JOURNAL OF CRITICAL REVIEWS
ISSN- 2394-5125 VOL 7, ISSUE 08, 2020

Defect Analysis of Resistance Spot Welding Results Using Fault Tree Analysis and Comparison of Optimizing Parameter in the Process of Spot Welding Process Using Taguchi Techniques and Response Surface Methodology in PT X

[1]Pretty Princess Pontororing, [2]Stanley, [3]Aditya Andika

[1],[2],[3]Industrial Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

[1] pontororingchika@gmail.com

[2] stann.2996@gmail.com

[3]aandika@binus.edu

Received: 11.03.2020 Revised: 12.04.2020 Accepted: 28.05.2020

Abstract— The quality of a product depends on the production process, one of them is resistance spot welding process. Defect is named for the products that failed to fulfill the company's standard. There are 2 causes of defect, no nugget diameter on spot welding and spot welding crack. These 2 causes of defect will be analyzed using fault tree analysis. To reduce the amount of defect on resistance spot welding process, therefore parameter optimization is done by using 2 parameter optimization methods namely, Taguchi Technique and Response Surface Methodology. Parameter optimization focus on 3 parameters is, welding current (kA), welding time (cycle), and electrode force (kN). Based on Taguchi Technique, the optimal parameters are 8,7 kA on welding current, 18 cycles on welding time, and 1,6 kN on electrode force. Meanwhile, Response Surface Methodology are 8,7 kA on welding current, 19 cycles on welding time, and 1,6 kN on electrode force. The differences between the both methods are cost, time based on the number of runs orders, and how it processed.

Index Terms—Failure Mode and Effect Methods, Fault Tree Analysis, Quality, Resistance Spot Welding, Response Surface Methodology, Taguchi Technique.

I. INTRODUCTION

The automotive industry will continue to make progress every year so that consumers remain interested in buying these products. The government is targeting car sales to reach 1.1 million - 1.2 million units to be able to realize the industry growth target of 5.67%. The automotive industry is not only focused on quantity, but still maintains and improves product quality. Therefore, so that this can be achieved an analysis of the occurrence of defects and optimization in the process of making a car.

One of the process of making a car is resistance spot welding at PT X. Resistance Spot Welding (RSW) is a process of combining two or more materials that form the structure of a car. In general, there are around 4000-6000 welding points on a car [1].

The results of the RSW will not always match the quality provisions that already exist (defects) because the performance of a tool will decrease along with the frequent use of spot welding tools. One way to prevent the performance of spot welding tools is to optimize parameters in the RSW process. RSW has several parameters that can affect the results of the process, namely welding current, welding time, electrode force, conditions on the surface, type of electrode, etc.

The causes of defects in RSW results can be determined by using the Fault Tree Analysis (FTA) method which is assisted by the Failure Mode and Effect Analysis (FMEA) Method, Pareto Diagram, and Scatter Diagram to reduce failure mode. Whereas for parameter optimization using the Taguchi Technique and Response Surface Methodology with 3 parameters that can affect welding quality, namely welding current, welding time, and electrode force. Quality testing of spot welding results using diameter nugget evaluation.

II. RESEARCH METHOD

This research was conducted in one of the processes of making a car, namely Resistance Spot Welding (RSW). Spot welding resistance is an amalgamation process that is often used today, especially in the automotive industry. RSW is more applied in the automotive industry because it has excellent techno-economic benefits such as low operating costs, high production levels due to the strength, speed, flexibility that exists in RSW, and the ability to adapt to automation which makes RSW a good choice for assemblies auto-body [1]. This research was conducted to optimize three predetermined parameters, namely welding current, welding time, and electrode force and the variable response of the three parameters is the diameter nugget. This study uses the design of the Taguchi Technique and Response Surface Methodology (Box-Behnken Design) and the material used is SCGA270D with different thicknesses of 1.2 mm and 2.0 mm and different sizes according to the JIS G 3136 standard.

