MECHANICAL PERFORMANCE OF FRICTION STIR SPOT WELDED AA6082-T6 SHEETS

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Abstract- This study was executed to evaluate how the process parameters, namely rotational speed, feed rate, plunge depth and dwell time, affect the mechanical performances of friction stir spot welded (FSSWed) AA6082-T6 sheets. The mechanical performances of the joints were evaluated using tensile shear tests and correlations between process parameters and joint performances were established. The optimum welding parameters for tensile shear load (7.89 kN) were obtained as tool rotational speed of 1000 rpm, feed rate of 50 mm/min, plunge depth of 5 mm and dwell time of 7 s. The experimental results showed that tensile shear load increased almost linearly with increasing plunge depth and dwell time, and the tensile shear load decreased almost linearly with increasing rotational speed and feed rate. The most effective parameter was found as dwell time. The tensile shear load of the FSSWed joints increased roughly 44% when the dwell time increased from 2 s to 7 s.

Keywords- Friction Stir Spot Welding, Aa6082-T6, Tensile Shear Load, Mechanical Properties.

I. INTRODUCTION

In the automotive industry the current trend is towards use of lightweight alloys instead of the conventional iron based alloys. The use of aluminum alloys for auto body panels leads to a significant reduction in the vehicle body weight, improve fuel economy and increase performance [1]. After the body panels are formed into the desired shapes they will require joining to other parts of the automobile [2]. Resistance spot welding (RSW) is a typical traditional fusion welding process, which is the most commonly used joining technique for automobile parts made of steel sheets due to its low capital cost, and ease of maintenance [3]. However, this welding technique can't be applied easily to aluminum alloys, because of its physical properties, high conductivity, low strength at elevated temperature, tendency to degrade the electrodes and particularly surface oxide film [4]. The substantially higher melting point of this oxide film requires significantly higher resistance heating to break it down and thus allow weld formation to take place [5]. A new solid state welding technique, friction stir spot welding (FSSW) has been developed by Mazda Motor Corporation and Kawasaki Heavy Industries in 2003 to lap join aluminum sheets [6] FSSW is a derivative process of friction stir welding (FSW), and the main difference is the type of the joint [7-9]. In FSSW, the plates form a lap-joint and the tool penetrates the plates only in a point [10,11]. No compressed air and coolant area need in FSSW process, and compared with RSW, FSSW offers 90% energy saving and 40% equipment saving due to its minimal equipment requirement [12,13].

A schematic illustration of the FSSW process is shown in Figure 1. The process respectively consist of three phases: (a) plunging (b) stirring (c) drawing out [14,15]. In plunging phase, a rotating tool with a probe pin plunge slowly until the shoulder contacts the top surface of work piece and reaches the desire depth. In the stirring phase, the heated and softened materials owing to the tool downward force and the tool rotation speed deform plastically and the two work pieces are mixed together. Finally, the solid state bonding is achieved between the surfaces of the upper and lower sheets, the process stops, and the tool is drawn out [16].

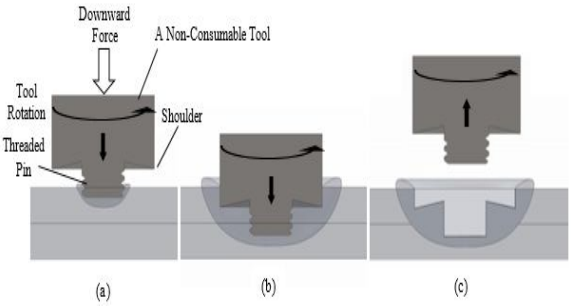


Figure 1. A schematic illustration of FSSW process (a) Plunging; (b) Stirring (Dwell); (c) Retracting [14].

