Int. J. of Applied Mechanics and Engineering, 2022, vol.27, No.2, pp.217-225
DOI: 10.2478/ijame-2022-0029

INFLUENCE OF WELDING PARAMETERS OF RESISTANCE SPOT WELDING ON JOINING ALUMINUM WITH COPPER

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The resistance spot welding (RSW) method was used to join aluminum alloy AA 1050 and copper alloy UNS C50100 sheets. Mechanical properties of the joints were examined. The influence of welding process parameters on tensile shear force of the joints was discussed. The design of experiments (DOE) method was used to analyze the influence of welding parameters on the mechanical properties of the joints. Three RSW parameters were used: welding current, squeeze time, and welding time. The results showed that the joint shear stress increased with increasing the welding current until a value of 12000 Amp. Then the shear stress decreased. The tensile shear stress increased with increasing the welding and squeeze time. As a consequence, it can be possible to weld copper with aluminum by RSW.

Key words: resistance spot welding (RSW), aluminum (Al), copper (Cu), RSW parameter, DOE.

1. Introduction

Resistance spot welding (RSW) can be classified as a collection of welding processes. This method is widely used in joining consisting of intricate heat and mass transfers with electrical, mechanical, and metallurgical phenomena. In RSW, the overlapping joint is situated between two water-cooled electrodes. The heat is generated by a tremendous electric current for a short period of time [1-3]. RSW is a broadly used joining method for manufacturing sheet metal structures like rail vehicles, automobiles, and home applications. The technique is efficient and frequently applied in automation; an auto-body assembly needs *5000* to *11000* spots for welding according to the vehicle size, so the RSW is an essential method. The RSW, owing to its characteristics of excellent operating speed and automation feasibility, could be a favorable process to join thin-walled structures [4-6].

Aluminum (Al) and copper (Cu) have great thermal and electrical conductivity with excellent mechanical properties; therefore, they are used for bus bars and battery tabs. Joining these materials with different conditions employing the traditional fusion welding process is difficult due to their noticeable differences in metallurgical and physical properties. Nowadays, the concept of lightweight design in the manufacturing is a global request because of energy-saving requirements and the need to decrease CO_2 emissions. Reduction of automotive weight, improving fuel consumption, and enhancing crash safety are the

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main aims behind the development of metals in the automotive manufacturing. Design of lightweight structures for low-density and high-strength metal alloys has become a new approach to environmentally sustainable transportation [7-10].

Aluminum alloys are characterized as lightweight and high strength materials. Joining of dissimilar materials (such as copper to aluminum) is considered as multi-materials lightweight design. Joining of different materials (such as copper and aluminum) can be accomplished by formation of three distinguished types of interfaces: solid to solid interface (maximum welding temperature is lower than the melting temperature of aluminum), solid to liquid interface (aluminum material reaches the melting point and wets the solid copper), and liquid to liquid interface (aluminum and copper metals reach the melting points). Difficulties welding of dissimilar materials (copper and aluminum) involve variations in thermal properties (e.g. thermal conductivity, melting point, electrical resistivity and coefficient of thermal expansion), aluminum oxide presence and formation of intermetallic compounds (IMCs) at the joint interface [11-14].

Aluminum alloys and copper were welded in different conditions by different methods like RSW, friction stir spot welding and ultrasonic spot welding. Failure and quality of spot weld depend on welding parameters levels. Lihu Cui *et al*. [15] joined copper-coated steel with aluminum alloy (AA6061) using the RSW technique. The results showed that nugget diameter and joint strength increased by increasing welding current and time, and decreasing electrode force. Consequently, copper coating as middle layer of RSW was appropriate for welding the aluminum alloy to steel [15].

