# The Process of Optimization of Spot-Welding Conditions and Analyze of the Effect on the Nugget Diameter by Using Taguchi Methodology

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**Abstract:** Joining dissimilar metals has become very used in many industries, the resistance spot welding has increased in the automotive industry and the aerospace industry, because, it has a lot advantages like high speed, high productivity in assembly automatic line. The complicated behavior of this process is a green field to be analyzed and have the optimum parameters in the purpose to get an excellent quality weld.

This paper presents the process of the optimization of the parameters of resistance spot welding by using the method of plans of experiences with the approach Taguchi. The experimental studies were made to describe the effect of all the parameters on the nugget diameter of the welded spot such as the cooling water and holding time, a few researchers have been study the effect of all parameters and their interactions (current, electrode force, welding time, holding time and cooling water). The optimal combination of the parameters of resistance spot welding for the metal sheet was obtained by using the analysis of signal to noise by calculating the ratio (S/N). The tests of confirmation indicated that it is possible to improve the parameters to have more significant results (profits) in this process of production. The effect of electrode force, current and the cooling water was observed important to have more significant result. The holding time is not significant comparing to the other parameters.

Key words: Welding spot, approach Taguchi, nugget diameter, welding parameters.

# 1. Introduction

Spot welding is a discontinuous, overlapping assembly process. It used to assembly metal sheet and mild steel assemblies, alloy steel, stainless steel and aluminum, generally with a thick between 0.5 and 10 mm [1]. The resistance spot welding is widely used in sheet metal fabrication as an important joining process in many industries. It's an uncomplicated process that use two copper electrodes to press the work sheets together and force high current to pass through it [2]. The joining dissimilar materials have many advantages, including complex mechanical proprieties, which reduces the cost and weight of the welded parts which necessary in the field of the automotive and aerospace industries [3].

To produce a spot weld, electrodes are applied to an overlapping region of two pieces of metal as illustrated in Fig. 1, producing a single lap joint. The heat is used in joining the work parts of metal. Heat is generated from electrical resistance across the two work parts of metal are joined together by applying electric current and pressure in the zone to be weld, spot welding is based on four factors that are necessary for the operation [4]:

- Amount the current that passes through the work piece,
- Pressure that the electrodes applied on the work piece,
- The time of current flow through the work piece,
- The area of the electrode tip contact with the work piece.



Fig. 1. Resistance spot welding [4].

During this process, the electric current is flow through electrode tips to separate work pieces of metal to be joined. The heat generated is a function of current, time and resistance between the electrode. The heat that generates in resistance spot welding according to joule's law is expressed by "Equation (1)":

$$H = I^2 R t \tag{1}$$

*H* = Heat is generated (in joules)

*I* = Current (in amperes)

*R* = Resistance (in Ohms)

*t* = time to current flow (in seconds).

The Fig. 2 shows the most conventional configuration of spot welding of two parts by means of a series of weld points performed by an operator on a welding machine.



Fig. 2. Welding machine [1].

The two pieces are placed and held in their respective assembly position, then introduced into the arms of the machine. The action of a pedal for each of the points realize a complete cycle which includes the phases of Fig. 3.



Fig. 3. Phases of a complete weld cycle.

## 2. Previous Investigation

Many articles report that work has been done on different aspects of modeling, simulation, and process optimization in the resistance spot welding.

Many experiences and studies conducted to establish the effects of parameters on the quality, weld strength and productivity. The main target to select a welding parameters leading to an optimal process.

Uğur Eşme (2009) [5] propose an application of Taguchi method to determine the welding process parameters with the optimal tensile shear strength, he use the method to improve the quality and the productivity and he confirm that the high quality can be produced at low cost with this tool. According to his study the most effective parameters with respect to tensile shear strength (current, effort, electrode diameter and welding time), and the current was more important two times than the force electrode. The results showed that the shear strength was increased by 2.03 and 1.20 times for 1 mm and 2 mm, respectively.

