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Effect of welding speed on the mechanical properties of friction stir welded aluminium alloy 5083

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Abstract:

The influence of welding speed on the properties of friction stir welded aluminium alloy 5083 was explored. The effects of various welding regimes on the defect formation, hardness distribution, tensile strength, and bending strength of the joint were experimentally investigated. Kissing bond defects were prevalent in the joint, however, this kissing bond was eliminated at high welding rates. The welded zone was softened significantly; all the tensile specimens were fractured in the welding zone with shear mode. The tensile strength of the joint reached 85% of the base aluminium alloy 5083 while the bending ductility of the joint was higher than that of base aluminium alloy 5083.

Keywords: **aluminium alloy 5083, defects, friction stir welding, mechanical properties.**

Classification number: **2.3**

Introduction

Aluminium alloys possess high specific strength and are suitable for high-speed vehicles and among other applications. Aluminium alloy 5083 (abbreviated as AA5083) is an advanced alloy with excellent corrosive resistance; thus, this alloy is used dominantly in shipbuilding. One of the significant challenges in using aluminium alloys is associated with their low weldability. Recently, friction stir welding (FSW) has emerged as a new method for welding aluminium alloys [1-7]. In FSW, the tool heats and moves the metal beneath the tool shoulder to produce the joint [8, 9]. During the FSW process, the microstructure in the welded zone dramatically recrystallizes through the interaction between the tool geometry and welding parameters. Thus, the welded zone becomes inhomogeneous and possesses varied properties [2-3]. Even though this welding technology possesses several preeminent points, application of this technology is still quite limited due to the deficiency of equipment (especially in the case of Vietnam). In this work, which is based on the NTU-FSW equipment at the Friction Research Center, Nha Trang University, the FSW butt-joint of AA5083 plate with 3.0 mm thickness is investigated experimentally and the effect of various welding regimes on the mechanical properties of the joint is evaluated.

Materials and experiments

The AA5083 plates with 3 mm thickness (Korea) were butt joined by the NTU-FSW machine in Friction Stir Welding Lab of Nha Trang University. Two AA5083 plates were joined by a tool with a concave shoulder and a truncated probe. The probe of the tool possessed a 4.0 mm diameter at its middle (with respect to length) and was 2.8 mm in height. The tilt angle of the pin was set at 2.0 deg. Various regimes of welding speed rates (denoted as WSR, mm/rev) were performed to fabricate the joints. The WSR defined as the ratio of weld speed and rotation speed. The microstructure of the welded zone and the base AA5083 was observed by an optical microscope (Olympus, Japan). The hardness property in and around the welded zone was measured by the HM-125 equipment (Japan) using 100 gf loading. Both the tensile specimens and bending specimens

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*Corresponding author: Email: tra@ntu.edu.vn were tested by the 3366 Instron (Instron, USA) at a constant strain rate of 10^{-3}/s. Here, the tensile specimen geometry was designed based on the standards ASTM E08; the bending specimen geometry relied on ASTM E290. Here the tested specimens were manufactured such that the loading direction was perpendicular to the welding direction, as shown in Fig. 1. Tables 1&2 show a data summary of the chemical composition and mechanical properties of AA5083, respectively.

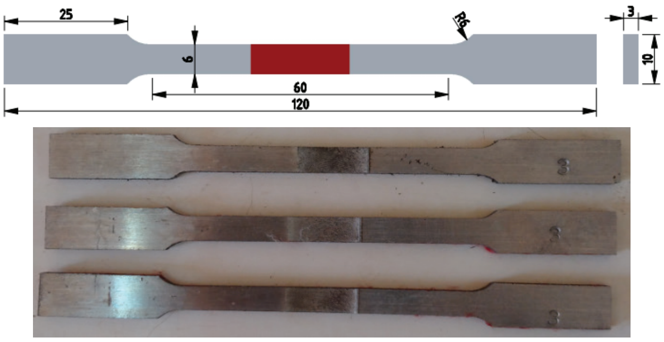


Fig. 1. The geometry of the tensile specimen (ASTM E290), dimension in mm.

Table 1. The chemical composition of AA5083, wt. %

Element	Al	Mg	Mn	Cu	Si	Zn	Mn	Ti	Cr
Percentage (%)	balance	4.0-4.9	0.4-1	Max 0.1	Max 0.4	Max 0.25	Max 0.3	Max 0.15	0.05-0.25

Table 2. The mechanical properties of AA5083 aluminium alloy.

Mechanical properties	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (HRB)	Elastic modulus (GPa)	Poisson ratio
Value	190	300	16	50	70.3	0.33

Results and discussion

Several welding speed rates were used to fabricate the joints. Afterwards, the defects formations and mechanical properties of the FSW joint were investigated. The typical microstructure of the FSW AA5083 (fabricated at *WSR*=0.71 mm/rev.) is presented in Fig. 2. It can be seen that the welded zone is characterized by dynamic recrystallization (Fig. 2). The grain size in the welded zone was refined significantly. The average grain size diameter in the stirred zone was about 10 µm, whereas the grain size of the base AA5083 was about 40 µm (see Fig. 2(I) and Fig. 2(IV)). The grain of the heat-affected zone (HAZ) was similar to that of the base alloy 5083, see Fig. 2(II&III).