Zhao *et al.* [16] studied the effect of ultrasonic spot welding energy on copper / aluminum joints. An inadequate welding power led to disperse bonding joint, and activated a combination of Al/Cu IMCs that appeared under a significant energy input. By increasing the welding energy, a sound Cu/Al USW joint had been accomplished through mechanical interlocking at the weld interface. Cao *et al*. [17] used resistance heat to promote the USW quality in small workpieces for electronic operation. USW formed a tiny joint layer of $CuAl_2$ with a *1.1* kAmp. DC. The maximum value of lap shear force for *0.3 mm* diameter (6061-C1100) was *550 N*. Friction stir and stir spot welding (FSW and FSSW) are too possibly suitable techniques to join copper together with aluminum. Ouyang *et al*. [19] studied the effect of FSW of AA6061 together with copper on joint's microstructure. IMCs like $CuAl_2$, CuAl and Cu_9Al_4 were formed in the joint. Travel speed, rotating speed of the tool and joint design exhibited important influences on the FSW joint quality.

In spite of many advantages of the previous techniques, solid-state joining technique of aluminum to copper still has several limitations. A complex fixture design is required against torque produced by the tool during the FSW/FSSW process. Dimensions of a part are restrained by the USW process due to the excessive welding energy which is spent on a large workpiece. In several solid-state joining methods, like cold pressure welding and magnetic plus welding, shape is monotonous; consequently, it is essential to improve an efficient Cu/Al joints that give high robustness and flexibility [19, 20].

2. Experimental procedure

Aluminum and copper sheets of *1 mm* thickness were cut into dimensions of *100 mm* length and *25 mm* width, as shown in Fig.1. Chemical compositions of the materials are listed in Tab.1. An ASW machine (DAIDEN, Japan), with (*4.5 kN*) electrode force of squeeze and cooled-water electrodes, was used in the welding process. Mechanical properties of the materials are listed in Tab.2.

Table 1. Chemical composition of materials.

Element wt. %	Si	Fe	Sn	Mn	Mg	Zn	Ti	P	Pb	Sb	V	AL	Cu
AA 1050	*0.116*	*0.29*	-	*0.03*	*0.01*	*0.01*	*0.02*	-	*0.0005*	-	*0.01*	*Bal.*	*0.02*
UNS C50100	*0.008*	*0.036*	*0.61*	*0.0004*	-	*0.003*	*0.006*	*0.04*	*0.03*	*0.005*	-	*0.2*	*Bal.*

Table 2. Mechanical properties of the materials.

Material Property	Yield Strength $\sigma_y\,(MPa)$	Tensile Strength $\sigma_u\,(MPa)$	Elongation EL (%)
AA 1050	*30*	*91*	*44*
UNS C50100	*98*	*320*	*48*

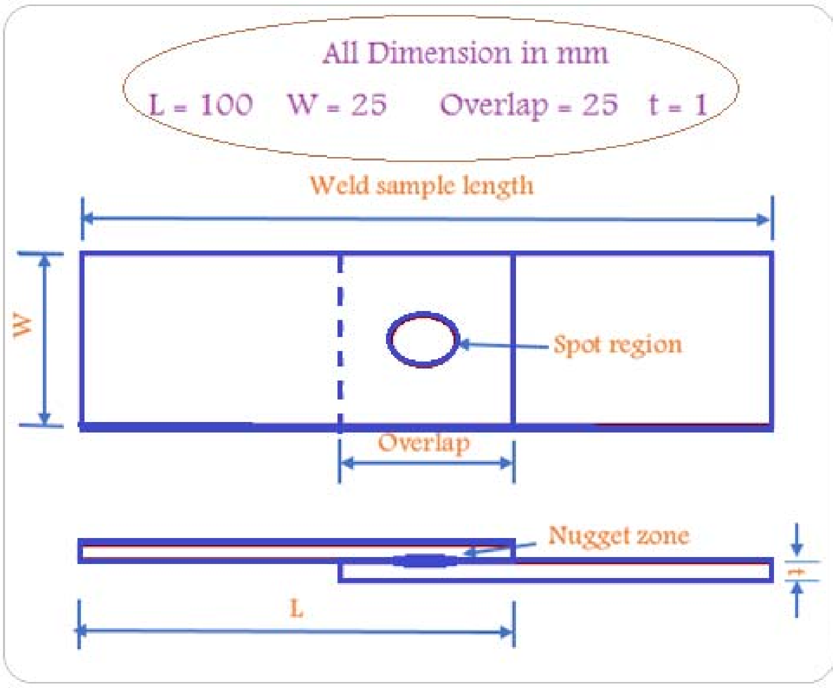

Fig.1. Dimensions of the specimen.

