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The effect of Spot Welding Parameters for Dissimilar Material Mild Steel and Galvanized Steel on Nugget Size and Mechanical Strength

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Abstract

The objective of this research was to analyze the effect of spot welding parameters on the size of the weld nugget and the maximum shear strength on dissimilar material mild steel and galvanized steel. The Taguchi and ANOVA methods were used to determine the welding parameters' contribution to joint quality. Experimental design using Minitab-19 software with Taguchi method of 3 level 3 factor with L27 runs. Specimen size and dimensions were made using ASTM D1002 standard, with a plate thickness of 0.8 mm. Taguchi analysis S/N ratio data mean for weld nugget diameter with three levels of current used, 4 kA, 6 kA, and 8kA, shows the most influential on the diameter of the weld nugget was at 8 kA. The three levels of welding time used, 2s, 4s, and 6s, show the most influential on the diameter of the nugget the weld was at the third level for 6 seconds. It found that there was no significant difference in the size nugget at the three electrode pressure levels of 30 Ppsi, 40 Psi, and 50 Psi. Based on the tensile test and Taguchi analysis, the lowest shear strength was found in a weld nugget size of 3.15 mm at a welding current of 4 kA, a welding time of 2 seconds, an electrode pressure of 30 Psi, with a shear tensile strength of 300.19 N. Along with an increase in the size weld nugget correlated to an increase of shear strength. The highest shear tensile strength was found in the nugget size of 4.16 mm, with a welding current of 8 kA, welding time of 2 seconds, electrode pressure of 50 Psi, with a shear tensile strength of 3383.43 N. From the ANOVA, it found that the three factors of spot welding parameters were used, the most influential parameter in the formation of weld nuggets was welding current with a contribution of 84.86% then followed by welding time with a contribution of 14.86% and electrodes force with a contribution of 0.13%. Then from the three factors of spot welding parameters that were used the most influential parameter on the maximum shear tensile strength was the welding current with a contribution of 95.86 % then followed by welding time with a contribution of 0.52% and electrodes force with a contribution of 0.05%.

Keywords: Spot welding; weld nugget diameter; tensile-shear

1. Introduction

Spot welding is a method of joining sheet plates in the automotive industry [1]. The spot welding process occurs during a certain cycle time in the welding current, welding time, and electrode force are the most important parameters [2]. Spot welding is used in the automotive industry for car bodies or frameworks. There are about 5000 spot welds in modern vehicles [3].

Spot welding is a method of joining metals by providing electrical resistance as a heat source on two or more metal surfaces so that nuggets are formed in the welding area [4]. The connection is done by pressing the surface of the plate to be connected with the two electrodes. At the same time, an electric current flows to the electrodes so that the two metal surfaces are hot and melt due to electrical resistance [5].

The spot welding method has the advantages of being easy to operate since it does not require special skills like other welding methods, the time is shorter, so it will increase the speed of mass production, and the heat supply provided is sufficient [6].

Control of welding parameters greatly affects the characteristics of the weld results, its affects the quality of the mechanical properties of the weld results, such as tensile strength, hardness, and microstructure. One of crutial thing is controlling the electric current. If the welding current used is too low, the heat that occurs is not enough to melt the material, resulting in a small area of weld metal and lack of penetration, conversely, if the welding current is too high, the melting of the base metal is too fast and produces a wide area of weld metal. as well as deep penetration resulting in low tensile strength and increased brittleness [7].

Variations in electric voltage (V) and pressing time (dt) affect the shear strength of the weld. The higher the stress used, the higher the value of the shear stress strength. When the pressure or welding time is long, the value of the shear stress strength is higher and if the welding time is not constant, the welding results will be damaged [8]. It takes sufficient heat input to form a good

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nugget structure so as to produce maximum joint strength. The welding pressure time must be adjusted in order to get the results of the weld joint and good tensile strength [9].

