International Journal of Research in Engineering, Science and Management
Volume-3, Issue-2, February-2020
www.ijresm.com | ISSN (Online): 2581-5792

Study the Effect of Different Parameters on Resistance Spot Weld of ASS 316L Material

Ravinderjeet Singh[1], D. S. Sahota[2], Mandeep Singh[3]
[1]*Student, Department of Mechanical Engineering Department, University College of Engineering, Punjabi University, Patiala, India*
[2,3]*Assistant Professor, Department of Mechanical Engineering Department, University College of Engineering, Punjabi University, Patiala, India*

***Abstract*: The paper represents the optimization of Resistance spot welding parameters at different values of electric current, electrode force and weld cycle. In this investigation the quality characteristic hardness and tensile strength has been considered using ANOVA method. To study and analyses of austenitic stainless steel (ASS 316L) 1mm thickness sheet is used. The result indicated that Optimization solution finding the most suitable parameter value for maximum hardness and tensile strength within the given parameters values. Optimization graph show the best parameter values for resistance spot welding of ASS316L using higher electrode force of 3 kg/cm^2, higher electric current 11KA and low weld cycle 10 cycles.**

***Keywords*: Resistance Spot welding (RSW), Austenite Stainless Steel (ASS) Analysis of Variance (ANOVA), Electrode Force, Electric Current, Number of Welding Cycles.**

1. Introduction

Resistance spot welding (RSW) is the oldest method of joining metals. It is broadly used for joining sheet metals in today's industries because of its simplicity, easy for automation and reliability for mass construction. RSW is an auto-genius welding processes, as compared to other process; it does not involve filler metal. RSW uses the metal's ordinary electrical resistance and constriction in the path of current flow, to generate high temperature at the interface. In the beginning of the process electrodes hold two metal sheets tightly. The current pass through the sheets from one electrode to the other and this flowing current is the cause of heat generation. High temperature converts solid metals into molten state at the point of joining the sheets. When the current supply is off, it forms a solid nugget. The original innovation by Professor Elihu Thomson in 1877, the spot welding process has been used actively for the assembly of metal sheets in the automobile and aircraft industries [1]. Resistance spot welding is a widely implemented method which is used in many industries for joining sheets of metal. And also in automobile, air craft, and space craft fabrications. In a car body there approximately 6000 spot welds which show the level of importance of spot welding in today's industry. The benefits of resistance spot welding process are low cost of welding joint, high manufacture rate, smooth finishing and adoptability for automation etc. [2].

2. Literature Survey

Pandey. et al. [3] used Taguchi method on low carbon cold rolled 0.9mm thick mild steel sheets to discover the effect of parameters on quality of weld strength. According to the results, current contribute 61%, holding time 28.7% and pressure 4% on tensile strength. For best possible result, current should be 6.8KA, pressure 0.79KPa, and holding time of 5 sec. Shamsul et al. [4] study the effect of welding current on nugget size and hardness distribution on the nugget zone of austenitic stainless steel (AISI 304), from varying current value the result show that with increase weld current increase the nugget size. The nugget size does not influence the hardness distribution. Also hardness distribution does not increase with increase in welding current. ShaikShafee.et al. [5] study the strength of the low carbon steel with resistance spot welding experiment. Most suitable Parameters value finds out by analysis of variance (ANOVA) method which is used for improving the weld strength. BayramKocabekir.et al. [6] approved their work in resistance spot welding of metal sheet of ASS 316L with different cooling medium. Mainly three cooling medium are use Atmosphere air, nitrogen and 10% of borax solution during the welding. From these three cooling medium nitrogen has higher tensile shear load bearing capacity than other two cooling mediums. D. S. Sahota et. al. [7] study the effect of process parameters (electric current, electrode force and weld cycle) on ASS316. They investigate that with increase in weld current, weld time and electrode force weld nugget diameter and width also increase. And electrode indentation also increases with increase in these three parameters. Thakur.et al. [8] optimize tensile shear strength for galvanized steel using L27 orthogonal array method. Particularly effective parameters are current and time, where force and diameter are less effective parameters. Using S/N ratio, tests indicate the tensile shear strength can be increased significantly (13.43%) by using the planned statistical technique. Arvinder Singh.et al. [13] used Taguchi L9 orthogonal array method to find the effect of process parameters (pressure, weld time, and welding current) on tensile strength of austenitic stainless steel ASS 316L. They found highest tensile strength at pressure 3.1KN, welding time 4 cycle and current 15KA. Darshan Shah.et al. [15] used neural network-based systems to find the optimum process parameters for resistance spot welding and weld quality evaluation. Parameters used are welding current, sheet thickness and weld cycle. Analysis of parameter is carried out for the quality of the resistance spot welding, i.e. weld strength. This parametric analysis (ANOVA) using weld strength as quality gauge shows the percentage contribution of parameters independently, i.e. welding current as 49.81 %, thickness of 37.94 % and cycle time of 2.61 % and the error is of 9.62 %. And they found that weld strength increases as welding current increases and weld strength decreases as thickness of the material increases. Pradeep M.et al. [16] studies the optimum weld parameters in spot welding for different material thickness. Parameters for welding of dissimilar thickness material are not available more than 4mm. Low carbon steel used by them having 0.8mm thick metal strips and a composition of 0.101 C, 0.33 Mg, 0.011 S, and 0.019 P (wt.%). Taguchi approach has been used for the optimization of welding current and time using L9 orthogonal array. There result indicates best range of current as 3.5KA and time 10 cycles.

