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Exploring Resistance Spot Welding of Similar Triple Thin Sheets

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Abstract

Resistance spot welding of two sheets of thickness greater than 0.75mm is often required in an industry. Sometimes lower than 0.75mm thickness of sheets are also needed to be joined. In this work, triple galvanized iron, triple 6061 aluminum alloy and triple AISI 430 stainless steel are spot welded separately and are explored in terms of weld strength. Weld current, weld time and electrode pressure are varied throughout the experiments to find out the weld strength for different sets of materials. Every set of experiments has two types of joint design and its weld strength in different interfaces is tested and nugget diameter is measured. High current is found to cause expulsions in case of the joint of aluminium alloy triple sheets although results are found to be good in case of similar triple sheet joint of the materials selected with appropriate process parameters.

Keywords: Welding, Resistant Spot Welding, Similar welding, Nugget, Triple joint.

1.0 INTRODUCTION

A common welding technique in the automotive, aerospace, and rail sectors is resistance spot welding. By swapping out the rivet joint, it has helped to lighten the structural body's weight [1]. Self-pierce riveting performed well in recent studies in terms of mechanical qualities, but resistance spot welding performed better in terms of output rate, production flexibility, and cost [2]. Steel and aluminum alloys are employed increasingly frequently for structural purposes in the automobile sectors. Aluminum alloys are used as lightweight building materials for automotive bodies, etc. RSW is a procedure that uses the heat produced by the current passing through the materials to fuse the components together. Two or three sheets are held between two electrodes under pressure while current is allowed to pass through them to perform spot welding. When electricity is resisted by an interface resistance, heat is produced as a result of the current flowing. The primary process variables for resistance spot welding are electrode pressure (p), welding time (t), and welding current (I).

Due to the fact that heat generation is related to the square of the welding current, it is more efficient than the other two factors. The interface material is typically melted and joined together by the heat produced. The creation of a nugget determines the strength of the joint. Up to a certain point, the nugget diameter affects the tensile strength of the welded joint. So, it should be optimized to find process conditions to have desired nugget formation to get sound welding. Roest and Rager [3] experimented on resistance spot welding parameter profile of aluminum alloys. When tip force was increased, welding current and weld duration showed variation in order to get a good weld. They also observed that longer weld current duration reduced the chance of cracks appearing in the sheet under the electrode. According to Patel et al. [4], the tensile shear load rose with an increase in welding current and with longer weld times. Weld indentation depth was observed by Florea et al. [5] to be caused by varying electrode tip force and current. Additionally, they discovered that excellent results were obtained under higher conditions than under low or nominal welding conditions. For all three situations, the resistance spot welding coupons broke down in an interfacial failure mode. Zhao et al. [6] noticed that temperature in the middle of the fusion zone increased with the increase of welding time and reached a maximum of 52ms welding time. It proposed that a high current, short welding time were better for welding ultra-thin steel sheets. Aravinthan et al. [7] performed the tensile peel test for every sample where they found most of the samples tearing off from base materials, and among them, some samples showed a button pull-out fracture which was welded at low current and considered to be of poor weld quality. Alenius et al. [8] found that sheet thickness had an effect on fatigue strength where different strengths of base materials did not affect. If sheet thickness increased then fatigue strength got increased. Oikawa et al. [9] mentioned that increased electrode force prevented the chance of bad weld quality. Along with this, they also proposed that electric resistivity should be kept in mind during resistance spot welding as it contributed to the formation of weld nugget, though there were also other parameters responsible for the formation of weld nugget.

Safanama et al. [10] observed that the martensitic phase made up nearly the entire fusion zone microstructure for the M130/M130 and LCS/M130 welds. Mondal et al. [11] applied the analytic hierarchy process during resistance spot welding of 17-4PH stainless steel to find out the optimum parameter. Applying the analytic hierarchy process, they found good weld nugget obtained at 2.5kA weld current at weld time of 6 to 7 cycles and 6 to 7 kA of welding current at 6 to 7 cycles welding time. Sun et al. [12] found two different fusion zones developed during welding of aluminum to steel using a transition material. One was regular nugget formation at the steel side and the other was the top half of elliptical shape at Aluminum side. They observed during peel test interfacial failure often occurred from Aluminum/Steel interface rather than Aluminum and transition material interface. They suggested that the pore and gaps could be responsible for the failure. Cui et al. [13] found that the thickness of the reaction layer was in random order and was higher at the nugget area. It continued to decrease as the distance from the center of the nugget increased. They also investigated the reaction layer dependability on reaction time and temperature. The cooling pace also slowed down near the nugget's core because the nugget's center experienced greater heat generation than its edge. As a result, the nugget's center was highly energetic. According to Sreenivasulu [14], as the nugget's cross-sectional area expanded, the tensile shear force increased as the nugget's diameter increased. He also observed that elongation of the Al6063 material was greater than AISI304 due to softness of the material. The residual stress was much more at the centre of the nugget and decreased from centre to edge. Residual stress decreased when welding time increased.

