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Friction Stir Spot Welding Applied to Weld Dissimilar Metals of AA1100 Al-alloy and C11000 Copper

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Abstract. Friction stir spot welding is a non-conventional joining process that use for welding sheet metal and alloy as solid state process which can be used instead of electric resistance spot welding process. In this project, AA1100 Al-alloy and C11000 copper with 3 mm thickness have welded by friction stir spot welding with tapper cylinder tool made fro m high speed steel materials with pin diameter of 3 mm and shoulder diameter of 10 mm. Manual and automatic friction welding process have been applied in drilling machine with different rotational speed of 760, 1065, 1445 and 2000 mm. Heat generation, dwell t ime and applied load have been measured during the welding process as well as tensile test and tool depth penetration with surface quality were evaluated. The result shows that heat generated equal to 50 °C in case of automatic process and 210 °C in case of manual process. However, the dwell time that's required to complete the welding process in case of automatic process reduced to be 14% of the time that consume in the case of the manual welding process because applied load will be twice the time of manual applied load. Moreover, the ma ximu m tensile strength of welded plates equal to 406 MPa at rotational speed of 1065 RPM.

Keyword: Key words should be: friction stir spot welding, bimetallic jo int, Al/Cu, mechanical properties.

1. Introduction

Friction stir welding FSW that developed by Thomas in 1991 can be considered as a solid-state welding process that used for welding similar and dissimilar metals [1]. Several methodologies have been used to develop this technology for using as friction stir spot welding, friction stir diffusion bonding (FSDB), hybrid friction stir welding and under water friction stir welding [2].
Many studies are discussed the ability of welding copper alloys with aluminium alloys using FSW techniques. They joint AA1100-H24 and pure Cu to study the intermediate layer and improve bonding with 1 mm thickness and 2 mm thickness [3, 4]. Most of these studies welded pure copper sheet of 3 mm thickness with different Al-alloys in thickness up to 12.7 mm such as copper metal with AA1050-H16, AA1060, AA1350, AA5052, AA6101, AA8011, AA6061, Al-5A02 and pure aluminium. They studied the influence of welding tool pin offset on the welding heat generation and the influence of

heat generation on the electrical resistivity of the joint as well as they compare the hardness values of nugget between the Cu side and Al side. Also, study the thermomechanical affected zone between two layers with the ability of using aluminium barrier layer to eliminate welding defects. Moreover, study the microhardness variation due to complex material flow in welding region and the effect of shoulder diameter, tool pin offset and workpiece positioning on the quality of the welding zone [5-21].
The dissimilarity in welding means the welding of dissimilar base metals which offer some compatibility or miscibility on the phase diagram without any solubility between these metals. Moreover, welding of similar base metals with different thickness or shape or different alloy compositions can be considered as a dissimilar welding process [22].
Nowadays, dissimilar joining technology uses in many industrial applications such as in aeromechanical applications, automotive, nuclear reactor materials and medical fields etc. This is due to reducing the welding cost and increasing the energy efficiency with optimum properties can be considering as the main advantages of dissimilar welding process. Moreover, good thermal conductivities of both copper and aluminium alloys leads to increase the industrial demand of these metals especially in electrical and thermal applications such as heat exchangers, refrigeration units, electrical transformers and many electrical parts i.e. condensers, capacitors and conductors. In spite of these advantages, the welding defects due to the high hardness of Intermetallic compounds and the cracks during the solidification and liquefaction process leads to not recommended to join these alloys by fusion welding process [22, 23]. Therefore, FSW technology was applied as a solid state welding to overcome these limitations in welding of aluminium and copper alloys [24, 25].