A. Resistance Spot Welding (RSW)

In the Resistance spot welding process, two overlapped or stacked stamped components are welded together as an effect of the resistance heating caused of electric current passed through it. This resistance heat is provided by the work pieces which are held together under pressure between two electrodes as shown in Figure 1 (a) and (b) Shown a setup of resistance spot weld machine. The copper alloy electrode is used in the process to apply pressure and transmit the electrical current through the work piece for the duration of the formation of nugget. In the spot welding process, a weld nugget will start to appear after sufficient energy has been put into the weld zone to raise the material to the solid to liquid. The amount and interval of the current and the resistance of the work pieces determine the size of the formed nugget. [9], [10].

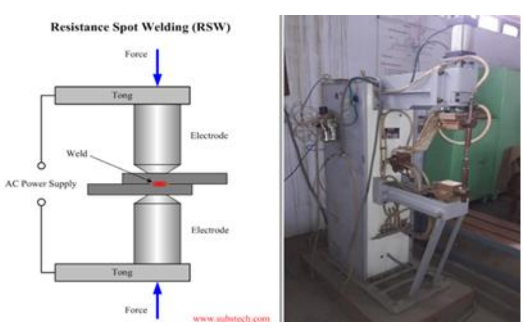

Fig. 1. (a)Resistance spot welding [8], (b) resistance spot welding machine setup

3. Material and Methodology

Austenite Stainless steel (ASS) is widely used in industrial application due to its high strength to weight ratio then other steel grades. The austenite stainless steel grade 316L is the most important type of steel which consist of austenite and ferrite phases in the microstructure. The carbon concentration in ASS 316L is more as compared to ASS 316 due to this ASS 316L is high corrosion resistance. Due to its high corrosion resistance they are also used in houses for making grills, doors and in kitchen racks. Because of this specific application 316L is preferred for RSW study. For Parametric design 23-factorial methodology is adopt. The three process parameter i.e. electric current, force of electrode and welding cycle selected as indicated in table 2. Experiments performed according to the test conditions specified by the 23-factorial method. Each experiment repeated one times in each of the conditions of the trial and the experiment at the center value is repeated three times. Thus, 11 work pieces were selected. In each of the conditions of the trial and for each replication, the characteristics of hardness and tensile strength were calculated

A. Chemical composition of ASS (Grade 316L)

Material used in the present work is Austenitic Stainless Steel (ASS 316 L) sheets of (1 mm) thickness. The normal chemical composition for each element of the above material is listed below in table 1.

Table 1
Chemical composition of AISI 316L Austenitic stainless steel (wt. %)

Element	C	Mn	Si	Cr	Ni	Mo	P	S	N	Fe
Wt. %	0.03	2.00	0.75	16-18	10-14	2-3	0.045	0.030	0.10	Balanced

B. Identification of parameters

For the appropriate spot welding and fault free testing of welding parameters on the strength of the spot Welding nugget size, level of electrode indented and hardness of the Weld nugget, four main parameters that decide to carry out an investigation.

- Weld current, I (KA)
- Electrode force, F (bar)
- Weld time, T (cycles/ms)
- Thickness, (mm)

The variable process parameter and their value at different levels are used during experiment perform are given in the table 2 below.

Table 2
Variable process parameter and their value at different levels Specimen configuration and dimensions

Symbol	Process Parameter	Unit	Level 1	Level 2	Level 3
C	Electric Current	KA	7	9	11
P	Electrode Force	Kg/cm²	2	2.5	3
N	Weld Cycles	Number(nil)	10	12	14

C. Specimen configuration and dimensions

The specimens were cut into pieces (140mm x 40mm) parallel to the direction of rolling of the sheet. Tensile-shear specimen was made by lapping two pieces one on the other. The dimensions are length 140 mm and width 40 mm as indicated in figure 2. the overlap is equal to the width of the sample. This overlap has been chosen in accordance with the recommendation of the AWS [11].

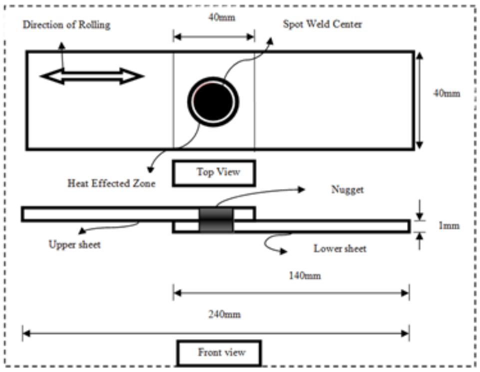

Fig. 2. The geometric representation of specimen

4. Joining Procedure

A series of controls are planned to control the welding process, in which each set was designed to determine the effect of the only variable for a selected geometry. Welding has been established in such a way that a full game should be run on a once. This was done to reduce the variation effect which may produce at metal surface on a whole range of samples that is not because of the factor under consideration. Similarly, within each set all the specimens with a unique mix of variables have been welded before conversion sequentially test variables. For example, all specimens for the welding of different currents (in KA) were welded into a single sequence. As a result, work piece are welded in a sequence firstly with changing current 7 KA, 9 KA and so on while other parameter are constant and repeat it for all parameter values. Overlap has been registered identical to the width of the sample. Size of the diameter of the electrode has been maintained as per the recommendation of the AWS [11].