Makwana Brijesh "and all". (2017) [6] used the austenitic stainless steel304 material for 2.0 mm of thickness to study the resistance spot welding behavior. He used Taguchi method to reduce the number to run for experimental work and find the optimum results, with total experiences 27. He finds that the pressure was observed less effective factor, and the significant parameter is the welding power and weld time increases whereas pressure is decreases. Also, the contributions of each parameter, pressure is contributing with 46,46%, weld time 9,10%.

Yash Modi "and all". (2017) [7] present an experimental work and approach to determine the effect of different process parameters on weld quality and tensile strength of the weld, by using mild steel with 3 mm of thickness. The experience showed that the welding parameters are the most important factors for the strength, also the good combination is mandatory to have a high level of the strength of joining weld. In his experience, the most important parameter is holding time and the parameter that influence less is the weld time.

A.G Thakur and V.M Nandedkar (2010) [8] use the stainless steel AISI 304 to determine the effect of pressure, weld time and current. According to his study, the result confirm that the percentage contribution of current was 31.18% and weld time was 17.77%, comparing to the contribution of pressure 2.89%, the current and weld time are more significant for tensile shear strength.

Maomgtemsu Pongener and G.gopinath (2016) [9] conduct an experimental study to join aluminium by spot welding process by varring parameters welding current, weld time and voltage. The experiment results show that the current effect on the tensile strength is increasing when the current is increase and the tensile strength decrease with the velocity increase. the effect of weld time on the tensile strength is increasing. To get high tensile strength, the optimal parameters are current 30 maps, voltage 220V and welding time 6 secs.

Shaik Shafee, B. Balu Naik, K. Sammaiah and Mohd. Mohinoddin. (2014) [10] presents an experimental study on the optimization and the effect of RSW process on the tensile shear strength and direct tensile strength of spot-welded low carbon steel sheets. The highly effective parameter was found as welding current and welding time for 0.8 mm thickness of sheets. For 1mm thickness, the effective parameter on tensile shear strength were found as welding current and electrode force. The confirmation tests indicated that it's possible to increase tensile shear strength significantly.

Arjun Kumar and Sanjeev Sharma (2017) [11], this experience was carried out to analyze the effect of weld current and weld time on the weld nugget diameter, the work piece used to conduct this study is materiel JSC270C sheet with 6 mm thick. In this experience the spot aesthetic quality decrease when the welding current is increasing and the weld time is reducing. As a result, the weld current 10KA and weld cycle 10 is the optimal parameter for 6 mm thick sheet.

From the literature that we mentioned before, a few researchers have been study the effects of all welding parameters such as the cooling time and holding time, all the studies are concentrated on the effects of the three significant parameters (Current, effort and welding time).

In this paper, an experimental study is launched to analyze the effect of all welding parameters on the weld nugget diameter by using a steel sheet with thickness 0.8 mm, and propose the optimal combinaison of all parameters. The welding parameters concerned by the study are the Current, electrode force, welding time, holding time, and the cooling time.

According to last studies, the reduction of the electric intensity and the pressure force will increase the life of the machine and the tool. The goal of this optimization is to have a useful product quality without increasing the cost of its implementation.

The study about optimizing welding conditions finds its position in the significant improvement plans and the optimization leads to be launched to bring gains to the automotive company.

#### 3. Approach Used

Taguchi approach to design parameter provides the design engineer with a systematic and efficient method to determine the optimum parameters for performance and the cost. The goal is to choose the best combination of control parameters so that the product or process is the most robust in terms of sound factors in this case, electrode force, current, welding time, holding time and the cooling time [12].

Many experiments must be carried out when the number process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiences. Using an orthogonal chart to design, the experiment could help designers to study the influence of controllable factors. Using the signal-to-noise ratio to analyze the experimental data could help the product's co- receivers and the manufacturer to easily discover optimal parametric combinations [13].

The goal of using the loss function is to calculate the difference between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise. Usually, there are three categories of quality characteristic in ratio analysis, that is, lower-better, more-big-best and more nominal better. The ratio for each level of process parameters is calculated based on the analysis.