2. Friction Stir Spot Welding

The friction stir spot welding FSSW is one of the non-consumable tool welding process can be applied for joining two or more of lightweight metals such as aluminium alloys depending on the heat that generation by friction between rotating pin and work pieces by using milling machine or a drilling machine [26,27].
Ozdemir et al, have been successfully welded dissimilar metals by using friction stir spot welding process. AA1050 Al-alloy and C11000 copper metal with 3 mm thickness have been welded as well as AA6061-T6 Al-alloy and oxygen free copper metals with thickness of 1.5 mm was welded too. Three depths of plunge of 2.8, 4 and 5 mm, have been used to weld these dissimilar metals by applied tool with shoulder diameter of 20 mm and pin diameter of 5 mm. In addition, rotation speed with 1600 RPM was applied with holding time of 10 seconds. The results show that there are no macro defects and the finer grains size were appeared on the copper side closed to the Al/Cu interface. This is due to the effect of the rotating pin and heat input. It was deformed the grains in the place close to the interface and the recrystallization of the grains in the stir welding zone of the copper metal. Moreover, tensile shear test showed that plunge depth of 2.8 mm produced poor results and 4 mm depth exhibited the highest values of shear tensile strength due to the penetration of copper into Al-alloy with more diffusion. In addition, the hardness was increased in the bottom zone of pin hole in copper metal because of heat generation by rotational pin tool. Additionally, when the depth of plunge increase to be 5 mm, the grain size will decrease, which lead to increase the hardness of copper metal and Al-alloy because of diffusion and penetration of copper[28].
Heideman et al, have been welded AA 6061-T6 Al-alloy with oxygen free copper metal by applied FSSW process. The process applied by using thread pin tool made from pre-hardened tool steel type H13 with shoulder and pin diameter of 10 mm and 4 mm, respectively with thread pitch of 0.7 mm. Plunge depths of 0 and 0.13 mm with welding time of 3 and 6 sec. were applied. The spot welding process was done by using rotational speeds from 1000 to 2000 rpm. The result shows that the main factors that affecting the strength of welds are the depth of plunge, rotational welding tool speed and welding tool length. There is no intermetallic interface in the strong welds and the copper ring was appeared on the vertical cross sectional area of each side of the keyhole [29].
Mukunaet et al, have been joined pure copper C11000 and pure aluminium AA1060 sheets by applying FSSW process. Different rotational welding tool speed, shoulder plunge depth and tool geometries were used. The result shows that there is an intermetallic face between copper particles and aluminium metal which was observed by the energy dispersive spectroscopy and X-ray diffraction. In

addition, the maximum tensile load increases with increasing shoulder plunge depth, except for the weld that welded at rotational speed of 800 rpm using a conical welding tool pin with concave shoulder. Moreover, a nugget pull-out failure mode occurred in all the welds under the lap-shear loading conditions. Additionally, high peaks of Vickers microhardness values were obtained in the vicinity of the keyhole of most of the samples [30].

Toroghinejad Toroghinejad and Jazani, have been performed the FSSW of Al-Cu composite materials produced by triangular tool pin with accumulative roll-bonding process. The effect of rotational welding tool rate on the microstructure and mechanical properties were evaluated. The result shows that there is no bonded when the weld made at lower rotational speed due to no intermixing area between upper and lower sheets. Likewise, the maximum shear failure load was increased with increasing the rotational speed of welding tool and reached the maximum load value at rotational speed of 1400 rpm. This is due to the increasing the area and length of stir zone[31].

There are a few articles reporting in the field of using FSSW process for joining copper metal with aluminium metal sheets. Therefore, in this research friction stir spot welding was applied for welding Al-alloy with pure copper sheets with thickness of 3 mm.

3. Mechanism of FSSW

The mechanism of FSSW process can be summarized within three stages; plunging, stirring and retracting as present in figure 1. At the first stage, tool contacts the upper sheet by its pin or shoulder and applied top ward force from milling or drilling machine. The anvil which is located under the lower sheet used to support both sheets and supply downward force. The second stage begins when the tool downward force plunges and the rotational welding tool speed maintains for a suitable time to generate heat by friction between tool and workpiece. During this stage, the two layers heated and softened to obtain the plastic deform and solid state bond between these layers. But, in the third stage, the tool is drawn out from the welded sheets[32].

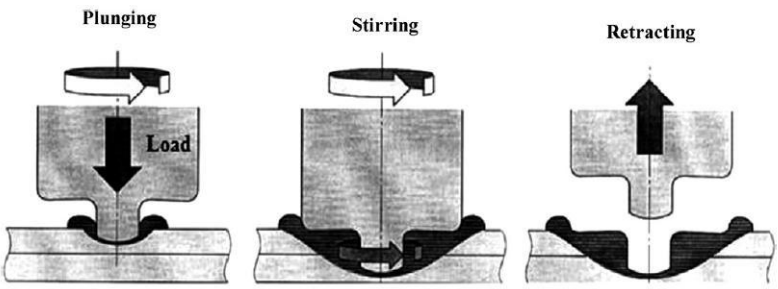

Figure 1. A schematic illustration of the spot friction welding process [32]

4. Experimental Work

4.1. Materials

AA1100 Al-alloy sheets and copper metal sheets with thickness of 3 mm, width of 25 mm and 100 mm length as shown in figure 2, have been welded by friction stir spot welding process. The chemical composition and mechanical properties of these metals are shown in table1 and 2.