Many works have been carried out concerning FSSW of Al alloy base materials: S. Babu et al. [17] showed that the mechanical performance of FSSW is mainly governed by its geometrical features (hook height and bond width) and mechanical properties of FSSW's are not very sensitive to the base material temper condition. G. Buffa et al. [18] presented the experimental results of FSSWed 1.5 mm thick AA6082 aluminum alloy sheets and reported that the decrease in the failure load observed with increasing tool rotation speed due to the enlargement of the area characterized by low microhardness at the boundary between heat affected zone (HAZ) and thermo-mechanically affected zone (TMAZ). Y. F. Sun et al. [19] studied microstructure and mechanical properties of dissimilar Al alloy/steel jointsprepared by a FSSW technique. V.-X. Tran et al. [20] investigated the

fatigue behavior of aluminum 5754-O and 6061-T4 friction spot welds in lap-shear specimens. They stated that the fatique life estimations based on the kinked fatique crack growth model and the structural stress model appear to agree well with the experimental results for both types of welds. Z. Shen et al. [21] studied the microstructure and mechanical properties of refill FSSWed 7075-T6 aluminum alloy and reported that microstructure of the weld exhibits variations in the grain sizes in the width and the thickness directions. Moreover, defects associated to the material flow were observed, such as hook, voids, bonding ligament and incomplete refill.

The mechanical properties of FSSWed joints strongly depend on welding parameters. The main welding parameters of FSSW process are feed rate, rotational speed, plunge depth and dwell time [22]. In the present study, the test were conducted using lap-shear specimens of FSSWed AA6082-T6 aluminum alloy. The mechanical performance of FSSWed joints has been determined using tensile shear test and correlations between process parameters (rotational speed, plunge depth, dwell time and feed rate) and tensile shear loads of the joints were established.

II. EXPERIMENTAL PROCEDURE

In this study, 3mm thick AA6082-T6 aluminum alloy sheets were used to investigate the mechanical performance of FSSWed joints. The chemical composition and mechanical properties of base metal are listed in Table 1 and 2, respectively. Samples were cut into pieces in dimensions of 100 mm x 40 mm and these pieces were FSSWed in the overlapping configuration using a vertical CNC milling machine. The two sheets were overlapped by 40 mm. The FSSW joints were obtained by varying rotational speed (S), feed rate (F), plunge depth (Z) and dwell time (t). The welding parameters used in this study are listed in Table 3. A non-consumable tool made of H13 hot work tool steel, having a 10° concave shoulder of 15 mm in diameter, was used for all welds. A threaded cylindrical pin used for the welds has a length 3.5 mm along with a right-hand screw of 0.8 mm pitch and 6 mm diameter. Two curvilinear grooves, opposite to each other, were milled on the threaded pin by using a tool with a diameter of 2 mm (Figure 2). The welding tool was rotated in the clockwise direction during the process. Additionally, a specific clamping fixture for the work pieces was fabricated to ensure correct axial positions and obtain precise plunge depth values (Figure 3).

Table 1. Chemical composition of AA6082-T6 aluminum alloys (wt. %).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other impurities total	Aluminum
0.9	0.44	0.08	0.54	0.7	0.03	0.04	0.04	0.03	Balance

%).

Table 2. Mechanical properties of AA6082-T6 aluminum alloys used in this study.

Yield Strength [MPa]	Tensile Strength [MPa]	Elongation [%]
298	342	16

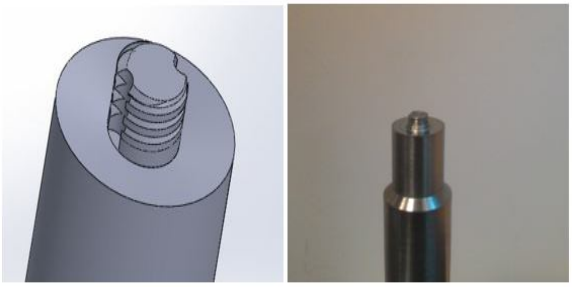


Figure 2. The welding tool used in this study.

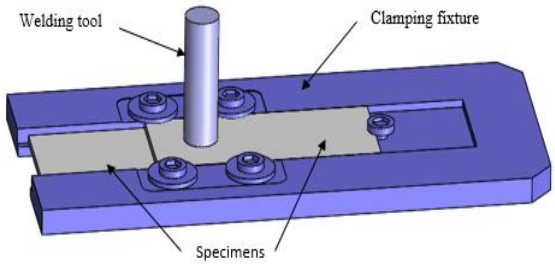


Figure 3. Details of the clamping fixture used in this study.

