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# Parameter optimisation and failure load prediction of resistance spot welding of aluminium alloy 57547

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**Abstract.** This paper will also present single objective optimization and Failure load prediction of Resistance spot welding of Aluminium alloy 57547. The experimental studies were conducted under varying welding currents  $I$ , electrode forces  $F$ , welding times  $T$ , preheating currents  $IA$ . The settings of welding parameters were determined by using the Taguchi experimental design of L9 Orthogonal array method. For optimization and prediction will be used analysis of Signal-to-Noise (S/N) ratio and Response surface modelling RSM.

## 1. Introduction

Resistance spot welding (RSW) is the most commonly used method of joining in the automotive industry, more than 60% of the total number of joining technology is by the RSW [1], so one car has, for example, over 5000 RSW points [2] and each car factory has more than 200 RSW welding machines [3]. Traditionally, steels have been the material of choice for the fabrication of automobile structures. However, in order to respond appropriately to economic and environmental requirements for lighter but faster vehicles, many automobile manufacturers are re-directing their research and development efforts towards advanced high strength steels (e.g. TRIP steels and dual phase steels) and aluminium alloys [4]. Aluminium alloy has already gained popularity among automakers, because it is lightweight and virtually non-corrosive. Aluminium car bodies have already reached the level of mass production, although only on expensive models. Many parts of the chassis have been mastered from aluminium instead of steel, as well as lighter components [5]. Recently several groups of aluminium alloys are applied in car manufacturing, among them for example AA5754 H22 and AA6082 T6. Concerning for example AA5754 (AlMg3) alloy, it is widely used in sports cars. This alloy has medium strength among aluminium alloys [6]. Therefore, a lot of authors in different papers analysing the joining of aluminium alloy using RSW, what is shown in review paper of S. M. Manlada and el [7].

Zhen Luo and el. [8] were analysing application of pre-heating to joining two sheets from aluminium alloy AA5052 and they conclude that all parameters need to be studied and optimized for specific application such as different aluminium alloys, thicknesses, or same aluminium alloy but with different aging time, which will have different oxide layers on the surface of the sheet. Harry Atherton and el. [4] conclude that mechanical properties of resistance spot welded structures from AA5754 are dependent on the geometry of the spot weld distribution.

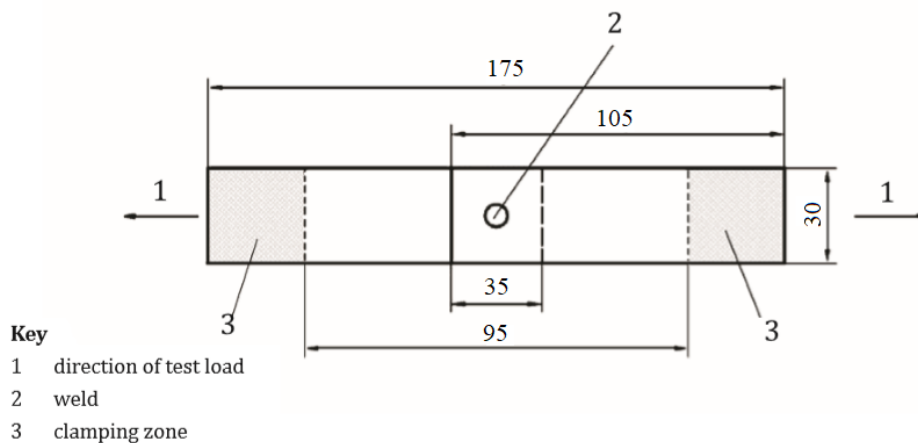


The parameter settings of each welding machine have been difficult because there are many sensitive factors [3]. Therefore, it is necessary to analyse the parameters affecting the quality and mechanical properties of the RSW joint using optimization method. There are plentiful literature about optimisation and lot of papers who dealt with parameter optimisation for RSW. Most of them have been done on single objective optimization, what is showed in in review paper of Zoha Nasir and M. I. Khan [9]. Karthikeyan R. and el [10] applies response surface methodology (RSM) to explore the effects of process parameters of spot welded aluminium alloy AA2024-T3 on the Tensile shear strength. Arick. M. Lakhani and Darji P.H. [11] in them research use Taguchi to generate design matrix for experimental work.