The size of the nugget diameter increases with increasing stress which causes a pullout failure mode. The size of the nugget diameter decreases after the pre-strain is applied to the test specimen and creates an interfacial failure mode [10]. Research effects of holding time on microstructure and shear strength of resistance spot-welded joints between mild steel and aluminum with zinc powder filler. The materials used are 0.9 mm thick mild steel, 1.2 mm thick 3000 series aluminum, and 200 mesh zinc powder. The tensile test results showed that applying an electric current of 8000 A, welding time of 0.5 s, and holding time of 1 s produced the joint with the weakest shear strength of 130 N. The highest joint shear strength of 790 N is obtained with the condition: electric current of 9000 A, welding time of 0.5 s, and holding time of 5 s [11].

This research uses several variations of parameters that can affect the characteristics of mechanical properties, in order to improve the quality of the welded joints. Research on spot welding with variations in the parameters of welding current, welding time, electrode force, and its mechanical properties are the focus of the study.

2. Research Method

2.1. Materials and tools

Materials used for this study were Mild steel and Galvanized steel. The chemical composition of both materials can be seen in Table 1.

The tool that would be used in this research was spot welding to joints galvanized steel and mild steel materials with an electric current capacity of 1 to 8 kA and an electrode pressure capacity of 10 to 50 Psi, grinding machine. To determine the mechanical strength of a material, a Tensile test was conducted to spot welded 0.8 mm thick of mild steel iron plate and 0.8 mm thick of galvanized steel plate. The process of making specimens follow ASTM D1002 standards.

The process of selecting welding parameters selected based on the capacity of the tool to be used was then designed using Minitab-19 software, the Taguci 3 level 3 factor method with L27 runs, and further analyzed with ANOVA.

Table 1. Chemical composition of materials (wt %)

Chemical Composition	Mild steel	Galvanized steel
Cu	0.0067	0.053
Fe	99.3	
Si	0.16	0.009
Cr	0.0093	0.01
Mn	0.192	0.40
Ti	0.0015	
S	0.0035	0.017
C	0.114	0.065
P	0.0073	0.018

2.2. Specimen making

The process of making specimens was by cutting mild steel and galvanized steel plates, with specimen dimensions according to ASTM D1002 standards with a thickness of 0.8 mm, a length of 100 mm, and a width of 25.4 mm as shown in Fig. 1. The connection method was made overlapping (lap joints).

2.3. Specimen welding

In the process of welding the specimens of this research would be used of 3 (three) welding parameters, namely welding time, welding current, and electrode pressure. Three welding parameters have three different levels of variation were used, namely, welding currents of 4, 6, and 8 kA, welding times of 2, 4, and 6 seconds, and electrode pressures of 30, 40, and 50 Psi.

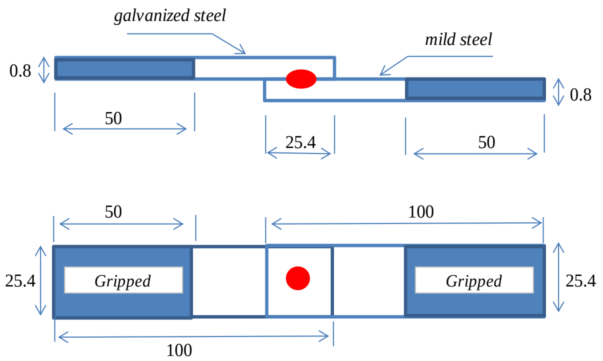


Figure 1. Specimen sizes based on ASTM D1002 [12]

Table 2. Taguchi design welding parameters

Runs	Welding current (kA)	welding time (seconds)	electrode force (Psi)
1	4	2	30
2	4	2	30
3	4	2	30
4	4	4	40
5	4	4	40
6	4	4	40
7	4	6	50
8	4	6	50
9	4	6	50
10	6	2	40
11	6	2	40
12	6	2	40
13	6	4	50
14	6	4	50
15	6	4	50
16	6	6	30
17	6	6	30
18	6	6	30
19	8	2	50
20	8	2	50
21	8	2	50
22	8	4	30
23	8	4	30
24	8	4	30
25	8	6	40
26	8	6	40
27	8	6	40