Table 1. Chemical composition of AA1100 aluminium alloy sheet and Copper metal sheet

Sheet Metal	Zn	Ni	Fe	Mg	Mn	Si	Others	Al	Cu
AA1100 Al-alloy	0.008	0.71	0.41	2.43	0.099	0.11	0.411	95.8	0.022
C11000 Copper	0.003	0.0008	0.017	0.0005	0.004	0.004	0.0652	0.0055	99.9

Table 2. Mechanical composition of AA1100 aluminium alloy sheet and Copper metal sheet [33-34]

Sheet Metal	Hardness HV	Tensile Strength MPa	Yield Strength MPa	Elongation %
AA1100 Al-alloy	50-65	90-135	34-150	9.9-25
C11000 Copper	55-115	210-310	-	7-40

Figure 2. Al and Cu Samples

4.2. Welding Equipment

Drilling machine type Breda R915L with spindle rotational speed between 40 to 2000 RPM has been used as friction stir spot welding machine to weld Al-alloy sheet with copper metal sheet that assembled as lap joint.

4.3. Welding Tool

A non-consumable rotational tool made from high speed steel HSS was used as a FSSWtool with taper cylinder shape to fabricate the lap joints. The shoulder tool diameter is 10 mm and the pin diameter is 3 mm with height of 5 mm which equal to 83% of plates thickness as presented in figure 3.

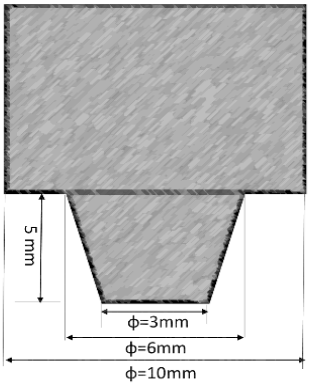

Figure 3. Welding Tool Dimensions

4.4. Welding Process

The procedure of friction stir spot welding was started by fixed welding tool in the drilling holder. Then, fixed Al-alloy sheet and copper metal sheet in the drilling machine anvil as a lab joint type by using rigid fixtures to prevent the movement of sheets during the welding process. Manual and automatic processes were used to weld the sheets with different rotational speed of 760, 1065, 1445, and 2000 RPM. Moreover, infrared device and SS300 beam load cell with signal-conditioning module LJTIA device were fixed in the machine and connected with computer to measure the heat generation and the pressure applied during the weldingprocess.

5. Result and Discussion

The welded samples produced in this research were examined to evaluate their properties. Surface quality, depth of penetration, hardness, tensile strength and heat generation during the welding process were measured for studying the effect of friction stir spot welding process on the quality of welding joint. FSSW samples were prepared according to electric resistance welding handbook of American Welding Society (AWS) [35] as shown in figure 4.

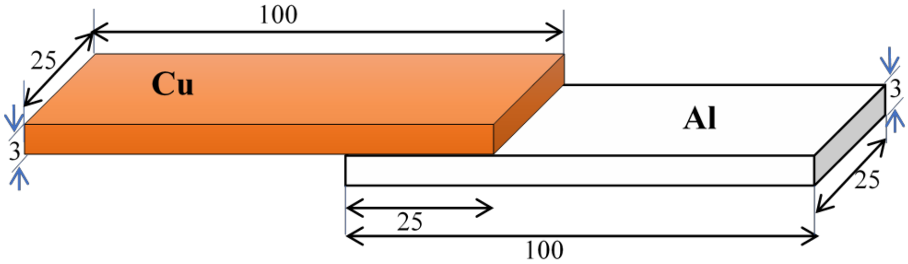

Figure 4. Dimensions of the overlap specimen that to be welded in mm

5.1 Welding Process

Figure 5 shows FSSW sheets welded with different rotational speed. The results show that welded samples have a good surface with some surface flash that can be removed easily.

