



COMPARATIVE STUDIES ON RESISTANT SPOT WELDING OF ALUMINIUM-6061

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Abstract: The present research work consists of the reviewed study of RSW of Al-6061. The different reviews and research work comprise the study of different parameters such as nugget formation, welding time and current according to their respective ASTM (American Standard Testing of Materials). This article helps for the improving the different physical-mechanical properties of this particular material, along with the highlighted parameters. Different references for the detailed studies of the materials and their results are being comprised and compared.

Index Terms - Parameters, Testing, Review, Al standards.

Introduction:

Resistance spot welding (RSW) is widely used in automobile and aeronautical industries [40]. This method of welding needs a massive amount of current and a very low voltage. Metals like Steel, Aluminium (Al), Magnesium (Mg), Titanium (Ti), Copper (Cu), and their alloys. Mostly, metal sheets of small thickness of same or different type of metals are joined by RSW. RSW also suffers from a few limitations like liquation cracking, voids, misalignment, electrode wear, etc. Metal sheets of high thickness are difficult to join by RSW method because the heat flows into the surrounding metal very easily[1].

Fundamentals of resistance spot welding:

The purpose of the RSW process is to generate heat efficiently in the joints of the welded material while minimizing heat conduction of cooler adjoining material. This heat generation is a term that can be used to describe,

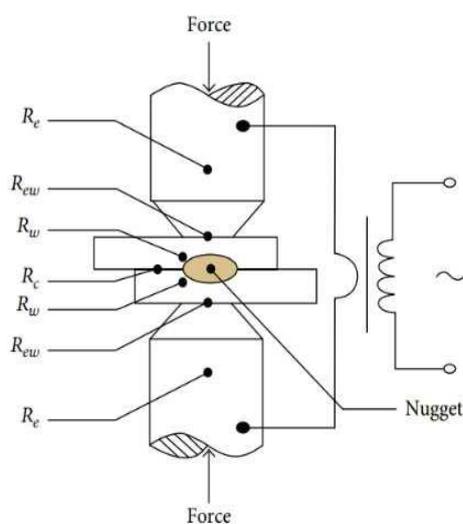


Figure 1: the resistance in RSW process

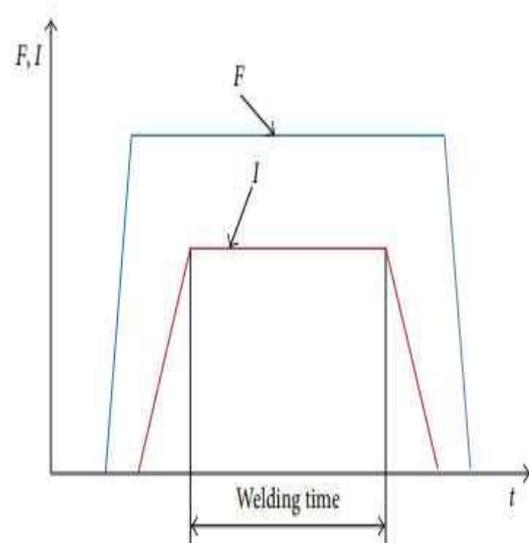


Figure 2: RSW schematic diagram

Where, Q is the heat energy in joules, I is the current in amperes, R is the resistance in ohms, and t is the time in seconds [9]. Fig. 1 illustrates the resistances contributed by the secondary circuit resistance welding machine.

As shown in Figure 1, the RSW process resistance is determined by the total resistance, which can be represented as,

$$R = R_c + 2R_w + 2R_{ew} + 2R_e \quad (1)$$

Where, R is the total resistance, R_e is the electrode resistance, R_{ew} is the specimen electrode contact resistance, R_w is the specimen resistance, and R_c is the specimen's contact resistance.

