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Influence of Friction Stir Welding Variables on Hardness, UTS and Yield Strength of Joints Produced in SSM Cast A356 Aluminum Alloy

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Abstract: The relationship between Friction Stir Welding variables and hardness, UTS, and, Yield strength of A356 aluminum alloy joints was investigated in this study. For this aim, the tool travel speeds (welding speeds) were chosen as 45, 60, and 75 mm/min and tool rotation speeds were chosen as 400, 600, and 800 rpm, and after the welding process, Brinell Hardness (HB) test and tensile test were performed on all welding joints at room temperature. The results clearly illustrated that the hardness and strength of welding joints are low in 45 mm/min welding speed and 400 rpm tool rotation speed. With increasing the welding speed and/or tool rotation speed, the hardness and strength of the welding joints increased and reached to the highest values in 75 mm/min welding speed and 800 rpm tool rotation speed.

Keywords: Welding parameters; mechanical properties; aluminum alloy.

INTRODUCTION

There are two types of semi-solid forming technologies available at present, Rheo and Thixo casting. Rheo casting involves the preparation of SSM slurry directly from liquid alloys by stirring during solidification and casting the slurry with a HPDC machine directly into a die for component manufacturing. Thixo casting is a two-step process, which involves the preparation of a feedstock material with thixotropic characteristic (globular microstructure), and reheating of the material to semi-solid temperature to produce SSM slurry to be used to form components (Jung *et al.*, 2001 and Brabazon *et al.*, 2003). Friction stir welding (FSW) is a solid-state joining process developed and patented by The Welding Institute (TW I) in UK in 1991 (Dawes and Thomas, 1996). Since inception, FSW had been restricted to the lower melting temperature materials, such as aluminum (Al) and magnesium (Mg) alloys (Mahoney *et al.*, 1998; Sato *et al.*, 1999; Sato and Kokawa, 2001; Heinz and Skrotzki, 2002; Hassan *et al.*, 2003; Su *et al.*, 2003; Park *et al.*, 2003; Liu *et al.*, 2003; Sato *et al.*, 2004 and Sato *et al.*, 2003). This process is a continuous, hot shear, autogenous process involving non-consumable rotating tool of harder material than the substrate material. Defect-free welds with good mechanical properties have been made in a variet of aluminum alloys, even those previously thought to be not weldable (Zeng *et al.*, 2006). Many published papers have focused on the effect of FSW parameters and tool profiles on mechanical properties of weld. However, as far as our knowledge, there exists no information about relationship between FSW tool parameters and mechanical properties of SSM cast aluminum alloy welded joint in the available literatures. The present paper has attempted to study the effect of welding speed and tool rotation speed on mechanical properties of welding joints in A356 aluminum alloy.

MATERIALS AND METHODS

The examinations were carried out on A356 aluminum alloy plates of about 275 mm×100 mm size with 8 mm thickness. Chemical composition of base metal is given in Table (1). The square butt joint configurations were prepared to produce the friction stir welding joints.

Table 1: Chemical composition of base metal.

Base Metal	Al	Si	Mg	Fe	Ti	Cu	Mn	Cr	Ni	Sr
% wt.	Balance	7.28	0.35	0.18	0.12	0.006	0.0065	0.005	0.005	0.039

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Before welding process, the aluminum oxide layers were removed from the base metal surface by grinding and then the edges were cleaned.

The equipment used for welding process was a TURBO three channel load cell with recording ability of both forces along the tool axis and along the welding direction (F_Z and F_X , respectively) for all welding process. The welding tool parameters used in this study and limits are given in Table (2).

Table 2: The welding tool parameters and limits.

Welding Tool Parameter	Amount (mm)
Shoulder Diameter	12
Pin Diameter	4
Pin Length	5

The tool was tilted 4° from the plate normal direction. Welding process was performed at three different welding speeds and tool rotation speeds, the variables and limits are given in Table (3).

Table 3: Welding variables and limits.

