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Assess425ment for Friction Stir Spot Welding of 6082 Aluminum alloy

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Abstract
One of the crucial variations of the friction stir welding (FSW) method is friction stir spot welding. FSSW was primarily created for automotive and aerospace purposes. In the present work, sheet thickness is 2 mm of 6082-T6, were welded using FSSW at a different dwell time range from 3 to 4.5 s and different rotation speeds of 1500, 2500, and 3000 rpm. The FSSW load to weld is noted, and the load cycle experience during the FSSW process was recorded. The produced FSSW joints were investigated by macro- and microstructureexamination. Tensile shear test and microhardness measurements were conducted on FSSW joints.The fracture surfaces were examined using a scanning electron microscope (SEM). The macro examination showed that defect-free spot joints were produced at a wide range of rotation speeds (1500–3000 rpm). The microstructural results in terms of grain refining of the stir zone (SZ) of the joints show good support for the mechanical properties of FSSW joints.

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I. INTRODUCTION

Friction stir spot welding (FSSW) is a type of friction stir welding. FSSW is a promising solution to construct spot junctions between similar and dissimilar materials. During FSSW a rotating tool with a pin tip is gradually plunged into the two-butt base metal at a predefined speed until a desired plunge depth is obtained. The tool is rotated in that position for a short length of time before being released, the tool is retracted, and a weld is done.

The strength of an FSSW joint is highly dependent on welding process factors such as rotation speed, plunge speed, plunge depth, and dwell time, force applied, tool geometry . Aldanondo et al. [1] welded 2mm thick DP1200 ultra high strength steel and reported that dwell time and plunge depth were the most crucial parameters for influencing shear strength of the joints.

Lathabai et al. [2] performed FSSW on the aluminum alloy Al 6060-T5 and discovered that the plunge depth had a significant impact on joint strength due to a strong association with the dimension of the annular bond region between the two sheets. Karthikeyan et al. [3] investigated the impact of process factors on friction stir spot welding of aluminum alloy 2024 using the response surface approach. They discovered that plunge speed, plunge depth, dwell time, and tool rotation speed all had a significant influence on tensile shear fracture load. Sakamura et al. [4] showed that increasing plunge depth produce higher strength for FSSW of aluminum alloy 5052 to low carbon steel. Zhang et al. [5] employed FSSW to join aluminum alloy 5052-H112 sheets. The maximum tensile-shear strength they achieved was obtained from the condition where rotation speed and dwelltime were 1541 rpm and dwell time of 5 seconds respectively.

Lakshminarayanan et al. [6] investigated the effect of FSSW on low carbon automobile steels. The tool spinning speed in their work ranged from 1200rpm to 1600rpm. The distance between the top sheet surface and the tool shoulder surface was between 0 and 0.2mm. Dwell time ranged from 5 to 25 seconds. They discovered that the greatest tensile shear strength was reached with 1157 rpm rotational speed, 5mm plunge depth, and a dwell time of 22 seconds. Furthermore, Dwell time was found to be the most important factor in defining joint characteristics.

Several investigations on the FSSW of aluminum alloy to steel had been fulfilled. Bozzi et al. [7] welded different materials. Materials ranging from 1.2 mm aluminum alloy 6016 to 2 mm IF-steel. It was said that an intermetallic compound (IMC) layer was required to provide weld strength. However, if the thickness of the IMC layer surpassed a particular value, cracks would be initiated and propagated quickly via the brittle IMCs strangles, which resulted to a weak weld strength. For welding 1mm aluminum alloy 6111-T4 to steel DC04, Chen et al. [8] used an abrasion circle friction spot welding technique. A probing tool was used in their procedure to abrade the steel sheet, which was placed on the bottom.

Sun et al. [9] used a flat spot FSW approach to join 1mm aluminum alloy 6061 to mild steel, using a probe-less rotating tool to flatten the weld surface after the spot weld. The keyhole flaw was removed, which enhanced the qualities of the joint. At the interface betweenaluminum and mild steel, no intermetallic compound layer was discovered. They also found that the length of the tool probe had minimal effect on the welding qualities. Aluminum alloy 5754 was welded to galvanized steel HX 340LAD by Figner et al. [10]. They discovered that a longer dwell time or a slower spindle speed reduced weld strength.

