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Optimization of Process Parameters for Resistance Spot Welding process using Taguchi Method for Austenitic SS304

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Abstract: *Resistance Spot Welding (RSW) is joining purpose especially in automobile industry due to its robustness, speed, flexibility and low cost operation. It depends on the resistance of the base metal and the amount of current flowing to produce the heat necessary to make the spot weld. There are various process parameters like as electrode pressure, welding power, weld time & so on which affects the weld nugget and its strength. So it is necessary to optimize the process parameters of resistance spot welding process. From the experimental setup, we choose Pressure, Power/Welding current, Weld time at three different levels. The approach is based on Taguchi Method to optimize the resistance spot welding process parameters for effective welding. Austenitic Stainless Steel 304 was selected as work piece material and Taguchi method was used to design the experiments.*

Keywords*: Resistance Spot Welding Machine, Austenitic SS304, Taguchi Method.*

I. INTRODUCTION

The spot welding is one form of resistance welding, which is a method of welding two or more metal sheets together without using any filler material by applying pressure and heat to the area to be welded. The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the workpieces. In all forms of resistance welding, the parts are locally heated. The material between the electrodes yields and is squeezed together. It then melts, destroying the interface between the parts. The current is switched off and the "nugget" of molten materials solidifies forming the joint [8]. **Figure 1** shows the general setup of the resistance spot welding with the two electrodes.

Figure 1: *Resistance Spot Welding machine & its components*

This process is used extensively for joining low and mild carbon steel sheet metal components for automobiles, cabinets, furniture and similar products. Stainless steel, aluminum and copper alloys are also spot welded commercially. Excessive heating in resistance welding results in metal expulsion during the welding operation. Since accurate method for selection of welding variables i.e. welding current, welding time and electrode force, thickness of sheet, electrode type, electrode tip diameter, gap in the electrodes, shape of electrode tip, electrode material etc. are lacking.

The principle of Resistance Spot Welding is based on joule heating process. Two metal sheets are welded together. Electrode force is applied to hold the sheets tightly together, and electrical current flows through the electrodes and the material. The resistance of the material being welded is much higher than the resistance of the electrodes. Thus, enough heat is generated to melt the metal. The pressure on the electrodes forces the molten spots in the two pieces of metal to unite, forming the final spot (nugget).

II. LITERATURE SURVEY

Dursun Ozyurek (2007) [1] studied the effect of weld current and weld atmosphere in the resistance spot welding process. He used Austenitic Stainless Steel 304 as material for the experiments. For the experimental work, the welding current was chosen at three different levels whereas, weld time, hold time and electrode pressure were chosen as constant. He conclude that current is the most effective parameters than others and also to optimum welding parameter for maximum joint strength at 9kA. **Hessamoddin Moshayedi & Iradj Sattari-far (2011) [2]** developed a model of electro-thermo-mechanical finite element to study the effect of welding time and current intensity on nugget size for resistance spot welding process using Austenitic SS304L steel sheets. Form the experimental results to shows that compare the diameter & thickness of computed weld nugget size, and also to FE model predicted to weld nugget growth and nugget size. **R.J.Bowers, *et al* (1990) [3]** had investigated the electrode geometry on current distribution by both mathematical modeling and experimental testing. The experimental setup was used to develop a mathematical model to evaluate current distribution and also to find the electrode life. The results indicates that on both side an angle of 90 degree provide more uniform current distribution and affect wear and life of electrode on local current distribution. **Nachimani Charde(2012) [4]** have focused on the effect of parametric changes for joint together two dissimilar materials such as austenitic stainless steel 304 and carbon steel with 1mm and 2 mm thicknesses. The welding current and welding time were selected as varying parameters whereas electrode force and electrode tips size were kept constant. To analyze the effect on nugget growth and then to optimize the results, the tensile test, hardness test and metallurgical test had been performed on welded workpieces. **Nachimani Charde & Aravinthan Arumugam (2011) [5]** had analysis the effect on weld nugget growth for Mild steel & Stainless steel for 1mm & 2mm sheet thickness. From the experimental work at varying process parameters like welding current, weld time, electrode pressure & tip size of electrode used. For the results, the mechanical tensile test & hardness test to carried out to characterize the formation of weld nugget growth for different thickness while Macro examination of weld nugget shows the differences in weld growth in both thicknesses. **A. K. Pandey *et al* (2013) [6]** have represented the optimization of various process parameters for resistance spot welding process using Taguchi Method. The experimental result shows that current is most effective machining parameters where the holding time and pressure are less.