Welding speed (mm /min)	45	60	75
Tool Rotation Speed (rpm)	400	600	800

For revealing the welding defects on the surfaces and in the inner zones, visual inspection and ultrasonic test (by SITESCAN 140) were performed as much as possible on the FSW joints after finishing the welding process. The Brinell hardness of welds was measured on the cross-section of joints perpendicular to the welding direction and at the center of the thickness with a 15.625 kgf according to ASTM E10 guidelines. Perpendicular tensile specimens were extracted from the welding joints and prepared according to ASTM E8M-04 guidelines. Dimensions of the tensile test specimens are shown in Fig. (1).

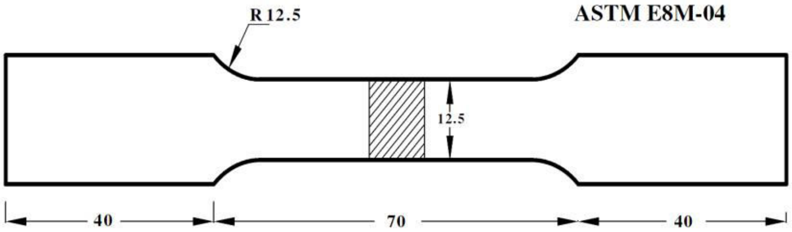

Fig. 1: Dimensions of the tensile test specimen (Elangovan *et al.* 2009).

All of mechanical tests were performed at room temperature. All mechanical tests in this work were carried out at Semnan University in Iran during 2009.

RESULTS AND DISCUSSION

The mechanical properties of A356 aluminum alloy joints produced by the FSW process in different conditions were investigated in this work. The results are shown in Figs. (2-4). According to the results, at lower welding speed (45 mm/min), hardness, UTS, and yield strength of the FSW joints were low. When welding speed was increased from 45 to 75 mm/min, correspondingly the hardness, UTS, and yield strength also increased. The welding speed has a strong impact on productivity in streamlined production of friction stir welding of aluminum alloy sections. A significant increase in welding speed is achieved with high weld quality and excellent joint properties (Lee, 2004). Frigaard et al. (2001) showed that the heat input of FSW has a reversed proportion with welding speed. Hence, increasing welding speed results in reducing the welding heat input. On the other hand, reducing heat input causes increasing the cooling rate of the weld. In lower cooling times, the phenomenon of grain coarsening and softener transformations will have a low chance to occur during the solidification of weld metal molten. At lower tool rotation speed (400 rpm), hardness, UTS and yield strength of the welding joints were low. When tool rotation speed was increased from 400 to 800 rpm, correspondingly the hardness, UTS, and yield strength of welding joints also increased. It may be related to that the welding joints fabricated at lower tool rotation speeds contain defects like pinhole or crack in friction stir processed (FSP) region and results in lower tensile properties (Elangovan and Balasubramanian, 2009).