The melting temperature in the spot weld in the RSW process and the material's weldability are affected by the resistance transformation of the material work piece [11, 28]. During material smelting, electrode force is required for explosive solutions, and also the intensity of the electric welding current has a significant impact on heat generation leading to smelting. The spot weld will generate a lot of heat if the electric intensity is significant. This will have an impact on the nugget size and weld joint strength [15]. The resistance and welding time affect the nugget size and weld joint strength, so the welding duration affects the mechanical properties of the weld joints [16, 17]. As illustrated in schematic diagram RSW cycle Figure 2, melting occurs as a result of the relationship between welding current, welding time, and electrode force, where I is welding current, t is welding time, and F is electrode force.

Researchers had investigated the relationship between RSW parameters and concluded that welding process parameters have a significant impact on weld quality. Furthermore, the resistance of the material due to the thickness of the work piece is important, as indicated by the fact that thicker pieces develop more nuggets than thin pieces. High resistance materials or materials with lesser thermal conductivity will generate a satisfactory nugget in different materials. As a result, resistance is included in this study as a factor.

Experimental:

Material:

Aluminium 6061 is one of the most common alloys of aluminium for general-purpose use. 6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties, and exhibits good weldability. Aluminium and its alloys have been used extensively in modern life, from soda cans, household cookers to automotive and aircraft structures. low density, high strength, high ductility, excellent formability and high corrosion resistance in the ambient environment make them promising candidates for vehicles, particularly the closure panel such as hoods that decklids and lift-gates.

The weldability of aluminium alloys varies depending on the chemical composition of alloy used. The 6xxx series aluminium alloys mainly used in this project designating the Al-Mg-Si-(Cu) alloys, are most commonly used for extrusion purpose and are widely used as automobile body sheets. This 6xxx series alloys are heat treatable and have the following qualities,

- Good corrosion resistance
- Perfect surface finish
- Good formability
- Medium strength
- Hemming behavior
- Easy recyclability

All these advantages make them suitable for these structural applications. Magnesium and silicon are the main additions and combine to form the stoichiometric compound Mg_2Si . which makes 6xxx series alloys heat treatable and capable of achieving medium strength after artificial aging and increase in the Mg_2Si content result in improve tensile properties.

The materials used in this study was 6000 series aluminium alloy (Al 6061) Its chemical composition is presented,

Table 1: chemical composition of Al-6061

Aluminium Alloy	Si	Fe	Cu	Cr	Zn	Mn	Mg	B	Other Each	Other Total	Al
6101	0.40-0.80	0.50	0.10	0.03	0.10	0.03	0.50-0.80	0.06	0.03	0.10	REM
6103	0.50-0.90	0.50	0.10	0.03	0.10	0.03	0.60-0.90	0.06	0.03	0.10	REM

Sheets of thickness 1.5 mm were cut into 50×50 mm strips, roughly polished using 400 grit silicon carbide papers to remove surface contamination, and then cleaned with acetone.

Machine and equipment used during the experiment:

Spot/Projection welder:

Resistance spot welding is the joining of overlapping pieces of metal by applying pressure and electrical current. These joints created by resistance spot welding form a "button" or "fused nugget." Resistance spot welds are found typically on flanges, staggered in a single row of consecutive welds. Vehicle manufacturers use resistance spot welding in the factory because they can produce high quality welds at a very low cost.



Figure 3: Spot welding machine

Spot Welding Procedure

1. Electrodes seated in a weld head are brought to the surface of the parts to be joined and force (pressure) is applied
2. Current is applied through the electrodes to the workpiece to melt the material
3. Current is removed but electrodes remain in place at force to allow the material to cool and solidify

Spot welding times range from 0.01 sec to 0.63 sec depending on the thickness of the metal, the electrode force and the diameter of the electrodes themselves.