The design of the experiments (DOE) method was used, with the aid of Minitab program to investigate the influence of welding parameters on mechanical properties of the joints. The RSW parameters were: welding current (*Amp.*), squeeze time (*s*), and welding time (*s*). The experiments were designed according to Taguchi method as presented in Tab.3.

Table 3. Conditions of welding.

No.	Welding current (*Amp.*)	Squeeze time (*sec*)	Welding time (*sec*)
1	*12000*	*0.55*	*0.8*
2	*14000*	*0.6*	*0.9*
3	*14000*	*0.65*	*1*
4	*12000*	*0.55*	*0.9*
5	*10000*	*0.6*	*0.8*
6	*12000*	*0.65*	*1*

The tensile sheer stress test stand to investigate the best conditions for RSW parameters is shown in Fig.2.

Fig.2. The tensile test machines.

3. Results and discussion

According to the results of the RSW of Al/Cu, the welding current, welding time, and squeeze time affect the mechanical properties of the welded joints. The welded joints were tested by a tensile shear test machine, as shown in Fig.3.

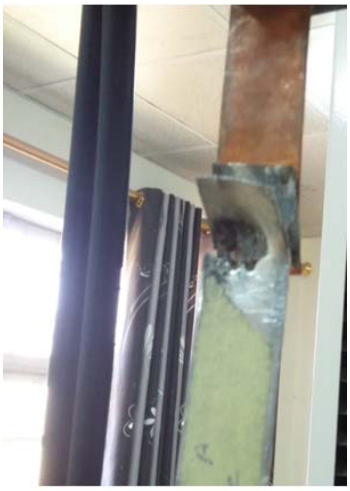

Fig.3. Tensile shear test machine.

The tensile-shear tests indicated that is all the specimens recorded tensile-shear stress was recorded, which is varied from sample to sample. The sample No.6 was welded at *12000 Amp* welding current, *1 sec* welding time and *0.65 sec* squeeze time, and exhibited maximum tensile shear stress of *14.3 MPa*, as shown in Fig.4. A minimum tensile-shear stress of *6.3 MPa* was observed in the sample No.1 which was welded at welding current *12000 A*, (*0.55 sec*) squeeze time, and (*0.8 sec*) welding time.