Regardless of the category of the quality feature, a higher S/N ratio is a better-quality characteristic. So, the optimal level of the process parameters is the level with the highest S/N ratio. In addition, an analysis of variations statistic is performed to determine the parameters which are statistically significant. The optimal combination of process parameters can then be provided.

Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design. the experiments were performed on welding machines with welding options by point and by projection used in the automotive industry.

# 3.1. Experience Details

The present work has been planned to optimize the welding parameters of steel parts having a thickness of 0.8 mm.



Fig. 4. Drawing of the part to be welded.

Table 1. The Chemical Composition and Mechanical Properties of the Material Used in This Experience						
Chemical		С	Mn	Si	Р	S
composition %	-	0.08	0.4	-	0.03	0.03
Mechanical property	R <sub>p 0.2</sub> min (MPa)		Rm min (MPa)	Rm max (MPa)		
	210		270	350		

# 3.2. Materials and Methods

The part used during the experience is a metal sheet cut in rectangular form with the same dimensions "Fig. 4". To perform the test 27 cross pieces will be needed to complete the combination. During the study, the electrode used is an electrode alloy of Cu-Cr-Zr. The choice of electrode was made using the following "Equation (2)"

$$D = 5\sqrt{E} \tag{2}$$

*D*: The diameter of the active face of the electrode (mm).

*E*: The thickness of the metal sheet to weld, this parameter was kept constant during the experiment.



Fig. 5. Welding machine and the tool.

# 3.3. Machine and Tool to Weld

The machine used to perform the spot welding is a machine with a power 125 kVA. The tool used for welding has been designed and manufactured to ensure the assembly of cross pieces "Fig. 5".

The template has been manufactured in such a way that the welding is centered and the two parts are properly docked. After placing each cross piece in the tool, the 27 pieces obtained with the combination established by the Taguchi plan are shown in Fig. 6.



Fig. 6. Welded parts after test launch.

# 4. Optimal Process Parameters "Results and Discussion"

## 4.1. Taguchi Methods

In this study, five welding parameters were taken into consideration to constitute the Taguchi table, and three levels, such as welding force, current, welding time, holding time and forging time. Table 2 illustrates the set of parameters and levels:

	ocess r aranne	ciers and i	Then values at	Different Levels	
Welding parameters	Symbol	Unit	Level 1	Level 2	Level 3
Electrode force	Е	daN	285	300	315
Welding intensity	Ι	kA	7.88	8.3	8.71
Welding time	Tw	Cycle	7.6	8	8.4
Holding time	Th	Cycle	57	60	63
Forging time	Tf	Cycle	14.25	15	15.75

Table 2. Process Parameters and Their Values at Different Levels

Table 5. The Design Matrix for Tagueni L27						
No. experience	I (kA)	E (kN)	Tw	Т	Th	
1	1	1	1	1	1	
2	1	1	1	1	2	
3	1	1	1	1	3	
4	1	2	2	2	1	
5	1	2	2	2	2	
6	1	2	2	2	3	
7	1	3	3	3	1	
8	1	3	3	3	2	
9	1	3	3	3	3	
10	2	1	2	3	1	
11	2	1	2	3	2	
12	2	1	2	3	3	

13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

The diameter of the electrode has been taken as a constant parameter. The correct Taguchi table obtained by the calculation of factor numbers and levels. In this study the table contains twenty-seven L27experiments (number of rows) (3<sup>5</sup>) (Table 3).

The values in the Taguchi table corresponding to each level are represented in Table 4. The study of the influence of welding parameters on the quality of the product begins with determining the most optimal combination, identifying an answer for each test is mandatory.