Table 2: Trials of experiment

Sr No.	Number	SQ	W ₁	C ₁	S ₁	W ₂	C ₂	W ₃	S ₂	HO	OFF
1	01	30	08 (0)	05	8	8 (1.1)	5	0	05	5	00
2	02	20	0	05	8	8 (1.5)	5	7	05	5	00
3	03	35	0	05	8	12 (1.5)	5	0	05	8	00
4	04	20	0	05	8	8 (2.9)	5	23	05	5	00
5	05	20	0	06	8	10 (4.1)	5	28 (0.2)	05	5	00
6	06	35	00	05	8	15	5	0	5	8	00
7	06	35	0	5	8	20 (4.1)	5	0	5	8	00
8	06	35	0	5	8	12 (4.1)	5	0	5	8	00
9	06	35	0	5	8	10 (4.1)	5	15 (4.0)	5	8	00
10	06	35	0	5	8	15 (4.3)	5	20 (4.1)	5	8	00
11	06	35	0	5	8	20 (4.3)	5	25 (4.5)	5	8	00
12	06	35	0	5	8	25 (3.5)	5	25 (3.5)	5	8	00
13	06	35	0	5	8	25 (4.5)	5	25 (3.5)	5	8	00
14	06	20	0	5	8	25 (4.5)	5	25 (3.5)	5	8	00
15	06	35	0	5	8	25 (5.5)	5	25 (3.5)	5	8	00
16	06	35	08 (3.5)	5	8	12 (4.5)	5	23 (3.5)	5	8	00
17	06	20	10 (1.0)	5	8	12 (4.5)	5	23 (3.5)	5	8	00

18	06	20	10 (8.0)	5	8	12 (8.0)	5	12 (8.0)	5	8	00
19	06	20	10 (9.0)	5	8	12 (9.0)	5	12 (9.0)	5	8	00
20	06	20	0	5	8	12 (10.0)	5	12 (10.0)	5	8	00
21	06	35	8 (4.3)	6	8	10 (4.0)	5	25 (5.0)	5	8	00
22	06	35	8 (4.5)	6	8	10 (4.5)	5	25 (5.0)	5	8	00
23	06	35	8 (5.0)	6	8	10 (5.0)	5	25 (5.0)	5	8	00
24	06	35	8 (4.7)	6	8	10 (5.0)	5	25 (5.0)	5	8	00
25	06	35	8 (4.6)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
26	06	35	8 (4.7)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
27	06	35	8 (5.0)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
28	06	35	8 (4.5)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
29	06	35	8 (4.2)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
30	06	35	8 (4.1)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
31	06	35	8 (4.0)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
32	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (5.0)	5	8	00
33	06	35	8 (4.0)	6	8	10 (4.6)	05	25 (5.0)	5	8	00
34	06	35	8 (4.0)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
35	06	35	8 (4.0)	6	8	10 (4.7)	05	25 (5.0)	5	8	00
36	06	35	8 (4.0)	6	8	10 (4.9)	05	25 (5.0)	5	8	00
37	06	35	8 (4.0)	6	8	10 (5.0)	05	25 (5.0)	5	8	00
38	06	35	8 (4.0)	6	8	10 (4.3)	05	25 (5.0)	5	8	00
39	06	35	8 (4.0)	6	8	10 (4.4)	05	25 (4.0)	5	8	00
40	06	35	8 (4.0)	6	8	10 (4.3)	05	25 (4.9)	5	8	00
41	06	35	8 (4.0)	6	8	10 (4.3)	05	25 (4.8)	5	8	00
42	06	35	8 (4.0)	6	8	10 (4.3)	05	25 (5.0)	5	8	00
43	06	35	8 (4.5)	6	8	10 (4.3)	05	25 (4.7)	5	8	00
44	06	35	8 (4.4)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
45	06	35	8 (3.9)	6	8	10 (3.9)	05	25 (3.9)	5	8	00
46	06	35	8 (4.0)	6	8	10 (4.0)	05	25 (4.0)	5	8	00
47	06	35	8 (4.1)	6	8	10 (4.1)	05	25 (4.1)	5	8	00
48	06	35	8 (4.2)	6	8	10 (4.2)	05	25 (4.2)	5	8	00
49	06	35	8 (4.3)	6	8	10 (4.3)	05	25 (4.3)	5	8	00
50	06	35	8 (4.4)	6	8	10 (4.4)	05	25 (4.4)	5	8	00
51	06	35	8	6	8	10	05	25	5	8	00