In this research, friction stir spot welding was applied for joining two sheets of aluminum alloy 6082-T6 with thickness of 2 mm. Rotation speed and plunge depth, were kept constant during all the experiments. Effects of plunge speed and dwell time and force applied on weld strength were investigated also macrostructure of joint cross section was characterized.

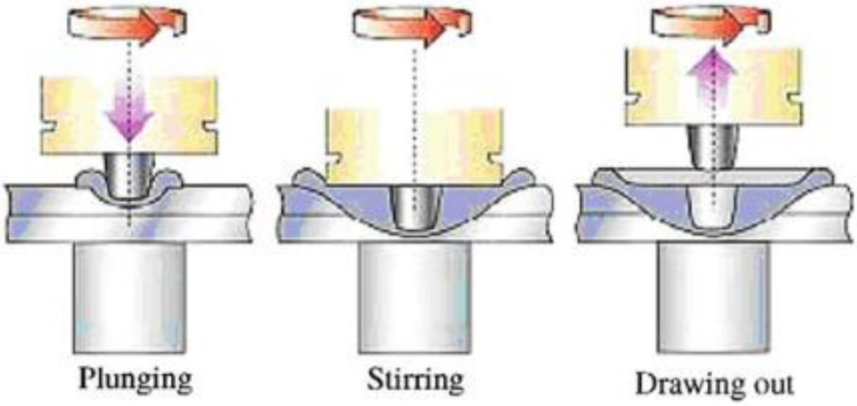


Figure1: Schematic illustration of friction stir spot welding process[11]

II. EXPERIMENTAL WORK

In this work, the base metal is sheet of 6080-T6 aluminum alloy with 2 mm thickness. Table (1) shows the chemical composition of 6082 Al- alloy.

The FSSW joints were produced using a milling machine model BR2J with various rotation speeds of 1500, 2500, and 3000 rpm. The two sheets were cut to specimen with overall length of 160mm and 40mm widthusing hydraulic shear machine. These dimensions are appropriate for both designed FSSW fixture and tensile shear test specimen. The specimens were spot welded with 40 *25mm^2 overlapped area. Different dwell time of 3.5, 4 and 4.5 sec were used. The other friction spot welding parameters in terms of plunge depth, and tilt angle were kept constant at 3 mm, and zero degree, respectively. Table 2 summarizes the FSSW variables for welding 6082-T6 Al sheets.

Table 1Chemical composition of 6082Al-ally (wt%)

Table 1: represent 6082-T6 alloy

Si%	Fe%	Cu%	Mn%	Mg%	Zn%	Ni%	Pb%	Sn%	Al%
0.957	0.4918	0.0513	0.535	0.935	0.0438	0.0207	0.0067	0.0020	Balance

A cylindrical tool made of steel (AISI H13) was used. The tool has40mm shoulder diameter and 100 mm pin length. The tool has a flat shoulder and a cylindrical pin tip with 4 mm diameter and 3mm length. The detailed features oftool are shown in Figure 2.