The above literature review insists that resistance spot welding process is fast and efficient than other joining processes and widely used in industrial applications. However, very few researchers have used the Austenitic Stainless Steel 304 material with 1.5mm thickness for their research work. Hence here the experimental work has been done with the aim to optimize the weld process parameters by using SS304 material having 1.5 mm thickness.

III. MATERIAL AND METHOD

Type 304 series is the most versatile and widely used of all the stainless steels. Their chemical composition, mechanical properties, Weldability and corrosion/oxidation resistance provides the best all-round performance stainless steels at relatively low cost. They have excellent low-temperature properties and respond well to hardening by cold working. The 304 types SS have good welding characteristics. Following Table-1 & Table-2 represents the Mechanical properties and Chemical Compositions of Austenitic Stainless Steel 304 material.

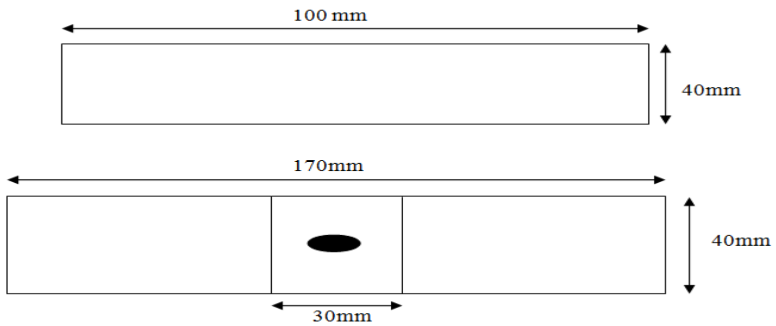


Figure-2: *Standard Specimen size of SS304*

Table-1 Mechanical Properties of SS304

Property	**Ultimate Tensile Strength (Mpa)**	**Compressive Strength (Mpa)**	**Elongation Min. (%)**	**Hardness (HRB)**
Value	520 to 720	200	45	95

Table 2 Chemical Composition of SS304

Elements	Carbon (C)	Chromium (Cr)	Manganese (Mn)	Silicon (Si)	Phosphorus (P)	Sulphur (S)	Nickel (Ni)	Iron (Fe)
% Present	0.0 - 0.07	18.50	0.0 – 2.00	0.0 – 1.0	0.0 – 0.05	0.0 – 0.2	8.30	--

For the good welding characteristics of SS304, we have selected the dimension of 100×40×1.5mm as per standard ASTM A240. In addition, side effects should be prevented and minimum materials waste was aimed. These factors were evaluated in designing sizes of test specimens. **Figure 2** shows the shape and size with the prescribed dimensions of the specimens which were cut from a large sheet. The above literature survey revealed that there are three main processes parameters which affect the weld nugget size and ultimately the quality of weld namely pressure, welding current and weld time with respect to others. Hence as per the dimensions for the SS304 material, three levels of each process parameters have been chosen which are given in **Table 3**.

Table 3 Level of Experiments

Factor	Column	Level 1	Level 2	Level 3
Pressure (Bar)	A	2	2.5	3
Welding Power (%)	B	45	50	55
Weld time (cycle/sec)	C	12	14	16

Three levels for three process parameters were selected to cover the more specific effect of each parameter on weld quality in resistance welding process. In the beginning some sample experiments have also been performed to set the values of process parameters at various levels.