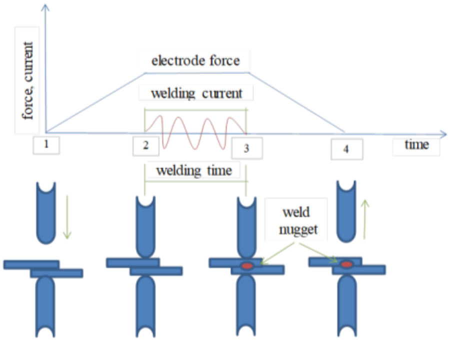


Figure 2. Schematic of the stages of the welding process

Schematic of the stages of the welding process according to Fig. 2 are as follows;

- Stage 1 was the initial condition where the two materials have not been clamped by the two electrodes.
- Stage 2 was the stage where welding began.
- Stages 2 and 3 were the welding stages where at this stage an electric current of 4, 5, and 8kA flowed through the electrode to the workpiece, and the electrode pressure force of 30, 40, and 50 Psi was maintained for 2, 4 and 6 seconds to produce heat and form weld nuggets.
- Stage 4 was the final stage where the electric current is turned off and the electrode pressure was lifted when the weld nugget has been formed.

3. Results and Discussion

3.1. Weld nugget

The nugget was an area of welded metal that has melted and then solidified. The size of the weld nugget is the most important parameter in determining the mechanical behavior of the spot welding joint since its predominantly determined by the shape and size of the weld nugget [13].

From Table 3, it could be seen that the relationship between each welding parameter and the diameter of the welding nugget varies. Where the measurement results showed that for every increase in electric current, there was also an increase in the size of the nugget as well as an increase in the level of time there was an increase in the size of the weld nugget. From the calculation data, the smallest average nugget diameter was found in the parameter of welding current of 4 kA, welding time of 2 seconds, and electrode pressure of 30 Psi with a value of 3.15 mm.

The largest nugget size was found in the parameters of a welding current of 8 kA, welding time of 6 seconds, and electrode pressure of 40 Psi with a value of 4.75 mm.

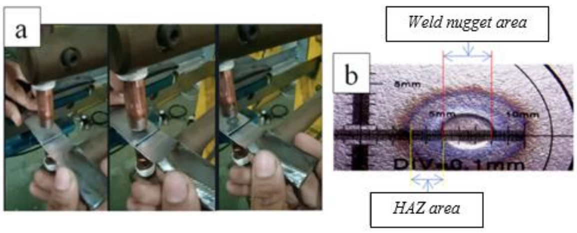
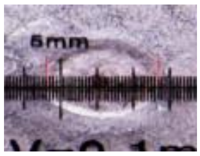
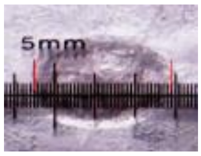
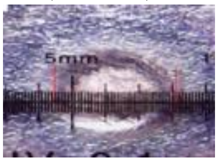
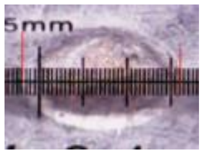
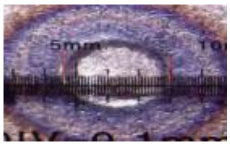
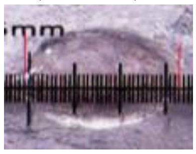
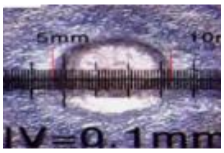
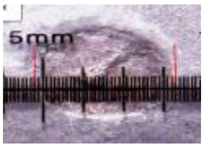
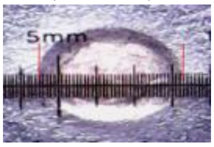
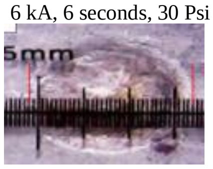
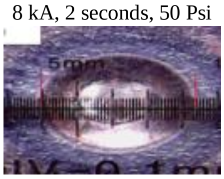
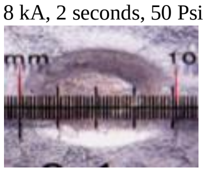
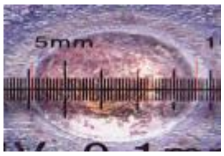
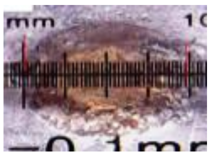
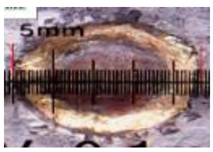