Fig. 3. Overlaped joining of ASS (316L) welded with difference parameter range

5. Tests Performed

A. *Rockwell Hardness Test*

For check the hardness Rockwell hardness test is use, ASS grade 316L are belong to scale B, a Steel ball indenter of 1/16-inch (1.5875mm) diameter is used for B scale. The readings for B scale are measured on red scale. 316L is the low carbon version of 316 ASS which protected a particle boundary from carbide rainfall. This makes it suited to use in heavy Gauge welded components [12].

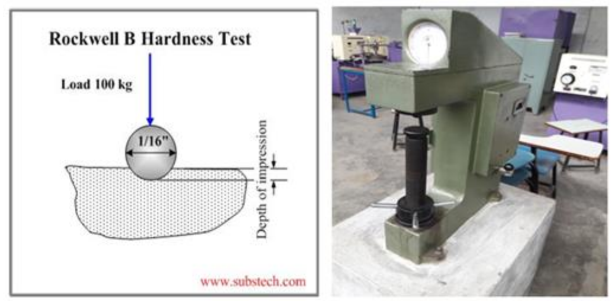

Fig. 4. (a) 1/16 (inch) steel ball indenter [13], (b) Rockwell hardness test machine setup

B. *Tensile Testing*

UTM universal testing machine, imported from England, is used to test on a metal piece. Universal test machine consists of two main units, one is a unit of measure and another is testing the device. Tensile test also called tension test, a look at strong point be most important type of mechanical test which may be executed on material. Tensile tests are straightforward, rather inexpensive, and fully standardized. By pulling on something, there can be very rapidly determined how material will react to load being carried out in tension. As material is being pulled, there we are capable to find its strength together with how a lot it will get longer.


Fig. 5 (a) UTM setup, (b) Specimen after checking tensile strength

6. Observations

Observations recorded are conducted according to the test conditions specified by 23-factorial (ANOVA) method with design expert 7.0 versions. Each experiment repeats two times with higher and lower limit of parameter while other two parameters are constant. Repeat it also for remaining parameters values with higher and lower limits when other two are constant and experiment repeat at the central value of parameter three times with the same procedure. Consequently 11 work pieces were conceder according to the ANOVA design experiment. For each of the trial conditions hardness and tensile strength were measured with the help of 3D diagram. In table 3. Show the Observation of spot weld for measuring the tensile strength and hardness with all parameters values.

Table 3
Observation of spot weld

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Nugget diameter
Run	A:Electrode Force	B:Electric Current	C: weld cycle	Hardness	Tensile Strength	
1	2	7	10	70.85	4.51	2.9
2	3	11	10	79	9.28	3.9
3	2	11	10	67.3	9.1	3.7
4	2	11	14	60.56	9.52	4
5	2.5	9	12	77.25	7.15	3.4
6	2.5	9	12	77.63	7.44	3.3
7	3	11	14	72.3	9.38	4
8	3	7	10	79.46	4.82	3.1
9	2.5	9	12	78.6	7.92	3.3
10	2	7	14	65.2	4.51	3.1
11	3	7	14	75.13	5.18	3.2

7. Analysis and discussion of results

Analysis of variance (ANOVA) is the numerical action which is most frequently applied to the results of the experiments to decide the percentage contribution of each parameter against a confirmed level of confidence [14]. The analysis of variance ANOVA is performed to identify the significant parameter and to quantify their effect on the response characteristics. The most favorable solution is obtained by optimization.

A. Effect on hardness with variation of electric current and electrode pressure

The effect of electric current and electrode pressure on nugget hardness has been reported in Fig. 6. It has been observed that in case of 1 mm thick specimen, actual factor: 3 (C: weld cycle) is 12, and factor: 1 (A: electrode force) and factor: 2 (B: electric current) is varying from 2 kg/cm^2 to 3 kg/cm^2 and 7 KA to 11 KA respectively. The value of hardness is decrease slightly when electric current is increase from 7 KA to 11 KA at electrode force 2 kg/cm^2. Similarly, hardness is decrease slightly with increase in the value of current from 7KA to 11KA at 3 kg/cm^2 electrode pressure. Hardness is increased with increase in electrode force from 2 kg/cm^2 to 3 kg/cm^2 at electric current 11 KA. Maximum hardness observed when electrode force increase from 2 kg/cm^2 to 3 kg/cm^2 at electric current 7 KA. But these hardness values are less than the hardness of base metal at both low and high electric current and electrode force when actual factor c: weld cycle is 12.