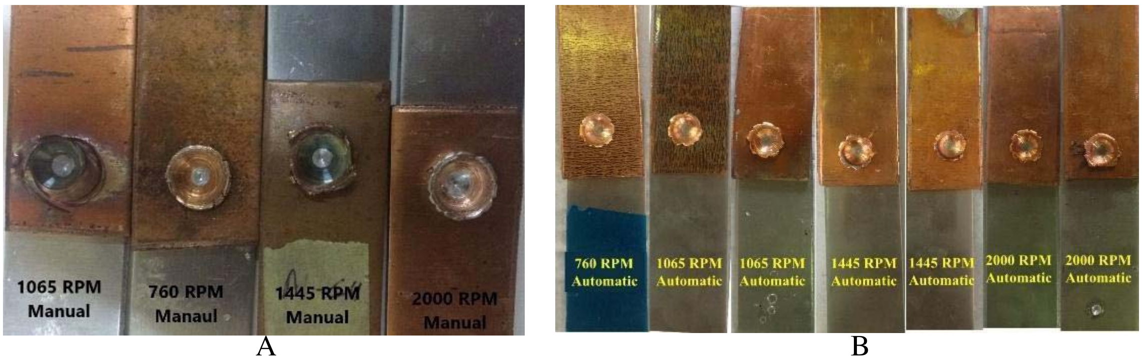

Figure 5. FSSW sheets welded with different rotational speed (A-Manual, B-automatic)

5.2 Heat Generation

Heat generated during the welded process was measured by using infrared device. The results show that heat generated increased with increasing the rotational tool speed and the maximum heat generated was 210 °C in case of manual friction stir spot process and equal to 50 °C in case of automatic process. Heat generation on pin tool is greater than welded zone. So, automatic and manual welding process can be classified as solid state welding process.

5.3 Tool Penetration depth

The experimental work demonstrations that hard metal sheet should be put over the soft metal sheet to achieve suitable heat distribution because soft metal will have destroyed in case of putting over hard plate. Figure 6 shows the shape of friction stir spot welded point that produced in this work. Some of these points have hole in the middle happened due to high load and high heat generated during the welding process. Table 3 shows that the total penetration depth (TPD) is equal to 6 mm and the minimum depth of penetration is 3.25 mm depending on the load and heat. The average of penetration depth is equal to 5 mm approximately in manual process while it is 4.13 mm in the automaticprocess.

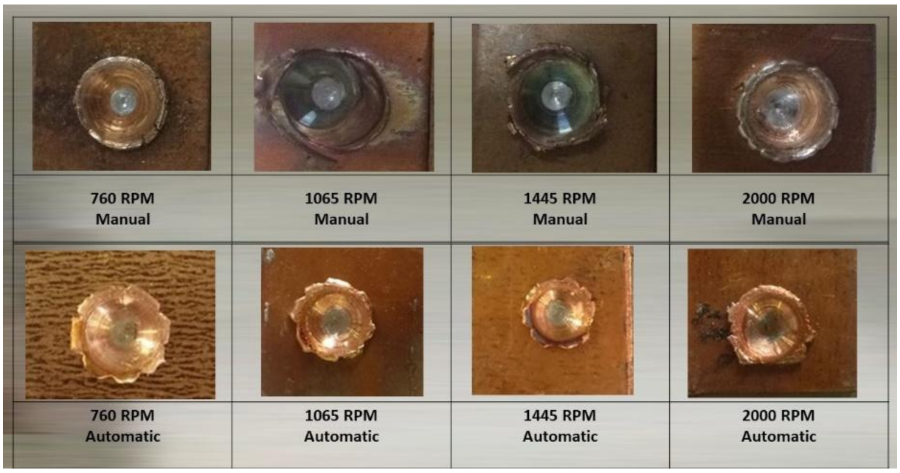

Figure 6. The shape of friction stir spot welded point

Table 3. Total Penetration Depth (TPD) during manual and automatic FSSW

Expe riment No.	Speed (RPM)	Total Penetration Depth (TPD) in mm	
		Manual FSSW	Automatic FSSW
1	760	3.38	3.1
2	760	3.9	3.2
3	760	6	4.77
4	760	6	4.88
5	1065	5.41	4.3
6	1065	5.89	5.1
7	1065	5.3	4.1
8	1065	5.66	4.4
9	1445	4.69	3.88
10	1445	5.1	3.9
11	1445	5.29	4.1
12	1445	5.88	5.99
13	2000	3.9	3.21
14	2000	4.45	3.66
15	2000	4.5	3.99
16	2000	4.77	3.55

5.4 Tensile Strength

The results show that tensile strength was obtained by manual FSSW lied in the range of 268 to 406 MPa depending on the rotational welding tool speed and applied load. However, the maximum tensile strength was found in rotational speed of 1065 RPM which equal to 406 MPa as shown in table 4 and figure 7. Moreover, the minimum dwell time that consumed is equal to 16 seconds which are depending on the heat generation during the welding process and rotational speed. Unfortunately, in case of automatic friction stir spot welding process the tensile test was failed due to difficulty for adjustment penetration depth.