During the cross-tension test, Li et al. [15] observed that failure occurred from interfacial surface of two sheets during interfacial failure but in case of three sheets, joint failure occurred from interior of the weld nugget rather than interfacial surface. Interfacial failure occurred when heat input was low to give uneven nugget formation. For the coach peel test, results were the same as observed by them. Li et al. [16] divided microstructures of nugget area into three different parts such as partially melted zone (PMZ), columnar grain zone (CGZ), and equiaxed grain zone (EGZ). Formation of CGZ was reported to be due to the relatively high-temperature gradient and low supercooling at the edge of the weld nugget. In the center of the weld nugget, a low-temperature gradient and supercooling contributed to the formation of the EGZ. Nielsen et al. [17] documented that with small electrodes, the strength of the welded joint decreased and with larger electrode, strength of the welded joint increased if welding time increased. Small electrode covered small area so more weld time caused splash. In case of larger electrode, it covered more area which caused larger nugget diameter to increase strength.

Lots of works was done by researchers on resistance spot welding of sheets. Most of them were involving two sheets through spot welding and the thickness was greater than 0.75mm. The materials less than thickness of 0.75 mm are difficult to spot weld as thin sheets got stuck with the electrode during spot welding. Resistance spot welding of triple sheets introduce one extra interface which complicate the nugget formation mechanism. In this paper, three sheets spot welding was done and the strength and nugget diameter was measured.

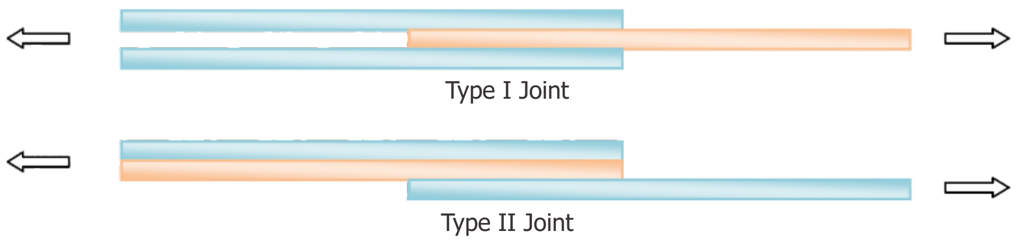


Fig. 1 : Schematic diagram of joint design

2.0 EXPERIMENTAL DESIGN

In this experimental investigation, three types of materials are used to make similar joints. Two types of joint designs are used to spot weld three thin sheets as given in **Fig. 1**.

Before the joining of the materials, they are cut into the desired shape in a guillotine machine. Some trial experimentations are done to observe the possibility of three sheet joints then the final experiment is carried out. Different combinations are made to test the tensile strength of spot welded similar joints. Those combinations are given in **Table 1**.

Table 1: Different combination of materials

Sl. No.	Materials	Combinations	Joint Type
1	Aluminium Alloy	Al-Al-Al	Type I & II
2	Galvanized Iron	GI-GI-GI	Type I & II
3	Stainless Steel	SS-SS-SS	Type I & II

Mechelonic engineers spot/ projection welding machine was used for these experiments whose model no was SS-25-300. The maximum current capacity of the machine was 15kA at which spot welding was done. The spot welded specimens were tested in the universal testing machine having a maximum capacity of 200kN. The coupon size was 120mm X 50mm and during welding, the overlap area was 40mm X 50mm. The parameters were set for every combination of the sheets based on some trial and error methods. Those are given in **Table 2**.

3.0 RESULTS AND DISCUSSION

3.1 Welded Joint Analysis of Triple Aluminum Alloy Sheets

Electrical conductivity of aluminum alloy is greater than steel, and so, for this experiment, more current is needed to join aluminium alloy than steel. Due to higher conductivity, current passes through aluminium alloy without generating heat at low current. The experiment was carried out according to the parameters which are given in **Table 3**. Using response surface methodology the R square value was found to be 85.85% for triple aluminium alloy sheets joint.

The actual current that passes through the welded joint was observed and found to be lower than the set current in every case. In case of triple aluminium sheets joint at higher current (12kA), higher welding time, and higher electrode pressure the strength of the joint was 1200N. When the current was set at 9kA then the joint strength was 400N. These values of joint strength were obtained for type-I joint design. The type-II joint design was specially prepared only to observe the strength of the upper and lower sheets. The upper and lower sheets became separated at 800N force and 12kA current that is lower than the type-I joint. The weld strength is 1200N for both the specimens at 2.5 and 1.5kg/cm^2 electrode pressure but due to higher electrode pressure, some materials flash out from the upper and lower sheet that is noticeable in **Fig. 2(a)**. On the other hand at 1.5 kg/cm^2 sheets get joined without flashing out the materials as shown in **Fig. 2(b)**. So at 12kA current, lower electrode pressure and lower weld time are preferable than higher electrode pressure and weld time.

Lower weld current (9kA) produces lower weld strength and smaller nugget diameter due to that the sheets get separated without breaking the middle sheets as shown in **Fig. 2(c)**. Here the weld time and electrode pressure have no effects. Proper welding is done at 10.5kA current and 2kg/cm^2 electrode pressure where the strength is 800N but no flashing of materials from the upper and lower sheets has occurred as shown in **Fig. 2(d)**.