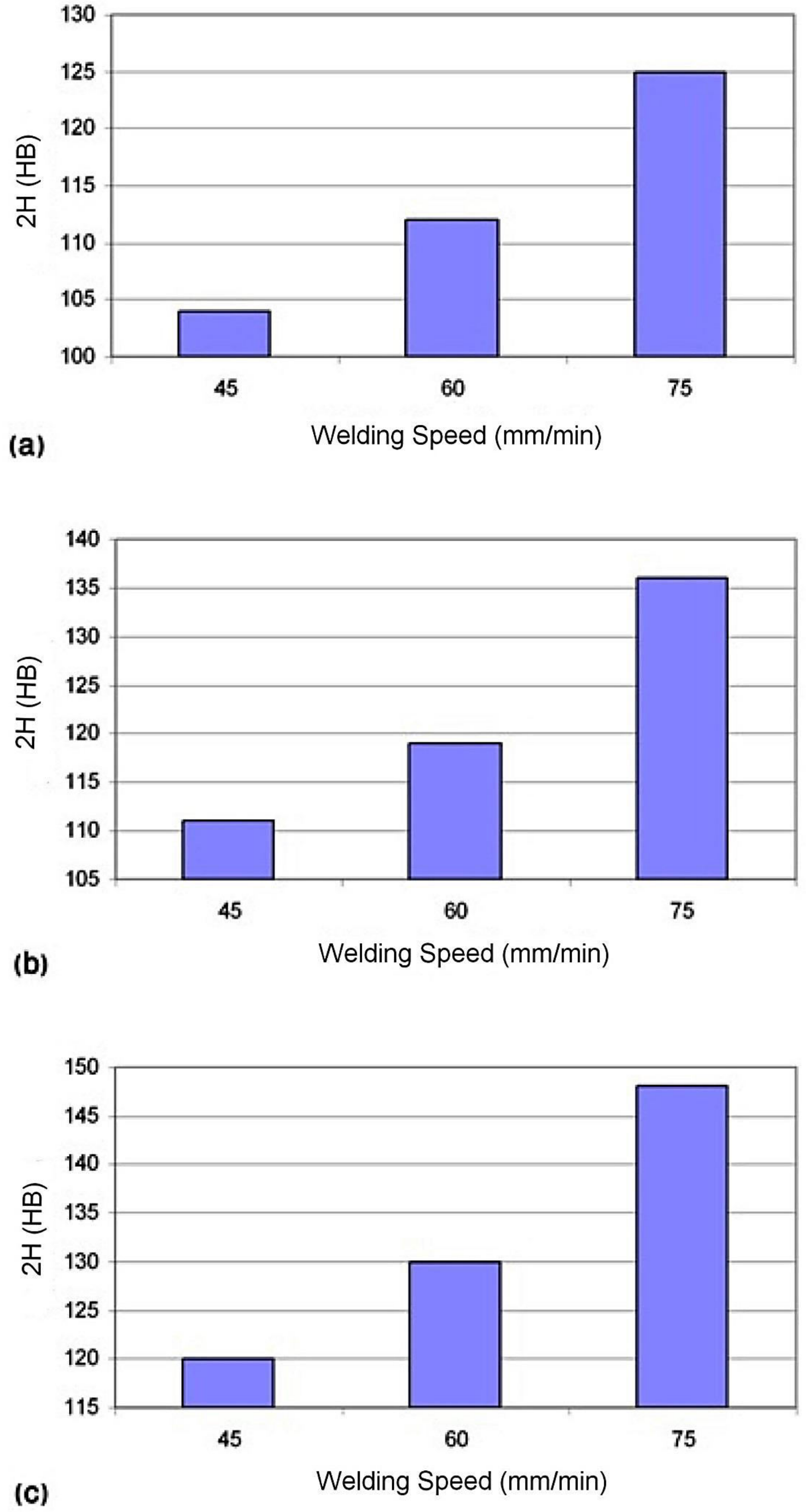

Fig. 2: Brinell hardness of FSW joints vs. welding speed for tool rotation speed of (a) 400, (b) 600, and (c) 800 rpm.

