DESIGN OF EXPERIMENT METHOD IN OBTAINING THE OPTIMUM WELD PARAMETER IN A 3-LAYER SPOT WELDING

Mohd. Harris Fadhilah[1], Mohamed Saiful Firdaus Bin Hussin[1], Raihani Binti Mohd. Said[2] and Muhammad Syahrul Nezar Bin Mohd. Amer[1]
[1]Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia, Melaka, Malaysia
[2]Faculty of Electric and Electronic Engineering Technology, Universiti Teknikal Malaysia, Melaka, Malaysia
E-Mail: mohdharris@utem.edu.my

ABSTRACT

The study is to find the optimum weld parameter in a 3-layer spot welding. The materials used in this research are the most common materials found in the body of a car, which were galvanneal, SPCC and Advanced High Strength Steel (AHSS). The stacking orientation of the materials were done similar to the stacking orientation in a side structure assembly of a car. Full factorial DOE method were conducted, using 3 factors with 2 levels. The factors were of 3 different parameters; weld current weld time and electrode pressure. The responses used were nugget size and tensile strength. The results had shown that the most important factor which affect the nugget size and tensile strength was weld current, followed by weld time and electrode pressure. The optimum weld parameter for the 3-layer spot welding was also obtained, which were 10kA, 20 cycles and 2.0bar for the weld current, weld time and electrode pressure.

Keywords: DOE, weld parameter, 3-layer spot welding, tensile strength.

INTRODUCTION

Spot welding is one of the main processes in automotive manufacturing. With more than hundreds of metal parts in a car, there are thousands of welding nugget. Since it is the most important joining process, the quality of spot weld is crucial in ensuring a sturdy body in white to ensure safety of occupant during crash. There are many indicators of a strong body in white. (Nordin, Hamdi, Yang, & Hagiwara, 2014) through FEA analysis found that the nugget size plays a vital role in determining the crashworthiness of a car. In their research it was found that the peak load which is the initial load on the structure that initiates crushing tend to be lower in a higher nugget diameter. They compared the peak load of panels with nugget diameter of 8mm and 4mm. (Liu, Sun, Xu, Zuo, & Lin, 2012) also found that the size of different size of welding nugget gave effect on the weld properties and the failure mode. (Manoj Raut, 2014) in their research concluded that the weld parameter is important factor in the determination of the tensile shear strength. The weld parameters of a spot welding process are of three different parameters. Those are weld current, weld time and pressure of the electrode. With different kind of material stacking, the right parameter to obtain the intended value of the weld nugget requires the right weld current, weld time and pressure. Due to the difference in the properties of material, it is quite difficult to get the right parameter to weld the material together. Furthermore, with the dependencies of weld nugget to heating and melting process, it is more difficult to find the right parameter in welding of different material using spot welding process. The weld parameter which is an important factor to the quality of spot weld and body in white sturdiness is agreed by many researchers. The effect on hold time to the weld quality of a dissimilar spot welding was investigated by (Long, Hu, Jin, Shao, & Zhu, 2016). The conclusion of this work was that the increase of holding time increase the tensile shear. *(Long et al.*, 2016) also suggested that weld time to be lower than 15 cycles to get a high efficiency welding. In another research of dissimilar spot welding research, (Yuan *et al.*, 2017) investigated of the different welding parameter. It was found that the nugget size increased proportionally with the increment of weld current and weld time. However, that did not guarantee the increment of tensile shear strength. In their research, it was found that the tensile shear increased initially but slightly decreased when the diameter hit a certain value.

With many kind of material used in automotive industry, the research on weld parameter is expansive. Many researchers focused in obtaining the optimum weld parameter using statistical method(Manoj Raut, 2014; Muhammad & Manurung, 2012; Thakur, Rao, Mukhedkar, & Nandedkar, 2010). Even though research on 2-layer spot welding is extensively investigated, research on a 3-layer spot welding is limited. This study is to determine the optimum parameter in a 3-layer spot welding, using DOE method. The material used in this research are the most common material used in a side structure of a car. Those are galvanneal steel, mild steel and Advanced High Strength Steel (AHSS). The galvanneal steel represents the outer panel, mild steel represents the inner part and Advanced High Strength Steel represents the reinforced part. The numbers of factor used in this experiment were 3, which were weld current, weld time and electrode pressure. The responses were the nugget size and tensile strength.

METHODOLOGY

The materials used in this study were of three different kind of material. The table below shows the materials used in this study.

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Materials and thicknesses.

