Optimization of Welding Parameters for Resistance Spot Welding with Variations in the Roughness of the Surface of the AISI 304 Stainless Steel Joint to Increase Joint Quality

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***Abstract*—Resistance spot welding is widely used in the automobile, ship, and food industries. The durability and safety of the product being produced from these different industries depend on the spot welding joint's connection quality, which makes it very important. However, there are a lot of poor quality resistance spot welding connections and this is caused by several factors, namely: material preparation, welding time, welding current, electrode pressure applied during welding, and post-welding treatment. This research was conducted to analyze how changing the joint surface's roughness before welding and current parameters during welding could improve the quality of resistance spot welding joints. The experiments were conducted using a stainless steel plate material 304 with a size of 175x25 mm. Furthermore, mechanical testing was carried out the tensile shear and macrostructure using the Gwyddion software. The results showed that the parameters of the welding current, significantly affect the width of the welding nuggets and the quality of the spot welding resistance joint is improved by even the slightest roughness variation on the joint surface.**

***Index Terms*—resistance spot welding, welding time, electrode pressure, nugget, surface roughness**

I. Introduction

The quality of AISI 304 stainless steel joints is very important. Furthermore, it is currently being used by many industries, among which are: the marine [1], chemical, aeronautics, and naval industries [2], [3]. Unfortunately, the AISI 304 stainless steel is weaker at the welded joint and this is caused by some occasional flaws which tend to reduce the quality of the weld joint [4].

Therefore, the resistance spot welding (RSW) parameters are processes that must be considered to ensure a stronger connection between two high-quality components. [5] In general, numerous factors including thenugget size [6], [8], material grain size [9], surface roughness [10][11], tensile shear strength [12], hardness value [13], and failure type [14] can be used to determine the quality of welding joints. Accordingly, the quality of the AISI 304 stainless steel joint can be mechanically improved with variations in surface roughness prior to welding. This is also possible with the application of the right amount of current. According to Kumar et al [5] there is a correlation between the tensile shear and the nugget diameter. Luo et al [15] also discovered nanoparticles with an average of 20 μm on the surface of the AISI 304 steel with the use of photographs, which had an impact on the mechanical properties of the joint.

The following research has been conducted by some researchers to improve the quality of resistance spot welding joints,: : surface fiber in welded friction[16], geometry [17], sealing [18], resistance spot welding parameter with a focus on electrode force [19][20], resistance spot welding with focus in parameter current [21], the holding time varies[22], and PWHT on the hydrogen [23].

Furthermore, surface roughness has been the subject of numerous investigations. Jhe-Yu Lin et al [24] used ultrasonic welding to join Ni and steel while also examining how roughness affected the evolution of their bonding strength. Their findings showed that the binding strength evolves quickly when the surface is smooth and that the formation of the contact plane region affects the strength of the welded joint. In another study, Hyeonggeun Jo et al [25] examined the effects of the surface roughness treatment of electrodes resistance spot welding on the strength of welded joints. The procedure involved the use of sandpaper to increase surface roughness, followed by measurements of the nuggets' diameter, tensile strength, and welded joint hardness. It was observed that roughness has an impact on the strength of welded joints. Furthermore, another research

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conducted by Michaela et al [26] examined the impact of surface roughness on the Laser Beam Welding of Aluminium Alloys. They examined the effects of different surface roughness which was monitored in the range Ra 0.8 to Ra 15. The research results also showed that welded joints are impacted by surface roughness. Mechanical testing and macrostructures are methods used to test the strength of welded joints and several studies have been conducted in this regard. They include M. Sabzi et al's [27] study, which examined the mechanical properties of AISI 316L-AISI 310S stainless steels with mechanical tests, specifically the tensile shear, Charpy impact, and Vickers micro-hardness tests. In a different study, M. Sabzi et al [28] investigated the relationship between the AISI 316L and the AISI 310S stainless steels using mechanical testing, among others (tensile, impact, and Vickers micro-hardness tests). Following this, R. Sokkalingam et al [29] explored the joints of Dissimilar welding of high-entropy alloy to Inconel 718 super-alloy using macrostructures testing. Furthermore, Jilin Xie et al [30] tested the different cross-sectional macrostructures of the TiNi SMA and Ti6Al4V dissimilar. Lastly, Saurabh Akulwar et al [31] explored the resistance spot welding behavior of automotive steels by testing macro structures in a fusion zone, heat-affected zone (HAZ), and the base metal.