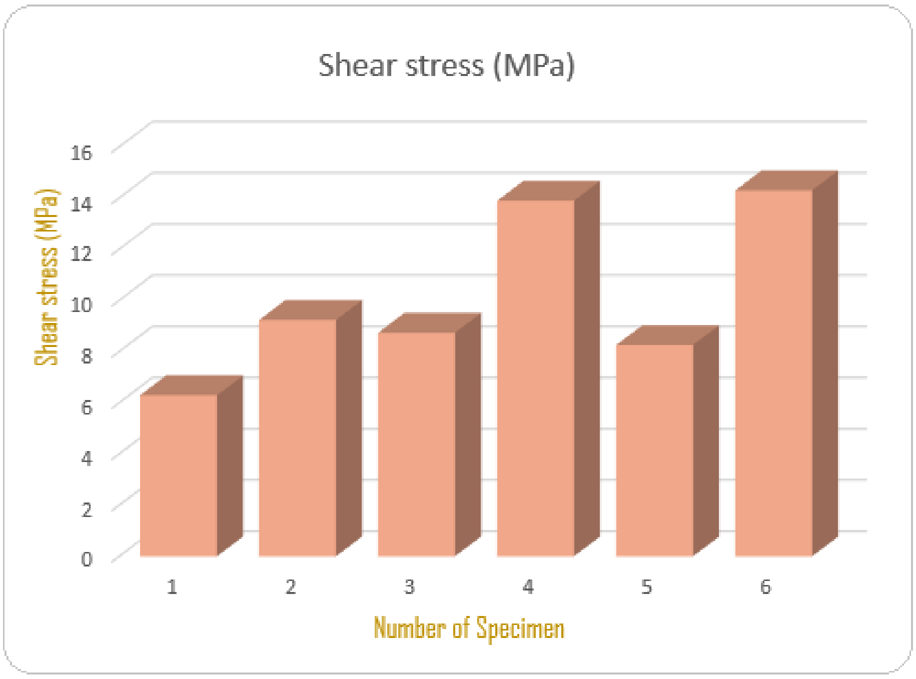

Fig.4. Tensile-shear stress.

In this research, the influence of the RSW parameters was analyzed as follows:

Fig.5. Main effect of welding parameters on shear stress.

Figure 5 illustrates the influence of the welding current, squeeze time, and welding time on the tensile shear stress, respectively. The welding current was the main parameter that impacts the resistance heat. Initially, the shear tensile stress raised with increasing the welding current, then the shear tensile stress decreased with increasing the welding current due to generation of a higher heat at welding or nugget zone, and formation of IMC at the welding interface. The maximum tensile shear stress was *14.3 MPa* at *12 kA* welding current. The squeeze and welding time exhibited, approximately, the same effect on the welded joints. Increasing the squeeze and welding time resulted in increasing the tensile shear stress. Without welding current (the main factor) the squeeze and welding time had no effect. Although the welding time was more important than the squeeze time.

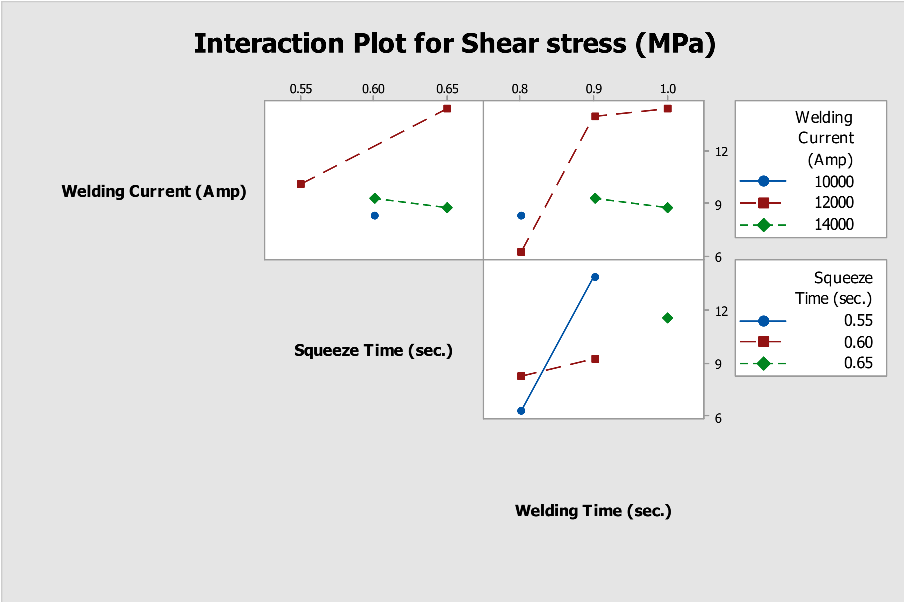

Fig.6. Interaction plot of tensile shear stress.