Processing and analysis of data using the Fault Tree Analysis Method, Failure Mode and Effect Analysis, Taguchi Techniques, and Response Surface Methodology. Fault Tree Analysis (FTA) is one of the most frequently used techniques for usable and safe analysis, and evaluates large amounts of risk and difficult systems by utilizing logic and probability. FTA provides an effective method for evaluating risks at the system level by utilizing various tools [2]. Failure Mode and Effect Analysis (FMEA) is an analysis technique that combines the technology and experience of people in identifying possible modes of error in a product or process and planning to be eliminated. FMEA is a "before-the-event" action that requires team efforts to easily and cheaply mitigate changes in design and production [3]. The Taguchi technique is a technique developed by a scientist Dr. Genichi Taguchi. According to Taguchi, quality must be assessed directly from the final product itself and not merely assessed. Taguchi is a methodology that aims to improve quality and processes with varying output conditions [4]. The characteristics used to determine a spot welding quality using the Taguchi Technique are larger the better, because the larger the diameter of the nugget, the better the quality of spot welding. Response Surface Methodology (RSM) is a statistical and mathematical technique that is useful for developing, improving, and optimizing processes. The application of RSM is also important in the design, development, and formulation of new products, as well as improving the design of existing products. The use of RSM is most widely used in the industrial world, more precisely in situations where several input variables have the potential to affect performance measures or quality characteristics of a product or process. The measure of performance or quality characteristics is the response. Input variables are usually called variable variables [5]. RSM has two designs namely the Central Composite Design (CCD) with a minimum of 20 runs orders and the Box-Behnken Design with a minimum of 15 runs orders. This research uses Box-Behnken Design because it has fewer runs orders compared to CCD with the aim of minimizing costs and requires less time in research.

III. RESULT AND DISCUSSION

A. Fault Tree Analysis (FTA)

The first result that has the potential to cause spot welding results to not have a nugget diameter is equipment. Potential causes of defects in the equipment part are touching parts, short circuit in the cable and tip off center. Short-circuiting occurs because heavy manoeuvres are skipped due to overly long kick less and NG balancers. Short-circuit also occurs because the shank is bent due to heavy pressure and is hit by a jig / part. The next factor is a short circuit in the cable which can occur due to deteriorating cable conditions and due to large loads due to forced movements. And for the last factor is because the tip is not center, due to the bent shank, wrong tip type and rocking gun. Potential causes of defects in the condition section are caused by lack of current and short welding time. Insufficient current can occur due to the deteriorating condition of the cable due to the usage period of the cable and the large number of spots, also caused by a faulty timer caused by the usage period and overheat of the timer. And what can cause less current is the NG setting due to incorrect data input and wrong program usage. The next factor is the short welding time caused by a faulty timer and an NG timer. Next is the Material (tip gun) has five factors that have the potential to cause defects are dressings, worn tips, tucked in dirt, exceeds the wear limit of tips, and loose tips. Defect caused by the dressing factor is due to a blunt knife which is due to lack of maintenance on the blade and lack of training because there is no training material related to the dressing process. Next is the wear tip factor caused by excess electricity flow and large pressure. Excess electricity can occur, because the timer is broken so that it cannot indicate the time correctly, then setting the electric current incorrectly, and forgetting to reset the step up. Potential defects are also caused by the presence of dirt tucked into the tipgun, which can cause foreign objects on the panel to be spot welding. Defect occurs because 4S is not implemented. Defect tucked dirt can also be caused by excess anti-rust that is affected by weather conditions, and also the condition of the tip deteriorates due to the tipgun not being replaced. The next factor is due to the use of tips that exceed the limit. This can occur because of excessive dressings and scorched tips because the water channels are not smooth. The last factor that has the potential to cause defects is loose tips. Tips are released because the tips are sticky with the tip panel overheat and also because the pressure is lacking so the tips melt and are sticky. Next is because the tips are not tight and the NG taper is due to worn tips. Potential defects in the material can occur due to panel matching (large GAP) and panel matching. The potential cause is panel matching which can be caused by three factors, namely press defect, NG clamp, and bent flange. The cause of NG clamps is the press defect and also the worn datum. Whereas the bent flange is caused by the gun being attracted, bumping and the pin being attracted. Whereas panel matching is due to NG settings caused by incorrect data input and incorrect use of program settings and the latter is due to large pressures that cause NG settings. The first result that has the potential to cause spot welding cracks is equipment. Explanation of factors that have the potential to cause defects by equipment is due to the tip off center (the electrode is not right at the welding point) and the NG angle is the tip position is incorrect. Failures caused by tip not centered are bent shank and rocking gun which can be caused by large pressure, bumping parts / jigs, wrong tip type, or main wear pin shaft. Whereas for NG angle, it is caused by teaching defect and workability which is not good. Workability occurs because there is no gun guide and NG gun guide. Potential causes of defects in the conditions section are excess electrical flow caused by three factors, namely forgetting to reset step up, a broken timer and NG settings. The cause of the defect in the broken timer factor is due to the usage period which results in the functional decline of a timer and the occurrence of overheat due to an incorrect indication of the timer. Whereas in the NG setting factor, the cause is the incorrect input of data and the program used to set the parameter of the wrong electrical current. The last part of the cause of defects caused by crack is the material. The potential cause is panel matching which can be caused by three factors, namely press defect, NG clamp, and bent flange. The cause of NG clamps is the press defect and also the worn datum. Whereas the bent flange is caused by the gun being attracted, bumping and the pin being attracted.

B. Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis is used to analyse the effects that are at risk of causing product defects. In evaluating using the FMEA Method, previously the FTA Method was used to elucidate the causes of spot welding results not having diameter and crack nuggets. From the results of the FTA, the FMEA Method uses this description to be able to calculate the RPN and RSV values. In the FMEA Method there are three failure mode factors used, namely effects, causes of failure, and control and all three of these factors have their own assessment with a range of 1-10. After an assessment of each effect, cause of failure, and control is available, an RPN and RSV calculation will be performed to see the effect which is at risk of getting spot welding results without having a diameter and crack nugget. After that, evaluate for the S, O and D recommendations and assessments on all the effects which are at risk for doing the RPN calculation, as can be seen in the figure below.

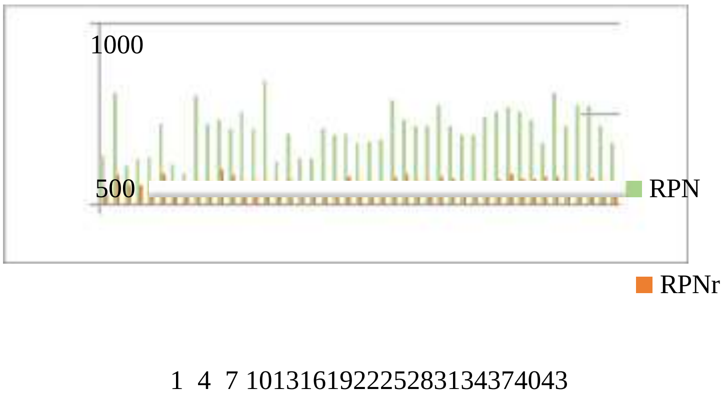

Fig. 1. Comparison of RPN and RPNr Results on Spot Welding Not Having a Nugget Diameter