Prior to this time, no in-depth analysis has been carried out to examine how the correlation of material preparation and the selection of suitable currents can improve the quality of welded joints. Therefore, The goal of this investigation is to determine whether there is a relationship between the roughness variation treatment, preparation, and welding current selection for AISI 304 stainless steel material to improve the quality of the joint. This is an important research since the preparation of materials with variations in roughness will make the adhesion between the two specimens better, thus having an impact on the quality of welded joints.

II. Research Methods

This study consisted of several stages, namely: material preparation, welding, and testing.

A. Material Preparation

The Foundry Master Oxford instruments were used to examine the material composition of AISI 304. These instruments are high performance metal analyzers with a small tread observation method.

TABLE I. Summarization of the Components of AISI 304

Composition	C	Si	Mn	Cr	S	P	Ni	Fe	Mo
wt%	0.0531	0.533	1.05	19.0	< 0.0005	0.0205	7.84	71.0	0.0010

The AISI 304 stainless steel plate, was cut using a sample metallographic AWS D8.9-2002 Sq-100 cutting machine, with a standard size of 105x45x1 mm as shown in Fig. 1. When the metallographic cutting machine was working, a cooling stream was used to ensure that the cutting did not affect the properties of the material.

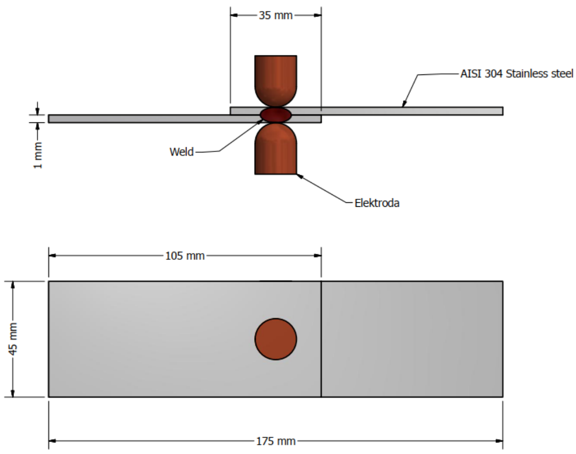


Figure 1. A Schematic diagram of the test objects used in the experiments

B. Treatment Before Welding

Prior to welding the surface side, was treated by sanding with a modern sandpaper machine M2500-B. This was conducted by installing sandpaper and sanding each specimen's surface for three minutes. Furthermore, the surface roughness machine and the following variations were applied for the connecting surface's roughness: (0.34, 0.33, 0.24, and 0.20 μm). Fig. 2 is a photograph of the equipment used.

Figure 2. Roughness test process with surftest SJ 310 Mitutoyo

C. Treatment During Welding

Figure 3. Resistance spot welding machine

The welding process was carried out using a pressurized air electrode suppression system that had a pressure adjustable mechanism. Also, analog settings were employed in thecurrent setting system and the system's welding time is adjusted using digital parameters as shown in Fig. 3

Following this, the welding parameter optimization settings were based on the standards of AWS C1.1-MC.1:2012 The parameter settings for the different rough specimen surfaces observed are as follows: for base metals with a roughness of 0.34 µm, the setting parameters were, an electrode pressure of 30 Psi, welding current of 5 kA, and welding time of 5 seconds , and this is the same for specimens with a surface roughness of 0.33 µm. The electrode pressure, welding current, and welding time were all optimized for surface roughness of 0.24 µm, at 40 Psi, 6 kW, and 6 seconds. , respectively. Furthermore, specimens with a surface roughness of 0.20 µm, have the parameters; 50 psi electrode pressure, 7 kW welding current, and 7 seconds welding time. The total number of specimens used was 36, with Each experiment consisting of 3 specimens. and their average values were determined to provide more accurate findings. Details of the welding settings and roughness conditions are shown in Table I.

TABLE I. WELDING PARAMETERS AND CONDITIONS

Experiment	Welding Parameters **Process**			Surface Roughness
	Electrode Force (Psi)	Welding Current (kA)	Weld Time (S)	
1	30	5	5	0.34 µm
2	30	5	5	0.33 µm
3	40	6	6	0.24 µm
4	50	7	7	0.20 µm

D. Connection Testing

The quality of the welded sample was tested using the tensile shear method [32] as shown in Fig. 4.

Figure 4. Tensile test machine

Sample quality for electrode-subjected surface contours was tested using macro photos. The surface contours were then analyzed by Gwydion software.

III. RESULT AND DISCUSSION

Tensile strength [33][32], macrostructure [34], and surface conditions [35]in the region of electrode pressure were parameters used by the guidance software to examine the weld quality.

