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Comparative study on local and global mechanical properties of bobbin tool and conventional friction stir welded 7085-T7452 aluminum thick plate

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ABSTRACT

7085-T7452 plates with a thickness of 12 mm were welded by conventional single side and bobbin tool friction stir welding (SS-FSW and BB-FSW, respectively) at different welding parameters. The temperature distribution, microstructure evolution and mechanical properties of joints along the thickness direction were investigated, and digital image correlation (DIC) was utilized to evaluate quantitatively the deformation of different zones during tensile tests. The results indicated that heat-affected zone (HAZ), the local softening region, was responsible for the early plastic deformation and also the fracture location for SS-FSW samples, while a rapid fracture was observed in weld nugget zone (WNZ) before yield behavior for all BB-FSW specimens. The ultimate tensile strength (UTS) of SS-FSW joints presented the highest value of 410 MPa, 82% of the base material, at a rotational speed of 300 rpm and welding speed of 60 mm/min, much higher than that of BB-FSW joints, with a joint efficiency of only 47%. This should be attributed to the Lazy S defect produced by a larger extent of heat input during the BB-FSW process. The whole joint exhibited a much higher elongation than the slices. Scanning electron microscopic (SEM) analysis of the fracture morphologies showed that joints failed through ductile fracture for SS-FSW and brittle fracture for BB-FSW.

1. Introduction

Bobbin tool friction stir welding (BB-FSW) is a type of solid-state welding technology based on the principle of conventional FSW [1–4]. During the BB-FSW process, the bobbin tool consists of two shoulders connected by the tool pin, the lower shoulder replaces the backing plate used in conventional FSW [1], which allows for welding machines with substantially lower stiffness and adds extra flexibility of FSW. It is possible to carry out the FSW of closed profiles and complex shaped structures by using bobbin tool. As the bottom shoulder also functions as heat source, the temperature gradient is significantly reduced along the thickness direction. In addition, the ability to weld a workpiece simultaneously from both sides makes BB-FSW an effective technology to eliminate the occurrence of root flaw [5,6].

For FSW, the temperature field determines not only the flow behavior of base material (BM) but also the microstructure evolution of different weld regions, and further influences the mechanical properties of joints [3,7]. Until now, investigations on the temperature distribution, microstructure and mechanical properties of BB-FSW joints have focused mainly on 2000 [6,8,9] and 6000 [10–13] series aluminum alloys. A thermo-mechanical model of the BB-FSW for 2014 aluminum alloy was established by Liu et al. [14], and simulation results indicated that the temperature field of the weld cross section presented symmetry approximately about the mid-thickness of the work piece, and the peak temperature for the point at retreating side (RS) was higher than advancing side (AS). Wan et al. [12] found that the typical weld shape of the BB-FSW joint differed from the conventional FSW joint, and was roughly hourglass-shaped. Zhang et al. [6] carried out BB-FSW of 2A14 aluminum alloy, and the weld formation and mechanical properties of

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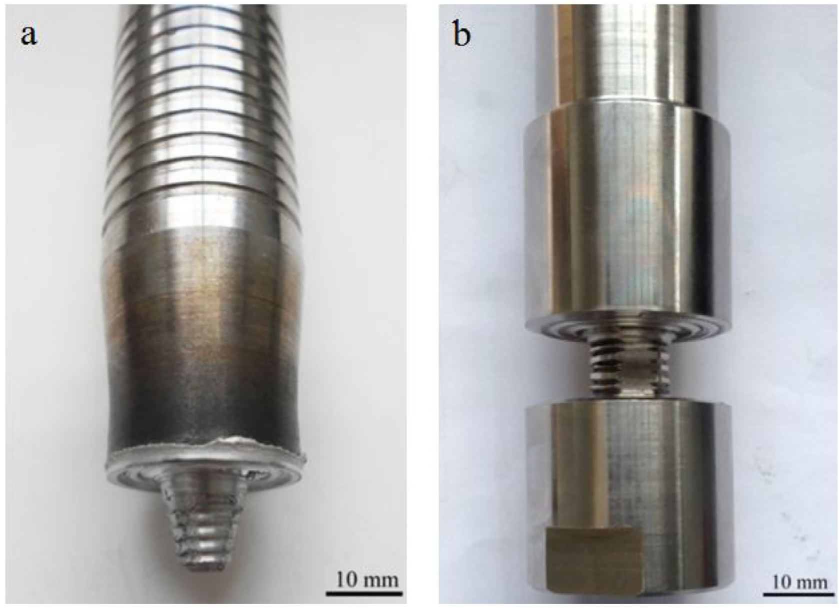

Fig. 1. Tools of single side (a), bobbin tool (b) during FSW process.