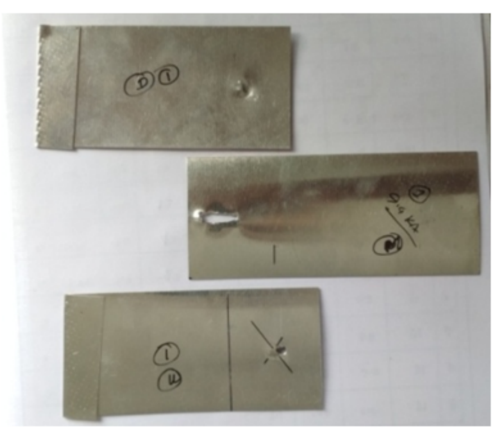
Electrode pressure is less effective to weld strength when the current is higher but at higher pressure the flashing tendency increases. In the contour plot shown in **Fig. 3(b)** it is noticeable that the nugget diameter is smaller at higher pressure and lower weld time. From **Fig. 3(a)** it is observed that at higher current the effect of electrode pressure is insignificant. Similarly from **Fig. 3(c)** and **(d)** it is noticed that at higher current the weld strength and nugget diameter increased.

Table 2 : Details of parameter settings

Sl. No.	Materials	Weld Current (kA)	Weld time (Cycle)	Electrode Pressure (kg/cm^2)
1	Aluminium Alloy	9, 10.5, 12	20, 30, 40	1.5, 2, 2.5
2	Galvanized Iron	10.6, 14.25, 14.85	20, 30, 40	1.5, 2, 2.5
3	Stainless Steel	6, 9, 12	20, 30, 40	1.5, 2, 2.5

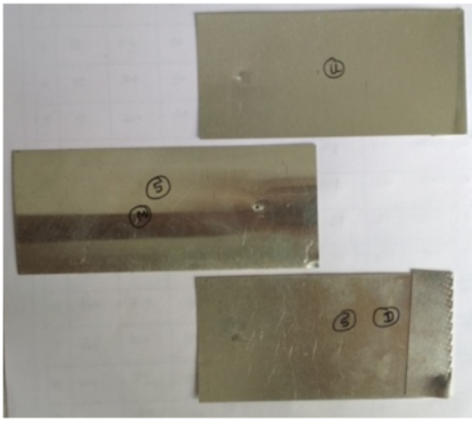
Table 3 : Experimental results of triple aluminium alloy sheet joint.

Sl. No.	Current (kA)		Weld Time (Cycles)	Electrode Pressure (kg/cm^2)	Tensile Strength (N)	Nuggle Diameter (mm)
	Set Up	Actual				
1	12	9.4	40	2.5	1200	3.29
2	12	9.2	40	1.5	1200	3.13
3	12	9.3	20	1.5	800	2.0
4	12	9.2	20	2.5	800	2.75
5	9	7.3	40	2.5	400	2.61
6	9	7.2	40	1.5	400	2.55
7	9	7.1	20	1.5	400	2.60
8	9	6.9	20	2.5	400	2.42
9	10.5	8.3	30	2	800	2.7
10	10.5	8.3	30	2	800	2.5
11	10.5	8.2	30	2	800	2.71
12	10.5	8.3	30	2	800	2.62
13	10.5	8.3	30	2	400	2.55
14	10.5	8.3	30	2	800	2.58