In order to determine the effect of particular parameter on weld nugget the design of experiments is essential. Taguchi Method has been used to design the experiments more strategically. It is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. It can be efficiently used for designing a system that operates consistently and optimally over a variety of conditions. Taguchi Method is important in designing, formulating, developing & analyzing new scientific studying and products [7]. Using Taguchi orthogonal array, we have performed the experiments at different levels as described in **Table-4**.

Table-4 L27 Orthogonal array (D.O.E)

Sr. No.	Pressure (bar)	Power (%)	Weld Time (cycle/sec)	Sr. No.	Pressure (bar)	Power (%)	Weld Time (cycle/sec)
1	2	45	12	**15**	2.5	50	16
2	2	45	14	**16**	2.5	55	12
3	2	45	16	**17**	2.5	55	14
4	2	50	12	**18**	2.5	55	16
5	2	50	14	**19**	3	45	12
6	2	50	16	**20**	3	45	14
7	2	55	12	**21**	3	45	16
8	2	55	14	**22**	3	50	12
9	2	55	16	**23**	3	50	14
10	2.5	45	12	**24**	3	50	16
11	2.5	45	14	**25**	3	55	12
12	2.5	45	16	**26**	3	55	14
13	2.5	50	12	**27**	3	55	16
14	2.5	50	14				

IV. EXPERIMENTATION

The values of the process parameters as given in the above **Table 4** were used to perform the experimental work. The experimental work have been conducted on 15kVA, air operated, single phase AC spot welding machine at DARSH ENGINEERING, VADODARA. The specimens are prepared as shown in Figure 2 and cleaned. After that, these parts were overlapped with 30 mm. spacing and welded. The electrode force, power and weld cycle time were controlled and vary as given in table 4 during experiments. Clamping and hold times were kept constant as 25 cycles in all series. Welding was conducted using a 45-deg truncated cone RWMA Class 2 electrode with 5-mm face diameter. The chemical compositions and mechanical properties of electrodes are given in Table 5 below. The welded workpieces are as shown in **Figure 3.** In order to find out the tensile strength of the welded workpieces the Tensile Test have been carried out on each welded workpieces on Universal Tensile Machine at SICART. Samples for the metallographic examination were prepared using standard metallographic procedure. Weld nugget (fusion zone) sizes were measured for one sample on the metallographic cross-sections of the welds.

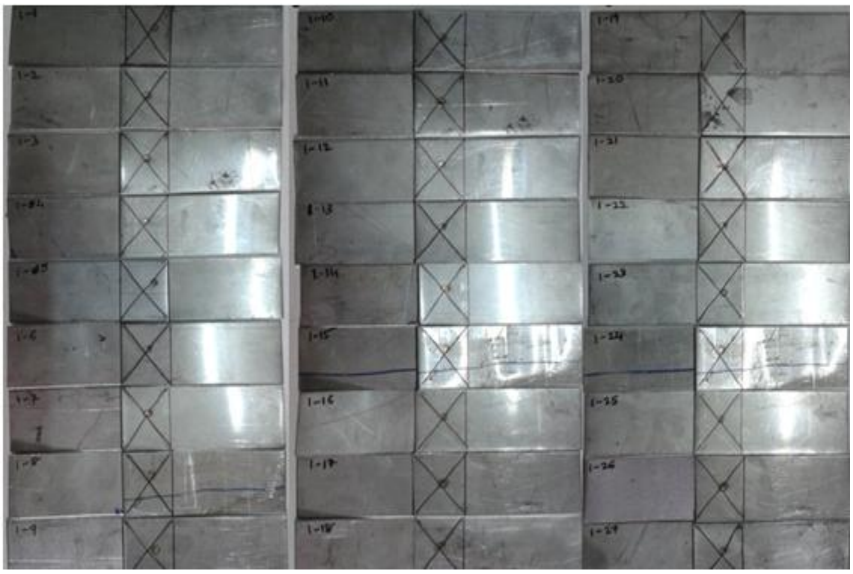


Figure 3: *Specimens of Spot welded for SS304*

V. RESULTS AND DISCUSSION

Tensile testing is used to provide basic design information on the strength of materials and is an acceptance test for the specification of materials. From the above testing the material by Universal Testing Machine, the result to be find in form of Maximum load and Break load as shown in **Table 5**. The experimental results for tensile shear strength for each thickness using the *L18* orthogonal array are shown in Table 5.