			(4.5)			(4.5)		(4.5)			
52	06	35	8 (4.6)	6	8	10 (4.6)	05	25 (4.6)	5	8	00
53	06	35	8 (4.7)	6	8	10 (4.7)	05	25 (4.7)	5	8	00
54	06	35	8 (4.8)	6	8	10 (4.8)	05	25 (4.8)	5	8	00
55	06	35	8 (4.9)	6	8	10 (4.9)	05	25 (4.9)	5	8	00
56	06	35	8 (3.9)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
57	06	35	8 (5.0)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
58	06	35	8 (4.8)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
59	06	35	8 (4.8)	6	8	10 (4.5)	05	25 (5.0)	5	8	00
60	06	35	8 (4.4)	6	8	10 (4.7)	05	25 (5.0)	5	8	00
61	06	35	8 (4.0)	6	8	10 (4.0)	05	25 (5.0)	5	8	00
62	06	35	8 (4.1)	6	8	10 (4.1)	05	25 (5.0)	5	8	00
63	06	35	8 (4.2)	6	8	10 (4.2)	05	25 (5.0)	5	8	00
64	06	35	8 (4.3)	6	8	10 (4.3)	05	25 (5.0)	5	8	00
65	06	35	8 (4.4)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
66	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (5.0)	5	8	00
67	06	35	8 (4.6)	6	8	10 (4.6)	05	25 (5.0)	5	8	00
68	06	35	8 (4.7)	6	8	10 (4.7)	05	25 (5.0)	5	8	00
69	06	35	8 (4.8)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
70	06	35	8 (4.9)	6	8	10 (4.9)	05	25 (5.0)	5	8	00
71	06	35	8 (3.9)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
72	06	35	8 (5.0)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
73	06	35	8 (4.5)	6	8	10 (4.0)	05	25 (5.0)	5	8	00
74	06	35	8 (4.5)	6	8	10 (4.1)	05	25 (5.0)	5	8	00
75	06	35	8 (4.5)	6	8	10 (4.2)	05	25 (5.0)	5	8	00
76	06	35	8 (4.5)	6	8	10 (4.3)	05	25 (5.0)	5	8	00
77	06	35	8 (4.5)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
78	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (5.0)	5	8	00
79	06	35	8 (4.5)	6	8	10 (4.6)	05	25 (5.0)	5	8	00
80	06	35	8 (4.5)	6	8	10 (4.7)	05	25 (5.0)	5	8	00
81	06	35	8 (4.5)	6	8	10 (4.8)	05	25 (5.0)	5	8	00
82	06	35	8 (4.5)	6	8	10 (4.9)	05	25 (5.0)	5	8	00
83	06	35	8 (4.5)	6	8	10 (4.4)	05	25 (5.0)	5	8	00
84	06	35	8 (4.5)	6	8	10 (3.8)	05	25 (5.0)	5	8	00
85	06	35	8	6	8	10	05	25	5	8	00