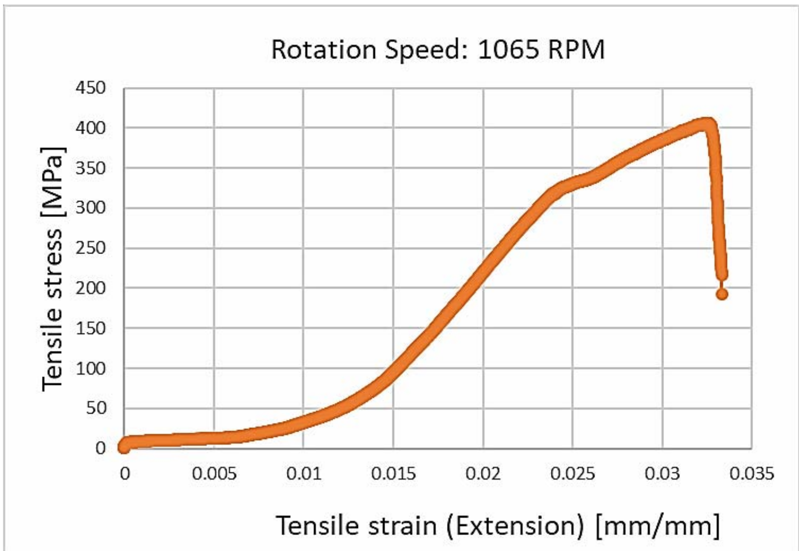

Figure 7. Tensile Strength of Cu-Al FSSW at rotation speed of 1065 RPM

Table 4. Tensile strength of manual friction stir spot welded Al-alloy and copper metal sheets

Rotational speed (RPM)	Tensile Strength (MPa)	Elongation (mm/ mm)
760	392	3.1
1065	406	2.2
1445	268	4
2000	275	1.6

5.5 Dwelling Time and Maximum load

The experimental work shows that the dwell time that required for completing friction stir welding in case of automatic process is less than time that required for manual process which are equal to 14% of manual process time. Table 5 shows that the minimum time required for automatic process is 2.28 seconds and 16 seconds for manual process. Additionally, the dwell time decreased with increasing rotational speed. Moreover, the maximum load that applied in case of automatic process is equal to 777 Kg which are greater than the maximum load that applied in case of manual process which equal to 329 Kg. For that reason, automatic process is better than manual, but there is a difficulty to adjust machine to have suitable penetration depth. Furthermore, the automatic process consumes time same as the time that consume in case of traditional resistance spot welding process.

Table 5. Dwell time and maximum applied load in case of manual and automatic FSSW welded

Rotational speed (RPM)	Manual Welded		Automatic Welded	
	Dwell time (Sec)	Max. Load (Kg)	Dwell time (Sec)	Max. Load (Kg)
760	40	290	5.03	777
1065	31	329	3.64	777
1445	21	250	3.16	777
2000	16	250	2.28	777

6 Result and Discussion

The results show that there is a possibility to weld dissimilar metal which are AA1100 aluminium alloy and copper metal sheets with thickness of 3 mm by using manual and automatic friction stir spot welding process with lap joint. Hard metal sheet should be put over the soft metal sheet to avoid any destroyed that happened for soft metal sheet before welding with hard metal sheet. The dwell time that required to complete friction stir spot welding in case of automatic process reduced to be 14% of time that consume in case of manual welding process because applied load will be twice time of manual applied load. Therefore, the maximum heat generation in automatic friction stir spot welding process is less than heat that generated during manual process which equal to 25% of heat generated during manual process. Moreover, the maximum tensile strength that achieved in case of manual friction process is equal to 406 MPa in rotational speed of 1065 RPM. However, it is difficult to made tensile strength test for automatic welded plates due to difficulty to adjust penetration depth in case of automatic friction stir spot welding process because of low thickness of workpieces.

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