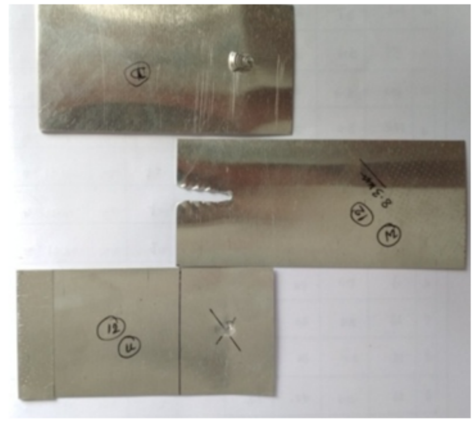


(a) Tested specimen at 12kA current and 2.5kg/cm^2 electrode pressure

(b)Tested specimen at 12kA current and 1.5kg/cm^2 electrode pressure

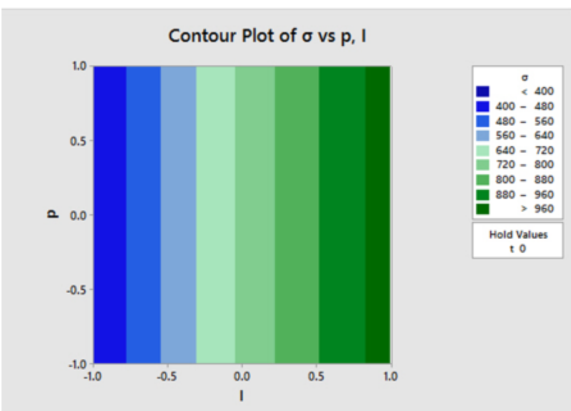


(c) Tested specimen at 9kA current and 2.5kg/cm^2 electrode pressure

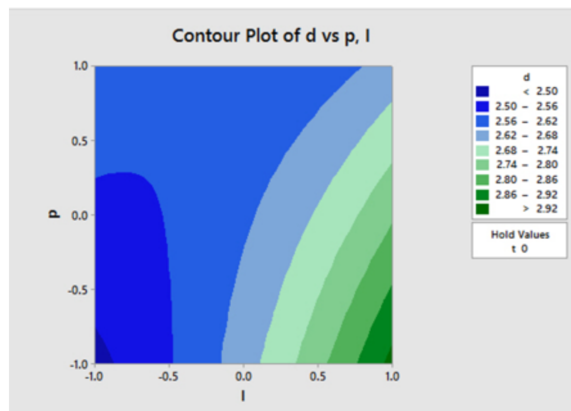


(d) Tested specimen at 10.5kA current and 2kg/cm^2 electrode pressure

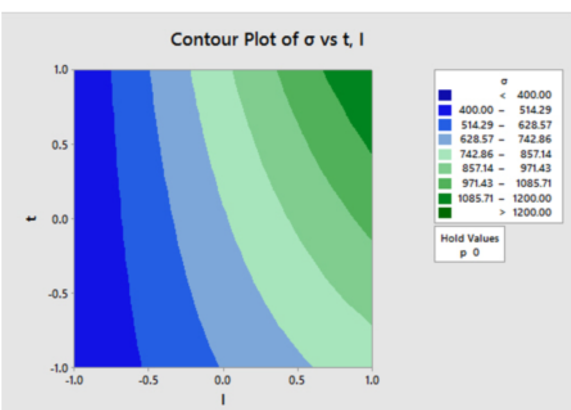
Fig. 2 : Photograph of tested triple aluminum alloy sheets at different conditions



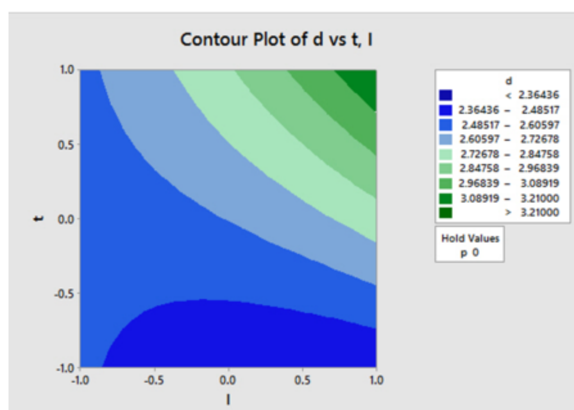
(a) Contour plot of strength vs electrode pressure and weld current



(b) Contour plot of nugget diameter vs electrode pressure and weld current



(c) Contour plot of strength vs weld time and weld current



(d) Contour plot of nugget diameter vs weld time and weld current

Fig. 3 : Contour plot diagram of triple aluminum alloy sheets joint.

It is found from the experiment that aluminium alloy needs a higher current to join. As current increases, the nugget diameter and tensile strength increase. Here weld time gives less influence to heat generation and weld strength because the heat generation is more dependent on weld current. The experimented materials were thin so, there was a limit of nugget diameter formation. At a higher weld current, the material melted without forming a nugget.

3.2 Welded Joint Analysis of Triple Galvanized Iron Sheets

During the triple sheet joint of galvanized iron, it has been found that more amount of heat or more amount of current was required to weld the galvanized iron sheets properly. It may be the cause that the thickness of the galvanized iron sheet is quite small and due to its small thickness, current flows through it without generating sufficient heat for welding. However, the experimental results of the triple sheet joint are given in **Table 4**.

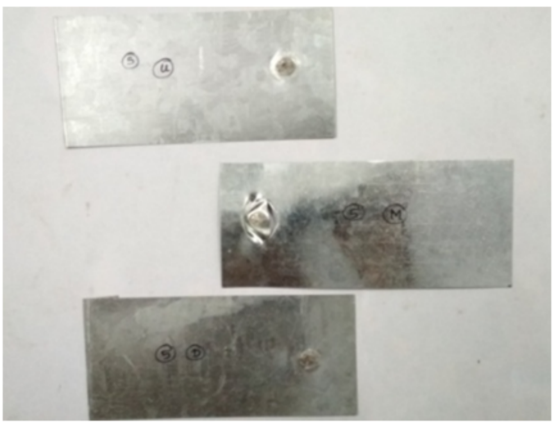
From **Table 4** it is noticeable that joint strength is higher in case higher value of weld current, weld time and electrode pressure. The value of weld strength is lower when the weld current, weld time and electrode pressure is lower. During tensile test the middle sheet tears out completely from the other two sheets which indicate the strength of the welded joint and that is clearly visible in **Fig. 4 (a)** and **(b)**.