In order to evaluate the overall mechanical performance of the FSSWed joints, the tensile tests were carried out on a UTEST-7014 tensile testing machine (200 kN load cell), at room temperature and with a displacement rate of 5 mm/min. The tensile shear test samples were prepared according to ANSI/AWS/SAE/D8.9-97 standard [23]. Two additional sheet pieces having a thickness of 3 mm were fixed on the edges of the tensile shear test samples in order to avoid the possible parasitic effects of the bending moment (Figure 4). Theproperty data for each weld were obtained by averaging four test results.

Table 3. Welding Parameters used in this study.

Sample No	Rotational speed (S) (rpm)	Feed Rate (F) (mm/min)	Plunge depth (Z) (mm)	Dwell Time (T) (s)
D1	1000	50	5	7
D2	1500	50	5	7
D3	2000	50	5	7
D4	2500	50	5	7
D5	1500	50	4	7
D6	1500	50	4.5	7
D7	1500	50	5.5	7
D8	1500	50	5	2
D9	1500	50	5	4
D10	1500	50	5	9
D11	1500	50	5	0
D12	1500	43	5	0
D13	1500	38	5	0
D14	1500	32	5	0

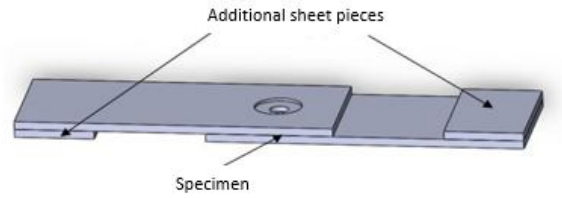


Figure 4. The tensile shear test samples with additional sheet pieces.

III. RESULTS AND DISCUSSION

The tensile shear performance of spot-welded joints is a significant factor in design stage. The results of the tensile shear tests are shown in Table 4. The highest tensile shear load was obtained at D1 sample (tool rotational speed of 1000 rpm, feed rate of 50 mm/min, plunge depth of 5 mm and dwell time of 7 s.) with 7.89 kN.

Table 4. The tensile properties of FSSW joints (average values).

Sample No	Tensile Shear Load (kN)	Standard Deviation
D1	7.89	0.35
D2	7.01	0.60
D3	6.92	0.69
D4	6.39	0.73
D5	6.46	0.33
D6	7.08	0.13
D7	7.27	0.48
D8	4.87	0.05
D9	5.00	0.28
D10	6.75	0.27
D11	3.21	0.12
D12	3.37	0.30
D13	3.76	0.14
D14	4.55	0.08

The relationship between the rotational speed and tensile shear load of FSSW joints can be seen in Figure 5. The tensile shear loads of joints decreased almost linearly with increasing rotational speed. The tensile shear loads of the spot welded joints decreased approximately 19% when rotational speed was increased from 1000 rpm to 2500 rpm.This may be attributed to the lower hardness in HAZ and TMAZ owing to the higher heat input with the increase of rotational speed.

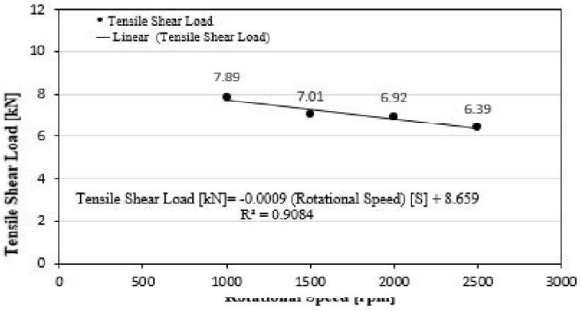


Figure 5. Tensile shear load of FSSW joints versus rotational speed.

The relationship between the plunge depth and tensile shear load of FSSW joints is seen in Figure 6. The tensile shear loads of joints increased almost linearly with increasing plunge depth. The tensile shear loads of the spot welded joints increased approximately 13% when plunge depth was increased from 4 mm to 5.5 mm. This may be associatedwith the larger bonded section size.