			(5.0)			(4.4)		(4.0)			
86	06	35	8 (4.5)	6	8	10 (4.0)	05	25 (4.1)	5	8	00
87	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.2)	5	8	00
88	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.3)	5	8	00
89	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.4)	5	8	00
90	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.5)	5	8	00
91	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.6)	5	8	00
92	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.7)	5	8	00
93	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.8)	5	8	00
94	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (4.9)	5	8	00
95	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (3.9)	5	8	00
96	06	35	8 (4.5)	6	8	10 (4.5)	05	25 (3.8)	5	8	00
97	06	35	8 (4.0)	6	8	10 (4.7)	05	25 (5.0)	5	8	00
98	06	20	8 (5.0)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
99	06	20	8 (4.5)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
100	06	20	8 (4.2)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
101	06	20	8 (4.1)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
102	06	20	8 (4.0)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
103	06	20	8 (4.5)	5	8	10 (4.5)	05	25 (5.0)	5	8	00
104	06	20	8 (4.0)	5	8	10 (4.6)	05	25 (5.0)	5	8	00
105	06	20	8 (4.0)	5	8	10 (4.8)	05	25 (5.0)	5	8	00
106	06	20	8 (4.0)	5	8	10 (4.7)	05	25 (5.0)	5	8	00
107	06	20	8 (4.0)	5	8	10 (4.9)	05	25 (5.0)	5	8	00
108	06	20	8 (4.0)	5	8	10 (5.0)	05	25 (5.0)	5	8	00
109	06	20	8 (4.0)	5	8	10 (4.3)	05	25 (5.0)	5	8	00
110	06	20	10 (4.5)	5	8	10 (4.9)	05	25 (5.0)	5	8	00
111	06	20	10 (4.5)	5	8	10 (4.4)	05	25 (5.0)	5	8	00

RESULTS AND DISCUSSION:

This chapter discusses about the results obtained by manual pull-out test, and mechanical tests. All the samples were prepared using the Welding parameters mentioned in table (2).

Results:

Nugget diameter and Spot diameter:

In RSW, the size of the nugget formed during welding is generally correlated to the strength of the lap-joint, and is therefore used as a key quality criterion in production

For Sample – I:

Table 3: Comparison of nuggets diameter and spot diameter of Sample – I

	Number	SQ	W ₁	C ₁	S ₁	W ₂	C ₂	W ₃	S ₂	HO	OFF
	06	35	8 (4.3)	6	8	10 (4.0)	5	25 (5.0)	5	8	00
Sr No	Spot Diameter		Nugget Diameter			Spot Diameter			Nugget Diameter		
1	4.5 mm		0.8 mm			4.5 mm			0.9 mm		
2	4.7 mm		0.5 mm			4.4 mm			0.8 mm		
3	4.7 mm		0.9 mm			4.5 mm			0.9 mm		



Figure 4: Nugget and spot formation of sample I

For Sample – II:

Table 4: Comparison of nuggets diameter and spot diameter of Sample – II

	Number	SQ	W ₁	C ₁	S ₁	W ₂	C ₂	W ₃	S ₂	HO	OFF
	06	35	8 (4.5)	6	8	10 (4.5)	5	25 (5.0)	5	8	00
Sr No	Spot Diameter		Nugget Diameter			Spot Diameter			Nugget Diameter		
1	3.7 mm		1.5 mm			4.8 mm			1.2 mm		
2	3.9 mm		1.1 mm			4.8 mm			1.2 mm		
3	3.9 mm		1.5 mm			4.6 mm			1.6 mm		



Figure 5: nuggets diameter and spot formation of Sample – II

For Sample – III:

Table 5: Comparison of nuggets diameter and spot diameter of Sample – III

	Number	SQ	W ₁	C ₁	S ₁	W ₂	C ₂	W ₃	S ₂	HO	OFF
	06	35	8 (4.5)	6	8	10 (5)	5	25 (5.0)	5	8	00
Sr No	Spot Diameter		Nugget Diameter			Spot Diameter			Nugget Diameter		
1	4.7 mm		1.7 mm			4.5 mm			1.2 mm		
2	4.6 mm		1.7 mm			4.6 mm			1.5 mm		
3	4.5 mm		1.6 mm			4.1 mm			1.6 mm		
4	4.7 mm		1.6 mm			4.6 mm			1.7 mm		



Figure 6: Nugget and spot formation of sample III

Conclusion:

The results gives details on the formation of the weld nugget and so predict the welding quality prior to the actual welding process. The input parameters to the model can be adjusted to give different dimensions of the weld nugget. As a result, appropriate setting of the welding parameters for the required quality and different materials of the workpiece can be obtained, without performing large number of physical experiments.

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