Table 4 : Experimental results of triple galvanized iron sheet joint

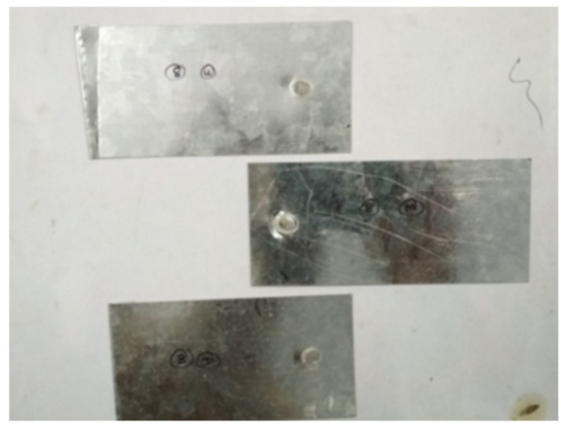
Sl. No.	Current (kA)		Weld Time (Cycles)	Electrode Pressure (kg/cm^2)	Tensile Strength (N)	Nuggle Diameter (mm)
	Set Up	Actual				
1	14.85	11.3	40	2.5	2800	6.75
2	14.85	11.2	40	1.5	2400	6.44
3	14.85	11.0	20	2.5	2400	6.00
4	14.85	10.9	20	1.5	2000	6.21
5	13.5	10.6	40	2.5	2000	6.00
6	13.5	10.4	40	1.5	2000	6.33
7	13.5	10.3	20	2.5	1600	5.75
8	13.5	10.2	20	1.5	1600	5.21
9	14.25	10.7	30	2	2000	5.68
10	14.25	10.7	30	2	2000	5.50
11	14.25	10.7	30	2	2400	5.42
12	14.25	10.7	30	2	2000	5.13
13	14.25	10.7	30	2	2000	5.52
14	14.25	10.8	30	2	2000	5.21

(a) Tested specimen at 14.85kA current and 2.5kg/cm^2 electrode pressure

(b) Tested specimen at 14.25kA current and 1.5kg/cm^2 electrode pressure



(c) Tested specimen at 13.5kA current with 40cycles weld time and 2.5kg/cm^2 electrode pressure



(d) Tested specimen at 13.5kA current with 20cycles weld time and 1.5kg/cm^2 electrode pressure

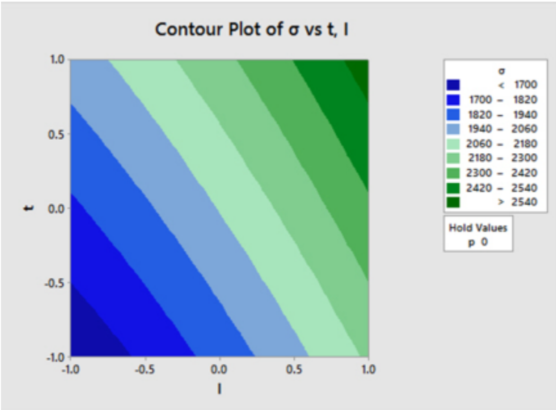
Fig. 4 : Photograph of tested triple galvanized iron sheets joint at different conditions

When the weld current is lower (13.5kA) then the tensile strength was 2000N and 1600N. At 13.5kA weld current and 40 weld cycles and 2.5kg/cm^2 electrode pressure the weld strength was 2000N but that value is 1600N in case of 1.5kg/cm^2 electrode pressure and 20 weld cycles. In **Fig. 4(c)**, the specimen is shown where small tear is found due relatively higher weld strength and in **Fig. 4(d)** the sheets are separated without any tearing due to lower weld strength.

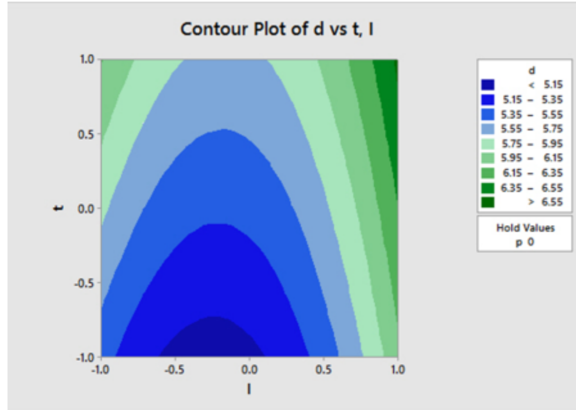
In the contour plot given in **Fig. 5 (a)** and **(b)** also, it is visible that when weld time and weld current are increased, the value of weld strength is increased and the nugget diameter is also increased. From the contour plot of nugget diameter, it is noticeable that at lower current also if weld time increased then the nugget diameter increased. The nugget diameter in case of galvanized iron sheet joint is different than other materials. Here the zinc layer is melted and spread over the area covered by electrode and helps sheets to be joined forming a bigger nugget than other materials. The contour plot of strength and nugget diameter with electrode pressure and weld current in **Fig. 5 (c)** and **(d)** also show the same results where strength and nugget diameter was increased when current and electrode pressure are increased.

3.3 Welded Joint Analysis of Triple Stainless Steel Sheets

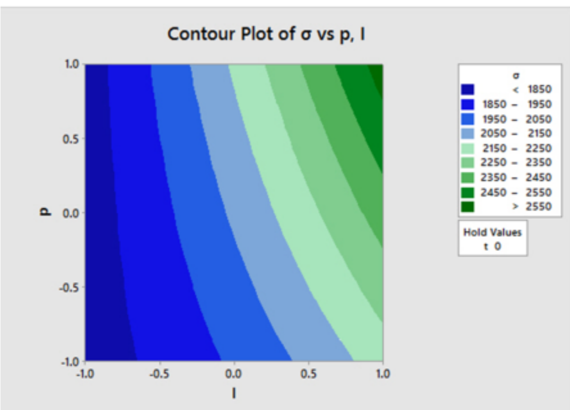
The electrical conductivity of stainless steel is lower than galvanized iron and aluminium. Due to lower electrical conductivity, current required to melt the steel is lower than galvanized iron sheet. However the experimental results are given in **Table 5**.