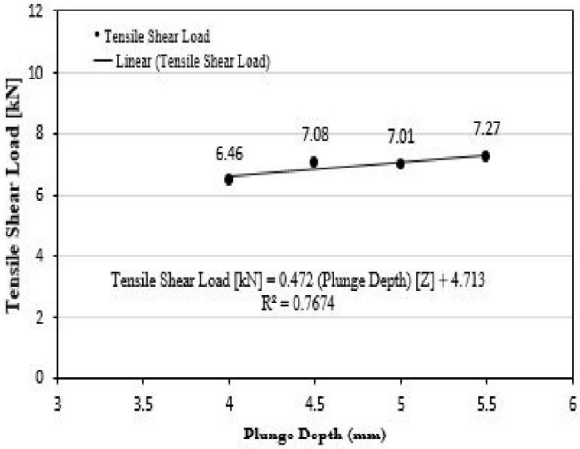


Figure 6. Tensile shear load of FSSW joints versus plunge depth.

The effect of dwell time on the tensile shear load of FSSW joints is shown in Figure 7. The tensile shear loads of the joints increased almost linearly with increasing dwell time. The tensile shear loads of the spot welded joints increased approximately 44% when dwell time was increased from 2 s to 7 s. This may be attributed to larger bonded size owing to the higher heat input with the increase of dwell time.

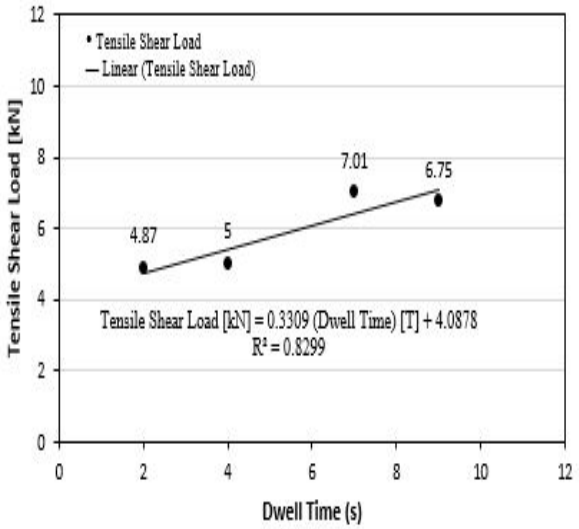


Figure 7. Tensile shear load of FSSW joints versus dwell time.

The effect of feed rate on the tensile shear load of FSSW joints can be seen in Figure 8. The tensile shear loads of joints decreased almost linearly with increasing feed rate. The tensile shear loads of the spot welded joints decreased approximately 30%

when feed rate was increased from 32 mm/min to 50 mm/min. This may be attributed to smallerbonded size owing to the lower heat input with the increase of feed. It should also be noted that the shear loads of FSSW joints are relatively low when the dwell time 0 s.

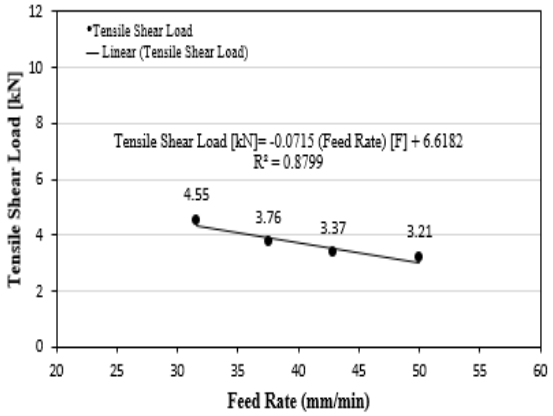


Figure 8. Tensile shear load of FSSW joints versus feed rate.

CONCLUSIONS

Based on the experimental results reported earlier, the following major conclusions were derived :

1. The peak tensile shear load was obtained with 7.89 kN for the welding parameters: rotational speed=1000 rpm, plunge depth=5 mm, dwell time= 7s, feed rate 50 mm/min.
2. The tensile shear loads of FSSW joints decreased almost linearly with increasing rotational speed and feed rate. The tensile shear loads of joints increased almost linearly with increasing plunge depth and dwell time.
3. As a result of experiment carried out, the most effective welding parameter was dwell time. The tensile shear load of FSSW joints increased approximately 44% when dwell time was increased from 2 s to 7 s.

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