A. Connection Quality Testing with Tensile Shear Test

A total of 36 specimens were examined in this study, with each experiment consisting of 3 specimens. To make the displayed data more accurate, each data point was an averaged value from each experiment. Following this, specimens with shear tensile strength and contouring of the connecting surface subjected to the electrodes are as follows:

a. The relationship between a surface's roughness and the maximum voltage points using the following welding parameter settings: 30 Psi electrode pressure, 5 kW Current, and 5 seconds, welding time, is shown in Fig. 5.

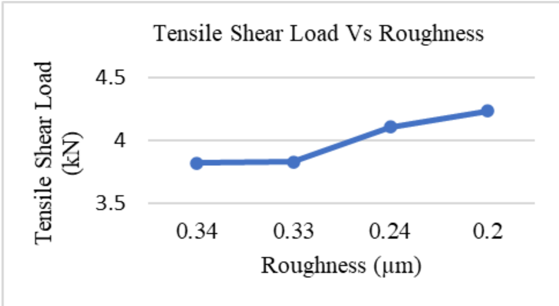


Figure 5. Welding parameters at 5 kA

Fig. 5 shows the tensile strength of base metal with a surface roughness of 0.34 µm using the following welding parameters: 30 Psi electrode pressure, 5 kW current, and 5 seconds welding time. the result showed that the tensile strength increases directly in proportion to how smooth the surface is. Likewise, a base metal having a surface roughness of 0.2 µm, had a tensile strength of 4.2±0.4 kN which also proves the relationship between the display smoothness and the shear tensile strength value. According to S. Akulwar et al [30], the smoother the connection surface, the better the electrical resistance and the more the heat input to the welding area , thus, improving the quality of the weld.

b. The relationship between a surface's roughness and maximum voltage points using the following welding parameter settings namely: 40 Psi electrode pressure, 6 kW current, and 6 seconds of welding time is illustrated in Fig. 6

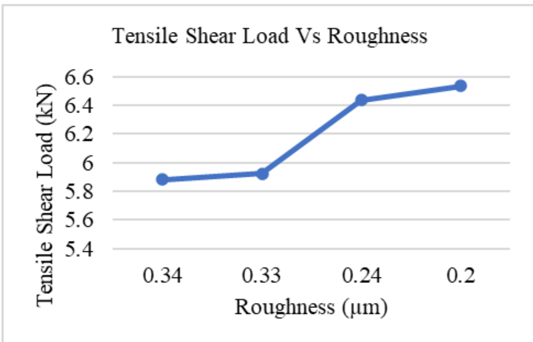


Figure 6. Current welding parameters 6 kA

Fig. 6 shows the relationship between the tensile strength and surface roughness of 0.33 µm for the welding parameter sets of 40 Psi electrode pressure, 6 kW current, and 6 seconds of welding time. There is a directly proportional relationship between the smoothness of a surface and the increases in the shear tensile strength. In addition, the highest tensile strength measured is 6.5±0.3 kN, exceeding the most optimal research findings (3.8 kN), which was obtained by Manoj Raut [36] . This is because Manoj's research focused only on optimization of parameters, whereas in this study, the optimization of parameters, as well as the preparation treatment welding with varying surface roughness Is the main point of attention.

c. The relationship between a surface's roughness and the maximum voltage point using the following welding parameter settings, namely: 50 Psi electrode pressure, 7 kW Current, and 7 seconds welding time, is illustrated in Fig. 7.

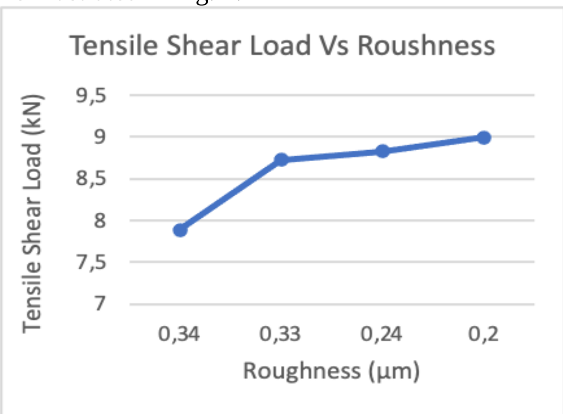


Figure 7. Welding parameters current 7 kA

Fig. 7 shows that there is a relationship between the tensile strength and the surface roughness of Ra 0.24 µm at the setting of the electrode pressure welding parameter of 50 Psi, Current 7 kW, and time 7 seconds. The results showed that an increase in current is directly proportional to the sheer tensile strength. This observation is valid because, an increase in current results to an increased heat input to the area being welded. This has an impact on the increase in tensile strength since the increase in heat input facilitates the melting process of the mild steel on the surface of the specimens being welded. Fig. 7 also shows the relationship between the surface smoothness and the sheer tensile strength. Furthermore, using the same parameter settings as those reported by Tanmoy [20], the highest tensile strength obtained was 9±0.2 kN, which is 2.4 kN greater than the result encountered by Manoj Raut [36].