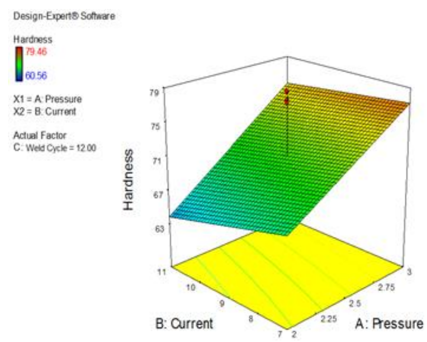

Fig. 6. The effect of electric current and electrode pressure on hardness

The obtained results show that hardness of weld nugget is lower as comparison to HAZ and base metal at both low and high welding currents and also at both low and high electrode pressure. This is because of the fact that when welding process is performed in atmosphere and the work pieces are cooled in air the heat dissipation rate is high [18]. Due to this Grains growth might occur in case of low carbon alloy (ASS 316L) in weld nugget region and it results reduction in hardness in weld nugget area [23]. In addition, results show that hardness in weld nugget region of specimen which is welded under low heat input (7 kA) is slightly higher than the ones which were welded under high heat input (9 kA and 11 kA). According to metallographic evaluations, grains growth also took place in HAZ. In the other word, decrease in hardness is related to the formation of delta ferrite morphology in weld nugget and somehow in HAZ regions. hardness value slowly but surely increased in the HAZ from near to the fusion zone to near the base metal because of the fact that cooling rate near to the fusion zone is low and high cooling rate near the base metal. In this study, decrease in hardness is related to the formation of delta ferrite morphology in weld nugget. Delta ferrite structure provides lower hardness in comparison to austenite morphology [23].

The effect of electrode force on nugget hardness has been reported that hardness is increase with increase in electrode force from 2 kg/cm^2 to 3 kg/cm^2 at constant weld cycle is 12.00. It was reported by Fukumoto et al. [21] and Kearns [17] that low electrode force or high electric current be able to the cause of large cavities, cracks, and porosity arise in weld nugget region. They are common defects in RSW process under severe condition. Because of this cavities and porosity arise in nugget and grain growth increase with a low value of electric current the value of hardness is decrease up to 69 RHB. Current is the most effective parameter in whole process which decreases in hardness value maximum up to 64 RHB. When the electrode force increase crack and porosity are decrease and grain growth also decrease at low and high electric current which is the cause of increase in hardness value.

B. Effect on hardness with variation of weld cycle and electrode pressure

The effect of weld cycle and electrode pressure on nugget hardness has been reported in Fig. 7. It has been observed that in case of 1 mm thick specimen, factor: 2 (B: electric current) is 9 KA, and factor: 1 (A: electrode force) and factor: 3 (C: weld cycle) is varying from 2 kg/cm^2 to 3 kg/cm^2 and 10cycles to 14 cycles respectively.

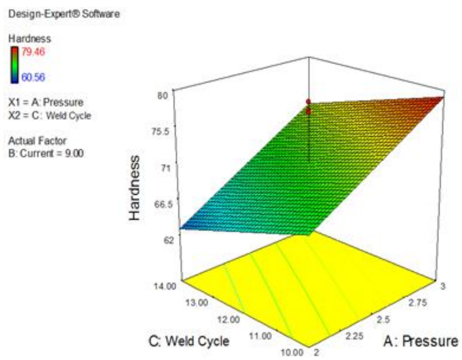

Fig. 7. Effect of weld cycle and electrode pressure on hardness

The value of hardness is decrease slightly with increase in weld cycle from 10 cycles to 14 cycles at electrode pressure of 2 kg/cm^2. Similarly, nature has been seen corresponding to 3 kg/cm^2 electrode pressure. The value of hardness increases rapidly with increase in electrode pressure from 2 kg/cm^2 to 3 kg/cm^2 at 10 weld cycle similarly trend has been observed at 14 weld cycle. The minimum value of hardness has been noticed at high range of weld cycle and low range of electrode pressure. However maximum value of hardness is seen at high level of electrode force and minimum range of weld cycle. But all hardness value measured on nugget area is always less than the hardness of base metal because of the percentage of Cr/Ni is low, skeletal delta ferrite will be formed in weld nugget. In other word variation in hardness in delta ferrite is depending upon the percentage of Ni and Cr in nugget [19, 20].

In AC systems, the weld time is express in cycles (one cycle is 1/50 of a second in a 50 Hz power system), Millisecond is use for DC systems. The time is set according to the material, thickness and the coating conditions are use. Weld cycle is the time throughout which welding current is apply to the metal sheets [24]. On the other words effect of weld cycle on hardness value is approximately equal to effect of electric current on nugget hardness. Because of this when weld cycle is increase at constant amount of current the grain growth is also increase in nugget. In addition, when a constant amount of currents is passed through metal sheet at varying weld cycle and welding process is performed at room temperature and cooled in air, heat dissipation rate is high [18]. Due to this in case of low carbon alloy Grains growth might occur in weld nugget and result in lower hardness in weld nugget area [23]. In the other word, the reduction of the hardness can be associated to the formation of delta ferrite morphology in weld nugget and somehow HAZ regions [22].

The effect of electrode pressure on nugget hardness has been reported that when electrode pressure is increase the value of hardness is also increase with low and higher weld cycle and at constant electric current is 9 KA. It was reported by Fukumoto et al. [21] and Kearns [17] that low electrode force or high electric current be able to the cause of large cavities, cracks, and porosity arise in weld nugget region. They are common defects in RSW process under severe condition. Because of this cavities and porosity arise in nugget and grain growth increase with a constant value of electric current the value of hardness is decrees up to 70 RHB. Current is the most effective parameter in whole process which decreases in hardness value maximum up to 62.5 RHB. When the electrode force increase crack and porosity are decrease and grain growth also decrease at low and high electric current which is the cause of increase in hardness value.

C. *Effect on Hardness with variation of weld cycle and electric current*

The effect of weld cycle and electric current on nugget hardness has been reported in Fig. 8. It has been observed that in case of 1 mm thick specimen, factor: 1 (A: electrode pressure) is 2.50 kg/cm^2, and factor: 2 (A: electric current) and factor: 3 (C: weld cycle) is varying from 7KA to 11 KA and 10 cycles to 14 cycles respectively.