Figure 3. (a) Spot welding process and (b) weld nugget measurement area

Table 3. Measurement results of weld nugget diameters

No	Figure of mild steel nugget	Figure of galvanized steel nugget
1	4 kA, 2 seconds, 30 Psi 	4 kA, 2 seconds, 30 Psi 
2	4 kA, 4 seconds, 40 Psi 	4 kA, 4 seconds, 40 Psi 
3	4 kA, 6 seconds, 50 Psi 	4 kA, 6 seconds, 50 Psi 
4	6 kA, 2 seconds, 40 Psi 	6 kA, 2 seconds, 40 Psi 
5	6 kA, 4 seconds, 50 Psi 	6 kA, 4 seconds, 50 Psi 
6	6 kA, 6 seconds,30 Psi 	6 kA, 6 seconds, 30 Psi 
7	8 kA, 2 seconds, 50 Psi 	8 kA, 2 seconds, 50 Psi 
8	8 kA, 4 seconds, 30 Psi 	8 kA, 4 seconds, 30 Psi 
9	8 kA, 6 seconds, 40 Psi 	8 kA, 6 seconds, 40 Psi 

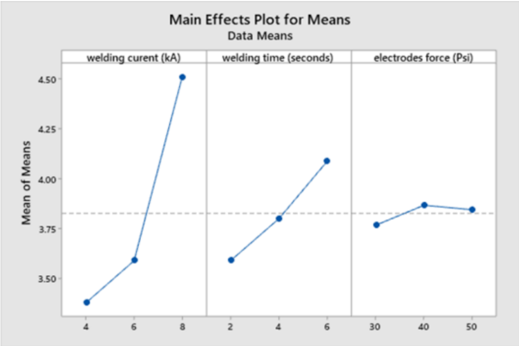


Figure 4. Taguchi Analysis S/N ratio data means for weld nugget diameter

Taguchi Method Software Minitab-19 weld nugget diameters are shown in Fig. 4. From Fig. 4 It could be seen that of the three current levels used that the most influential on the diameter of the weld nugget was at the third level of 8 kA, then of the three levels of welding time using the most influential the diameter of the weld nugget was at the third level of 6 seconds three levels of electrode pressure there was no significant difference.

Analysis of ANOVA in Minitab-19 weld nugget diameters can be seen in Table 4. From Table 4 ANOVA in Minitab-19 software could be seen from the three factors of spot welding parameters that were used the most influential parameter in the formation of welding nuggets was welding current with a contribution of 84.86% then followed by welding time with a contribution of 14.86%. and electrode force with a contribution of 0.13%.

3.2. Shear tensile testing

Tensile testing was carried out to determine the most influential parameter on shear tensile strength from three factors of welding current, welding time, and electrode pressure, three levels of variation of welding current 4 kA, 6 kA, and 8 kA. Welding time is 2 seconds, 4 seconds, and 6 seconds. Electrode pressure 30 Psi, 40 Psi, and 50 Psi.

Table 4. Analysis of Variance software Minitab-19 weld nugget diameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
welding current (kA)	2	2.05358	84.86%	2.05358	1.02679	545.38	0.002
welding time (seconds)	2	0.35951	14.86%	0.35951	0.17975	95.48	0.010
electrodes force (Psi)	2	0.00321	0.13%	0.00321	0.00160	0.85	0.540
Error	2	0.00377	0.16%	0.00377	0.00188		
Total	8	2.42006	100.00%				

