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Effect of rotation speed on mechanical properties and microstructure of friction stir spot welding (FSSW) Al 5052 - Steel SS400

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Abstract. In this study, the effect of welding parameter such as rotational speed on the mechanical properties and microstructure of friction stir spot welded Al 5052 and SS400 sheet have been investigated. The rotation speed of 1250, 1600, 2000 rpm and the dwell time of 10, were applied to fabricate the friction stir spot welded joint. The microstructure of the joint was observed using scanning electron microscope (SEM). The tensile shear load was measured using by universal testing machine. Base on the microstructure observation showed that the thickness of IMC increases due to the increase of rotational speed. The Maximum thickness of IMCs reached 7.15 µm at 2000 rpm. The result of the tensile shear test showed that the rotational speed is affecting the mechanical properties. The increase of tool rotation speed from 1250 up to 1600 rpm caused the increase of tensile shear load, however further increase up to at 2000 rpm resulted in the decrease of the shear tensile load. The highest shear tensile load reaches 2810.07 N at 1600 rpm.

1. Introduction

The method of resistance spot welding (RSW) [1].Which is often used in the automotive industry has a weakness in its welding process. The occurrence of defects due to metal melting process results in the formation of intermetallic compound (IMC) and high distortion. Therefore an alternative method is necessary, one-of the alternative methods that can be used is Friction stir spot welding (FSSW). FSSW is a welding process that takes place at a temperature below the melting point of temperature [2].

The FSSW process can reduce distortion, avoid defects due to metal melting and minimize the formation of intermetallic compound (IMC) because the welding process is done in low temperature. In addition, the FSSW method can avoid problems related to solidification and result in low weld distortion, better mechanical properties and less waste [3].

In its process, FSSW does not use protective gas and is safe from ultraviolet light radiation [4]. FSSW methods can also be used for dissimilar metal joint with different thermal and mechanical properties. In addition, FSSW has short welding time and does not require filler metal, thus minimizing distortion.

Intermetallic (IMC) thickness increases as dwelling time increases [6]. As the rotational speed increases the quantity and size of the porosity also increase. An increase in rotational speed causes Fe2Al5 IMC thickness to decrease, while FeAl3 IMC thickness remains constant at ~1 µm. An error in the parameter selection of FSSW technique will lead to low mechanical strength and welding defects [7]. Meanwhile, thewelding parameters such as tool rotation, dwell time, plunge depth and geometry tool contribute to the level of shear and tensile strength of the welding results [7], it is necessary to find out the optimum tool rotation parameters in FSSW Al5052-SS400 welding to obtain welding results with optimal mechanical properties and minimize the occurrence of intermetallic bonds. The optimum results of tool rotation effect and dwell time on Al-5083 sheet and St-12 steel were obtained at dwell time of 10 and 12 seconds and at 900 and 1100 rpm tool rotations[6], different with [15] which is find that the best result is obtained at 900 rpm tool rotation with dwell time of 9 seconds.

In this research, the FSSW method investigated the effect of rotation speed using SS400 and Al 5052 steel materials. Mechanical and microstructure tests were performed to determine the effect of rotation speed on the quality of FSSW steel connection with Al 5052.

2. Material and experiment

In this experiment, the materials used were aluminum 5052 with a thickness of 3 mm and steel SS400 with a thickness of 1.5 mm. Aluminum is placed on top of SS400 steel. The chemical composition of each material is showed in table 1.

Table 1. The chemical compositions (%wt) of the Al-5052 and SS400

	Al	Fe	Si	Mn	Mg	Cr	Al
Al-5052 alloy	0,25	0,40	0,10	0,10	2,2-2,8	0,15-0,35	Balance
	C	Si	Mn	P	S		
SS400	0,17-0,2	minor	1,4	0,04	0,045		

Tensile tests specimens were prepared to use JIS Z3136 standard as shown in the Figure 1. Tool material used in this welding was made from high speed steel (HSS). The tool was made without the pin (pinless tool) with a pin diameter size of 12 mm, as showed in Figure2. Table 2. showed the variations of theFSSW parameters process. The penetration rate was 0.9 mm/s with plunge depth of 3.5 mm.