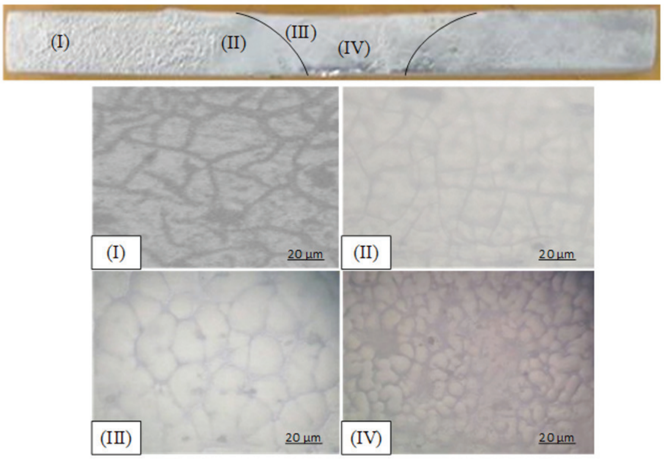
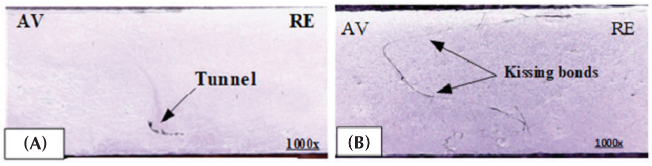


Fig. 2. The cross-section microstructure of the FSW fabricated at WSR = 0.71 mm/rev: base alloy (I), region (II), region (III), and region (IV).



WSR = 0.14 mm/rev.

WSR = 0.57 mm/rev

Fig. 3. Tunnel defect and kissing bond defect in the joints (AV and RE are abbreviations of the advancing side and retreating side, respectively).

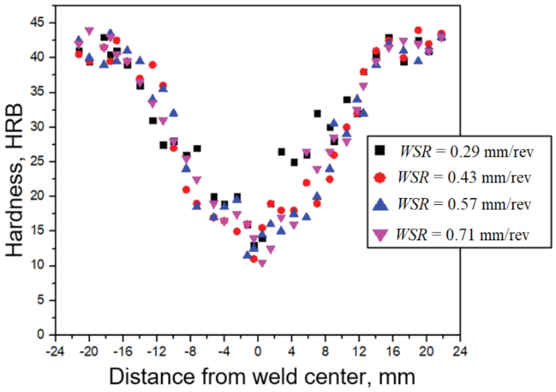


Fig. 4. Hardness distribution across the welding.

In the FSW, both the tunnel defect (see Fig. 3A) and kissing bond defect (see Fig. 3B) were found in the joints. The kissing bond was found to be dominant. The obtained joint was free of defects under the high *WSR* regime (*WSR* = 0.71 mm/rev).

The hardness distributions measured at the middle-line of the cross-sections are shown in Fig. 4 as a function of the *WSR*. For all the welding regimes, the material in the welded region was softened remarkably. This softened zone must be related to degradation of the material induced by the welding temperature. The lowest hardness took place in the stirred zone where the peak welding temperature is located. The effect of the welding regime on the hardness of the joint seems to be unremarkable. The width of the softened zones (see Fig. 4) also seemed to be independent of *WSR*.

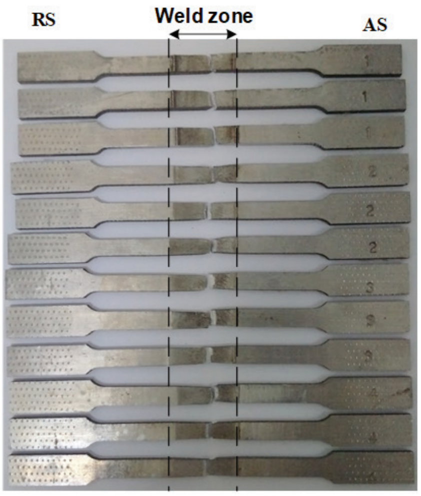


Fig. 5. Tensile specimens and the tensile fracture locations (the dash lines present the tool shoulder).

Fig. 6. Shear mode fracture of tensile specimens.

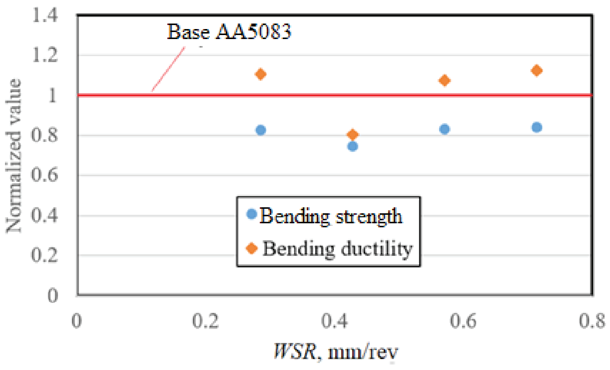


Fig. 7. Bending strength of the joint.