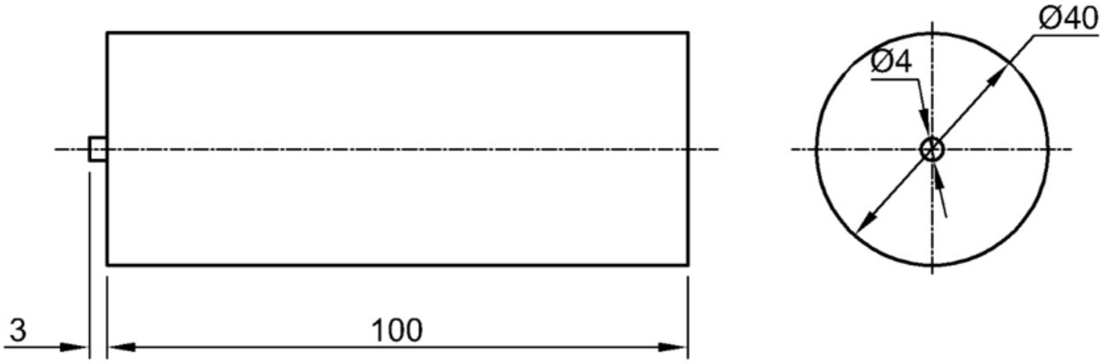
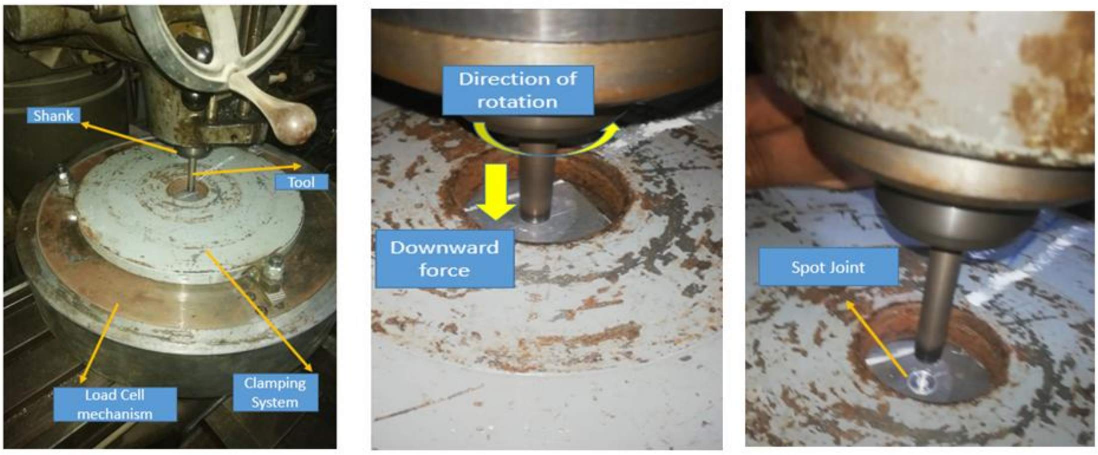


Figure2: detailed figure for fracture stir spot welding tool



(a) (b) (c)

Figure 3: The main steps of FSSWprocess (a) fixation for specimen and load cell, (b) rotation of spindle and welding in process, and (c) welding is done.

FSSW process carried out on 6082-T6 sheets has three main steps as following; lap joint fixing with a clamping system, plunge stage and stirring action with the rotating tool and the drawing out stage.A digital force meter setup which simulates a load cell mechanism was used to measure the applied force during process at different speeds. Figure 2 explains these steps visually.

The 6082-T6 joined sheets has four weld points as shown in Figure 3 The tensile shear samples were cutusing wire cut machining. The tensile tests were carried out on Tinius Olsen model H100KU. Universal Tensile Machine as shown in Figure 4. The test was conducted according to standardASTM [E8] with loading rate of 1mm/min.

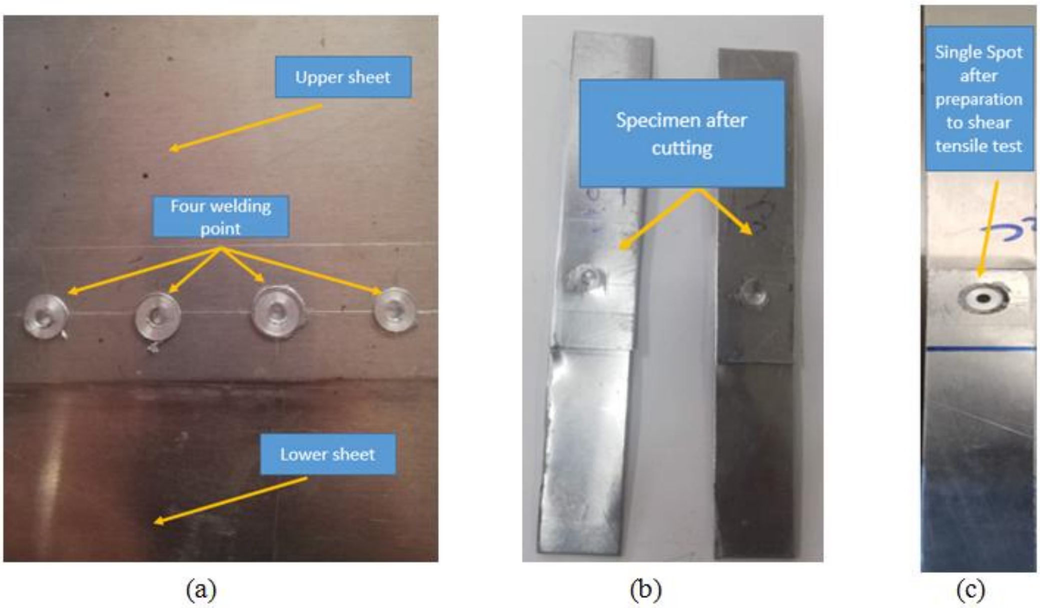


Figure4: Specimen preparation for tensile test at (a)joined sheets has four weld points, (b) specimen after cut, and (c) single spot after preparation to shear tensile test.