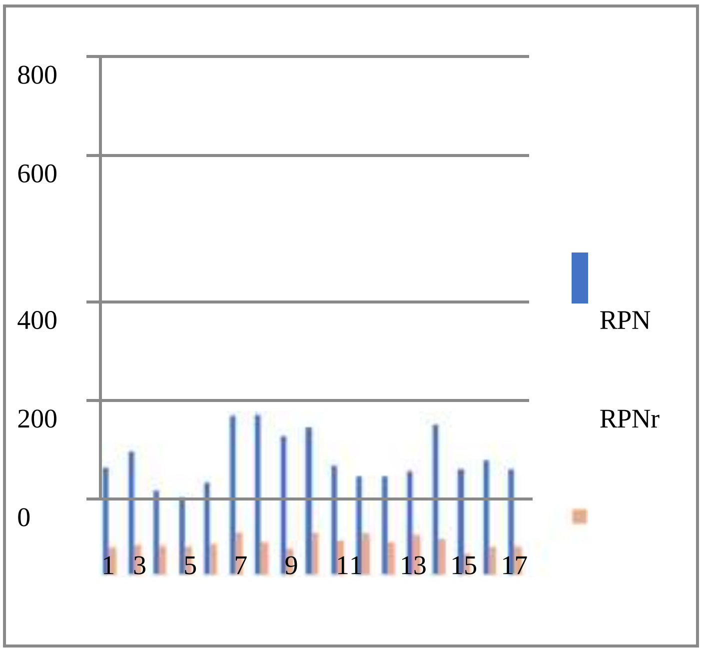

Fig. 2. Comparison of RPN and RPNr Results in Spot Welding Crack

In the picture above, the results of the comparison of the RPN and RPNr (recommended RPN values) it is clear that the results of the RPN value prior to evaluation have a high level of risk of the occurrence of spot welding results do not have a nugget diameter and crack is high. In contrast to the results on the RPNr which have a lower risk of the occurrence of spot welding results do not have diameter and crack nuggets. After knowing the results of the comparison between the value of RPN and RPNr is the opposite, where the results of the diagram on the value of RPNr is lower than the RPN. Then the effects that are at risk of failure mode are analysed using Pareto Diagrams and Scatter Diagrams. Pareto diagrams are used to see the effects that are at risk often occur in spot welding activities and the value of the principle of 80% or 20% is used on the Scatter Diagram. Scatter diagrams are used to see which effects are most at risk and action should be taken as soon as possible to reduce the results of spot welding having no diameter and crack nuggets. On the results of the spot welding scatter diagram results do not have a diameter nugget, of the 45 effects that are at risk there are 9 effects that are prioritized to be evaluated first, as can be seen in Table I.

Table I. Priority Effects on Spot Welding Results Not Having a Nugget Diameter

Spot Welding Results Have No Nugget Diameter

No	***Failure Mode***	***Effect***	***Recommended Action***
1	Tip offF	Taper NG	Always check shank
2	Tucked in dirt	The tip condition worsens	Check every 450 points
3	Dressing	Lack of training	Make a schedule for tip dressing training

4	Less OK current	Broken Timer	Measuring electric current first
5	Cable Shortage	Big burden due to forced movements	Replace the kick less cable
6	Tip off center	Bent shank	Check the spot welding process settings and conduct reset settings
7	Less OK current	Broken Timer	Flashing process 1 time in 2 months
8	Short welding time	Timer NG	Measuring electric current first
9	Touching part (short circuit)	Bent Shank	Fix crooked shanks

In the scatter diagram results of spot welding crack results, from 17 effects that are at risk there are 10 effects that are prioritized to be evaluated first, as can be seen in Table II.

JOURNAL OF CRITICAL REVIEWS
ISSN- 2394-5125 VOL 7, ISSUE 08, 2020

Table II. Priority Effects on Spot Welding Crack Results

Spot Welding Crack Results			
No	**Failure Mode**	**Effect**	**Recommended Action**
1	NG angle	Workability is not good	Make a gun guide
2	NG angle	Workability is not good	Replace the gun with a new one
3	Panel matching (large GAP)	Clamp NG	Check the clamp before doing the spot welding process
4	Electric current overload	Broken timer	Flashing process 1 time in 2 months
5	Electric current overload	Broken timer	Measuring electric current first
6	Tip off center	Bent shank	Check equipment and replace damaged equipment
7	Tip off center	Bent shank	Check and adjust pressure
8	Electric current overload	Setting NG	Check the spot welding process settings and make adjustments
9	Panel matching (large GAP)	Bent flange	Check the material and replace with a new one
10	Panel matching (large GAP)	Press Defect	Checking parts and returning if there are parts that are NG

C. Levels and Parameters Determination

Determination of levels and parameters is carried out to determine the scope to be used in the optimization process. Determination of levels and parameters is identified by brainstorming and cause-and-effect (FMEA) analysis conducted with supervisors and employees in the company. The result of the cause-and-effect (FMEA) analysis process is to determine the parameters used in the optimization. Next is to classify parameters into controlled and uncontrolled parameters. From the results of the FMEA based on the recommended actions, three actions can be classified as controlled parameters, as can be seen in Table III.

Table III. Classification of Controlled Parameters

No	Failure Mode	Effect	Recommended Action
1	Electric current overload	Broken timer	Measuring electric current first
2	Short welding time	Timer NG	Measuring electric current first
3	Tip off center	Bent shank	Check and adjust pressure

Based on Table IV the first is to measure the electric current first caused by an excess current. This can be interpreted as a problem related to welding current. Second is to measure the electric current first caused by a short welding time. This can be interpreted as a problem related to welding time. Third is checking and managing the pressure caused by the off center tip. This can be interpreted as a problem related to electrode force. These three parameters will be optimized with the aim of reducing or eliminating defects. These levels and parameters will be used in this research process, as shown in Table IV. Level 1 or -1 is the smallest limit for entering values in parameters, level 2 or 0 is the value of parameters used by companies today in conducting resistance spot welding, and level 3 or +1 is the highest limit for entering parameter values.

