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Friction Stir Spot Welding of AA5052 Aluminum Alloy and C11000 Copper Lap Joint

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Abstract

The article aims to apply a friction stir spot welding for producing the lap joint between AA5052 aluminum alloy and C11000 copper alloy. The dimension of the materials was 100 mm in length, 30 mm in width and 1.0 mm in thickness. The copper plate was set overlap the aluminum plate by 30 mm. The welding parameter was the rotating speed of 2500-4000 rpm, the pin inserting rate of 2-8 mm/min and the holding time of 6 sec. The mechanical properties test and the microstructure investigation were performed to evaluate the lap joint quality. The summarized results are as follows. The friction stir spot welding could produce effectively the lap joint between AA5052 and C11000 copper. Increase of the rotating speed and holding time directly affected to decrease the tensile shear strength of the lap joint. The optimized welding parameters in this study that indicated the tensile shear strength of 864 N was the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4sec. The experimental results also showed that the hardness of the weld metal was lower than that of the base materials.

Keywords*: friction stir spot welding, copper, aluminum, lap joint, strength,*

1. INTRODUCTION

A joint of a dissimilar metals such as the copper/aluminum is widely applied in various industries because the sound joint of the dissimilar metals could have the benefits in a flexible design and production processes [1], [2]. However, the joining of copper to aluminum by a welding process is difficult because of the differences in material properties, poor weldability, the formation of a residual stress and the formation of a brittle intermetallic compound [3]. Some fusion welding processes that were applied to join copper to

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aluminum and showed the interested data for research and development of quality joint. Zuo, et al.[1] applied a Nd:Yag laser welding for joining 1060 aluminum alloy to T2 copper and reported that the thickness of the γ2-Cu9Al4 intermetallic compound (IMC) and the shear–tensile strength of the joint decreased with the increase of welding speed in the weld. The IMC that was formed in the welding process deteriorated the joint strength. Wang at al. [4] welded the flyer plate of Al on Cu plate using various Nd YAG-GAIA R laser shock welding and reported that a wavy morphology of the joint interface, increased the intimate contact area and aided interlocking between two metal surfaces that led to strong bonding. However, the joint strength of the laser welding specimen was lower than that of the base materials and might not be suited to apply in the industry.

A solid state welding is one of the important welding processes that could produce the weld metal of the dissimilar metal joint under the melting temperature of the metals. The welding process such as a friction stir welding (FSW) or friction stir spot welding (FSSW) could successively weld the dissimilar metal joints, such as copper to aluminum joint or aluminum to steel, and showed the joint strength that was higher than that of the base metal. These welding joints were a FSW thick plate lap joint of Copper-DHP and AA6082 aluminum [2], a FSW thick plate lap joint of 10160 aluminum and pure copper [3,5], a FSW thick plate lap joint of pure copper and AA5083 aluminum [6], a FSSW thin sheet lap joint of Zr55Cu30Al10Ni5 alloy and pure copper [7], a FSSW thin sheet lap joint of AA1100 aluminum and AISI304 steel [9], or a FSSW thin sheet lap joint of AA5052 aluminum and AISI304 steel [10], *etc.*

From the previous reviews, it showed that no research work was systematically conducted for welding the thin sheet of aluminum alloy and pure copper lap joint. Therefore, this research work has an outline to weld a 1 mm thin sheet of AA5052 aluminium alloy and pure copper lap joint. The work is aimed to study the effects of FSSW parameter on tensile shear strength of the lap joint and study the relation between mechanical properties and microstructure of the lap joint.