This paper will also present single objective optimization and failure load prediction of Resistance spot welding of aluminium alloy 57547. The experimental studies were conducted under varying welding currents  $I$ , electrode forces  $F$ , welding times  $T$ , pred preheating currents  $I_A$ . The settings of welding parameters were determined by using the Taguchi experimental design of L9 Orthogonal array method. For optimization and prediction will be used analysis of Signal-to-Noise (S/N) ratio and Response surface modelling RSM.

## 2. Experimental set-up

Sheet metals of aluminium alloy AlMg3 - AW5754 H22 as the parent metal to be lap welded were used in this research. The dimensions of the specimen are defined according to the standard ISO 14273:2016 (figure 1).



**Figure 1.** Dimensions of specimen.

The experiment involved joining of two sheet metals using RSW machine manufactured by Kocevar & sinovi which is managed using the BOSH 6000 software. Welding was carried out using electrode type A0 with radius 75 mm. The welding machine and dimension of electrode obtained from standard ISO 5821:2009, are showed on figure 2.

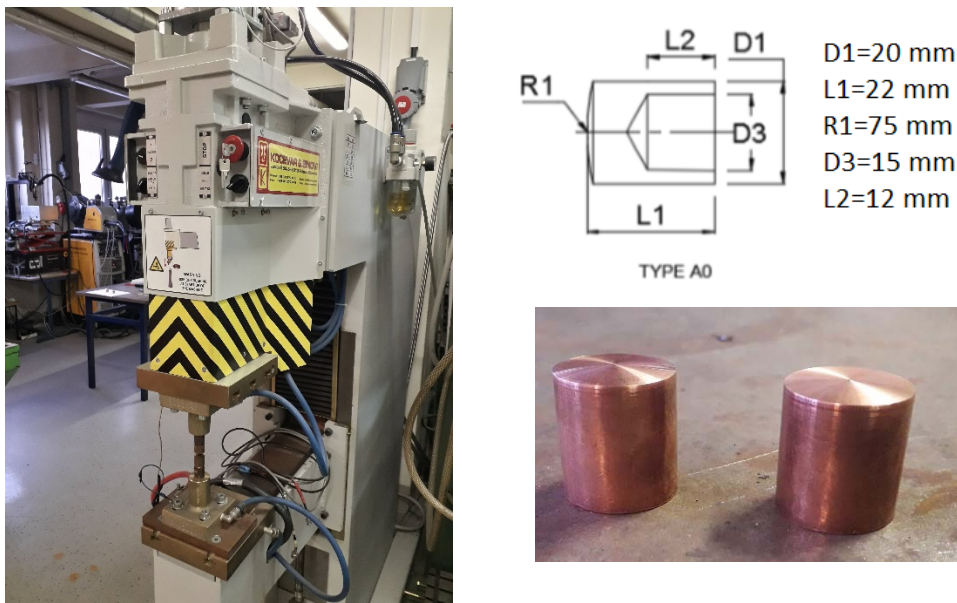


Figure 2. The welding machine and dimension of electrode.

Four welding parameters such as weld current  $I$ , electrode force  $F$ , weld time  $T$  and preheating current  $I_A$  were selected for experimentation for three levels of factors. The value of welding process parameter at different levels is tabulated in Table 1. Other welding parameters such as squeeze time (SQZ), hold time (HLD), pre-heating time (Pre-Weld), Cool Time (CT), Up Slope Time (UST) and Down Slope Time (DST) were constant during the experiment. Schedule obtained from software BOSH 6000, with values of this parameters is shown in figure 3.

Table 1. Selected levels for the parameters of the welding.

Factor/level	L1	L2	L3
Weld current $I$ [kA]	20	28	35
Electrode force $F$ [kN]	3,68	4,91	6,14
Welding time $T$ [ms]	80	140	200
Pre-heating current $I_A$ [kA]	6	8	10

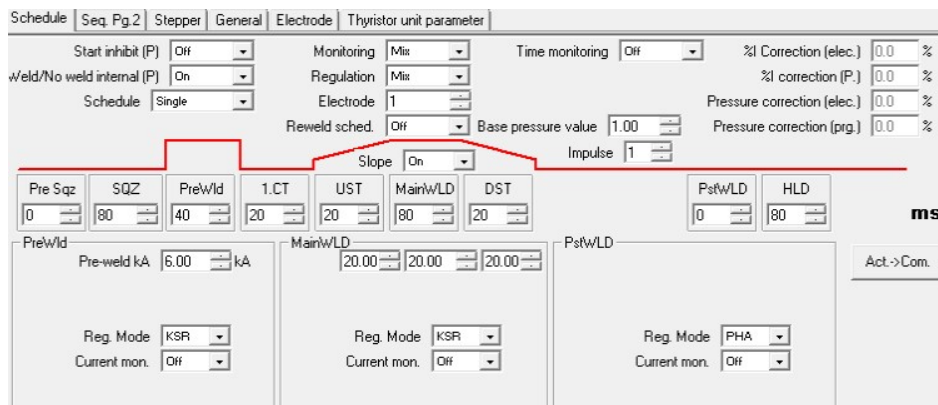


Figure 3. Schedule of RSW.

