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Microstructure and mechanical properties of friction stir welded 6082 AA in as welded and post weld heat treated conditions

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ABSTRACT

Friction stir welding of 6082 AA-T651 was performed using three different combinations of feed rates (90, 140 and 224 mm/min) and tool rotational speeds (850, 1070 and 1350 rpm). Mechanical properties of the weldments were evaluated by hardness measurements on the transverse section and tensile testing, while microstructure evaluation was done by optical microscopy and electron back scattered diffraction (EBSD). Irrespective to welding parameters the dynamically recrystallized grains in the stir zone were measured to be in the range of 2–3 μm for different feeds rates and rotational speeds. A considerable loss in hardness in the stir zone and more severely in the thermo-mechanically affected zone was noted due to dissolution of β′ and β″ second phase particles. A post weld heat treatment (PWHT) of 175 °C for 5 and 12 h was given to the weldments for all welding conditions and the mechanical properties and microstructure were re-evaluated. The hardness and strength were partially recovered and this was attributed to the possible re-precipitation of the β″ precipitates. The grain size barely exhibited a change, whereas the texture displayed a significant diminish in the Goss orientation after PWHT.

1. Introduction

Friction stir welding (FSW) is a relatively new solid state joining process. It requires no local melting in order to join pieces together. This joining technique is energy efficient, environment friendly, and versatile. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The tool serves two primary functions: (a) heating of work piece, and (b) stirring/intermixing of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in the generation of fine and equiaxed recrystallized grains [1]. The fine microstructure in friction stir welds produces good mechanical properties [1–4]. Recently friction stir processing (FSP) was developed by Mishra and Mahoney [5] as a generic tool for microstructural modification based on the basic principles of FSW. Among different severe plastic deformation techniques, friction stir processing (FSP) and equal channel angular pressing (ECAP) have possessed the main focus of researchers [6,7].

As the need for strong, lightweight, high corrosion resistance, high thermal and electrical conductivity, hot and warm formability materials has steadily been increasing, there has also been a growing interest in Aluminum Alloys which posses such properties like that found in age-hardenable Al–Mg–Si alloy. The 6xxx-group of Aluminum Alloys (AA) contains magnesium and silicon as the major alloying elements. Al–Mg–Si alloys have recently been used for automotive body sheet panel for weight saving. These multiphase alloys belong to a group of commercial AA, in which relative volume, chemical composition, and morphology of the structural constituents exert a significant influence on their useful properties [8–10]. The Al–Mg–Si alloys can be strengthened by the precipitation of the metastable precursors to the equilibrium β(Mg_2Si) phase. An understanding of these precipitation mechanisms during artificial aging is critical for achieving optimal properties. A number of studies on the aging behavior of Al–Mg–Si alloys [11,12] are available. Miao and Laughlin [13–15] suggested the following precipitation sequence for the 6022 Al–Mg–Si alloy:

$$\alpha(\text{sss}) \rightarrow \text{GP zones} \rightarrow \beta'' \text{ needles} \rightarrow \beta' \text{ rods} + \text{lath-like particles} \\ \rightarrow \beta + \text{Si (various morphologies)}$$

where α (sss) is the supersaturated solid solution and GP zones are spherical clusters having an unknown structure. The exact composition of the alloy and the casting condition will directly influence the volume fraction of intermetallic phases present [16,17].

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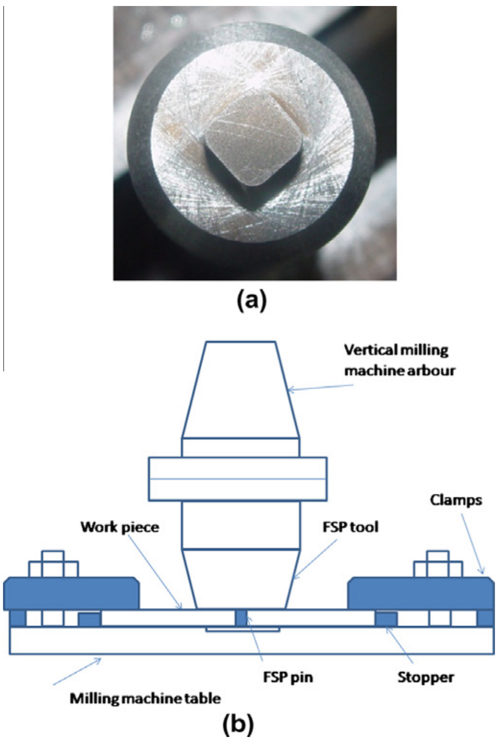

Fig. 1. (a) FSP tool photo showing the tool shoulder and the square pin. (b) Experimental set-up of FSP, El [6].