Material	Thickness
Galvanneal	0.7mm
SPCC	1.0mm
AHSS (TRIP)	1.4mm

The stacking orientation are shown as per picture below. The samples were prepared according to the standard ISO 14273.

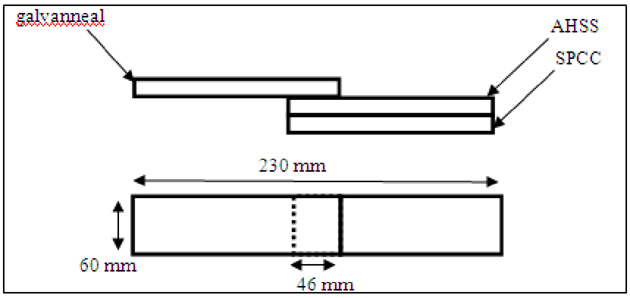

Figure-1. Size of sample and stacking orientation.

The welding parameter used for welding the material are shown as per table below. The DOE method used in this research was full factorial method. The responses chosen in this study were the nugget diameter and the maximum tensile strength. The nugget diameter was chosen as the quantitative measure since it is simple and widely used all over the automotive manufacturing plant in the world. AWS/ANSI/SAE suggested that the minimum nugget size has to be $4\sqrt{t}$, where t is the total thickness of the welded material. Tensile strength is another important parameter since it measures the amount of absorbed energy during crash. The higher tensile strength indicates of the better spot welding quality. The welding parameters selected for this study are shown as below.

Table-2. Weld parameters used in this study.

Level	Weld time (cycle)	Weld current (kA)	Electrode pressure (bar)
1	15	9	2.0
2	20	10	2.5

Table-3 depicts the choice of design which will be used in this experiment. The (-) symbol indicates of minimum value of the parameter and (+) symbol indicates the maximum value of the parameter. The alpha α value used in this study was 0.05

Table-3. Setting of Design of Experiment.

Experiment (run)	Parameter			Response	
	Weld time (cycle)	Weld current (kA)	Electrode pressure (bar)	Tensile Strength (MPa)	Nugget size (mm)
1	+	+	+		
2	+	+	-		
3	+	-	+		
4	+	-	-		
5	-	+	+		
6	-	+	-		
7	-	-	+		
8	-	-	-		

The analysis which were conducted were;

a) Pareto chart of Effects
b) Main Effects plot
c) Optimization plot

RESULTS AND DISCUSSIONS

The experimental data and result of tensile strength were collected and is illustrated in the Table-4.

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-4. Full Factorial Results.

Experiment (run)	Parameter			Response	
	Weld time (cycle)	Weld current (kA)	Electrode pressure (bar)	Tensile Strength (MPa)	Nugget size (mm)
1	20	10	2.5	229.81	8.34
2	20	10	2.0	237.99	8.45
3	20	9	2.5	208.69	7.39
4	20	9	2.0	206.36	7.22
5	15	10	2.5	208.92	8.05
6	15	10	2.0	211.45	8.15
7	15	9	2.5	204.89	7.20
8	15	9	2.0	198.10	7.16

The types of failure desired during tensile test is the pull out failure. The pull out failure is the desirable type of failure in spot welding. It is an indicator that the weld nugget has a high load carrying capacity. The tensile strength of the material obtained in this study were in the range of 198.10MPa to the 237.99Mpa. The nugget sizes of the samples were in the range of 7.16mm to 8.45mm, compared to the minimum requirement of the samples, which was 7.04 mm. The difference of the obtained nugget diameter compared to the recommended nugget was from 1.7% to 20%. Figure-2 shows the pull out failure of the samples.

Figure-2. Pull out failure of the samples.

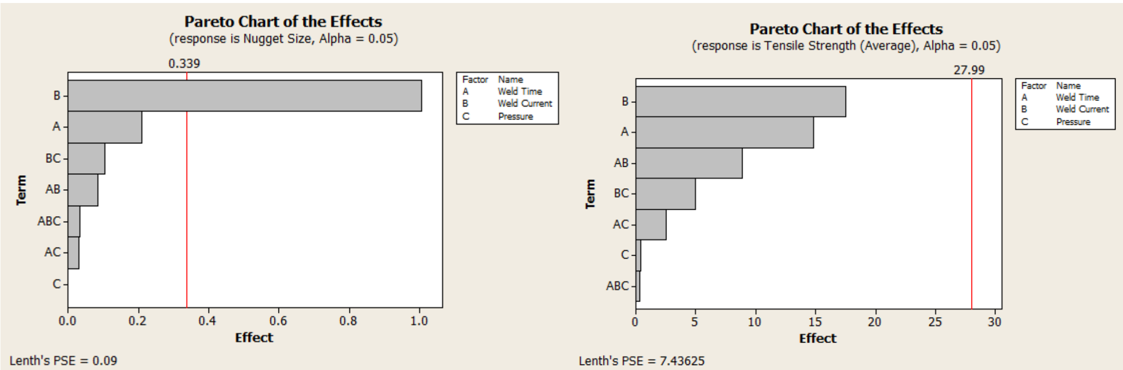

Figure-3. Pareto chart for the response Nugget Size and Tensile Strength.