Table 5. The average value of the tensile shear test results

No	Welding current (kA)	Welding time (second)	Eletrda force (Psi)	tensile- shear maximum (N)
1	4	2	30	300.19
2	4	4	40	543.96
3	4	6	50	595.56
4	6	2	40	703.56
5	6	4	50	592.38
6	6	6	30	1094.38
7	8	2	50	3383.43
8	8	4	30	3042.53
9	8	6	40	3130.70

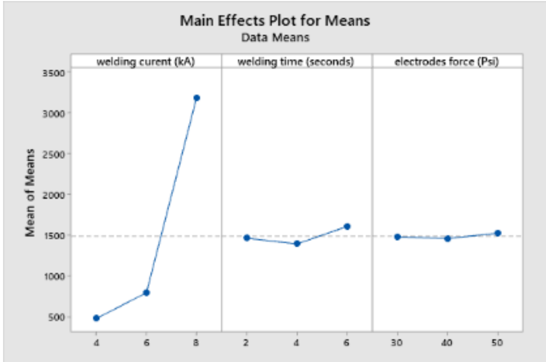


Figure 5. Taguchi Analysis S/N ratio data means for tensile- maximum shear

Taguchi Method Software Minitab-19 tensile-shear maximum is shown in Fig. 5. From Fig. 5 Taguchi Analysis S/N ratio data means for tensile-shear maximum. Of the three levels of welding current used, the most influential on the maximum tensile-shear is at the third level, 8 kA, of the three levels of welding time used, there was no level that significantly affects the maximum tensile-shear, which could be analyzed from Table 5. The welding time was adjusted according to the current used. And of the three electrode pressure levels there was no significant value affecting the maximum tensile-shear.

From Table 6 ANOVA in Minitab-19 software could be seen from the three factors of the spot welding parameter which was used the most influential parameter on the maximum shear tensile strength was the welding current with a contribution of 95.86% then followed by welding time with a contribution of 0.52% and electrodes force with a contribution of 0.05%. In line with research conducted by Sukarman et al which has the most effect on welding current than welding time [14].

Table 6. Analysis of Variance software Minitab-19 tensile-shear maximum

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
welding current (kA)	2	39381750	95.86%	39381750	19690875	268.62	0.000
welding time (seconds)	2	214384	0.52%	214384	107192	1.46	0.255
electrodes force (Psi)	2	19600	0.05%	19600	9800	0.13	0.876
Error	20	1466053	3.57%	1466053	73303		
Lack-of-Fit	2	520316	1.27%	520316	260158	4.95	0.019
Pure Error	18	945737	2.30%	945737	52541		
Total	26	41081786	100.00%				

Table 7. The average value of the results of nugget diameter measurements and maximum tensile shear testing

No	Welding current (kA)	Welding time (second)	Electrode force (Psi)	Diameter nugget (mm)	Tensile- Shear Maximum (N)
1.	4	2	30	3.15	300.19
2.	4	4	40	3.40	543.96
3.	4	6	50	3.60	595.56
4.	6	2	40	3.30	703.56
5.	6	4	50	3.55	592.38
6.	6	6	30	3.73	1094.38
7.	8	2	50	4.16	3383.43
8.	8	4	30	4.46	3042.53
9.	8	6	40	4.75	3130.70

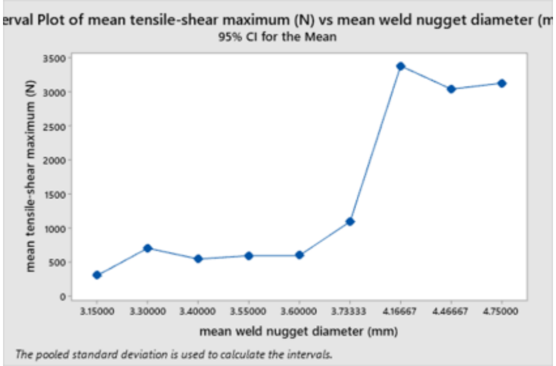


Figure 6. Mean tensile-shear maximum versus mean weld nugget diameter

From Table 7 and Fig. 6, it could be seen that the lowest shear tensile strength was found in the weld nugget size 3.15 mm at a welding current of 4 kA, welding time of 2 seconds, electrode pressure of 30 Psi, with a shear tensile strength of 300.19 N as the size increases The shear strength of weld nuggets increased and the highest shear strength was found in the size of the weld nugget 4.16 mm, with a welding current of 8 kA, welding time of 2 seconds, electrode pressure of 50 Psi, with a shear tensile strength of 3383.43 N. This gave knowledge about the effect of weld nugget size on spot welding shear tensile strength.