Table 5: Result Table for experimental work

Sr no.	Pressure (bar)	Power (%)	Weld time (cycle/sec)	Maximum load (N)	Break load (N)	Nugget Dia. (mm)	Tensile Strength (N/mm2)
1	2	45	12	3587.5	750	3.9	20.41
2	2	45	14	3485	660	3.7	18.94
3	2	45	16	3330	1045	3.5	31.70
4	2	50	12	5207.5	1472.5	3.9	40.08
5	2	50	14	4942.5	3610	3.2	119.76
6	2	50	16	4632.5	3457.5	3.4	107.95
7	2	55	12	4855	1167.5	3.1	39.98
8	2	55	14	6057.5	3880	3.9	105.61
9	2	55	16	6237.5	4625	4.1	119.75
10	2.5	45	12	4505	1575	4	41.80
11	2.5	45	14	4005	1880	3.8	52.52
12	2.5	45	16	3925	1120	3.5	33.97
13	2.5	50	12	5562.5	2702.5	4.1	69.97
14	2.5	50	14	4497.5	2062.5	4.1	53.40
15	2.5	50	16	3550	1450	3.5	43.98
16	2.5	55	12	5875	1890	4	50.16
17	2.5	55	14	5240	3457	3.8	96.58
18	2.5	55	16	5417.5	3364	4	89.28
19	3	45	12	4390	1677.5	4.1	43.43
20	3	45	14	4240	1245	3.9	33.89
21	3	45	16	3217.5	855	3.3	27.50
22	3	50	12	5280	3292.5	4	87.38
23	3	50	14	4382.5	1042.5	3.5	31.62
24	3	50	16	4587.5	695	3.9	18.92
25	3	55	12	6347.5	2567	4.1	66.46

26	3	55	14	6140	3680	4	97.66
27	3	55	16	6755	3280	4.3	80.98

Formula for strength= Breaking Load/ Shearing Area= $P/2\pi Dt$
Where D = Nugget diameter,
t= Thickness of specimen,
P=Breaking Load

In design of experiment the results are analyzed due to one or more of the following three objectives.
1. To establish the best or the optimum condition for a product or a process.
2. To estimate the contribution of individual factors.
3. To estimate the response under the optimum conditions.

The optimum condition is identified by studying the main effects of each of the factors. The main effect indicates the general trends of the influence of the factors. Knowing the characteristics i.e. whether a high error lower value produces the preferred results, the level of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution of individual factors is a key to deciding the nature of the control to be established on a production process.