Table IV. Level and Parameter

No.	Parameters	Level		
		1	2	3
		-1	0	+1
1.	Welding Current (kA)	6,7	7,7	8,7
2.	Welding Time (Cycle)	18	19	20
3.	Electrode Force (kN)	1,6	1,9	2,2

D. Parameter Optimization

In the process of optimizing parameters each requires 3 levels and 3 parameters obtained from the process of determining levels and parameters. Following are the optimization methods used in the RSW process:

1. Taguchi Technique

Can be seen in table 5, the actual optimal results of the diameter nugget obtained using the Taguchi Technique are at the 9th running order. The nugget diameter obtained is 6.76 mm with a welding current value of 6.7 kA, welding time of 18 cycles, and electrode force of 1.6 kN. Although the actual results of the experiment, the optimal value of the parameter is on the 9th running order, but it cannot be assumed that the parameter on the 9th running order is the most optimal. Then the subsequent data processing will be proven using the Taguchi Technique.

S / N Ratio is one of the Taguchi techniques to find the optimal parameter values and parameter values that have the greatest effect on nugget diameter. Characteristics of S / N Ratio used is larger the better, because the optimal result of the desired nugget diameter is the result of a large nugget diameter. Large nugget diameter are one of the characteristics of good spot welding results. After calculating the S / N Ratio is done, then the average of the S / N Ratio is then sought and then the results of the difference between the highest and lowest average S / N Ratio will be analyzed. Based on the provisions of the larger the better characteristic, the calculation results obtained in the welding current parameter can be said to meet these requirements because it has the greatest value of 3.17, after that the electrode force is 0.79, and the last is the welding time with a value of 0,63 (can be seen in Table VI). The highest points on the graph of the optimal parameters for S / N Ratio shows the optimal value for each parameter. The optimal value of the welding current parameter is 8.7 kA, the welding time is 18 cycles, and the electrode force is 16 kN, can be seen in the picture.

Table V. S / N Ratio Calculation Results

Runs Order	*Welding Current (kA)*	*Welding Time (Cycle)*	*Electrode Force (kN)*	*Nugget Diameter (mm)*	*S/N Ratio*
1	6,7	18	1,6	5,23	14,37
2	6,7	19	1,9	4,4	12,86
3	6,7	20	2,2	4,25	12,56
4	7,7	18	1,9	6,19	15,83
5	7,7	19	2,2	5,74	15,17
6	7,7	20	1,6	5,92	15,44
7	8,7	18	1,6	6,47	16,21
8	8,7	19	2,2	6,68	16,49
9	8,7	20	1,9	6,76	16,59

Table VI. Optimal Parameter Calculation Results

Level	*Welding Current (kA)*	*Welding Time (Cycle)*	*Electrode Force (kN)*
1	13,26	15,47	15,43
2	15,48	14,84	15,09
3	16,43	14,86	14,65
Delta*	3,17	0,63	0,79
Rank	1	3	2

***Delta* = Difference

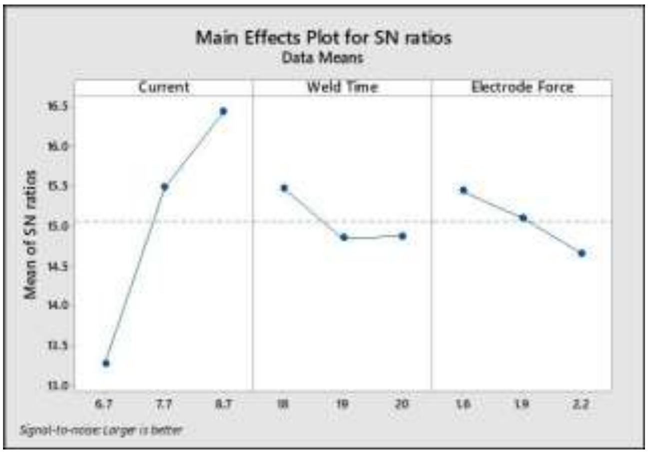

Fig. 3. Optimal Parameter Results for S / N Ratio (Main Effect Plot)

Analysis of Variance (ANOVA) is used in the Taguchi Technique with the aim, namely to see the parameters that most influence (significant) on the diameter nugget and see the results of the contribution of each parameter used in spot welding resistance. Based on data processing, a significant parameter that has a large contribution to spot welding resistance is welding current with a p-value smaller than α (0.029 ≤ 0.05) with a percent (%) contribution of 88.02%. As for the two parameters that are not significant, meaning that the parameters do not affect the diameter nugget (can be seen in Table VII). But optimization is still carried out because based on the results of the FMEA with these two insignificant parameters, it is a controlled parameter of the recommended action which means it must be evaluated first. Based on the results of data processing with the Taguchi Technique, the most optimal parameter results are the welding current of 8.7 kA, 18 cycle welding time, and an electrode force of 1.6 kN.