The tensile-shear tests were performed according to standard ISO 14273:2016 at cross-head speed of 2mm/min with a Beta 50-7 / 6x14 testing machine, as shown in Figure 4. As per the L9 orthogonal array for each combination of process parameters results obtained from the test are given in table 2.



**Figure 4.** Specimen prepared for testing.

**Table 2.** Experimental layout using L9 OA and result from tensile-shear tests (Failure load).

Runs	Weld current $I$ [kA]	Electrode force $F$ [kN]	Welding time $T$ [ms]	Pre-heating current $I_A$ [kA]	Failure load $F$ [N]
1	20	3,68	80	6	1504
2	20	4,91	140	8	1830
3	20	6,14	200	10	1638
4	28	3,68	140	10	2046
5	28	4,91	200	6	1581
6	28	6,14	80	8	1316
7	35	3,68	200	8	2719
8	35	4,91	80	10	1989
9	35	6,14	140	6	1862

### 2.1. Taguchi optimization and prediction

The total number of experiments can be substantially reduced with the help of a well-designed experimental plan without affecting the accuracy during the experimental study of any manufacturing process [12]. Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyse the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better [13].

In this research, the optimization will be done to maximizing the failure load, so it will be used larger-the-better categories to obtaining S/N ratio, as following equation:

$$\eta(S/N) = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^n \frac{1}{y^2} \right) \quad (1)$$

## 2.2. Response surface modeling (RSM)

Response surface methodology (RSM) is a multivariation analysis technique, in RSM, all the input process parameters are as sum to be measurable. It is required to find a suitable approximation for the true function relationship between independent variables and the response surface. Usually, a second-order regression model as given below is utilized in RSM:

$$y = b_0 + \sum_{i=1}^p b_i x_i + \sum_{i=1}^p b_{ii} x_i^2 + \sum_i \sum_j b_{ij} x_i x_j \quad (2)$$

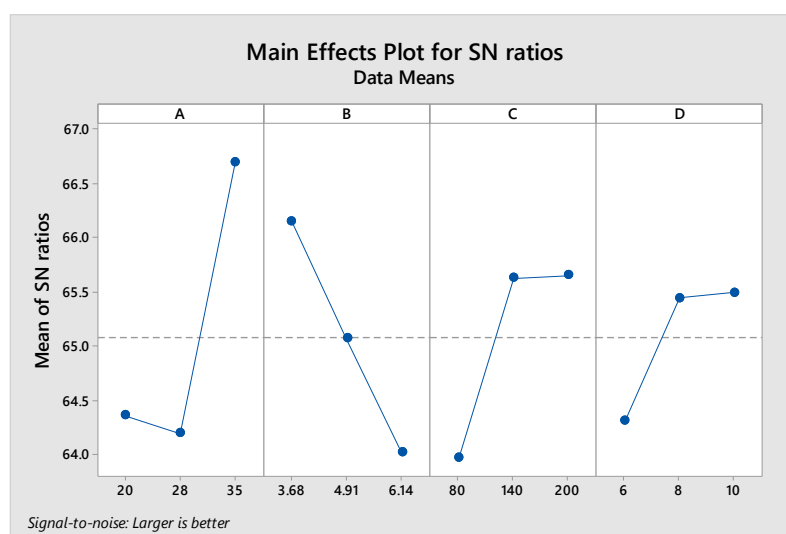
where all  $b$ 's are the regressions coefficients, determined numerically by using least square fit method,  $x_i$  are the different control factors changing from  $i=1$  to  $p$ ,  $p$  is the total number of control factors,  $y_j$  are the different responses ( $j$  are the number of responses used) [12].

## 3. Results and discussion

Optimization of the parameters of the process was carried out using the Taguchi method by computational software that indicated an optimal configuration according to the equation (1) for S/N ratio. The effect of different control factors on S/N ration is shown in Table 3. The optimum levels of different control factors for higher failure load are weld current at level 3 (35 kA), electrode force at level 1(3,68 kN), weld time at level 3 (0.2 s), and pre-weld current at level 3 (10 kA). The plot of S/N ration is showed in figure 5. It can also be concluded from table 3 that the welding current has the greatest influence on the failure force, while the pre-weld current has the slightest influence on the meaning of this force.