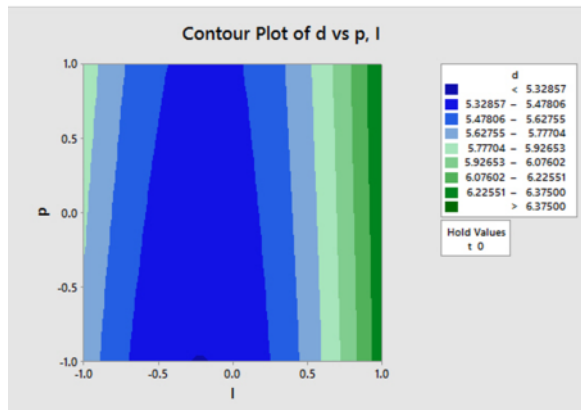
(a) Contour plot of strength vs weld time and weld current



(b) Contour plot of nugget diameter vs weld time and weld current



(c) Contour plot of strength vs electrode pressure and weld current



(d) Contour plot of nugget diameter vs electrode pressure and weld current

Fig. 5 : Contour plot diagram of triple galvanized iron sheet joints

From **Table 5**, it can be shown that weld strength becomes 4800N in case of higher current, higher weld time and higher electrode pressure. If weld time and electrode pressure are decreased, then weld strength becomes 4400N as it is shown in the table.

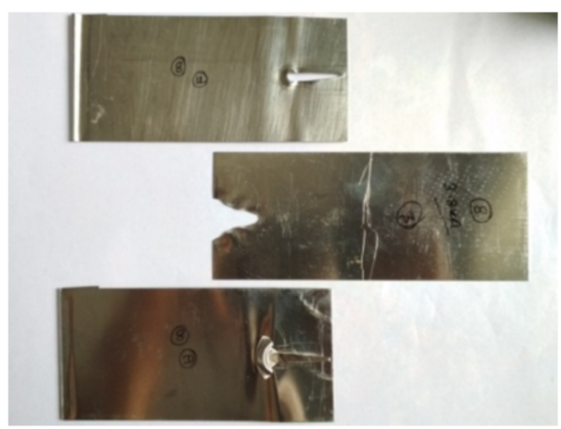
In **Fig. 6(a)** and **(b)**, two different types of failure are shown. **Fig. 6(a)** is the specimen welded at 12kA current, 40cycles weld time, and 2.5kg/cm^2 electrode force, and the specimen showed in **Fig. 6(b)** was welded at 12kA current, 20 cycles weld time, and 1.5kg/cm^2 electrode force. Due to the higher current, the nugget diameter was bigger and due to lower weld time, the nugget diameter was small so the failure occurred at a relatively lower value of tensile force. It is noticeable that due to the bigger size of the nugget, the torn-out portion was larger in the case of **Fig. 6(a)** than the other one in **Fig. 6 (b)**.

From the contour plot given in **Fig. 7(a)** and **(b)**, it is noticeable that higher weld current and higher weld time are responsible for the higher strength of the welded joint. Though at lower current if the weld time increased then also the weld strength is very much appreciable. The weld strength also is directly proportional to nugget diameter so, the contour plot of nugget diameter is also in the same nature as the contour plot of strength.

Table 5 : Experimental results of triple galvanized iron sheet joint

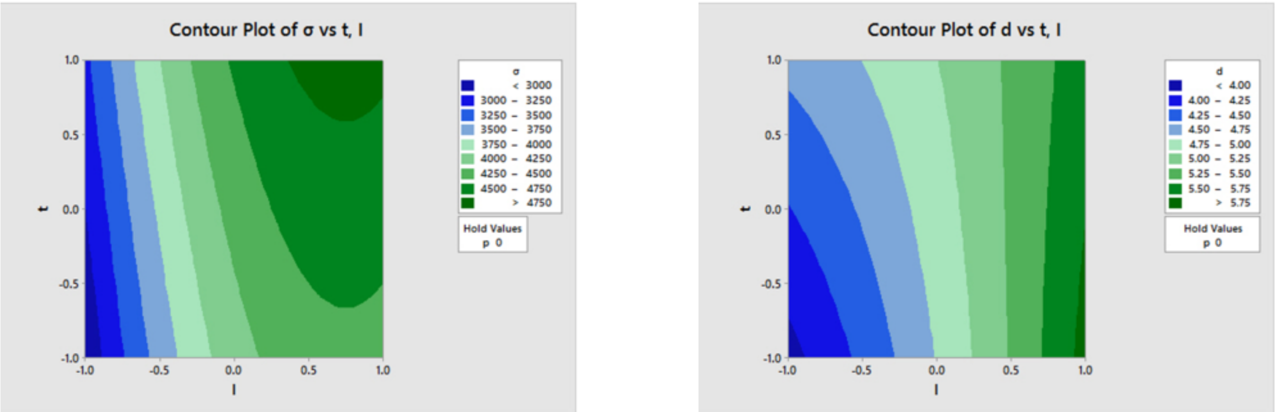
Sl. No.	Current (kA)		Weld Time (Cycles)	Electrode Pressure (kg/cm^2)	Tensile Strength (N)	Nuggle Diameter (mm)
	Set Up	Actual				
1	12	8.5	40	2.5	4800	6.0
2	12	8.3	40	1.5	4800	5.30
3	12	8.1	20	2.5	4400	5.78
4	12	8.0	20	1.5	4400	5.9
5	6	4.3	40	2.5	3200	4.52
6	6	4.1	40	1.5	3200	4.61
7	6	4.0	20	2.5	2800	3.71
8	6	3.8	20	1.5	2800	4.11
9	9	6.1	30	2	4400	4.81
10	9	6.2	30	2	4400	4.76
11	9	6.2	30	2	4400	4.65
12	9	6.2	30	2	4400	4.9
13	9	6.1	30	2	4000	4.96
14	9	6.3	30	2	4400	5.2