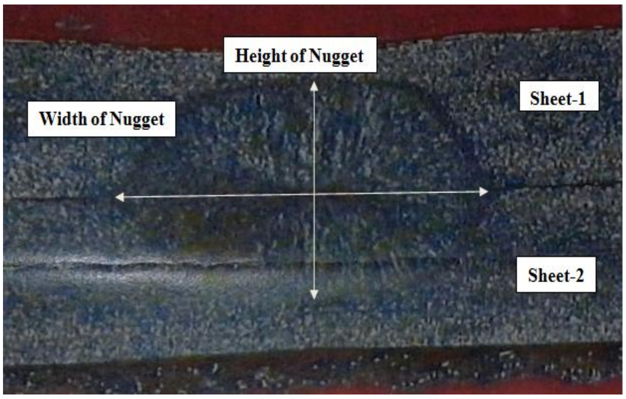
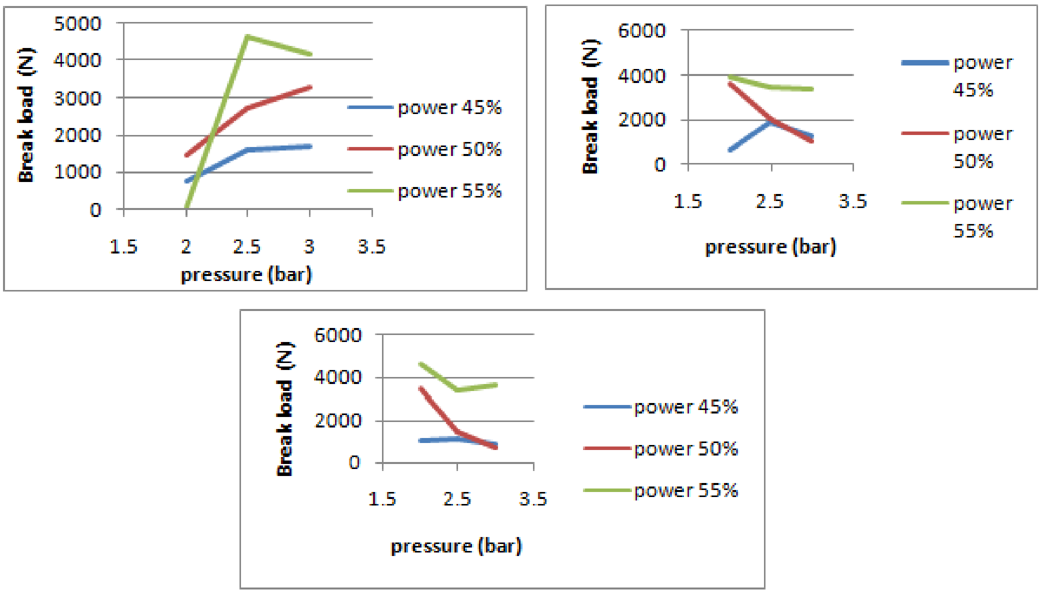


Figure 4: *Macroscopic examination of spot welded work piece for 1.5mm sheet thickness*

To measure the radius of weld nugget and width of HAZ, the welded metal was cut transversely from the middle position using a common cutting machine. The macrograph of weld zone was capture during a metallurgical microscope interfaced with an image analysis system as shown in **Figure 4**.

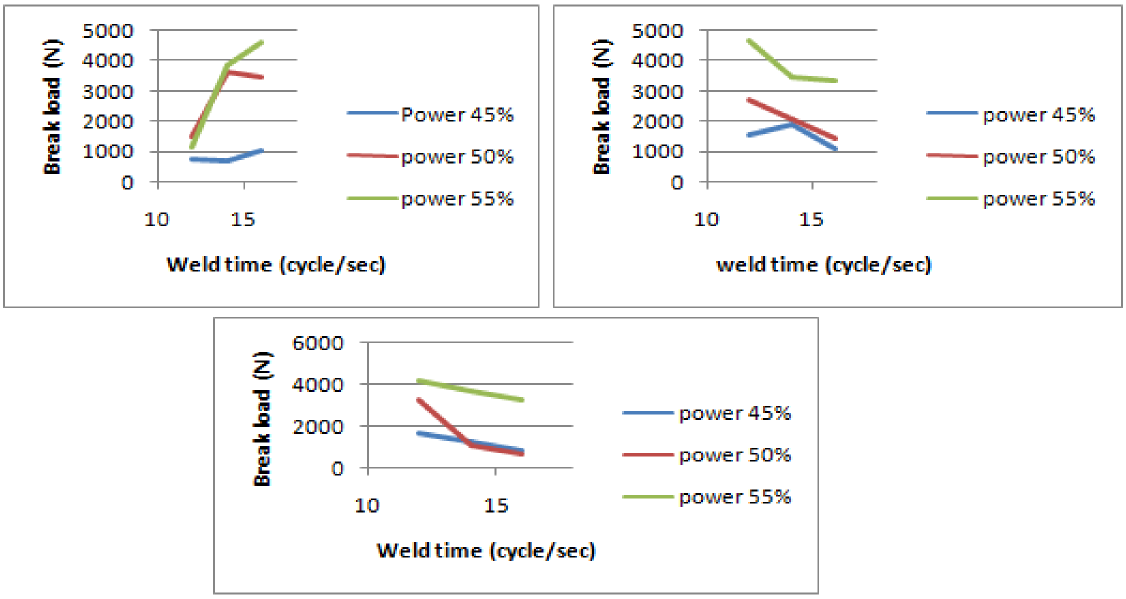
We have plotted various graphs for the break load v/s pressure & weld time effect as follow, which shows the effect of breaking load on the different process parameters in RSW process.