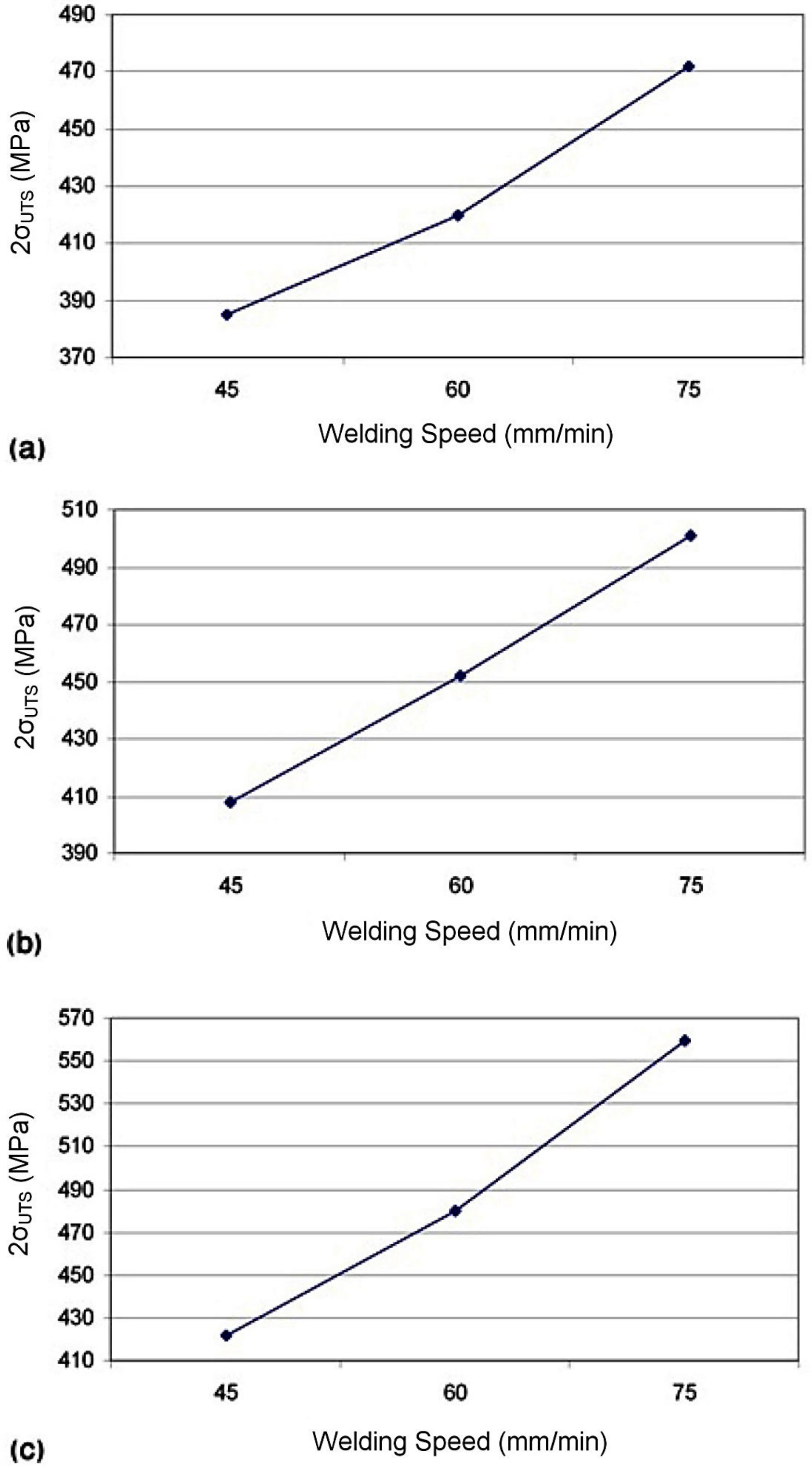

Fig. 3: UTS of FSW joints vs. welding speed for tool rotation speed of (a) 400, (b) 600, and (c) 800 rpm.