(a) Tested specimen at 12kA current with 40 cycles weld time and 2.5kg/cm^2 electrode pressure



(b) Tested specimen at 12kA current with 20 cycles weld time and 1.5kg/cm^2 electrode pressure

Fig. 6 : Photograph of tested triple stainless steel sheets joint at different conditions



(a) Contour plot of strength vs weld time and weld current

(b) Contour plot of nugget diameter vs weld time and weld current

Fig. 7 : Contour plot diagram of triple stainless steel sheet joints

3.4 Comparisons

The experimented results of three types of welding are put into one figure to observe their differences in terms of welding strength and nugget formation. Graphs shown in **Fig. 8** and **Fig. 9** are corresponding to variation of tensile strength with welding current and nugget diameter with welding current respectively. The weld strength of triple stainless steel sheet joint was found to be higher at higher weld current and this is also similar for triple aluminium alloy sheet and triple galvanized iron sheet joint. It is noticeable form the graph that the welding current span for stainless steel was larger than other two which means that stainless steel is much easier to join than aluminium alloy and galvanized iron sheet joint.

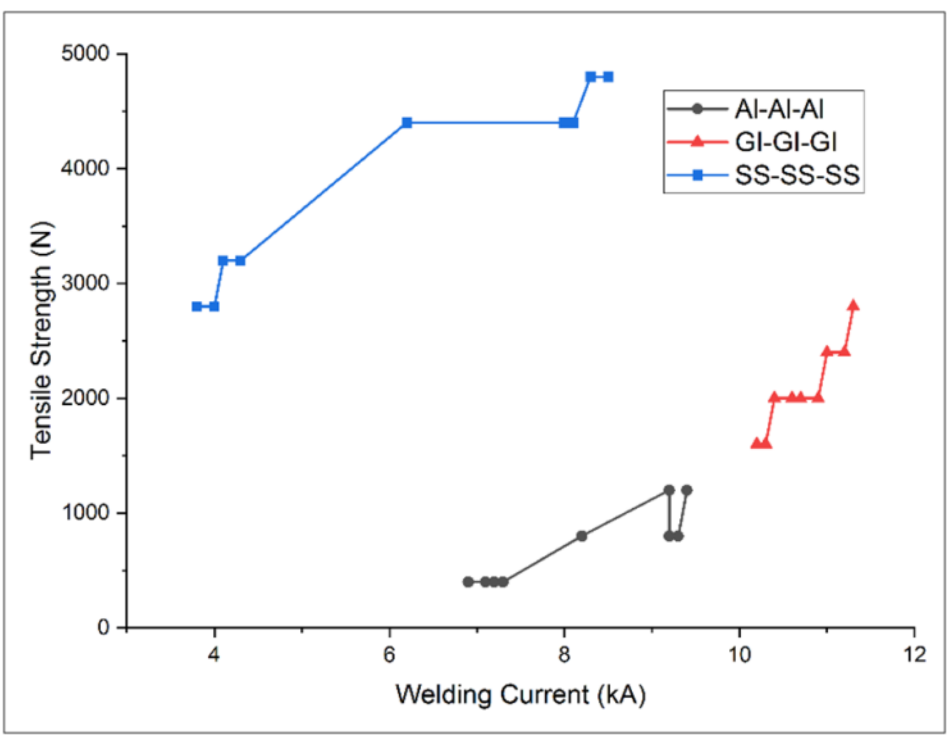


Fig.8 : Comparisons of tensile strength against welding current for three sets of joint