There was a decrease in shear tensile strength on the weld nugget size 4.46 mm, with a welding current of 8 kA, a welding time of 4 seconds, an electrode pressure of 30 Psi, and a weld nugget size of 4.75 mm, with a welding current of 8 kA, a welding time of 6 seconds, electrode pressure 40 Psi. This was because the higher the welding current and the longer the welding time, the greater the heat input that occurs [15].

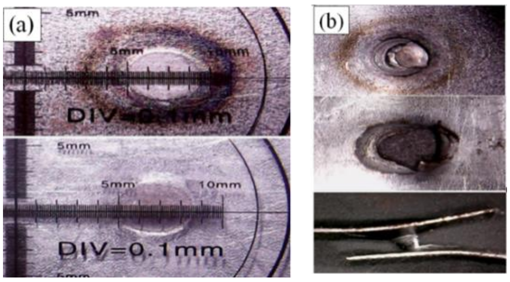


Figure 7. Type of failure of the tensile shear test results

From Fig. 7 It could be seen that the type of material failure resulting from the tensile shear test in Figure (a) was the result of the test with the lowest shear tensile strength of 300.19 N at a welding current of 4 kA, a welding time of 2 seconds, an electrode pressure of 30 Psi, with an interfacial failure mode failure type and in figure (b) was the highest shear tensile strength test result, namely 3383.43 N at a welding current of 8 kA, a welding time of 2 seconds, an electrode pressure of 50 Psi, with a pull-out failure mode failure type.

Table 8. The average value of the tensile shear test is mild steel with mild steel and galvanized steel with galvanized steel

Welding current (kA)	Welding time (seconds)	Eletroda force (Psi)	Tensile-shear maximum (N) mild steel	Tensile-shear maximum (N) galvanized steel
4	2	30	1731.07	195.14
8	2	50	3770.9	2765.47

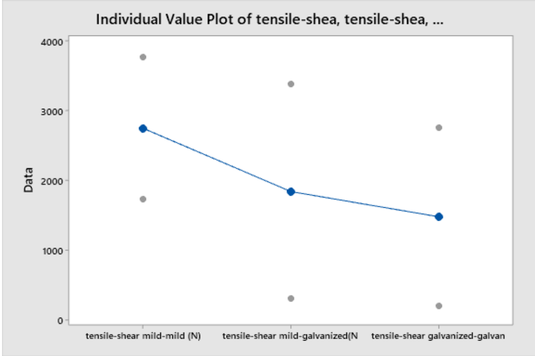


Figure 8. Comparative graph of the tensile-shear test results of mild steel with mild steel, galvanized steel with galvanized steel, and mild steel with galvanized steel

From Fig. 8, tt can be seen that the decrease in tensile-shear strength in the joints of mild steel with galvanized steel and galvanized steel with galvanized steel is caused by a galvanic coating on the material. in line with Sukarman et al decreased weldability due to zinc coating on the metal surface [14].