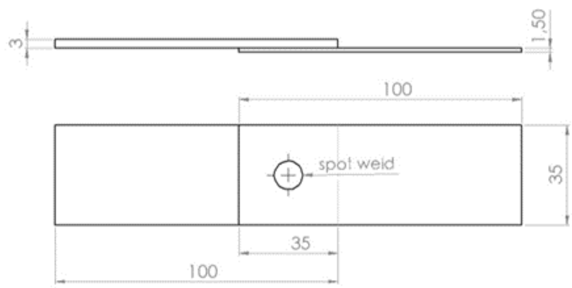

Figure 1. Dimensions of the samples

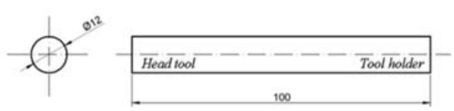

Figure 2. The pinless tool

After the welding was complete, the specimens were tested and observed. The macroscopic image of the FSSW joint were observed using by OLYMPUS SZ2-ILST. The tensile shear load were tested using UTM JTM-UTS510with strain speed 5 mm/min according JIS Z3136, 1999 todetermine the tensile strength of the specimens. Then the microstructure of the specimens was observed and polished using an abrasive paper and then etching with Pulton Reagent and then observed using SEM TESCAN VEGA3 to find new phase on FSSW joint process.

Table 2. Welding parameters used in this study

Sample	RPM	Dweel time (s)
A1	1250	10
A2	1600	10
A3	2000	10

3. Result and discussion

3.1 Macro Observation

In the macro photo observation, a hook was found between the Al-5052 sheet and SS400 steel as shown in figure 4.

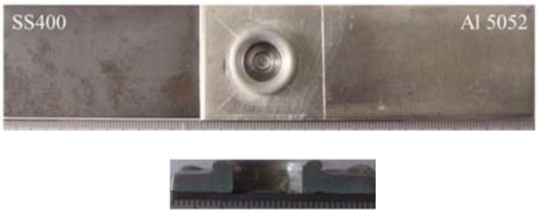

Figure 3. Result of FSSW joint in SS400 and Al5052

The hook is a common defect in FSSW.The hook is an area formed by the flow of heated material that softens it [5]. Hook defects are generated from the process of pinless tool welding and hooks generally occur around the pinless tools [12]. Hook occurrence can reduce the shear tensile strength of a joined[13]. The hook size will increase along with the increase in tool rotation [9].

Besides the hook defect, FSSW will also produce flash defect as shown in Figure 4. The tool rotation on the material causes friction which results in high heat and causes the upper layer of the material to deform. The softened upper layer material will be pushed upward while it is held down by the lower layer of the material which has not softened.

The process leads to the extrusion of the upper layer of the material. This extrusion is called flash. The amount of flash or pressed up material and the width of the welded area increase as an increase in tool rotation speed [10].

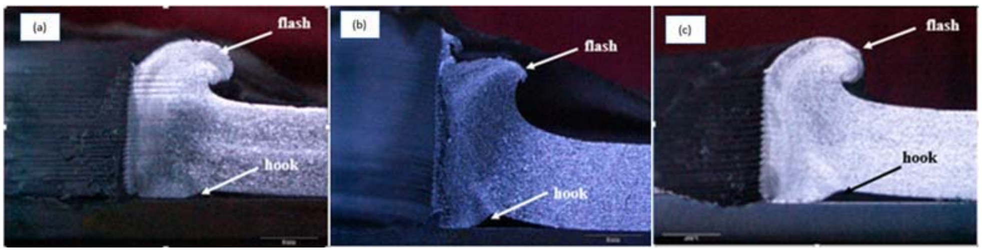

Figure 4. Geometry of the hooks and flash with rotational speed (a) 1250 (b) 1600 (c) 2000 rpm

FSSW with 1250 rpm tool rotation produced a relatively small hook. This was because the resulted heat input at 1250 rpm was also lower. Increased tool rotation from 1250 rpm to 1600 rpm and 2000 rpm resulted in larger hooks when compared to the hook produced at 1250 rpm. This is because rpm rotation can also increase heat that causes deformation along with each rotation. The largest hook was formed at 2000 rpm rotation.