2. EXPERIMENTAL PROCEDURE

Materials used in this experiment were AA5052 aluminum alloy and C11000 Copper alloy that had a chemical composition as shown in Table 1. The rolled plates were mechanically cut into rectangular shapes and have a dimension of 100 mm in length, 30 mm in width and 1 mm in thickness. The copper plate was set to be 30 mm overlapping the aluminum plate by 30 mm [8] as shown in figure 1 (a). The lap joint was mounted in a jig and then, clamped on a moving table of a CNC vertical milling machine. The FSSW tool was made of JIS-SKD 11 and that had a shoulder diameter of 10 mm, a pin diameter of 0.7 mm and a pin length of 0.7 mm as shown in figure 1 (b). The FSSW process consisted of 3 steps as follows. First step, the FSSW tool that was rotated at a speed of 2500-4000 rpm was inserted at a speed of 2-8 mm/min to a lap joint interface. Second step, the rotated tool was held at a given depth of 1.00 mm for a time of 2-8 seconds. The 0.0 mm in depth was the location that the FSSW pin end was touching the upper surface of the lap joint as shown in figure 1 (c). Third step, the FSSW tool was withdrawn from the joint at a constant speed.

Table 1. Chemical composition of the experimental materials (%wt)

Materials	Al	Cu	Fe	Si	Cr	Mn	Mg
AA5052	Bal.	0.15	0.40	0.25	0.15	0.10	2.8
CC11000	-	99.99	-	-	-	-	-

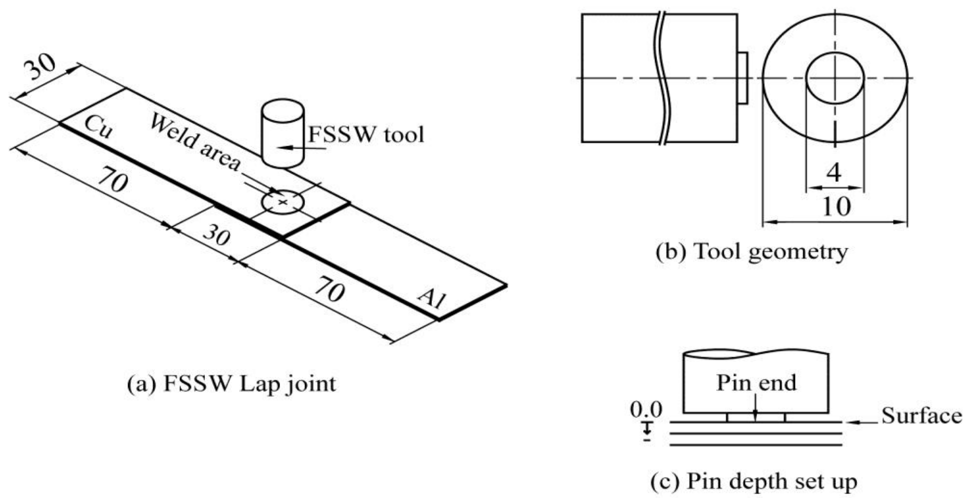

Figure 1. FSSW process set up.

After welding, the lap joint was removed from the jig and was tested within 24 hours for investigation of a tensile shear strength, a replacement, a fracture path and fracture location of the joint. A microstructure examination of the joint interface structure was performed with the purpose to reveal a metallurgical combination of the materials that might affect the joint strength. A cross section at a center of the lap joint was mechanically polished using the emery paper grit number of 150-2000 and 1 micron of diamond paste. The polished specimen was chemically etched using 5% HNO_3 on the copper side and Keller reagent at the aluminum side for revealing the metallurgical phase of the joint interface. A hardness of the microstructure of the weld metal and base metal was also applied to evaluate the different microstructure of the joint using a Micro-Vickers hardness test.