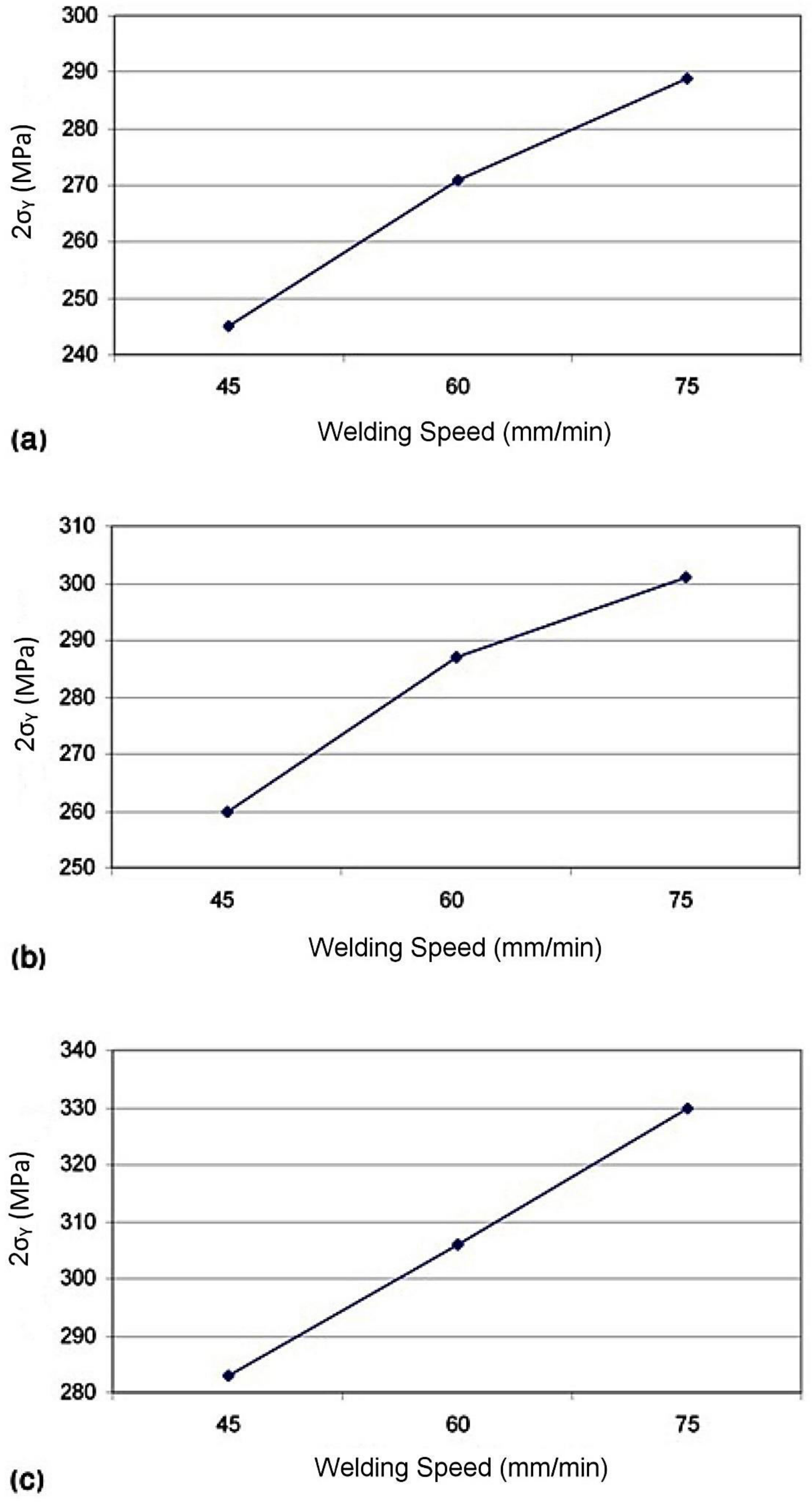

Fig. 4: Yield strength of FSW joints vs. welding speed for tool rotation speed of (a) 400, (b) 600, and (c) 800 rpm.

CONCLUTIONS

The effects of FSW variables on mechanical properties of A356 aluminum alloy joints were investigated in this study. According to results, at lower welding speed (45 mm/min), hardness, UTS, and yield strength of the FSW joints were low. When the welding speed was increased from 45 to 75 mm/min, correspondingly the hardness, UTS, and yield strength also increased. Also, at lower tool rotation speed (400 rpm), hardness, UTS, and yield strength of the FSW joints were low. When tool rotation speed was increased from 400 to 800 rpm, correspondingly the hardness, UTS, and yield strength also increased.

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