**Table 3.** S/N response and the level of parameters.

Level	A	B	C	D
1	64.36	66.15*	63.97	64.31
2	64.19	65.07	65.62	65.44
3	66.69*	64.02	65.65*	65.49*
Delta	2.49	2.13	1.68	1.18
Rank	1	2	3	4



**Figure 5.** Plot of S/N ratio.



Using the analysis of variance (ANOVA), the previous assertion that the most influence on failure load has a weld current is confirmed. The results in table 4 show that the welding current is with 43.65% contribution to maximize failure load.

**Table 4.** Results of ANOVA for Failure load.

Factors	DoF	Sum of Squares	Mean of squares	F	P	Contribution (%)
A	2	11.656	5.828	-	-	43,65%
B	2	6.786	3,393	-	-	25,41
C	2	5.573	2,7865	-	-	20,87
D	2	2.689	1,345	-	-	10,07
Error	0	2.91E-11	-	-	-	-
Total	8	26.704	-	-	-	100%

The predicted S/N ratio at the optimal level of the welding parameters can be calculated as:

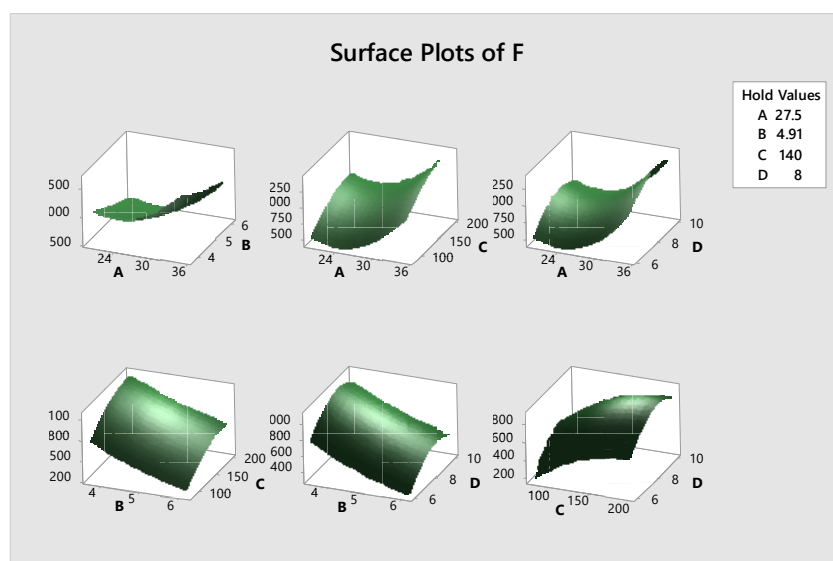
$$\eta = x + \sum_{i=1}^n Y_i - x \quad (3)$$

where  $x$  is the mean of S/N ration and  $Y$  is the average S/N at the optimal level. Using this equation, it turns out that S / N ratio at an optimal level is 68.74, so that failure load at the optimum level is 2735.179 N.

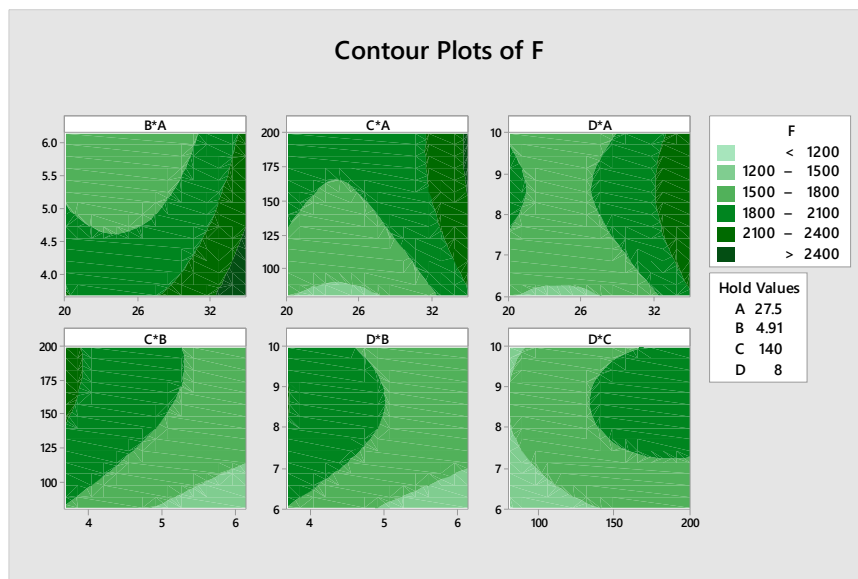
The response surface model (RSM) for failure load  $F$  has been developed from the experimental response values obtained using L9 OA experimental matrix. The above-mentioned model is presented below as the equation:

$$F = 1971 - 253A + 505,2B + 12,59C + 800,5D + 5,246A^2 + 31,4B^2 - 0,03375C^2 - 46,25D^2$$

To obtain the influencing nature and optimized condition of the process on failure load  $F$ , the surface plots and contour plots which are the indications of possible independence of factors have been developed for the proposed empirical relation by considering two parameters in the middle level and two parameters in the x- and y-axes as shown in Fig. 6 and 7.

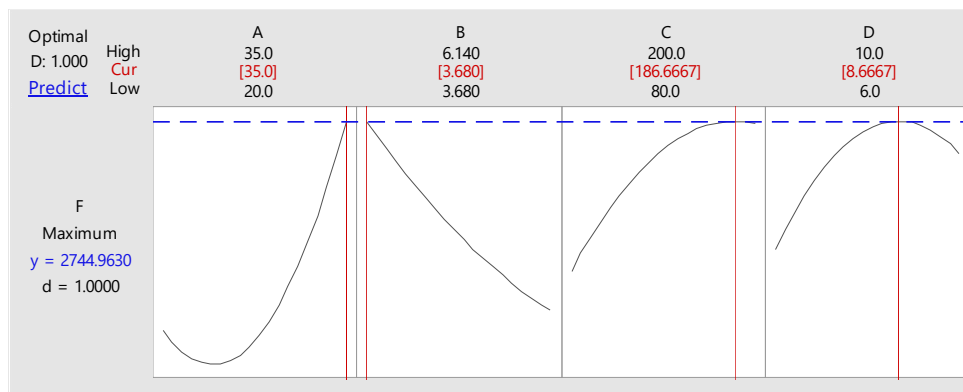


**Figure 6.** Surface plots of failure load (F).



**Figure 7.** Contour plots of failure load (F).

By analyzing the response surfaces and contour plots (Fig. 6 and 7), the maximum achievable failure load  $F$  value is found to be 2744,9630 kN. The corresponding parameters that yielded this maximum value are weld current 35 kA, electrode force 3,68 kN, weld time 0.1866667 s, and pre-weld current 8,667 kA, what is shown on the figure 8.



**Figure 8.** Response optimizer of RSW joint.

The percentage error between confirmation experiment and prediction is 10,3 % for the welding parameters  $I=20$  kA,  $F=3,68$  kN,  $T=120$  ms,  $I_A=8$  kA what is showed in table 5. The same table also shows the prediction error for parameters  $I=30$  kA,  $F=3,68$  kN,  $T=160$  ms,  $I_A=6$  kA and its value is 15.5%.

**Table 5.** Results of the confirmation tests for failure load (F).

Verifications	Actual F (N)	Predicted F (N)	Error %
1 (A=20 kA, B=3,68 kN, C=120 ms, D=8 kA)	2279	2043	10,3
2 (A=30 kA, B=3,68 kN, C=160 ms, D=6 kA)	2317	1955,72	15,5



#### 4. Conclusion

Taguchi method and response surface modelling has been used in this research for optimizing welding process parameters of RSW joint of AA5754 aluminium alloy. Based on the modelling and optimization results, the following conclusion can be drawn:

- (I) Optimum conditions for four parameters (weld current, welding time, electrodes force and pre-heating current) affecting failure load of the joints. Based on the results, the effectiveness of the parameters as follows: 1-weld current, 2- electrodes force, 3-welding time, and 4- pre-heating current;
- (II) The optimum conditions for the parameters based on Taguchi method as follows: current of 35kA, 3.68 kN as the electrode force, 0.2s as the welding time and 10 kA as the pre-heating current. The optimum conditions for the parameters based on RSM as follows: current of 35kA, 3.68 kN as the electrode force, 0.186667 s as the welding time and 8.667 kA as the pre-heating current;
- (III) The confirmation test results demonstrate that the use of parameter design of the Taguchi method and RSM provides a simple, systematic, and efficient methodology for optimizing the process parameters.

#### Acknowledgment

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