3. RESULTS AND DISCUSSIONS

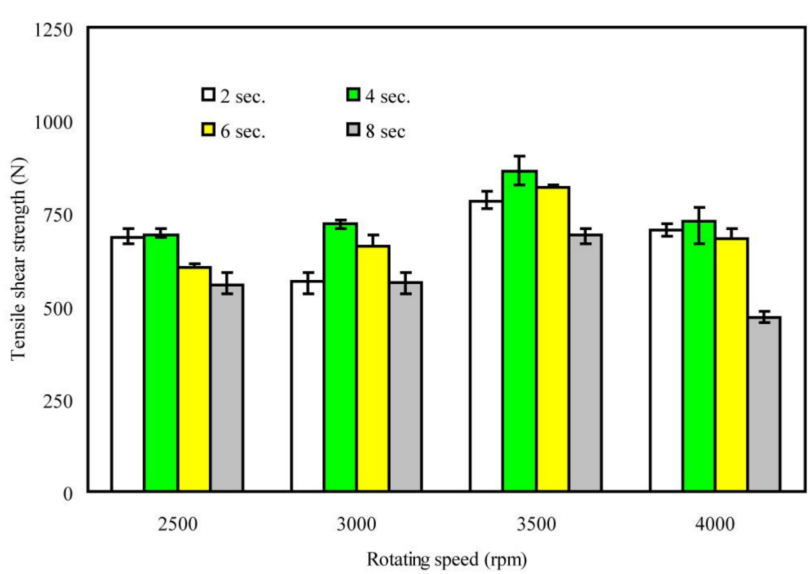

Figure 2. Relation of the rotating speed, the pin inserting rate and tensile shear strength.

Figure 2 shows the relation between the tensile shear strength, the rotating speed and the holding time at a given depth of the lap joints that were welded by the pin inserting rate of 6 mm/mm. The tensile shear strength of the lap joint could be increased when the pin inserting rate was increased. Increase of the rotating speed also affected to increase the tensile shear strength of the lap joint. However, when the rotating speed was higher upto 4000 rpm, it deteriorated the tensile shear strength. The optimum welding parameter that indicated the tensile shear strength of 870 N was the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4 seconds.

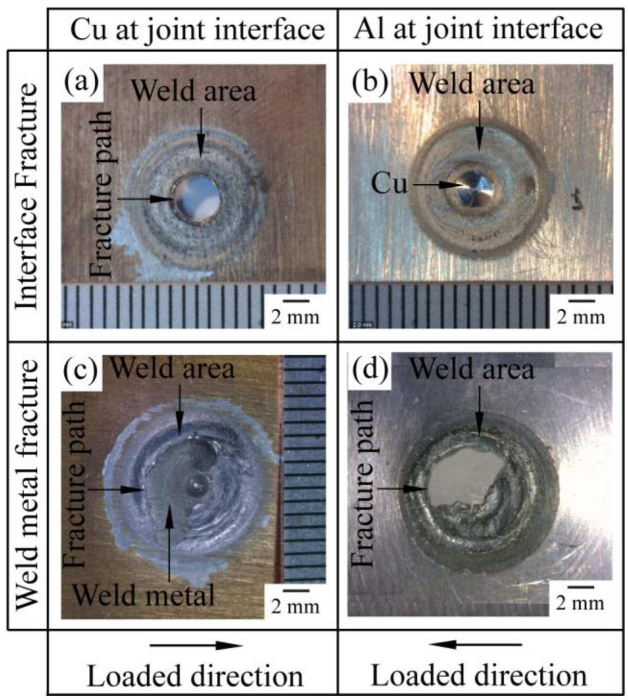

Figure 3. Fracture of tensile shear test specimens.

Table 2. Comparison of the fracture type of the tensile shear test specimen.

Holding time (s)	Rotaing speed (rpm)			
	2500	3000	3500	4000
2	I	I	I	I
4	I	I	II	II
6	I	I	II	II
8	I	I	I	I

The fracture characteristics of the tensile shear test specimen could be divided into 2 types as shown in figure 3. The loaded direction of the tensile specimen was left to right hand side for Cu plate and right to left for Al plate. Type I fracture location was occurring at the joint interface as shown in figure 3 (a) and (b). The fracture surface of the upper Cu plate showed the hole that was produced by the rotating pin and the rough surface around the hole that was occurred by the movement of the materials and the frictional heat as shown in figure 3 (a). The fracture surface of the lower Al plate showed some Cu was pushed, stirred and adhered to the Al plate at the center of the lap joint as shown in figure 3 (b). The rough surface that was occurred by the movement of the materials and the frictional heat as occurred on the Cu side was also formed around the center of the joint. This rough surface seemed to show the incomplete bonding between the materials and affected to indicate the joint with a lower strength. This fracture characteristic was found in this study when the lower rotating speeds were applied to produce the Cu/Al lap joint as shown in Table 2.