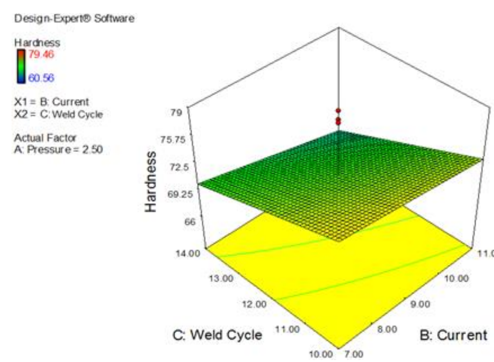

Fig. 8. Effect of weld cycle and electric current on hardness

Hardness is decrease slightly when weld cycle is increase from 10 cycles to 14 cycles at electric current is 7 KA. Similarly, nature has been seen corresponding to electric current 11 KA. The hardness is decrease maximum with increase in weld cycle and at electric current 11 KA. Hardness is also decrease when electric current increase from 7 KA to 11 KA and weld cycle is 10 cycles. Maximum hardness is observed at minimum weld cycle 10 cycles and minimum electric current 7 KA. The Effects of various welding currents and weld cycles on welds hardness are determine approximately same. According to the obtained results, hardness of the weld nugget is lower in comparison HAZ and base metal at both low and high welding currents and weld cycle. This behavior arises from the fact that when welding process is performed in atmosphere and the specimens are cooled in air, heat dissipation rate is high [18]. Due to this in case of low carbon alloy Grains growth might occur in weld nugget and result in lower hardness in weld nugget area [23]. In addition, results show that hardness in weld nugget region of specimen which is welded under low heat input (7 kA welding current)and at number of cycle is 10 is slightly higher than the ones which welded under high heat input (9 kA and 11 kA welding current) and number of cycles is 12 to 14. Weld cycle is the time throughout which welding current is applied to the metal sheets [24]. Due to this when an amount of current is passed through metal sheet at varying weld cycle at constant electrode force and welding process is performed at room temperature and cooled in air, heat dissipation rate is high [18]. Due to this in case of low carbon alloy Grains growth might occur in weld nugget and result in lower hardness in weld nugget area [23]. In the other word, the reduction of the hardness can be associated to the formation of delta ferrite morphology in weld nugget and somehow HAZ regions [22].

D. Effect on tensile strength with variation of electric current and electrode pressure

The effect of weld current and electrode force on tensile shear strength has been report in Fig.9. It had been observed that in case of 1 mm thick specimen, factor: 3 (C: weld cycle) is 12, and factor: 1 (A: electrode force) and factor: 2 (B: electric current) is varying from 2 kg/cm^2 to 3 kg/cm^2 and 7 KA to 11 KA respectively. The value of tensile strength is increase rapidly when electric current is increase from 7 KA to 11 KA at electrode pressure of 2 kg/cm^2. And maximum tensile strength is achieving with increase in electric current from 7 KA to 11KA at electrode pressure of 3 kg/cm^2. A literally change in tensile strength when electrode pressure is increase from 2 kg/cm^2 to 3 kg/cm^2 at electric current of 7 KA. Similarly, trend has been observed at electric current of 11 KA.

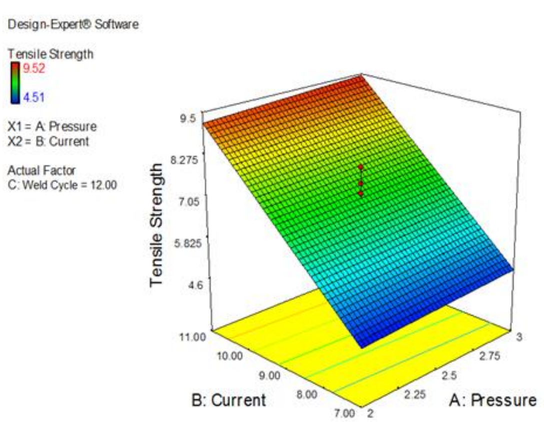

Fig. 9. Effect of electric current and electrode pressure on tensile strength

There are a number of factors which effect physical and mechanical properties of weld structure namely weld nugget diameter, weld penetration of the welded region, atmosphere condition [18]. Hasanbas og lu et al. reported that weld nugget diameter is the most important parameter affecting tensile–shear strength [22]. Additionally, Vural et al. mentioned that the more extension of nugget diameter size caused to reach the higher tensile–shear load bearing capacity of welded materials [25].

In addition, results show that tensile strength increase with increase in electric current and slightly increase in tensile strength with increase in electrode force. From the table 3, it shows that weld nuggets diameter increased when the welding current increased and weld cycle and electrode force also affected the tensile strength and nugget diameter slightly. When electrode force increases the spark which is produce on the surface due to electric current is reduce and this heat is utilize in formation of nugget and it is increase to some extent of nugget size. Because of this tensile strength is slightly increase when electrode force increase. From the result it shows that electrode force produces a very less effect on the tensile strength It was reported by Fukumoto et al. [21] and Kearns [17] that low electrode force or high electric current be able to the cause of large cavities, cracks, and porosity arise in weld nugget region. They are common defects in RSW process under severe condition. When electrode force is increased the porosity is decrease due to pressure arise on nugget and result in decrease in nugget size and tensile strength also but slightly increase in nugget because of the current which passed through it.