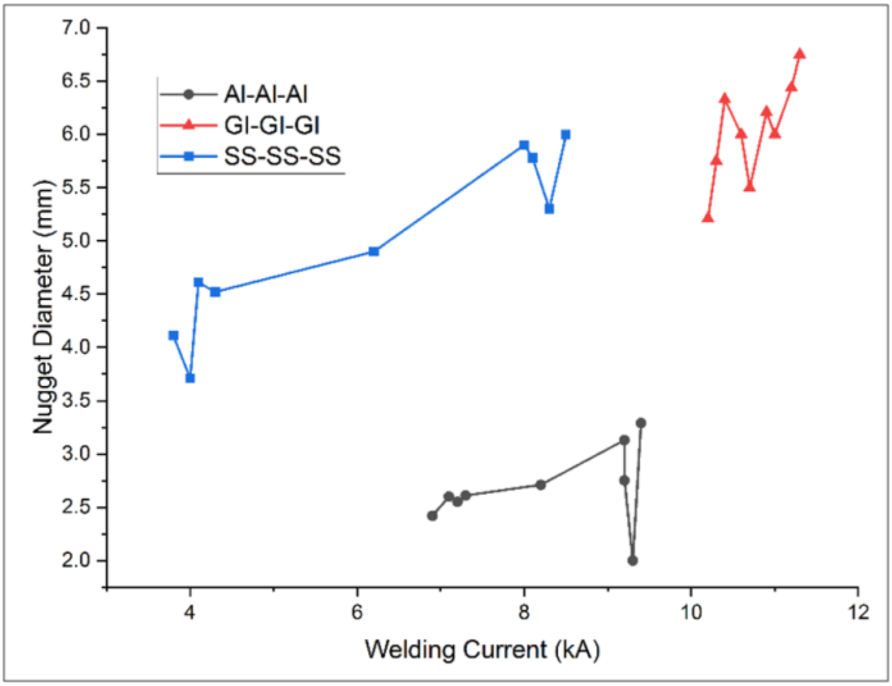
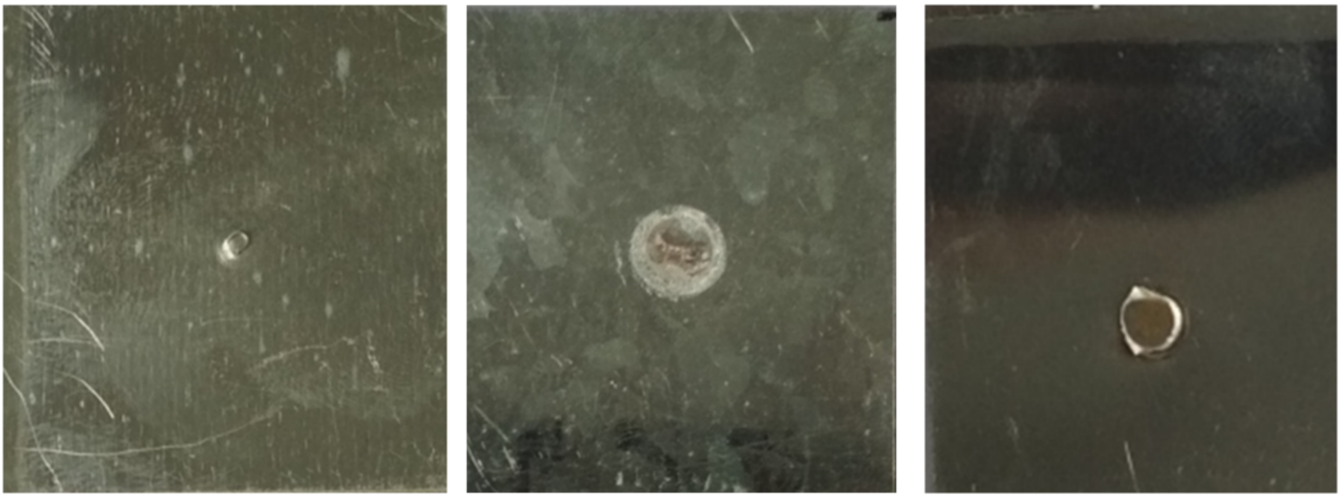


Fig. 9 : Comparisons of nugget diameter against welding current for three sets of joint

The most difficulty was found to join triple galvanized iron sheet due to its lower thickness. At lower weld current it was not possible to join GI sheet because the generation of nugget was not observed as the current flow through it without generating sufficient heat. **Fig.10** shows different nugget sizes for joining of different materials.

The nugget diameter was found to be larger for triple galvanized iron sheet joint as shown in **Fig.10(b)**. It can be said that the zinc layer helped a bit to spread the heat during welding which produce larger nugget. Generally the nature of graph was linear in upward direction but in some cases the drop was observed for tensile strength and nugget diameter also. Those drops were found due to lower electrode pressure which reduced the tensile strength and nugget diameter.



(a) Nugget size of triple aluminium sheets joint

(b) Nugget size of triple galvanized iron sheets joint

© Nugget size of triple stainless steel sheets joint

Fig. 10 : Photographic view of nugget formed during triple thin sheet joints

4.0 CONCLUSIONS

Mainly two difficulties were observed during the joining of triple thin sheets. Firstly the joining of thin sheets is harder than thick sheets as the thin sheets have its tendency to stick to the surface of the electrode secondly during triple sheet joint an extra interface is introduced. Due to that, the formation of the nugget is different from the two sheets joint. Three combinations were made for this experiment and from the results and analysis, the following conclusions are drawn.

- During joining of triple thin aluminium alloy sheets it was found that if the parameters value like weld current, weld time and electrode pressure increased then the strength of the joint also increased.
- When weld current and electrode pressure were higher some materials from the upper sheets flashed away. In this experiment, flashing was not observed at 10.5kA weld current.
- Triple galvanized iron sheets joint needed more amount of current than aluminium alloy and stainless steel sheets. Here also, at higher current and weld time, the weld strength was higher than lower current and weld time. At lower weld time no tear was observed during tensile strength testing though the current was higher.
- Joining Galvanized Iron sheets at higher weld time and higher current was good enough that indicates the requirement of more weld time during GI sheets welding.
- Joining of stainless steel sheet was relatively easier than GI and Aluminium sheets. If the weld current and weld time was higher, then the nugget diameter and weld strength also higher. If the weld current further increased then the materials melted away without forming a nugget.

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