No. experience	Intensity (kA)	Electrode force (kN)	Welding time (period)	Forging time (period)	Holding time (period)
1	7.88	285	7.6	14.25	57
2	7.88	285	7.6	14.25	60
3	7.88	285	7.6	14.25	63
4	7.88	300	8	15	57
5	7.88	300	8	15	60
6	7.88	300	8	15	63
7	7.88	315	8.4	15.75	57
8	7.88	315	8.4	15.75	60
9	7.88	315	8.4	15.75	63
10	8.3	285	8	15.75	57
11	8.3	285	8	15.75	60
12	8.3	285	8	15.75	63
13	8.3	300	8.4	14.25	57
14	8.3	300	8.4	14.25	60
15	8.3	300	8.4	14.25	63
16	8.3	315	7.6	15	57
17	8.3	315	7.6	15	60
18	8.3	315	7.6	15	63
19	8.71	285	8.4	15	57
20	8.71	285	8.4	15	60
21	8.71	285	8.4	15	63
22	8.71	300	7.6	15.75	57
23	8.71	300	7.6	15.75	60
24	8.71	300	7.6	15.75	63
25	8.71	315	8	14.25	57
26	8.71	315	8	14.25	60
27	8.71	315	8	14.25	63

Table 4. Values of Taguchi Table

The Table 5 shows the results of the destructive tests for combinations of the Taguchi table. In this case, the answer is the average of the nugget diameter. In the "Fig. 7", the part after destructive test.

No. experience	Average of nugget diameter (mm)
1	5.190
2	5.360
3	5.290
4	5.710
5	5.640
6	5.430
7	6.130
8	5.710
9	6.090
10	5.480
11	4.570
12	5.460
13	5.330
14	5.440
15	5.150
16	5.590
17	5.770
18	5.200
19	4,675
20	5.940
21	4.540
22	4.890
23	4.790
24	5.170
25	5.460
26	5.340
27	5.160

Table 5. The F	Results of the Nugget Diameter	
lo. experience	Average of nugget diameter (mm)	No.
1	5 190	

Tuble (	
No. experience	S/N dB ratio
1	14.3033472
2	14.5832958
3	14.4691134
4	15.1327222
5	15.0255821
6	14.6959966
7	15.7492095
8	15.1327222
9	15.6923459
10	14.7756112
11	13.198324
12	14.7438529
13	14.5345442
14	14.7119780
15	14.2361446
16	14.9482362
17	15.2235163
18	14.3200669
19	13.3956323
20	15.4757289
21	13.1411171
22	13.7861772
23	13.6067103
24	14.2698109
25	14.7438529
26	14.5508251
27	14.2529940

Table 6 S/N ratio



Fig. 7. The welded part after the destructive test.

# 4.2. Calculation of Quality Loss Function and Signal Noise (S/N) Rate

Maximize the response that is have the largest diameter after destructive test. The rule is to prefer the bigger one. The formula for calculating the quality loss function:

$$L_{i} = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_{i}^{2}}$$
(3)

The signal-to-noise ratio is obtained by "Equation (4)":

$$S/N_i = -10LogL_i \tag{4}$$

The number n represents the number of experiments carried out and  $y_i$  is the experimental values of the destructive test. To maximize the mechanical characteristics of the parts while optimizing the welding parameters, the approach "The optimum is a maximum" will be used. The effect of each combination of welding parameters on the variation of the S/N ratio is grouped on Table 6.

According to the table VI, the optimum diameter of spot-welding nugget corresponds to the largest value of the ratio S/N, and the value of parameters are:

$$(I_1. E_3. T_{w3}. T_{f2}. T_{h2})$$

The Table 7 shows the variation of the average ratio S/N based on the different combinations of the welding parameters.

		S/N Ratio				
Parameter	Symbol	Level 1	Level 2	Level 3	Total average	Extended
Welding intensity	Ι	14.98	14.52	14.14		0.84
Electrode force	E	14.23	14.44	14.96		0.73
Welding time	Tw	14.39	14.57	14.67	14.545	0.28
Holding time	Th	14.49	14.6	14.55		0.11
Forging time	Tf	14.6	14.61	14.42		0.19

#### Table 7. S/N Responses for the Destructive Tests

Fig. 9 represent the graphical evolution of the variation of the signal-noise average of each combination of the parameter levels.



Fig. 8. Variation of average «S/N» according to the levels.



Fig. 9. Effects of parameter interactions on the diameter of the weld button.