3.2 SEM Observation

SEM observation was conducted on the joint of the welding and the results indicated an existence of Intermetallic Compound (IMC). IMC formation in joined interface is caused by the heat input who resulted by tool rotation [6]. Increased heat gave a chance for Fe atoms to diffuse into aluminum. Al and Fe atoms can complement each other during the welding process resulting in intermetallic phase [16].

Fig.5 shows the Al-Fe phase diagram,were seven types of Al-Fe intermetalic formed namely (Fe_3Al, FeAl (α2), $FeAl_2$, Fe_2Al_3 (ε), Fe_2Al_5 and $FeAl_3$, $FeAl_6$). Increased formation of Al_xFe_y intermetalic phase will lead to the brittleness of the bond, thus decreasing the mechanical strength of the joint [16]. Heat inputs that are too high can result in higher thickness value of the formed IMC [6]. Thicker IMC formation caused a crack start on the joined, causing the shear tensile strength to be lower [14]. The SEM observation results show that intermetalic was formed at the interface joined area as shown in figure 6.

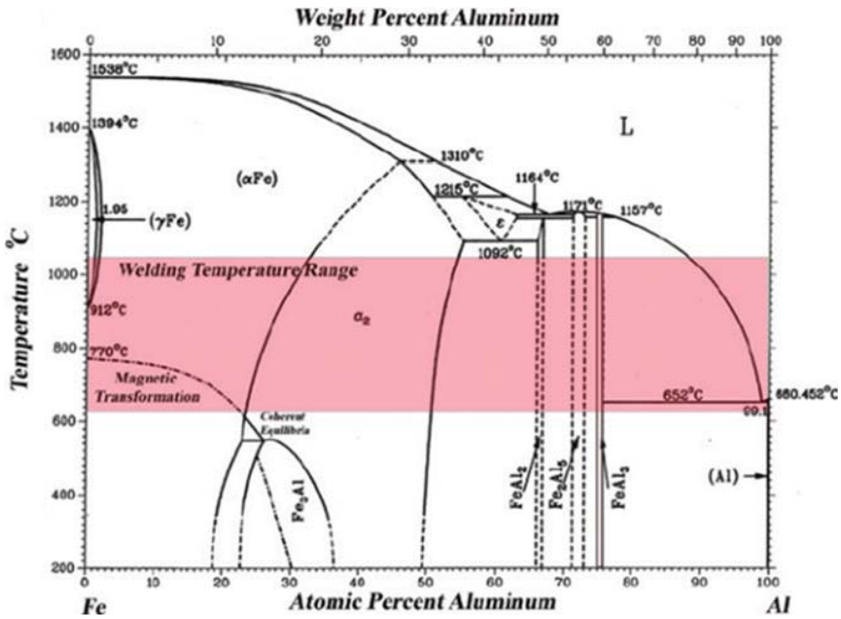

Figure 5. The phase diagram of the Fe-Al

The observation results show that IMC thickness increases with the increase of tool rotation speed as shown in figure 7. The tool rotation speed has an impact on IMC thickness [6]. The lowest value of IMC thickness was 5.6 µm and was achieved at 1250 rpm and the highest value of IMC thickness was 6.19 µm and was achieved at 2000 rpm as shown in figure 7.