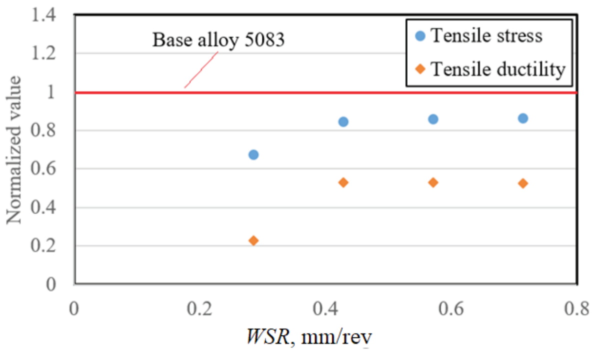
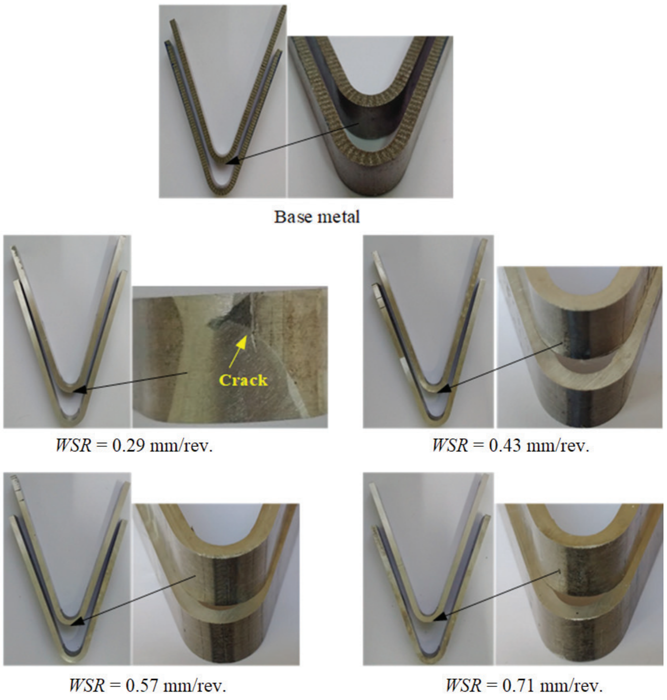


Fig. 8. Tensile strength and elongation of the joint.



WSR = 0.29 mm/rev. *WSR* = 0.43 mm/rev.

WSR = 0.57 mm/rev. *WSR* = 0.71 mm/rev.

Fig. 9. Bended FSW specimens under various WSR.

To evaluate the tensile properties of the joint, the tensile specimens were extruded from the FSW plate and tested by the 3366 Instron with a constant loading strain rate of 10^{-3}/s. For all cases, the specimens were fractured in the welded zone (see Fig. 5) with a typical shear mode (see Fig. 6). The fracture locations occurred in the lowest hardness zone (Figs. 5 and 4). This fact implies that the effect of welding temperature on the degradation of the welded zone seems to be inevitable.

The ultimate tensile strength and the fracture elongation of the FSW are plotted in Fig. 7. For all welding regimes, in comparison to the base AA5083, the tensile properties of the FSW alloys degraded remarkably. The highest tensile strength and ductility was obtained at a WSR around 0.6 mm/rev. Here, the ultimate strength and fracture elongation of the FSW alloys were about 85% and 57% that of the base AA5083, respectively. It should be noted that at low welding rates, a tunnel defect appeared in the joint (see Fig. 3A). However, high values of *WSR* could lead to an incomplete joint.

The results of bending strength and bending ductility of the FSW alloys under the various welding regimes are shown in Figs. 8&9. In all cases, the bending strength of the

FSW was lower than that of the base AA5083. However, the bending ductility of the FSWs was mostly higher than that of the base alloy. It should be noted that the joint was cracked in the stirred zone (at the bottom face) at a low *WSR* (see Fig. 9). Generally, the bending strength and bending ductility of the FSW alloys are about 86% and 114% that of base AA5083, respectively.

In summary, the kissing bond maintained a prominent factor in the strength of the FSW AA5083. The joint can be obtained with high strength and ductility. Even though the strength of the joint degraded dramatically in comparison to that of the base AA5083, the bending ductility of the joint improved remarkably.

Conclusions

The FSW of AA5083 was successfully fabricated and the effect of welding speed rate on its defects, hardness, tensile, and bending properties was investigated. The kissing bond defect was found to be dominant in the joint but all the defects could be eliminated at high welding rates. The 0.71 mm/rev *WSR* was found to be a suitable regime to obtain a good joint. The strength of the joint reached 85% that of the base AA5083 and the bending ductility improved significantly.

The authors declare that there is no conflict of interest regarding the publication of this article.

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