Precipitation hardening assume various forms (under-aged, peak-aged, and over-aged), and each has their specific type, size, and distribution of precipitates and can be expected to exhibit different behavior during plastic deformation. During the isothermal aging for solution treated AA 6082, the hardness displays an increase until the peak aged condition and finally a decrease in hardness is noted as the sample becomes over-aged. The higher the temperature, the faster the response to achieve peak- aged condition. However, the peak-aged hardness decreases with increasing aging temperature [12]. From an industrial point of view, it is interesting to note that at high temperatures the artificial aging response is quite rapid. As artificial aging commences, coherent needle-shaped β'' particles are precipitated leading to an increase in hardness. Urreta et al. [18] showed that when the β'' needles are still thin, they are sheared or cut by glide dislocations. As aging continues these needles gradually grow and further harden the material, as many of the larger β'' precipitates behave as impenetrable obstacles. This is particularly the case at the beginning of plasticity in the peak-aged condition. Formation of the β'' hardening phase is a thermally-activated process. As the aging process continues past the peak-aged condition, the β'' phase is reverted to larger, semi-coherent rod-like or lath-like β' particles, resulting in a softening of the material [18]. At the final aging stage, equilibrium non-coherent β Mg_2Si and silicon particles are precipitated. In this over-aged condition, precipitates are largely bypassed by dislocations through the Orowan mechanism. The low strength of over-aged samples is due to the poor solid solution hardening as the majority of the magnesium and silicon present in the alloy is precipitated as relatively large Mg_2Si or silicon particles. A second

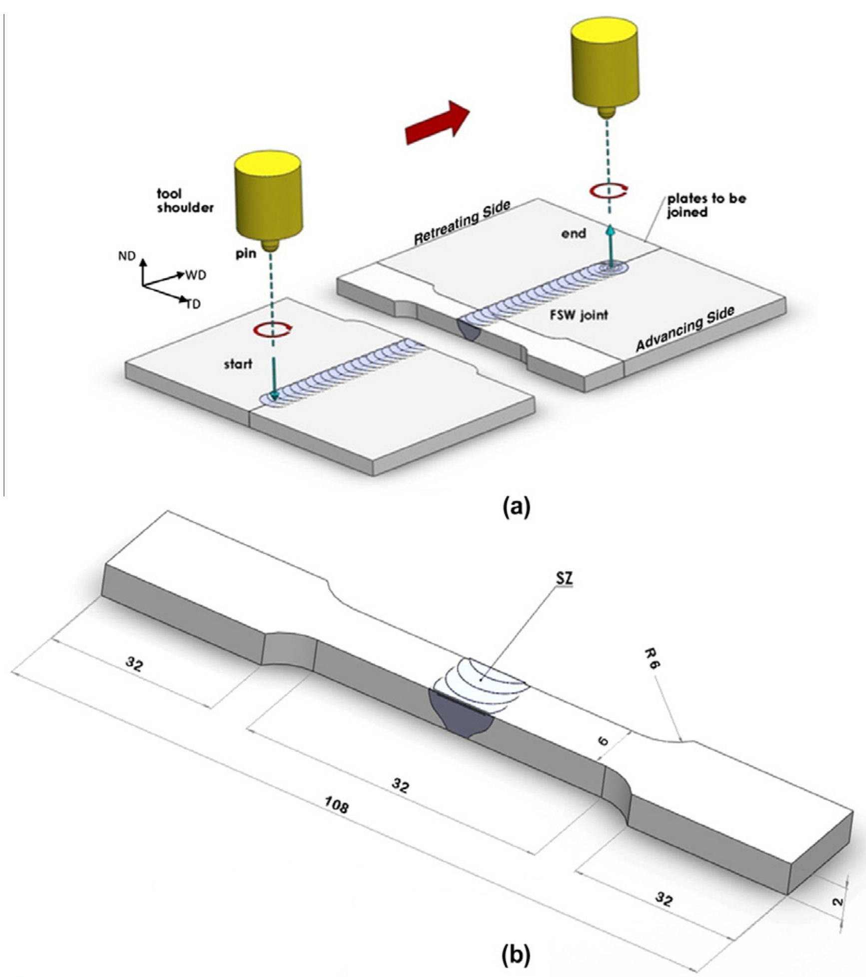

Fig. 2. Schematic of how the tensile sample was extracted from the welded piece and the dimensions of the tensile sample.