The result of the pareto chart showed that the most significant factor for both responses was weld current, followed by weld time. The interaction effect for both responses however had a slight difference. For the nugget size, the combination between the weld current and pressure is more important than the combination between weld current and weld time. While for tensile strength, it had shown an opposite effect. This can be explained from the Joule's Law formulae and mechanism of weld nugget formation. The Joule's law equation is shown below:

$Q=I^2Rt$ [1]

where Q is the heat generated, I is the current, R is the resistance and t is the time. From the Joule's law, it is understood that heat generation depends to three factors, which are current, resistance and time. The welding nugget as we know is the solidified molten metal. The mechanism of the weld nugget itself started with the heat generation from the electrode through the metal, and throughout that mili-seconds, the metal starts to melt, solidified and becoming weld nugget. The combination of weld current and pressure is important to the formation of weld nugget since they both will melt the material and at the same time ensuring the faying surfaces are in contact.

VOL. 14, NO. 21, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

The use of 3 different materials and Advanced High Strength Steel (AHSS) in this study required more pressure due to the high thickness and the high strength of the AHSS itself. Meanwhile, the area which were heated but somehow does not melt and solidified became Heat Affected Zone (HAZ). Figure-4 shows the differences of weld nugget and Heat Affected Zone.

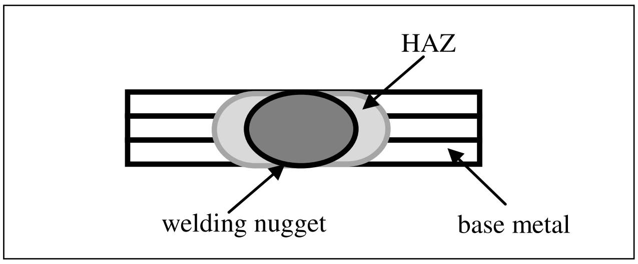

Figure-4. The difference of welding nugget and Heat Affected Zone (HAZ).

The tensile strength in pull out failure mode of spot welded material might initiate at the base metal, HAZ or at the Fusion Zone. The weld time and weld current, as being shown in the formulae [1] indicated of the generated heat throughout the spot welding process. Higher and longer current and weld time increased the heat generation and dissipation. Thus it expanded the nugget size and HAZ area which eventually increased the tensile strength.

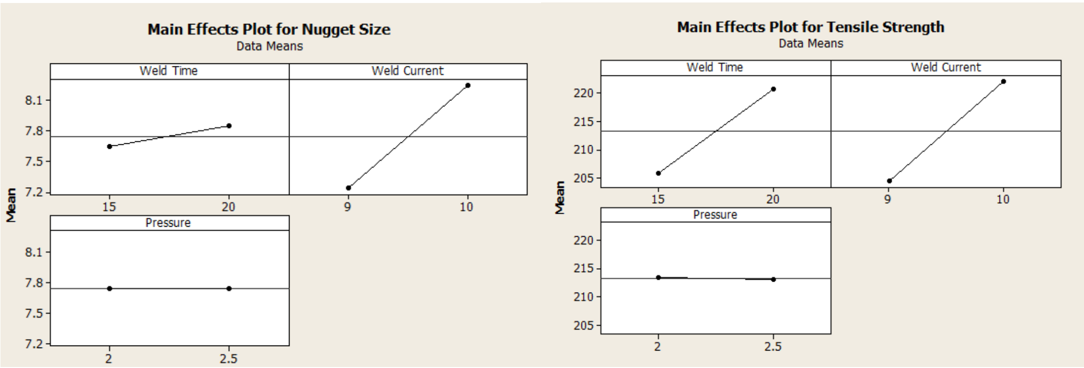

Figure-5. Main effect Plots for response Nugget Size and Tensile Strength.