3.3. Micro structure

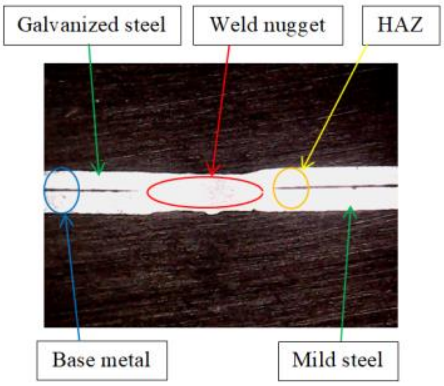


Figure 9. Microstructure observation area

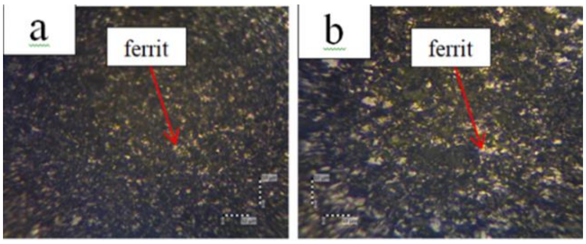


Figure 10. Structure midro base metal (a) galvanized steel (b) mild steel. It could be seen that the pearlite microstructure consists of layers of black cementite and white ferrite

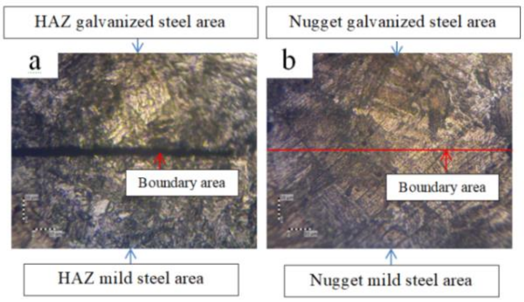


Figure 11. Microstructure 4 kA, 2 sec, 30 Psi, (a) HAZ area, and (b) nugget area

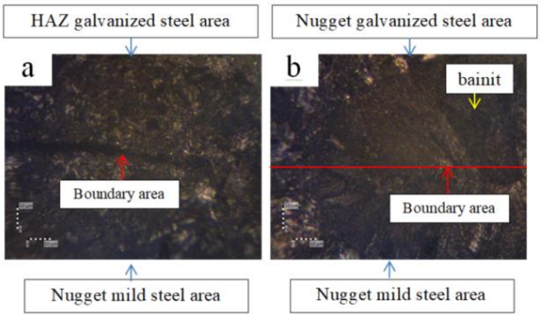


Figure 12. Microstructure 8 kA, 2 sec, 50 Psi (a) HAZ region and (b) nugget region

From the results of microstructural observations, structural changes could be seen between the base metal, the HAZ area, and the welding nugget. In the base metal area, a coarse pearlite microstructure was visible, consisting of layers of black cementite and white ferrite, in the HAZ region there was a structural change to a fine pearlite microstructure, and in the weld nugget area, a fine pearlite microstructure was visible. As the welding current increases, the weld nugget area was dominated by the bainite microstructure, this occurs due to the different heat inputs for each variation of the welding parameters [9]. The bainite structure was formed through the heat treatment process of steel which was heated to reach the austenite temperature and cooled at a high speed moderate [16].

4. Conclusion

From the analysis of Taguchi and Anova, it could be concluded that from the 3 factors and 3 levels of the spot welding parameters used, the increasing welding current and the increasing welding time, the size of the weld nugget also increases. The lowest shear strength was found in the weld nugget size 3.15 mm at a welding current of 4 kA, welding time of 2 seconds, and electrode pressure of 30 Psi, with a shear tensile strength of 300.19 N. As the size of the weld nugget increases, the shear tensile strength increases, and the highest shear tensile strength was found in the weld nugget size of 4.16 mm, with a welding current of 8 kA, a welding time of 2 seconds, an electrode pressure of 50 Psi, with a shear tensile strength of 3383.43 N. From the analysis of ANOVA software Minitab-19 it could be seen from three The spot welding parameter factor that was used as the most influential parameter in the formation of weld nuggets was the welding current with a contribution of 84.86%, followed by welding time with a contribution of 14.86% and electrodes force with a contribution of 0.13%.

Then from the three factors of spot welding parameters that were used the most influential parameter on the maximum shear tensile strength was the welding current with a contribution of 95.86% then followed by welding time with a contribution of 0.52% and electrodes force with a contribution of 0.05%. The results of microphoto observations along with increasing welding parameters in the weld nugget area formed a bainite microstructure.

But this research is still limited so it is suggested to clean the galvanized layer to see the effect on tensile-shear strength and nugget diameter.

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