechanism of evolution of the

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microstructure. Also, a few bulging are detected implying the fact that discontinuous dynamic recrystallization (DDRX) is a possible but limited mechanism for grain refinement. It is seen that the lowest rotational speed (600 rpm) is not able to induce enough deformation through the structure. Therefore, CDRX is partially occurred and volume fraction of the LABs remains high (26%) in comparison to the base metal (19%). Increasing the rotational speed to 1000 rpm, improves recrystallization process. Therefore, the grain size and volume fraction of LABs is reduced to 2.5 μm and 13%, respectively. On the other hand, once more strain is induced by applying higher rotational speed (1600 rpm), the grain size and volume fraction of LABs increases to 5.1 μm and 31%, respectively.

TEM was used to observe the morphology, size and distribution of precipitates, in the base metal and FSW samples (Fig. 3). The precipitates at the SZ is broken up and homogenously distributes or dissolves during FSW at 1000 rpm (Fig. 3(b) in respect to Fig. 3(a)). By increasing the induced strain, very few number of spherical shaped η' precipitates (< 20 nm) is observed at 1600 rpm (Fig. 3(c)).

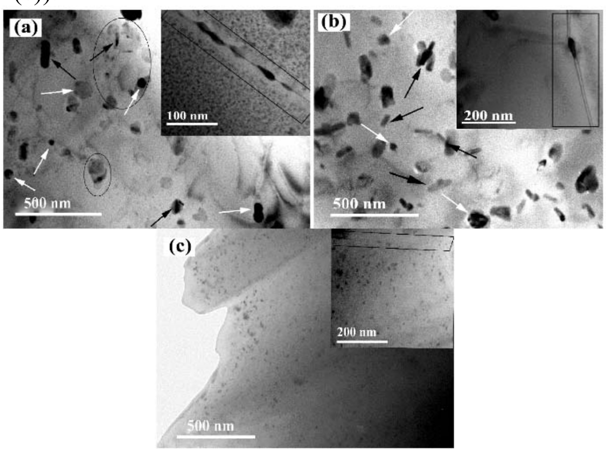

Fig. 3 Bright field TEM micrographs of (a) 7075-T6 aluminum alloy base metal: two different kinds of large precipitates that are inhomogenously dispersed within matrix, naturally aged SZ of (b) 1000 rpm: strain induced by FSW has distributed the precipitates in the matrix. A region of precipitation agglomeration is surrounded by an oval, and (c) 1600 rpm: large precipitates are dissolved. Fine spherical particles of η′ are reproduced. Black arrows: lath-like precipitates of η, white arrows: spherical precipitates of η′. (Insets: higher magnification images around the grain boundaries)

It can be seen that the specimen welded at 1000 rpm exhibited the highest UTS (381 MPa) and highest fracture elongation (6.3%) (Fig. 4).

In Fig. 4 can be seen that the formability of AA7075-T6 fall down dramatically after FSW. Minimum grain size and minimum amount of subgrain structures are obtained simultaneously at the traverse speed of 50 mm/min and the rotational speed of 1000 rpm. CDRX is almost completed in the welding region of the specimen. The reduction of formability observed at 1600 rpm is due to the increase in the mean grain size, which has led to the loss of strength and ductility. At 600 rpm, the grains undergo the partial recrystallization and preserve initial texture of the starting material.

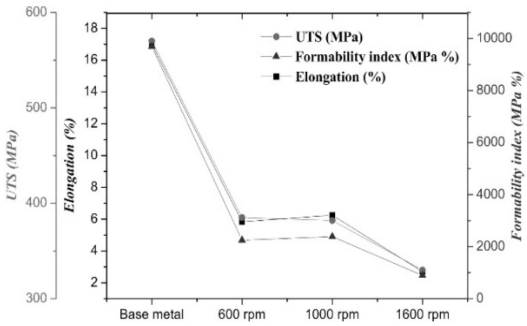

Fig. 4 mechanical properties of base metal as well as friction stir welded samples under different FSW conditions. FSW has led to an obvious reduction in formability index

At 1600 rpm, the particle dissolution makes the grain growth possible. Increasing the induced strain can increase the rate of dissolution. It is seen that there is an optimum rotational speed of 1000 rpm at welding speed of 50 mm/min below which, the microstructure doesn't fully change by induced strain of the FSW. At the optimum point, dynamic recrystallization thoroughly evolved the grain structures to the finest equiaxed shape. The complete recrystallization can improve the formability index of the joints. However, reduced formability of FSW samples is attributed to the precipitate partial dissolution in the SZ (Fig. 3(b) and 3(c)).

4- Conclusions

In the present research, for the first time a 1 mm of 7075-T6 aluminum alloy is welded by FSW. The welding rotational speed of 600 to 1600 rpm was used. It is observed that low thickness of the sheets, due to very high quenching rate of the weld region, leads to the low tensile strength of the joints. The heat input seems to have a negligible effect on the microstructure. Hence, the induced mechanical strain is the dominant factor for the microstructural evolution of the friction stir welded AA7075-T6 thin sheets. It seems that high strain value can partially dissolve back the precipitates to the matrix. CDRX is the dominant mechanism for grain structure refinement of AA7075-T6 thin sheets during FSW which have different effects on the mechanical properties. There is an optimum rotational speed of 1000 rpm at welding speed of 50 mm/min below which, the microstructure doesn't fully change by induced strain of the FSW. At the optimum point, dynamic recrystallization thoroughly evolve the grain structures to the finest equiaxed shape. The complete recrystallization can improve the formability index of the joints. However, reduced formability of FSW samples is attributed to the precipitate partial dissolution in the SZ.