The main effects plot in the Figure-5 for both responses had also shown similar effect to the pareto chart, where it indicated that the weld current and weld time had effect to the welding nugget and tensile strength. However, for both responses, the pressure had shown no change to the responses. Based on the 3 results, it was understood the importance of weld current and weld time to the nugget size and tensile strength of spot welded material. The optimization plot shown in the figure 6 gave the optimum setting for the response of maximum tensile strength and nugget size. The value of the composite desirability that was close to 1 indicated of the predicted value which was close to the targeted value. It was understood that the composite desirability for both effects were 0.99737 and 1.00. The optimum weld current, weld time and pressure were 10kA, 20 cycles and 2.0 bar respectively.

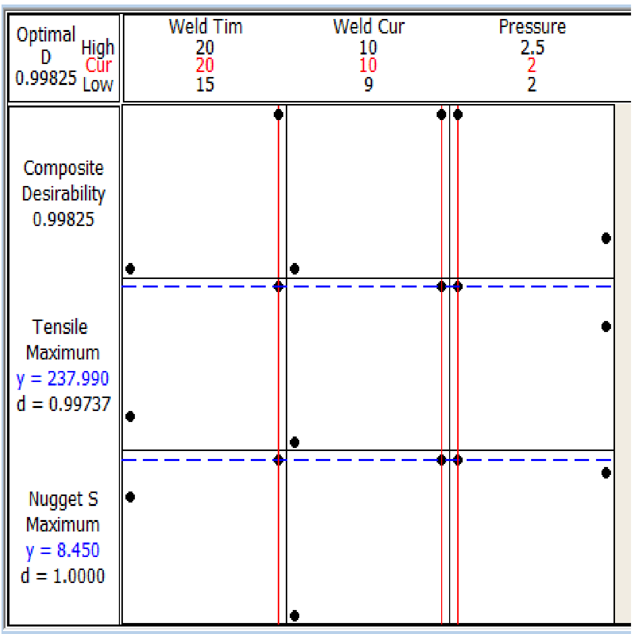

Figure-6. Optimization plot for Nugget Size and Tensile Strength.

CONCLUSIONS

Based on full factorial analysis, it can be concluded that the most important factor for the tensile strength and nugget size diameter is the weld current, followed by weld time and electrode pressure. The optimum weld parameter obtained in this study is10kA for weld current, 20 cycles for 2.0 bar for pressure. The weld current and weld time were found to be the most important factor in ensuring of nugget formation as well as the heat generation during the spot weld process. The weld pressure which somehow did not show a big impact to the responses somehow is still important in ensuring that the faying surfaces were in contact throughout the welding process.

ACKNOWLEDGEMENT

The author would like to express special thanks to Universiti Teknikal Malaysia Melaka for supporting this project through research grant PJP/2018/FTK (7B)/S01599. Special thanks to NICOM Steel Malaysia for sponsoring the material used in this study.

REFERENCE

Liu W., Sun C., Xu X., Zuo Y. & Lin J. 2012. The influences of nugget diameter on the mechanical properties and the failure mode of resistance spot-welded metastable austenitic stainless steel. Materials and Design. 33(1): 292-299. https://doi.org/10.1016/j.matdes.2011.06.071

Long H., Hu Y., Jin X., Shao J. & Zhu H. 2016. Effect of holding time on microstructure and mechanical properties of resistance spot welds between low carbon steel and advanced high strength steel. Computational Materials Science, 117, 556-563. https://doi.org/10.1016/j.commatsci.2016.01.011

Manoj Raut V. A. 2014. Optimization of spot welding process parameters for maximum tensile. International Journal of Mechanical Engineering and Robotics Research, 3(4).

Muhammad N. & Manurung Y. H. P. 2012. Design Parameters Selection and Optimization of Weld Zone Development in Resistance Spot Welding. 6(11): 2464-2469.

Nordin H., Hamdi M., Yang Y. & Hagiwara I. 2014. Investigation on Spot Welding Effect on Truss Core Panel for Crashworthiness. 774, 766-775. https://doi.org/10.4028/www.scientific.net/MSF.773-774.766

Thakur A. G., Rao T. E., Mukhedkar M. S. & Nandedkar V. M. 2010. Application of Taguchi method for resistance spot welding of galvanized steel. 5(11): 22-26.

Yuan X., Li, C., Chen J., Li, X., Liang X., & Pan X. 2017. Resistance spot welding of dissimilar DP600 and DC54D steels. Journal of Materials Processing Technology. 239, 31-41. https://doi.org/10.1016/j.jmatprotec.2016.08.012