E. Response Surface Methodology (RSM)

Based on the results of data processing, the mathematical model in the first-order cannot be used because of the lack of fit in the ANOVA results for the model is significant (p-value ≤ 0.05) which means the model is not suitable. Although the first-order mathematical model has obtained significant results, but in the lack of fit to get significant results, the mathematical model cannot be used. If the first-order mathematical model is not used, there will be a development of the model, namely the second-order model.

The mathematical model in the second-order can be used because in the ANOVA results, the mathematical model in the second-order gets a significant result (p-value ≤ 0.05) which means that the independent variable (parameter) influences the value of the fixed variable (response / nugget diameter). Next is the lack of fit which has a p-value = 0.0743 or greater than the degree of significance α = 0.05 (p-value ≥ 0.05) which shows insignificant results on the second-order model means that the model is suitable. After that, the R^2 results in the ANOVA table is 0.9331 which means that 93.31% of the mathematical model in the second order can be used to predict parameters in the spot welding process and has a strong relationship between the independent variable (parameter) and the fixed variable (nugget) diameter), see Table VIII.

Table VIII. ANOVA for Second-Order Model

Source	*Sum of Squares*	*df*	*Mean Square*	*F-value*	*P-value*	
Model	4,06	9	0,4507	7,74	0,0182	significant
A-Welding Current	2,05	1	2,05	35,23	0,0019	
B-Welding Time	0,1891	1	0,1891	3,25	0,1313	
C-Electrode Force	0,0882	1	0,0882	1,52	0,2731	
AxB	0,4422	1	0,4422	7,60	0,04	
AxC	0,0196	1	0,0196	0,3367	0,5869	

BxC	0,1600	1	0,16	2,75	0,1582	
A²	0,0036	1	0,0036	0,0619	0,8133	
Source	Sum of Squares	df	Mean Square	F-value	P-value	
B²	1,04	1	1,04	17,9	0,0082	
C²	0,0307	1	0,0307	0,5282	0,4999	
Residual	0,2910	5	0,0582			
Lack of Fit	0,2764	3	0,0921	12,62	0,0743	not significant
Pure Error	0,0146	2	0,0073			
Cor Total	4,35	14				
Std. Dev		0,2413	R2			0,9331
Mean		5,94	Adj. R2			0,8126
C.V.%		4,06	Pred R2			-0,0249
			Adeq Precision			10,0959

Once it is known that the mathematical model in the second-order will be used, it will be analyzed whether there is a deviation in the model by looking at the difference between the response of the optimization model and the actual model or it can be called a residual. In the normal graph (can be seen in Fig. 4) shows that the normal graph of the residual does not show signs of violation because every point in the graph follows a linear line, therefore it can be concluded that the difference between the response of the optimization model and the actual model does not differ greatly and Such optimization models can be used.

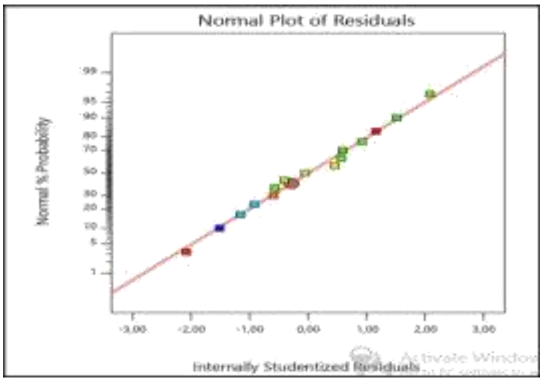

Fig. 4. Normal Plot of Residual Graph

The mathematical model that has been chosen to predict the results of the diameter nugget will be analyzed again by looking at the picture of the correlation between the results of the study with the results of the mathematical model. In Fig. 5, showing the correlation between research results and the predicted results of diameter nugget evaluations has a very strong correlation and positive linear correlation, because the distribution of points of the data pair approaches the positive straight line. This means that the mathematical model can be used because the results of the study did not differ much from the results of the prediction.