The type II fracture was occurring at the weld metal as shown in figure 3 (c) and (d). The fracture location of the upper Cu plate was occurring through the weld metal of the joint as shown in figure 3 (c). The Cu weld metal fracture surface showed that a half of the weld metal was torn out of the welded area and some rough surface that indicated no bonding metal was found as shown in figure 3 (c). The type II fracture surface was clearly observed on the Al weld metal fracture surface as shown in figure 3 (d). The tearing hole on the Al weld metal fracture surface was the weld metal that was completely welded and permanently adhered to the Cu fracture surface as shown in figure 3 (c). This type II fracture characteristic was found when the higher rotating speeds were applied to produce the lap joint as shown in Table 2.

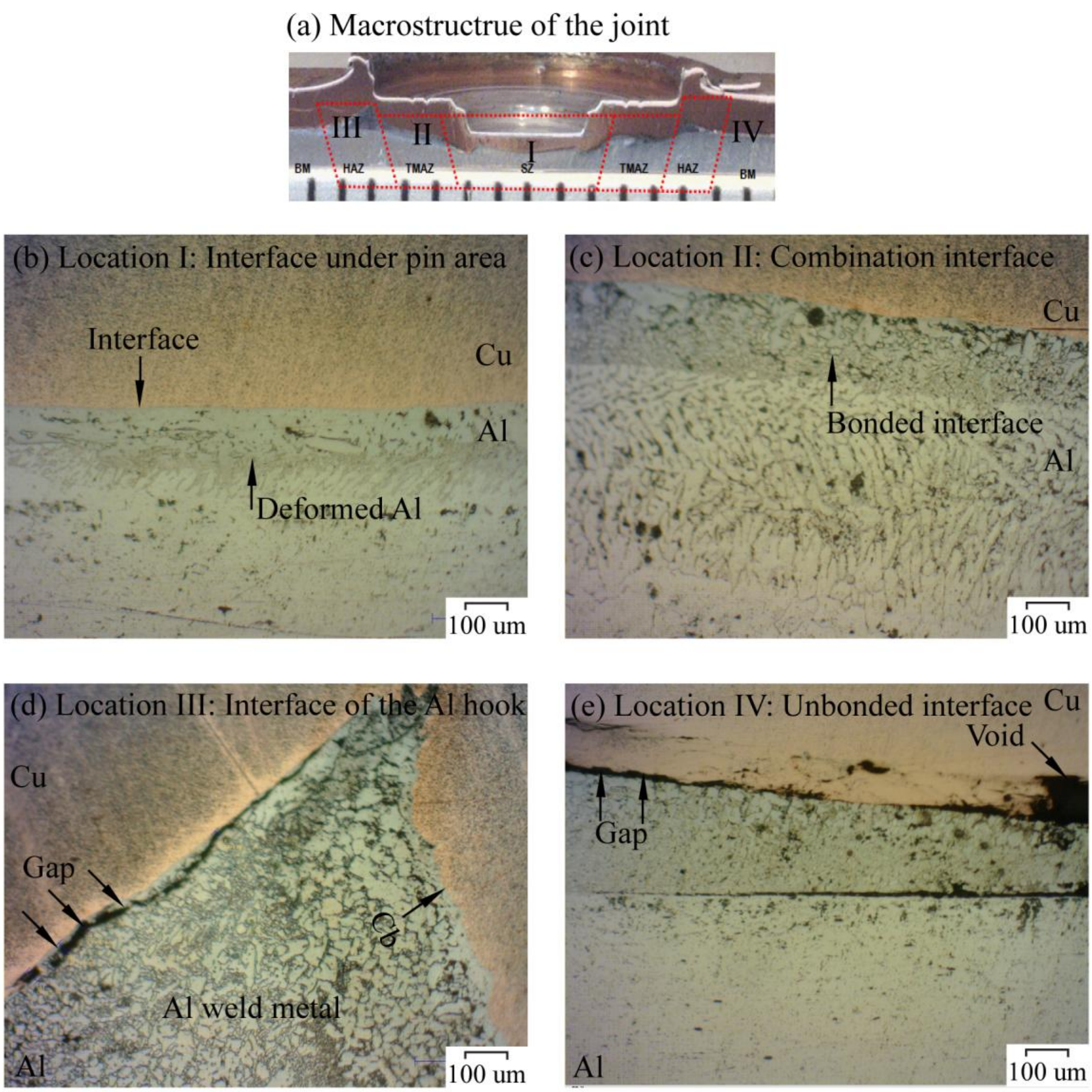

Figure 4. Microstructure of the lap joint produced by the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4 seconds.

Figure 4 shows microstructure photograph of the lap joint that was produced by the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4 seconds. The microstructure at the location I-IV as shown in Figure 4 (a) at the joint interface was examined. Interface structure at the location I showed the complete bonding at the joint interface and showed the deformation materials of Cu and Al as shown figure 4 (b). When compared to the deformation of the materials, it was found that the deformation of Cu (Upper part) that was stirred by the rotating pin was finer and rounder than the deformation of Al (Lower part).