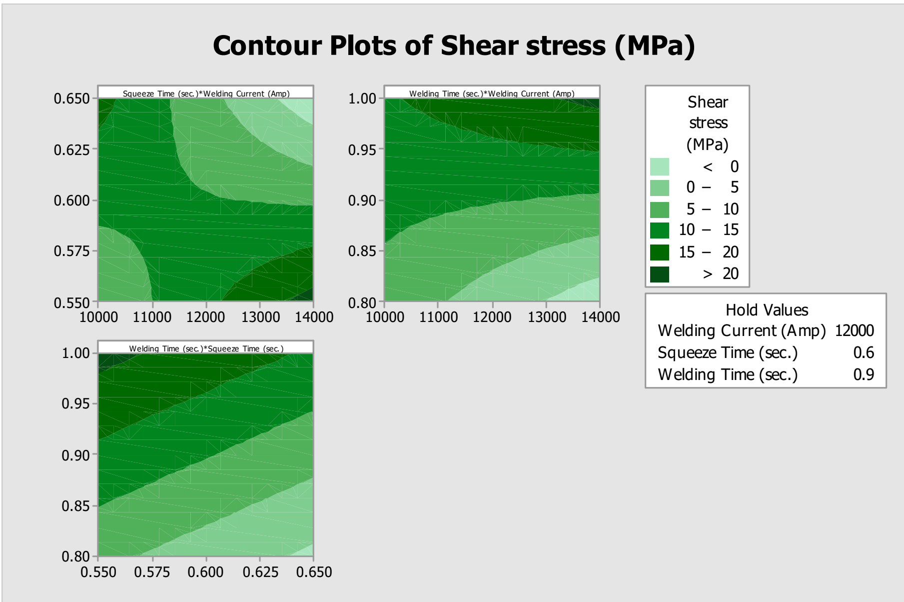

Fig.7. Contour plots of shear stress.

To analyze the interaction of each two process parameters of RSW on the tensile shear stress of the joints, the interaction graph was plotted by the DOE method using the MINITAB program, as shown in Fig.6. The results revealed the following influences:

1- At the interaction between the welding current and squeeze time, the tensile shear stress increased by increasing the squeeze time at welding current *12000 A*.

2- At the interaction between welding current and welding time, increasing the welding time raised the tensile shear stress of the joints at welding current *12000 A*.

An estimated simulation was made for the three process parameters to evaluate approximate results for the tensile-shear stress under variation of RSW parameters, as shown in Fig.7. In joining dissimilar materials like AA 1050 with UNS C50100, the tensile-shear stress is between *15-20 MPa* at the following values of welding parameters: welding current *12000 Amp.*, welding time *0.9 sec* and squeeze time *0.6 sec* and fixed other parameters.

4. Conclusion

The RSW technique was used to join aluminum AA 1050 with copper UNS C50100. The influence of the welding current, squeeze time and welding time on the joint tensile shear stress was investigated. The following conclusions were drawn:

1) The RSW process was a successful and suitable technique to join AA 1050 with UNS C50100.
2) The minimum tensile shear stress of the joints was *6.3 MPa* at a welding current of *12000 Amp.*, *sec* squeeze time of *0.55* and welding time of *0.8 sec*.
3) The maximum tensile shear stress of the joints reached a value of *14.3 MPa* at *12000 Amp.* welding current, *1 sec* welding time and *0.65 sec* squeeze time.
4) By increasing the welding current, the tensile shear stress increased until *12 kA* and then decreased.
5) With increasing the welding and squeeze time, the tensile shear stress increased.
6) The tensile shear stress of the joints was optimized to values ranging between *15* and *20 MPa* at a welding current of *12000 Amp.*, welding time of *0.9 sec* and squeeze time of *0.6 sec*.

Nomenclature

A – ampere
AA – aluminum alloy
Al – aluminum
CO_2 – carbon dioxide
Cu – copper
DC – direct current
DOE – design of experiments
EL – elongation
FSSW – friction stir spot welding
FSW – friction stir welding
MPa – megapascal
L – length
IMC – intermetallic compound
kN – kilonewton
mm – millimeter
RSW – resistance spot welding
s – second
t – thickness
USW – ultrasonic spot welding
w – width

σ_y − yield strength

σ_u − ultimate tensile strength

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Received: November 16, 2021
Revised: January 12, 2022