Graph 1.1 *Effect of break load when weld time is (a) 12cycle/sec, (b) 14cycle/sec and, (c) 16cycle/sec.*

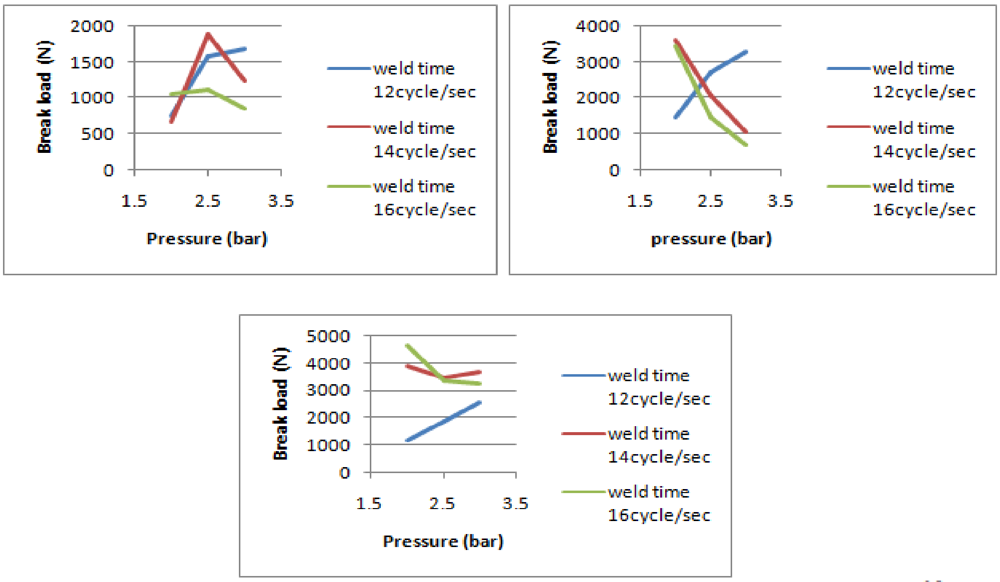
The graph 1.1 shows that the effect of break load for the different levels of power with increasing values of pressure from 2bar to 3bar. It indicates that for the pressure level 3bar at the power 55% we get maximum breaking load for a constant value of weld cycle (12cycle/sec). Similarly graph (b) & (c) shows the same effect at the maximum power and 14 &16 cycles/sec weld time respectively.

We have plotted various graphs for the break load v/s weld time effect as follow, which shows the effect of breaking load on the different process parameters in RSW process.



Graph 1.2 *Effect of break load when pressure is (a) 2bar, (b) 2.5bar and, (c) 3 bar*

The graph 1.2 displays the effect of break load for the different levels of power with increasing the values of weld time from 12cycle/sec to 16cycle/sec. It shows that weld time at 16cycles/sec give its higher value of strength at graph (a), whereas it's consistently decreases with increases the pressure range at 2.5bar to 3bar as shown in graph (b) & (c).



Graph 1.3 *Effect of break load when pressure is (a) 2bar, (b) 2.5bar and, (c) 3 bar*

The graph 1.3 represents the effect of break load for different levels of weld time with increasing the values of pressure from 2bar to 3bar. Its displays that pressure at 2.5bar give its higher value of strength at graph (a). From each graph, the weld time at 12cycle/sec shows that to the higher value of strength, when the pressure and power is changes.