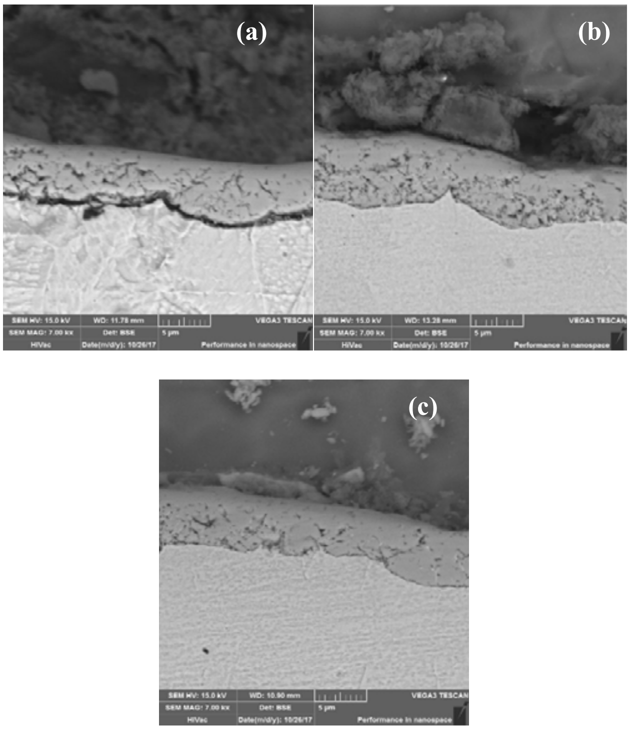

Figure 6. SEM images of the joint cross-section specimen at (a) 1250 rpm (b) 1600 rpm (c) 2000 rpm

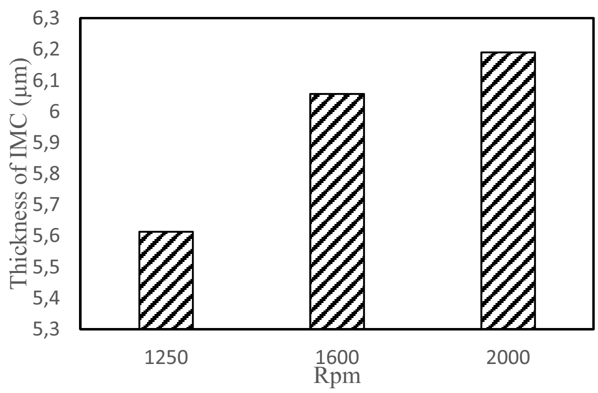

Figure 7. Thickness of IMC compound

3.3 Shear and Tensile Test

The tensile shear load tests were performed to determine the strength of the joined made by FSSW. The results of shear load tensile tests with variations of rotation speed are shown in Figure 8. Higher tool rotation resulted in increased shear tensile strength [7]. This was observed when the tool rotation speed was increased from 1250 rpm to 1600 rpm with dwell time of 10 s, which resulted in increased load from 1766.5 N to 2810.07 N.

However, at the tool rotation speed of the 2000 rpm, there was a decrease of tensile shear load to 1505.66 N. This happened because the heat generated at 2000 rpm tool rotation speed was too high so that the shear tensile load decreased. Heat input that is too high will increase the thickness of IMC, thus decreasing the mechanical strength of the joined.

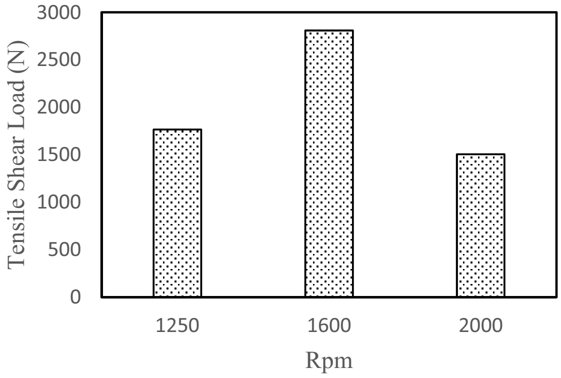

Figure 8. Tensile shear load of Al5052-SS400 FSSW

The shear tensile strength of the connection increased as the tool rotation increased from 1250 rpm to 1600 rpm. This corresponds to [7] research which concluded that the shear tensile load increases along with the increased RPM rotation. When the rotation speed was increased again from 1600 rpm to 2000 rpm, there was a decrease in shear tensile load. This was caused by the overly high input of heat[11]. The optimum tensile strength was obtained at 1600 rpm, because at 1600rpm, the resulted heat was sufficient to improve the bond.

4. Conclusions

The following conclusions were obtained from the experiment.

- The biggest Hook occurred at 2000 rpm
- Increased tool rotation from 1250, 1600 and 2000rpm caused an increased in flash at 10 s dwell time
- IMC thickness increased as the tool rotation increased from 1250 rpm, 1600 rpm and 2000 rpm. Highest value of IMC thickness was 6,19 ρm and was obtained at 2000 rpm.
- Maximum shear tensile stregth was 2810,07 N and was obtained at 1600 rpm. However, when the tool rotation was increased to 2000 rpm, the shear tensile strength decreased to 1505,66 N. The decrease in shear tensile strength was caused by the increased IMC thickness.

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