When the values of a signal-to-noise ratio are high, it means that the control factor parameters limit the effects of the noise factors. The analysis of interactions between factors are a diagram of the interactions is shows the effects of five parameters on the nugget diameter, there's an interaction when the effect of one factor depends on the level of the other factor.

In this parcel of interaction, we note that the lines of the effects are not parallel, which proves that there is an interaction between the five parameters in the three levels. Fig. 10 shows the effect of the interactions between the parameters on the solder button.

#### 4.3. ANOVA Analysis





The verification of the conditions of the ANOVA analysis is to ensure the following conditions: normality, heteroscedasticity and independence (the latter is checked because the tests were randomized).

The distribution of the different points tends to a linear line, which conforms to the hypothesis of normality. For the hypothesis of heteroscedasticity, the variation in the value of the error with respect to the predicted value is almost constant. hence, the validation of the hypothesis.

The Table 8 presents the contribution in percentages of the five parameters and their interactions:

Settings and interaction	Percentage of contribution %
I (current)	9.25
E (Electrode force)	11,67
Tw (welding time)	1.2
Tf (cooling time)	1.24
Th (Holding time)	1.14
Interaction	3.65

Table 8. Contribution of Parameters in the Process

The factor whose value is the largest is more significant from a statistical point of view, in this case is the effort, with a largest value of 3.56 and the P-value less than 0.05, which indicates that this parameter is statically significant.

The percentage of contributions from the welding force is highest and it reaches 11.67 %, which indicates that the power related to this parameter to reduce the variation is quite considerable. Therefore, a small variation of the force will have a significant influence on the nugget diameter.

The effort of welding and the welding current intensity are the parameters present considerable interest to improve the resistance welding.

#### 4.4. Confirmation of Tests

The main purpose of this test is to validate the conclusions deduced during the previous analytical phase. Generally, the confirmation test is based on the performance of a test with an optimal combination of parameters and the evaluated levels.

the experimental value of the weld button will be compared with the statistically predicted value to verify the improvement in the performance characteristics involved.

The Fig. 11 below shows the optimal combination of welding parameters who gives the maximum Pulldiameter, with the Minitab software (function: optimize of the answer).

The combination  $(I_1, E_3, T_{w3}, T_{f2}, T_{h2})$  is the most optimal for a stall diameter equal to 6.470 with a desirability equal to 1.



Fig. 11. Optimal combination (Minitab software) [14].

Factors controlled	Optimum level	optimum value
I (kA)	1	7.88
E (daN )	3	315
Tw (period)	3	8.4
Tf (period)	2	15
Th (period)	2	57

Table 9. Values with the Optimum Levels

By using the signal-noise approach, the optimum combination of the welding parameters is the combination of the levels that the parameters when the S/N ratio has a maximum. The optimal combination is the same determined by the Minitab software.

#### 4.5. Conclusion

This paper presents a study on the optimization of the conditions of spot-welding parameters, and presents the analysis on the effect of all welding parameters on metal steel sheet with 0.8 mm of thickness.

A combination of optimum parameter for the maximum nugget diameter was obtained using signal-tonoise analysis and the ratio (S/N). The Taguchi methodology was used during the study.

The experimental results confirmed the validity of the Taguchi method to improve the performance of welding and optimization of welding parameters in resistance spot welding operations.

Based on the previous analysis, we found that the welding current and electrode force are the most important factors in the process according to percentage of contribution. The experimental result show that the cooling time have a contribution much better than the holding time with 1.24%.

Also, the influence of spot-welding conditions is determined by two parameters welding force with a contribution 11,67 % and welding current intensity with 9.25%, the other factors, holding time and cooling time have other influence but not on the welding behavior.

Therefore, in order to get a desired weld nugget, the selection of suitable force value, current intensity and cooling time is mandatory.

#### **Conflict of Interest**

The authors declare no conflict of interest.

#### Author Contributions

MA and AO carried out the Study conception, design and previous investigation. MA Prepare all the materials and tools to perform the tests and experiences. IE contributes to data collection, MA and IE data analysis, statistical support and interpretation of data. Critical revision was conducted by AO and drafting of manuscript by MA.

All authors read and approved the final manuscript.

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