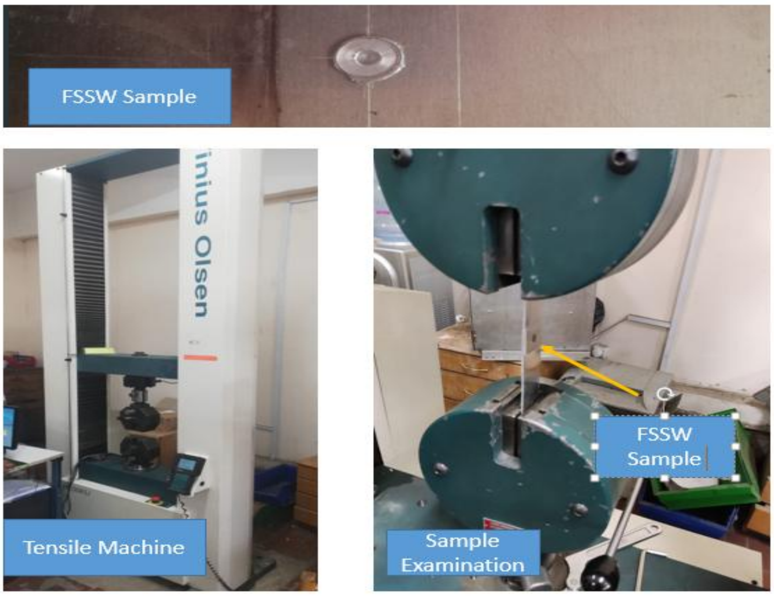


Figure5: universal tensile test machine

Table 2Summary of FSSW variables used to weld 6082/6082 Al sheets.

Table 2: represent RPM, Dwell time, Force needed to weld joint

Base metal	Rotational speed (rpm)	Dwell time (sec)	Applied Force (kg)
6082-T6/6082-T6	3000	3	160
	2500	3.5	170
	1500	4.5	270

The produced FSSW 6082/6082 joints with different processing variables were examined visually to detect any defects in both sides of the joint.The 6082/6082 joints were prepared for macrostructure examination across the stirring zone using wire cut machine to avoid any damage in the joint, as shown in Figure 5. Specimen surfaces were ground using grinding paper followed by polishing to mirror finish using diamond paste.After polishing the specimen surface was etched using Keller's reagent according to The ASM Metals Handbook [25] to reveal different zones across the joint and to evaluate the joint quality.

Vickers microhardness were conducted using Mitutoyo micro -hardness tester with 300 gm and indentation time of 10 sec. Indents were carried out onboth stirring zone (SZ) and heat affected zone (HAZ).The space between indentations were 0.5 mm.

We makes mounting and then etching The macrostructure of joints was revealed through immersion etching in Keller's etchant. The analysis of macrostructures allowed for the assessment of the joint quality.

III. RESULTS AND DISCUSSION

Visual inspection of FSSW joints between sheets of 6082-T6 with same thickness reveals that the used combination of variables led to joints with high quality. The top view of the spot-welded joints shows that the extruded material flashed to the sides of the shoulder projection is virtually identical. The circular indentations caused by shoulder projection are noticed at the various applied parameters. The friction spot welding processing parameters were carefully chosen to avoid excessive flash during the FSSW based on previous works Ref.[15,24].

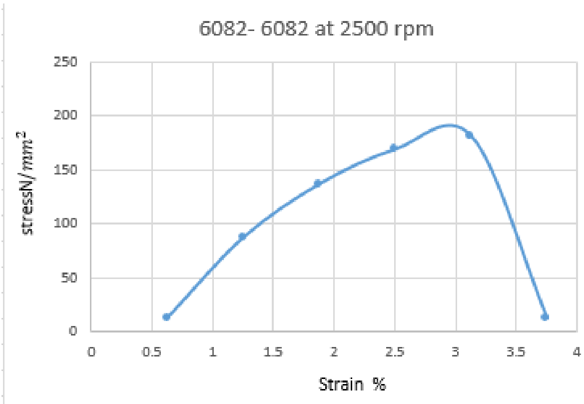


Figure6: The stress strain curve fortensile shear test for AA 6082-T6/6082-T6 FSSW at 2500rpm