It was reported by Pouranvari et at, when welding current increases, the amount of failure energy increases too [26]. Pouranvari et al. [27] reported that tensile shear strength of weld is increase with increasing of welding current is related to the weld nugget diameter size. The minimum tensile shear load bearing capacity of weld represented the minimum nugget diameter size. When welding current increases, enlargement in nugget diameter happens and as a result the tensile shear force increased. In the other words, due to the generation of high heat input, excessive growth in nugget size and result arise increase in tensile shear load [28, 23].

E. Effect on tensile strength with variation of weld cycle and electric current

The effect of weld cycle and electric current on tensile shear strength has been reported in figure: 10. It has been observed that in case of 1 mm thick specimen, factor: 1 (A: electrode force) is 2.50 kg/cm^2, and factor: 2 (A: electric current) and factor: 3 (C: weld cycle) is varying from 7KA to 11 KA and 10cycles to 14 cycles respectively.

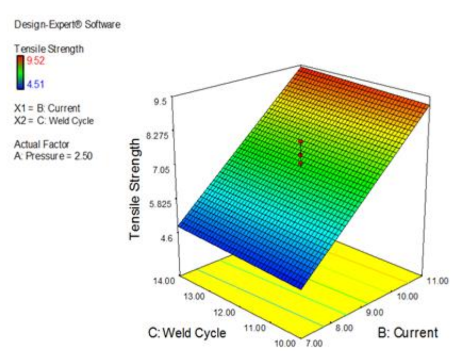

Fig. 10. The effect of weld cycle and electric current on tensile strength

In the above figure shows the value of tensile strength, there is a slightly increase in tensile strength when weld cycle is increased from 10 cycles to 14 cycles at electric current 7 KA. similar trend has been observed at electric current of 11 KA. The value of tensile strength increase rapidly when electric current is increase from 7 KA to 11 KA at 10 weld cycle. Similar trend has been observed at 14 weld cycle. The minimum value of tensile strength has been noticed at lower range of weld cycle and electric current. However maximum value of tensile strength is seen at high level of weld cycle and electric current. When weld cycle is increase from 10-14 cycles with a lower value of current there is a small change takes place in nugget diameter size due to which welding cycle has a very small effect produced on tensile strength. Spot welding process normally consists of four steps, squeezing, welding, holding and finishing [29]. In AC systems, the weld time is expressed in cycles (one cycle is 1/50 of a second in a 50 Hz power system), Millisecond is use for DC systems. The time is set according to the material, thickness and the coating conditions are use. Weld cycle is the time throughout which welding current is applied to the metal sheets [24]. When weld cycle is increased from 10-14 cycles and electric current is 11KA. The value of tensile strength is increase maximum because of nugget diameter is increase at that level. Table 3, Show the effect on nugget diameter and tensile shear load with different range of parameter.

Current is the most effective parameter that affects the tensile strength. The low tensile strength obtained from sample which weld at low welding current. When welding current increases, enlargement in nugget diameter happens and as a result the tensile shear force increased. In the other words, Due to the generation of high heat input, excessive growth in nugget size and result arise increase in tensile shear load [28, 23].

F. Effect on tensile strength with variation of electrode pressure and weld cycle

The effect of electrode pressure and weld cycle on tensile shear strength has been reported in figure 11. It has been observed that in case of 1 mm thick specimen, factor: 2 (B: electric current) is constant, and factor: 1 (A: electrode force) and factor: 3 (C: weld cycle) is varying 2 kg/cm^2 to 3 kg/cm^2 and 10 cycles to 14 cycles respectively.