Table 1
Chemical compositions of 7085-T7452 aluminum alloys.

Chemical compositions (wt%)						
Al	Zn	Mg	Cu	Fe	Si	Zr
Bal.	7.0–8.0	1.2–1.8	1.3–2.0	0.08	0.06	0.08–0.15

the joints were investigated, achieving a maximum strength efficiency of 75%. On the whole, there have been relatively few studies on the development of BB-FSW of high-strength aluminum alloy plate especially on the inhomogeneity of microstructure and joint properties along the thickness direction.

Al-Zn-Mg-Cu alloy with a brilliant application prospect has been already widely used in aerospace fields [15,16] due to its low density, high strength and so forth. Therefore, in this study, 7085 aluminum alloy plates were welded by SS-FSW and BB-FSW, respectively, and the focus is placed on the temperature distribution, weld formation, microstructure and mechanical properties along the thickness direction of the two types of joints.

2. Material and experimental procedures

The BM used in the present study was a 12 mm thick 7085-T7452 aluminum alloy plate. The nominal chemical composition of the BM is listed in Table 1. The plates were butt welded along the longitudinal direction of the samples by a medium-sized gantry FSW machine (FSW-LM-E154). For SS-FSW, the welding tool is made of die steel H13 with a shoulder 24 mm in diameter, and a conical threaded pin 11.8 mm in length, and 10.5 mm and 6 mm in root and tip diameter, respectively. The bobbin tool has scrolled feature on both shoulders and three flats feature on the cylindrical pin with thread. The two shoulders are made of die steel H13 and have a diameter of 34 mm, while the pin is made of high-temperature alloy MP159 with a diameter of 13 mm and a length of 11.8 mm, as shown in Fig. 1. Based on previous studies, the welding parameters selected to produce various joints are shown in Table 2.

The temperature evolution during the welding process was detected by K-type thermocouples plugged in feature points at different positions of the plates. In order to protect thermocouples from destruction by the tool, blind holes of 1.5 mm in diameter and 25 mm in depth were designed. Fig. 2 shows the positions of blind holes, which allow for the measurement of the temperature changing process with the AS (by points 1–9) and RS (by points 10–12) of welds, the outside of pins (by points 7–10) and the thickness direction of work pieces (by points 1–9).

Table 2
Parameters for SS-FSW and BB-FSW.

Welding technology	Rotational speed (rpm)	Welding speed (mm/min)
SS-FSW	300	60
	600	60
BB-FSW	150	150
	200	150

After welding, the specimens for metallographic analysis were cut perpendicular to the welding direction, and then grinded with #240-#7000 sandpaper, polished using a diamond paste and etched with Keller's reagent (3 mL HNO_3, 6 mL HCL, 6 mL HF and 150 mL H_2O). Macro morphology was observed using a laser scanning microscope (OLS4000), and microstructure analysis was performed by an optical microscope (OLYMPUS GX71) and the Image-Pro Plus software to measure the grains size. In this study, the cross section of weld is divided into three slices along the thickness direction, which are top layer, middle layer and bottom layer, respectively, to draw a comparison analysis of the microstructure evolution for two types of FSW welds.

The 2D microhardness maps were obtained at the whole weld region on the polished cross sections using a Vickers hardness tester (THV-1D) with a testing load of 200 g and a dwell time of 20 s. The spacing between adjacent indentations was 0.5 mm. The tensile samples were prepared according to ASTM E8 with a gauge of 32 mm long by 10 mm wide, and the specimens were cut into equal three slices. Tensile properties of both the whole and slices of joints were evaluated with two tensile specimens cut from the same joint. The room temperature tensile tests were carried out at

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