Figure 6 shows the stress strain curve for tensile shear test for AA 6082-T6/6082-T6 FSSW at 2500rpm. It was found that increasing the rotational speed from 1500 rpm to 2500rpm increases joint strength from 125MPto 195 MPa. While, increasing the rotational speed from 2500 rpm to 3000 rpm led to reducing the joint strength from 195MPa to 92 MPa, as shown in Figure 6 best stress strain curve AA 6082-T6/6082-T6 FSSW at 2500rpm.This was attributed to change occurred in grain size as reported by Mohamed M. Z. Ahmed [24]. The average grain size for FSSW joints at 1500rpm was 25µm compared to 35µm at 3000 rpm.

Figure 7 shows microstructure and grain size of 6082-T6 weld jointproduced at both 1500 rpm and 3000 rpm.The highest joint strength obtained at rotational speed of 2500 rpm, 3.5 dwell time and under load of 170 Kg.

5-Grain size:

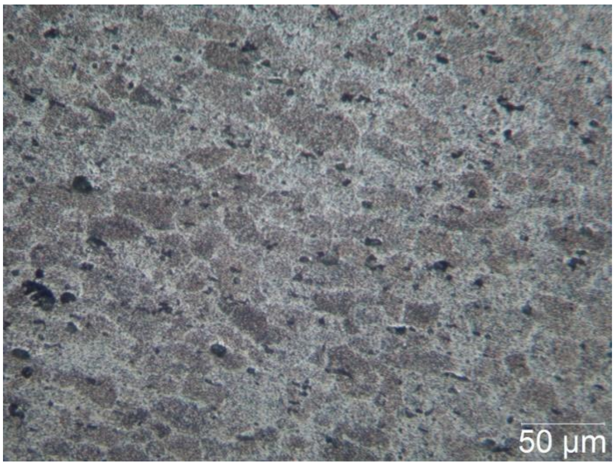


Figure7: grain size for FSSW at 3000rpm

Theaverage microhardness of the base metal AA6082- T6 was 120 HV.The hardness of all the FSSW joints was assessed on their cross-sections. It is widely known that thermal exposure during the FSSW process regulates the hardness through the thickness of the weld zones. Additionally, the startingbase metal condition has an impact on the hardness measurements map. Conducting FSSW on the AA6082- T6 sheets resulting in reducing the processed zone hardness due to the softening process resulting from generated heat by FSSW.

In this work, the starting condition of base metal is T6 condition, which denotes complete hardness through ageing. As a result, it is anticipated that the high heat exposure will cause the hardness in the weld zone to decrease either as a result of the coarsening or the dissolution of the hardening precipitates

The minimum hardness values in the HAZ were observed for each spot-welded joint within the weld zone due to grain structure and over aging effects, Figure 8. In contrast, the SZ had a higher hardness because to the dynamic recrystallized equated tiny grain structure and the reprecipitation process that might occur during the cooling cycle.