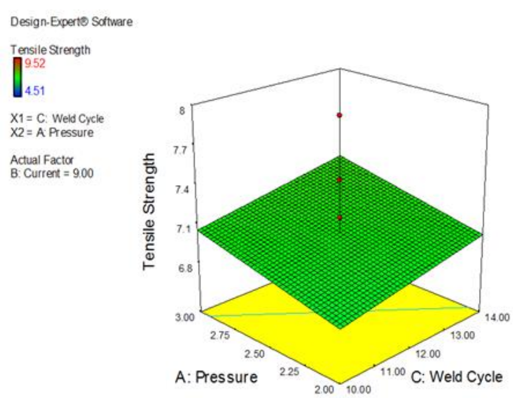

Fig. 11. Effect of electrode pressure and weld cycle on tensile strength

In the figure, show the value of tensile strength, which is increase slightly when weld cycle is 10 and electrode force is increase from 2 kg/cm^2 to 3 kg/cm^2. Similar nature has been seen corresponding to 14 weld cycle. And the value of tensile strength increases slightly with increase in weld cycle from 10 to 14 cycles at electrode force 2 kg/cm^2. Similar trend has been observed at electrode pressure of 3 kg/cm^2. The minimum value of tensile strength has been noticed at lower value of electrode pressure and lower value of weld cycle. However maximum value of tensile strength is seen at higher level of electrode pressure and higher level of weld cycle. In addition, results show that tensile strength slightly increases with increase in weld cycle and electrode pressure at 9KA electric current. From the table: 3. show that weld cycle and electrode pressure are also affect the tensile strength and nugget diameter slightly. When electrode pressure increase the spark which is produce on the surface of work piece due to electric current is reduce and this heat is utilize in formation of nugget and it is increase some extent of nugget size. Because of this extension in nugget tensile strength is slightly increase when electrode force increase. Hasanbas og ˘lu et al. reported that weld nugget diameter is the most important parameter affecting tensile–shear strength [22]. Additionally, Vural et al. mentioned that the more extension of nugget diameter size caused to reach the higher tensile–shear load bearing capacity of welded materials [25]. When weld cycle is increase from 10-14 cycles at constant current there is a small change takes place in nugget diameter size due to which welding cycle has a very small effect produce on tensile strength. Spot welding process normally consists of four steps, squeezing, welding, holding and finishing [29]. In AC systems, the weld time is expressed in cycles (one cycle is 1/50 of a second in a 50 Hz power system), Millisecond is use for DC systems. The time is set according to the material, thickness and the coating conditions are use. Weld cycle is the time throughout which welding current is applied to the metal sheets [24]. When weld cycle is increased from 10-14 cycles and electric current is 9KA. The value of tensile strength is increase minimum because of nugget diameter is small at that level. Table 3, Show the effect on nugget diameter and tensile shear load with different range of parameter. Because of the low electric current bond structure is week.

8. Optimization parameter value

Optimization solution finding the most suitable parameter value for maximum hardness and tensile strength within the given parameters values. Optimization graph show the best parameter values for resistance spot welding of ASS316L from all given parameters values. The optimized results are displayed as per the value of desirability and the maximum desirability 0.965 achieved by the variable parameters Electrode force, electric current and Weld cycle at 3.00 Kg/cm^2, 11.00 KA and 10 Cycle respectively and Maximum hardness 78.8398 RHB and maximum tensile strength is 9.33749 N/mm^2 observed.

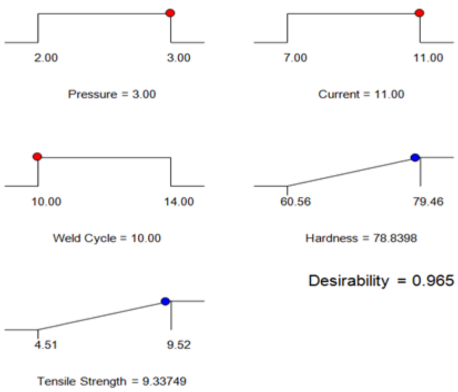

Fig. 12. Optimizing parameter value

A. *Confirmation by experiments*

In order to obtained the validate results, three confirmation experiments have been conduct for response characteristics at the optimal levels of electric current (C) = 11 KA, the electrode pressure (P) = 3 bars and the number of weld cycles (N) = 10.and repeat the same experiment up to 3 runs and the values of nugget hardness and tensile strength obtained through the confirmation experiments and chose the mean of these three values and find out the % error in experiment setup.

Table 4
Conformation by experiment

Run	Factor 1 Electrode pressure	Factor 2 Electric Current	Factor 3 Weld Cycle	Response 1 Hardness	Response 2 Tensile strength
1	3	11	10	80.3	9.41
2	3	11	10	79.16	9.87
3	3	11	10	82.31	9.21
mean	**3**	**11**	**10**	**80.590**	**9.497**

B. *Percentage error*

It is the difference between experiment and predicted value, divided by the experimental value, multiplied by the 100 to give a percentage error.

$$\text{percentage Error} = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Experimental value}} \times 100$$

1. *Percentage Error in case of hardness*

% Error (Hardness) = (80.590-79)/80.590×100 = 1.973%

2. *Percentage error in case of tensile strength*

% Error (Tensile strength) = (9.497-9.28)/9.497×100 = 2.285%

A. *Validation of result*

The % error between experiments measured value and software predicted value is less than 5%, thus confirmation experiments validation is statistical results.

9. Conclusion

Austenitic stainless steels are widely utilized in industrial applications due to their strength, corrosion resistance, mechanical workability, and excellent electrical and thermal conductivities. Among them, ASS316L stainless steel is of great practical interest because it is employed in pharmaceutical, petrochemical, water desalination, etc.

Optimum result has been found by ANOVA method using higher electrode force of 3 kg/cm^2, higher electric current 11KA and low weld cycle 10 cycles. Weld current is major governing factor affecting the tensile shear strength of the resistance spot welded specimens. As the weld current increases, results into increased values of tensile-shearing strength.

Hardness of the welded zone is negligible lesser than the hardness of the un-welded zone for ASS 316L joints. But as we go on increasing electrode force up to 3 kg/cm2 therefore nugget hardness increases with increase in electrode force. For the welding of sheets of austenitic stainless steels 316L, current is most effective parameter for tensile strength, with increase the value of electric current tensile strength of ASS316L is highest at current value is 11KA. Further study may be conducted the overlay technique and metal matrix using welding technique to improve the wear and hardness properties on austenitic stainless steel 316L.