As observed in Fig. 1, 2, and 3, the roughness treatment has a significant impact on the tensile strength of welding shear; the smoother the surface, the higher the value of the shear tensile strength. This occurs because the contact area that is covered by the heat input is larger with smoother surfaces [24].

B. *Connection Quality Testing with Macrostructures*

Result of the photographs taken using macro cameras and analyzed using Gwydion software are shown in Table II

TABLE II. PHOTO MACRO WITH VARIATIONS IN ROUGHNESS

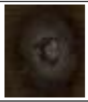
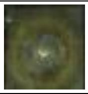
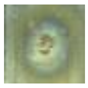
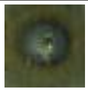
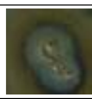
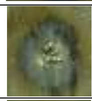
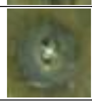
Level of Roughness (µm)	Current (kA)	Time (Second)	Pressure (Psi)	Photo
0.34	5	5	30	
	6	6	40	
	7	7	50	
0.33	5	5	30	
	6	6	40	
	7	7	50	
0.24	5	5	30	
	6	6	40	
	7	7	50	
0.20	5	5	30	
	6	6	40	
	7	7	50	

Table III shows the results of the photographs taken using macro cameras, and analyzed using Gwydion software to determine the contours of the surface subjected to electrodes. It was obtained that the surface subjected to the electrode becomes smoother using a connection surface with a roughness of 0.20 µm, a current of 7 kA, 7 seconds welding time, and 50 psi electrode pressure. This implies that the smoothness of the connection surface determines the quality of the surface contours exposed to the electrodes. Using Gwydion software, the detailed results are displayed as a three dimensional contour (Fig. 7).

C. Quality Testing with Gwydion Software Analysis

Using some high-resolution digital, macro pictures, the analysis done with the Gwydion software, revealed some of the electrode affected areas.

a. Fig. 8 depicts the surface contours of the area subjected to electrode pressure, at a roughness of 0.34 µm

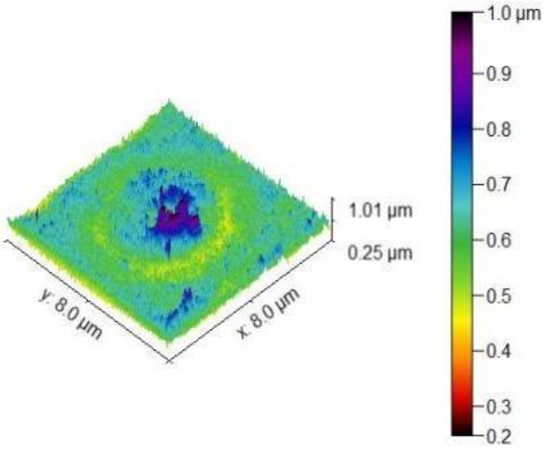


Figure 8. Surface contour of the area surface subjected to the electrode with a surface roughness of Ra 0.34 µm

Fig. 8. shows the contour of the area surface subjected to the electrode with a surface roughness Ra 0.34 µm, electrode pressure 30 Psi, current 5 kW, and time 5 seconds welding time. A macro photo was taken of the connecting area that was exposed to the electrodes, and the image was then further examined using the Gwydion software. The surface of the rough area is in the center subjected to electrode pressure with a roughness value of 1.01 µm. Furthemore, the specimen showed the lowest shear tensile strength of 4.2 kN. From these two phenomena, it is clear that the roughest surface is that of the area where the electrode will be placed, which has the lowest tensile strength at the time of preparation.

b. Fig. 9 shows the surface contours of the area subjected to electrode pressure, with a roughness of Ra 0.33 µm