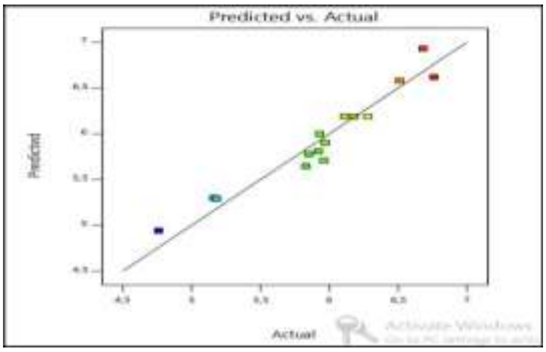

Fig. 5. Correlation Graph between Research Results and Prediction Results

After knowing the research results and predictions of nugget diameter do not differ much, then the second-order model will be analyzed to see the effect of the parameters on the nugget diameter. From the ANOVA results in the second-order model, the parameter that is very influential on the nugget diameter is welding current. To prove that welding current is very influential, can be seen in Fig. 6 shows the effect of the welding current and welding time parameters on the nugget diameter. If the welding current gets higher with a high welding time, the diameter of the nugget will be higher. If the welding current is low with a high welding time, the yield of the nugget diameter is low. If the welding current is high with a low welding time, the nugget diameter results are high.

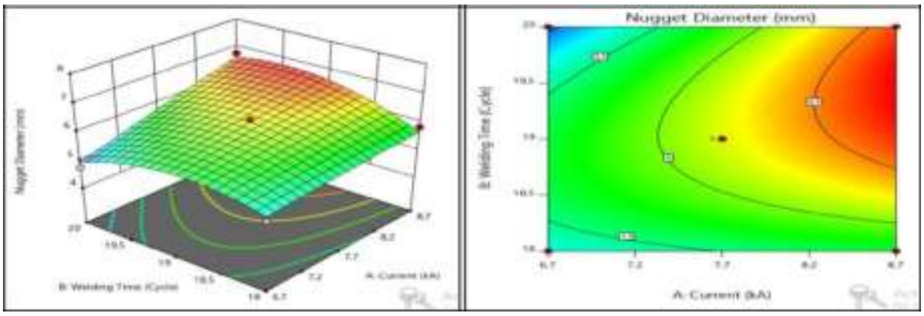

Fig. 6. 3D Graphics and Contour Plot Welding Current and Electrode Force

Fig. 7 shows the effect of the welding time and electrode force parameters on the nugget diameter results. If the welding time is higher and the electrode force value is high, the result of nugget diameter is high. If the welding time is low with a low electrode force value, the nugget diameter is low. From the results of this analysis, it is evident that welding current is very influential on nugget diameter.

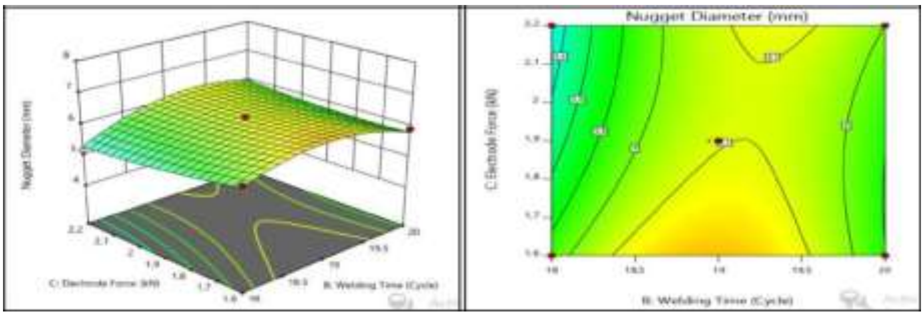

Fig. 7. 3D Graphics and Contour Plot Welding Time and Electrode Force

The parameter optimization results are welding current 8.7 kA, welding time 19.25 cycles and electrode force 1.6 kN with nugget diameter results are 6.969 mm (can be seen in Table IX) different from the research results obtained in runs order number 9. That is because, data processing uses RSM which means that data processing is developed with a mathematical model on the second order. The optimal parameter results have a desirability of 83.5%, which means that the optimization results for the parameters can be used. Fig. 8 shows that with desirability 0.835, the optimal parameter results are directly proportional to the nugget diameter results.