Figure 4 (c) shows the location II of the joint interface that was beside the rotating pin and was in the stir zone of the weld metal. The joint interface showed the material deformation of Cu and Al and also showed the finer grain on the Cu side and the columnar-like grain on the Al side as formed at the location I of the joint interface as shown in figure 4 (b). Compared with the joint interface at the location I, the bonding area between Al and Cu of this location was found and showed finer grain than the deformed Al. The width of the bonding area between Al and Cu at the joint interface of the location II was about 150 microns.

Figure 4 (d) shows the interface structure between the hook-like Al that was stirred and bent into the Cu weld metal by the rotating pin. The irregular grain shape and size was observed in the hook-like Al. The irregular grain shape and size were widely observed in the hook-like Al. The narrow bonding area of the materials at the joint interface between the hook-like Al and the Cu stirred zone was found as shown by the C arrow in figure 4 (d) but was smaller than that of the location II in figure 4 (c). The joint interface between the hook-like Al and the Cu unstirred zone was not completely produced by FSSW as shown by the arrows in figure 4 (d). This incomplete bonding of the materials at the joint interface was similar to the joint interface that was out of the welding area as shown by the arrows in figure 4 (e).

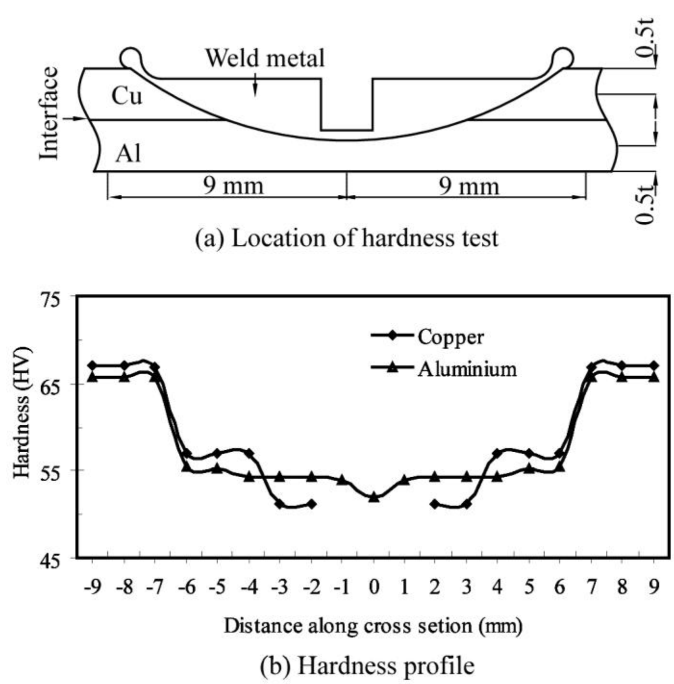

Figure 5. Hardness profile of the lap joint produced by the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4 seconds.