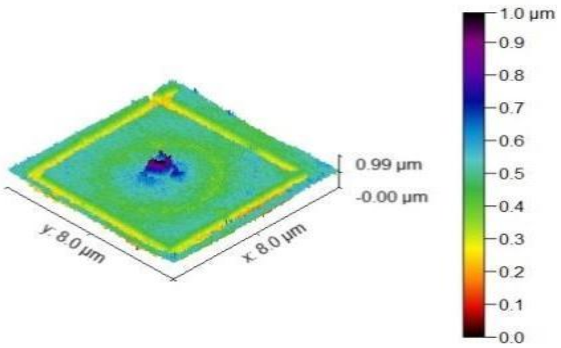


Figure 9. Surface contour Ra 0.33 µm of the area undergoing electrodes

Fig. 9 shows the surface contour of the electrode undergoing area with a surface roughness of 0.33 µm, an electrode pressure of 30 Psi, a current of 5 kA, and time 5 seconds. Meanwhile, the roughest area is on the edge of the area to which the electrode is subjected, with a roughness value of 0.99 µm.

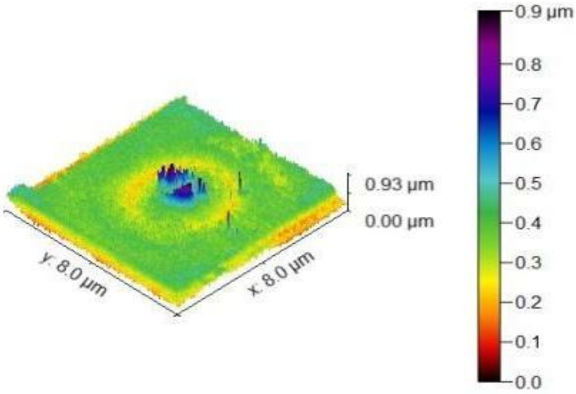


Figure 10. Depicts the surface contour of the area subjected to electrode pressure, at a roughness of Ra 0.24 µm

Fig. 10. Surface contour of the area undergoing electrodes surface subjected to the electrode with a surface roughness of Ra 0.24 µm

Fig. 10 shows that the contour of the area surface subjected to the electrode with a surface roughness of Ra 0.24 µm, pressure 40 Psi, the current of 6 kA, and t time 6 seconds, with the roughest area being on the edge subjected to the electrode, which is 0.93 µm.

c. Fig. 11 shows the surface contour of the area subjected to electrode pressure, with a roughness of Ra 0.20 µm

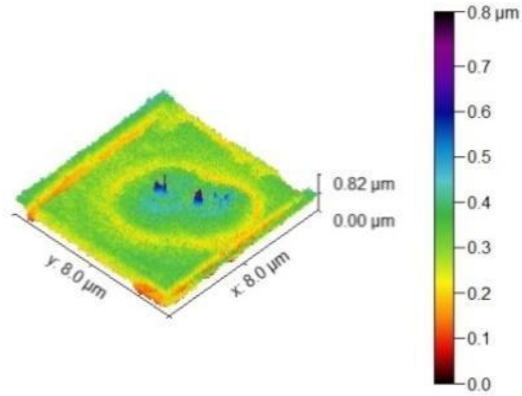


Figure 11. Surface contour of the area subjected to electrodes with a surface roughness of Ra 0.20 µm

Fig. 11, shows that the surface contour of the area subjected to electrodes with a surface roughness of Ra 0.20 µm, electrode pressure 50 Psi, current 7 kA, and time 7 seconds. Also the roughest area is on the edge that is subjected to electrodes, which is 0.82 µm.

Figs. 8,9,10, and 11 show that in terms of roughness, the contours of the surface are subjected to electrodes. The smoother the surface of the joint before welding, the lower the roughness in the area subjected to the electrode. This is excellent because it will cut down the cost of putty and paint during projects like finishing an automobile's body. However, this welding process still needs to be tested with other materials, especially those that differ from the surface. It is, therefore, essential to find an ideal setting point to get better surface contours.

IV. Conclusion

The results obtained from testing the tensile strength of the shear, the macrostructure, and surface roughness of the area subjected to electrodes using the Gwydion software, varied based on the optimization of the welding parameters and the surface treatment of the AISI 304 stainless steel joint. Furthermore, the results showed that the higher the level of the material's connection surface smoothness, the stronger the weld. Also the higher the welding current, the higher the tensile strength of the welding joint. and the higher the smoothness degree of the joint's surface, the more delicately exposed the surface area becomes to the electrode. Finally, by addressing joint's surface area during material preparation, resistance spot welding results in a stronger connection. However, this study is still limited to AISI 304 stainless steel material alone, so it is recommended to test on other materials, especially those that are dissimilar.

Author Contributions

During the process of data collection, the authors were assisted by students, especially in the specimen welding process, and BLKI Makassar which provided the labor that aided in the tensile test process, as well as in the collection of the test results.

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