Table IX. Parameter Optimization Results

Welding Current (kA)	**Welding Time (Cycle)**	**Electrode Force (kN)**	**Nugget Diameter (mm)**	**Desirability**
8,7	19,27	1,6	6,969	0,835

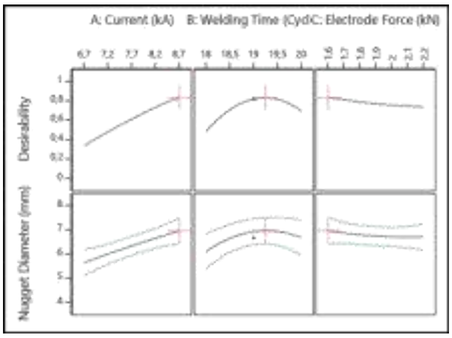

Fig. 8. Parameter Optimization Results

IV. CONCLUSION AND SUGGESTION

From the analysis that has been done, here are some conclusions obtained:

1. There are 4 main factors causing RSW results to not have nugget diameter, namely in equipment, condition, material (tip gun), and material. In the results of RSW crack has 3 main factors, namely the material, condition, and equipment.
2. The result of comparison between effects that are still at risk of failure mode is the opposite of effects that have a recommended action to reduce failure mode. The effects that are still at risk of failure mode have a very high risk of the occurrence of spot welding results do not have a nugget diameter, in contrast to the results of the effects that have recommended actions to reduce failure mode that has a low risk of spot welding crack results. The comparison results on spot welding cracks are the same as the results on spot welding having no nugget diameter.
3. On the spot welding results do not have a nugget diameter there are 9 effects that are prioritized to be evaluated first, namely the NG taper, the tip condition worsened, lack of training, the timer is broken, the load is heavy due to forced movements, bent shanks, broken timers, NG timers, and shanks crooked. As for the results of spot welding cracks there are 10 prioritized to be evaluated first, namely not good workability, not good workability, NG clamp, broken timer, broken timer, bent shank, bent shank, NG setting, bent flange, and press defect.
4. The optimum parameter results for the Taguchi Welding current technique are 8.7 kA, 18 cycle welding time and 1.6 kN electrode force. The optimum parameter results in Response Surface Methodology are welding current 8.7 kA, welding time 19 cycles, and electrode force 1.6 kN.
5. The difference between the Taguchi Technique and Response Surface Methodology (RSM) is on cost, time, and data processing. In the Taguchi Technique, the costs incurred to prepare material are less compared to RSM. That is because the Taguchi Technique only has 9 runs orders while in RSM there are 15 runs orders which cause RSM to use more

time. The Taguchi technique does not have a mathematical model, whereas RSM has a mathematical model that makes it easier for employees to predict parameter values so that employees do not have to always experiment to find the optimal value of each parameter. Taguchi data processing techniques only use MINITAB Software, while RSM can use two software, namely MINITAB and Design Expert.

From the results of research and analysis that have been done, here are some suggestions for companies:

1. It is better to use Response Surface Methodology to optimize parameters, because it is more efficient and effective in processing data, and the results of the mathematical model can be used continuously to optimize parameters without having to experiment again. Here are the results of the mathematical model obtained using the help of Software Design Expert Version 11:

Nugget Diameter = -120,64055 – (4,88667 x current) + (16,51433 x welding time) – (15,07278 x electrode force) + (0,332500 x current x welding time) – (0,233333 x current x electrode force) + (0,666667 x welding time x electrode force) – (0,031250 x Current^2) – (0,531250 x welding time^2) + (1,01389 x electrode force^2).

2. We recommend using Fault Tree Analysis (FTA) to facilitate employees in finding the causes of defects in spot welding results.

3. We recommend using the Failure Mode and Effect Analysis Method after using the FTA, in order to help employees to find out the priority effects first in order to reduce the failure mode that exists in the spot welding process.

V. REFERENCES

[1] M. Arumugam, A., & Nor, "Spot Welding Parameter Optimization To Improve Weld Characteristics For Dissimilar Metals," *Int. J. Sci. Technol. Res.*, pp. 75–80, 2015.

[2] A. Naik, S., & Singh, "Fault Tree Analysis of Single Cylinder Vertical Diesel Engine," *Int. Res. J. Eng. Technol.*, pp. 2278–2283, 2016.

[3] M. T. Parsana, T. S., & Patel, "A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry," *Bonfring Int. J. Ind. Eng. Manag. Sci.*, pp. 145–152, 2014.

[4] P. Krishnaiah, K., & Shahabudeen, *Applied Design of Experiments and Taguchi Methods*. Bahadurgarh: PHI Learning Pvt. Ltd., 2012.

[5] C. M. Myers, R. H., Montgomery, D. C., & Anderson-Cook, *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*. Canada: John Wiley & Sons., 2016.