Figure 5 shows the hardness profile of the lap joint produced by the rotating speed of 3500 rpm, the pin inserting rate of 6 mm/min and the holding time of 4 seconds. These 2 hardness profiles were measured at the 0.5 time of the thickness of each material and the distance of the measured points was about 1 mm followed ASTM E92-82. The hardness of the base materials (Al and Cu) was higher than that of the materials in the weld zone as shown in the distance of 6 mm from the center of the joint. In the stir zone, the hardness measurement result as shown in figure 5 shows that the hardness of the Cu weld metal was lower than that of the hardness of Al weld metal.

4. CONCLUSION

This research work studied the effect of the rotating speed and the pin inserting rate of the FSSW tool on the tensile shear strength of the lap joint between AA5052 aluminum alloy and C11000 copper alloy. The summarized results are as follows.

1) Friction stir spot welding could produce the lap joint between AA5052 aluminum alloy and C11000 copper alloy.
2) Increase of the rotating speed and decrease of the holding time of the FSSW tool affected to increase the tensile shear strength of the lap joint.
3) The microstructure of the lap joint showed the combination of the materials at the joint interface and showed the finer grain shape and size in the weld metal.
4) The hardness profile of the lap joint showed that the hardness of the weld metal was lower than that of the base metal.
5) The optimum welding parameter that indicated the tensile shear strength of 864 N was the rotating speed of 3500 rpm, the pin inserting rate of 4 mm/min and the holding time of 4 seconds.

REFERENCES

[1] Zuo, D., Hu, S., Shen, J., Xue, Z., "Intermediate layer characterization and fracture behavior of laser-welded copper/aluminum metal joints," *Materials & Design*, Vol. 58, pp. 357-362, 2014.

[2] Galvo, I., Verdera, D., Gesto, D., Loureiro, A., Rodrigues, D.M., "Influence of aluminium alloy type on dissimilar friction stir lap welding of aluminium to copper," *Journal of Materials Processing Technology*, Vol. 213, pp. 1920-1928, 2013.

[3] Saeid, T. Abdollah-zadeh, A., Sazgari, B., "Weldability and mechanical properties of dissimilar aluminum-copper lap joints made by friction stir welding," *Journal of Alloys and Compounds*, Vol. 490, pp. 652-655, 2010.

[4] Wang, X., Gu, C., Zheng, Y., Shen, Z., Liu, X., "Laser shock welding of aluminum/aluminum and aluminum/copper plates," *Materials & Design*, Vol. 56, pp. 26-30, 2014.

[5] Abdollah-Zadeh, A. Saeid, T., Sazgari, B., "Microstructural and mechanical properties of friction stir welded aluminum/copper lap joints," *Journal of alloys and Compounds*, Vol. 460, pp. 535-538, 2008.

[6] Bisadi, H., Tavakoli, A., Tour Sangsaraki, M., Tour Sangsaraki, K., "The influences of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints," *Materials and Design*, Vol. 43, pp. 80-88, 2013.

[7] Sun, Y.F., Fujii, H., "Microstructure and mechanical properties of dissimilar spot friction stir welded Zr55 Cu30 Al10 Ni5 bulk metallic glass to pure copper," *Intermetallics*, Vol. 33, pp. 113-119, 2013.

[8] Kimapong, K., “Friction stir spot welding of AA1100 aluminum alloy to AISI304 stainless steel,” *Engineering Journal of Siam University*, Vol. 2-15, pp. 56-61, In Thai, 2008.
[9] Hmeefureng, T., Kimapong, K., “Effect of friction stir spot welding on lap joint properties of AA5052 aluminum alloy and AISI430 stainless steel,” *Industrials Engineering Network Conference,* Songkla Thailand, pp. 834-839, In Thai, 2008.
[10] Shin, H.,S., Jung, Y.,C., “Characteristics of dissimilar friction stir spot welding of bulk metallic glass to lightweight crystalline metals,” *Intermetallics*, Vol. 18, pp. 2000-2004, 2010.