Analysis of variance (ANOVA) Terms & Notations:

n = numbers of trails T =Total of results
C.F. = correction factor e =Error

S = Sum of squares F = variance ratio
S'' = Pure sum of squares f = Degree of freedom
V = Mean squares (variance) Σyi = sum of all output values
P = Percent contribution

Table 6: Response Table for Signal to Noise Ratios for Maximum load& Break Load (Larger is better)

Level	A	B	C
1	67.18	63.68	68.29
2	67.47	67.75	67.15
3	67.63	70.84	66.83
Delta	0.45	7.16	1.46
Rank	3	1	2

- Analysis of Variance tables for the effect of parameter on weld strength. Minitab software significant parameters can be easily identified and also find the rank order.
- Rank order as per the significance level is that Weld time, Power and Pressure. The requirement of the optimum level can be decide by SN ratio plot.
- Here, the maximum % contribution in all three parameter is of power and weld time, whereas pressure is less.

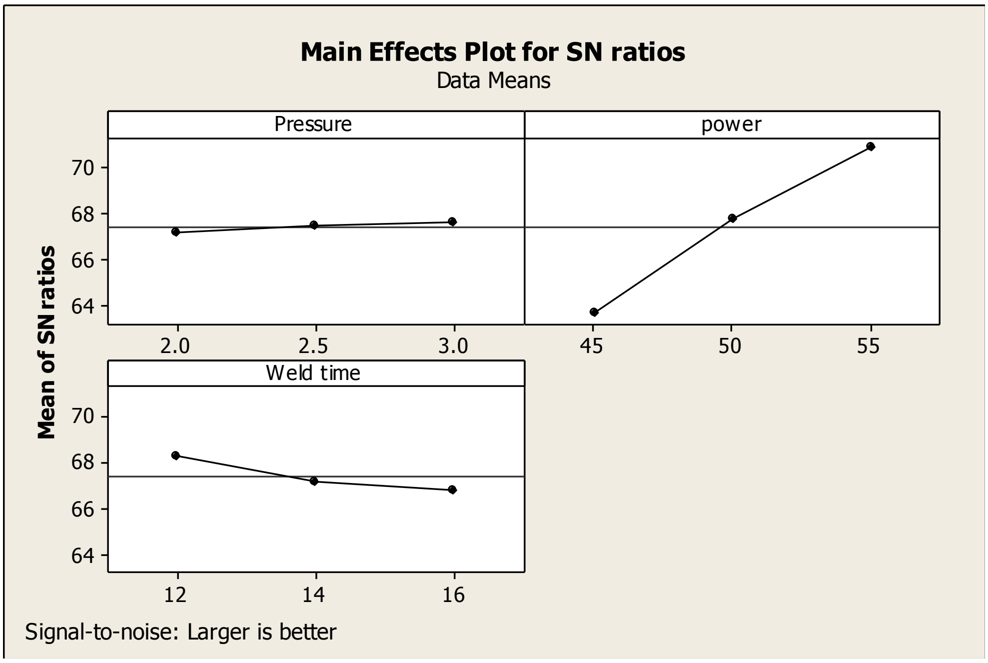


Figure 5: *Effect of S/N ratio for SS304*

VI. CONCLUSION

This paper has presented an investigation on the optimization and the effect of welding parameters on the tensile shear strength of spot welded SS 304 steel sheets. The level of importance of the welding parameters on the tensile shear strength is determined by using ANOVA. Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as Power and Weld time, whereas Pressure was less effective factor. An optimum parameter combination for the maximum tensile shear strength was obtained by using the analysis of signal-to-noise (S/N) ratio. The confirmation test results shows that,

- ➢ Resistance spot welding process is comparatively fast and efficient process; however the quality of weld changes w.r.t. sheet thickness, amount of pressure, weld current and time.
- ➢ The presented study shows that in resistance spot welding process, welding power (current) is a main affective parameter than any other parameters.
- ➢ In joining the two sheets of austenitic stainless steel 304 material, We can conclude from our experimental setup and result analysis that the maximum value of tensile shear strength is 66.46 N/mm2 and breaking load is 2576N at 55% of power, 12cycle/sec of weld time and 3bar pressure.

- The contributions of power, weld time, and pressure towards tensile strength is 15.77%, 14.04% and 4.21% respectively as determined by the ANOVA Method.

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