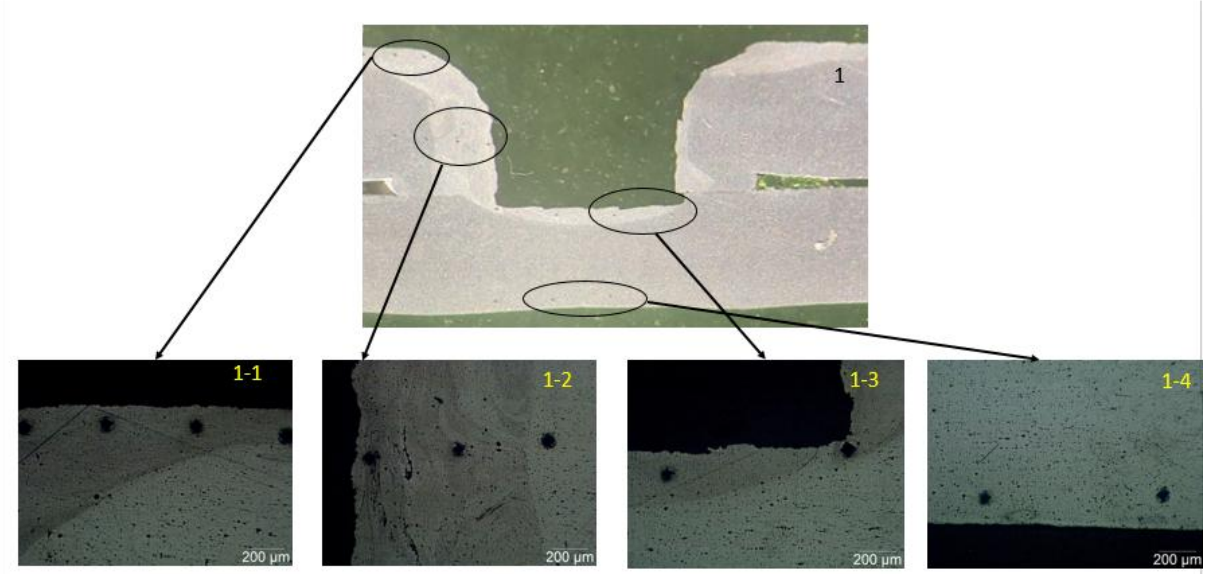


Figure8: shows the hardness test points(1-1) HAZ, (1-2) TAMZ, (1-3) Stirring zone, (1-4) Base Metal zone

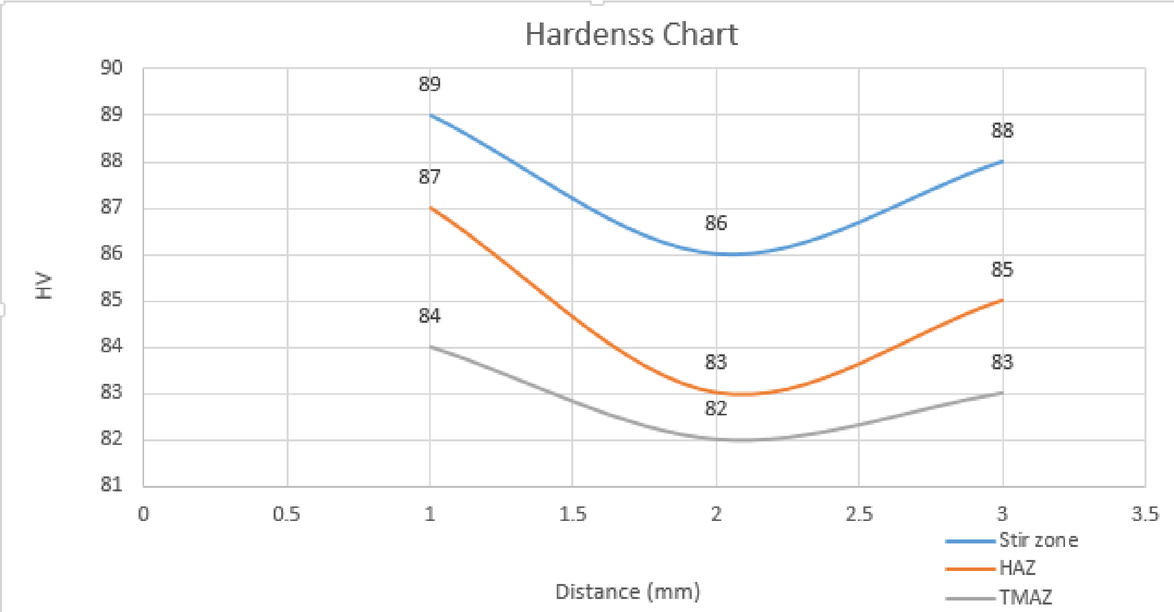


Figure9: shows the hardness test reading for Stir zone, HAZ and TMAZ

IV. Conclusions:

In the present study, two sheets of AA6082-T6 with 2 mm thickness were friction stirspot welded at a different dwell time of 3 ,3.5 ,4.5 sec and different rotation speeds of 1500, 2500, 3000 rpm. The spot-welded joints were characterized in terms of macrostructure, microstructure,hardness, and tensile shear testing. Based on the obtained results, the following conclusions can be outlined:

1) Increasing rotational speed from 1500 rpm to 2500 rpm lowereddwell time needed to obtain joint with no defect or hot cracks.

2) The spot-welded joint processed at 2500 rpm and applied force of 170kg achieved the maximum tensile shear load of 290 MPa.

3) The FSSW of AA6082-T6 condition significantly decreased the hardness in the weld zone compared to the BMs, and the SZ showed higher hardness values than the TMAZand HAZ.

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