References

[1] M. Hamedi and H. Pashazadeh: "Numerical Study of Nugget Formation in Resistance Spot Welding", International Journal of Mechanics, 2008, 2, 11-15.
[2] Aslanlar S, Ogur A, Ozsarac U, Ilhan E. Welding time effect on mechanical properties of automotive sheets in electrical resistance spot welding. J Mater Des 2008; 29: 1427–31.
[3] A. K. Pandey, M. I. Khan, K. M. Moeed "Optimization of resistance spot welding parameters using Taguchi method" A. K. Pandey et al./ International Journal of Engineering Science and Technology.
[4] Shamsul J. B. and Hisyam M. M. (2007),♂ study of spot welding of austenitic stainless steel type 304", Journal of applied science research, 911, pp. 1494-1499.
[5] Shaik Shafee, B. BaluNaik, and K. Sammaiaha, "Resistance Spot Weld Quality Characteristics Improvement by Taguchi Method", Materials Today: Proceedings, 2015, Vol. 2, pp. 2595 – 2604.
[6] Bayram Kocabekir, Ramazan Kacar, Suleyman Gunduz, and Fatih Hayat, "An effect of heat input, weld atmosphere and weld cooling conditions on the resistance spot weldability of 316L austenitic stainless steel", journal of materials processing technology, 2008, Vol. 198, pp. 327-335.
[7] D. S. Sahota, Ramandeep Singh, Rajesh Sharma and Harpreet Singh, "Study the effect of parameters on Resistance Spot Weld of ASS316 material", Vol. 2, No. 2, February-March 2013.
[8] A. G. Thakur, T. E. Rao, M. S. Mukhedkar and V. M. Nandedkar "Application of Taguchi method for resistance spot welding of galvanized steel", ARPN Journal of Engineering and Applied Sciences, vol. 5, no. 11, Nov. 2010.
[9] W. Li, S. J. H, and J. Ni, On-line quality estimation in resistance spot welding, Journal of Manufacturing Science and Engineering, Transaction of the ASME, Vol. 122, 2000.
[10] Salem, Meranda. Control and power supply for resistance spot welding (RSW). The University of Western Ontario 2011.
[11] Handbook for resistance spot welding (2005). http://www.millerwelds.com/pdf/Resistance.pdf
[12] file:///E:/RSW%20papers/316%20property.pdf
[13] Arvinder Singh, Vanraj, Kant Suman, Suri N.M "Parameter optimization for tensile strength of spot welds for 316l stainless steel" International Journal of Scientific & Engineering Research, Volume 4, Issue 7, July-2013.
[14] K. S. Yeung, and P.H. Thornton, "Transient Thermal Analysis of Spot Welding Electrodes", Welding Research, January, (1999), pp. 1–6.
[15] Darshan Shah, Prof. Dhaval P Patel "Prediction of Weld Strength of Resistance Spot Welding Using Artificial Neural Network" Darshan Shah

et al Int. Journal of Engineering Research and Applications, Vol. 3, Issue 5, Sep-Oct 2013, pp. 1486-1491.
[16] Pradeep M., N. S. Mahesh, Raja Hussain "Process Parameter Optimization in Resistance Spot Welding of Dissimilar Thickness Materials" World Academy of Science, Engineering and Technology International Journal of Mechanical, Industrial Science and Engineering, Vol. 8, No. 1, 2014.
[17] Kearns W. H. Welding processes, AWS welding handbook, vol. 3. 7th ed., London, England: American Welding Society, Macmillan Press Ltd.; 1980.
[18] Ozyurek D. An effect of weld current and weld atmosphere on the resistance spot weldability of 304L austenitic stainless steel. Mater Des 2008; 29:597–603.
[19] Lippold JC, Kotecki D. Welding metallurgy and weldability of stainless steels. Wiley Interscience publication. Chapter 3: Alloying elements and constitution diagrams, p.19–52. Chapter 6: Austenitic stainless ssteels; 2005.p. 143–225.
[20] Lippold JC, Kotecki D. Welding metallurgy and weldability of stainless steels: Wiley Interscience Publication. Chapter 6: Austenitic stainless steels; 2005. p. 143–225.
[21] Fukumoto S, Fujiwara K, Toji S, Yamamoto A. Small-scale resistance spot welding of austenitic stainless steels. Mater Sci Eng A 2008; 492:243–9.
[22] Hasanbas og ˘lu A, Kaçar R. Resistance spot weldability of dissimilar materials (AISI 316L-DIN EN 10130-99 steels). Mater Des 2007; 28:1794–800.
[23] Kocabekir B, Kacar R, Gunduz S, Hayat F. An effect of heat input, weld atmosphere and weld cooling conditions on the resistance spot weldability of 316L austenitic stainless steel. J Mater Process Technol 2008;195:327–35.
[24] W. Li, D. Cerjanec and G.A. Grzadzinski: "A comparative study of single-phase AC and multiphase DC resistance spot welding". Journal of Manufacturing Science and Engineering, Transactions of the ASME, 2005, 127, 583-589.
[25] Vural M, Akkus A, Eryurek B. Effect of welding nugget diameter on the fatigue strength of the resistance spot welded joints of different steel sheets. J Mater Process Technol 2006;176:127–32.
[26] Pouranvari M, Marashi SPH, Safanama DS. Failure mode transition in AHSS resistance spot welds. Part II: Experimental investigation and model validation. Mater Sci Eng A 2011;528:8344–52.
[27] Pouranvari M, Marashi SPH. Failure mode transition in AHSS resistance spot welds. Part I. controlling factors. Mater Sci Eng a 2011; 528:8337–43.
[28] Pouranvari M, Mousavizadeh S. M, Marashi S. P. H, Goodarzi M, Ghorbani M. Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of AISI 1008 low carbon steel and DP600 advanced high strength steel. Mater Des 2011;32:1390–8.
[29] "Handbook for resistance spot welding", 2005, Miller Electric Manufacturing Co., Appleton, WI.