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Variation of Welding Time with Resistance Spot Welding Method on Mechanical Properties and Metallographic of DIN 1.4003 Material on K612 Sidewall

Elza Febri Yusdetira[1], Ananda Nur Rahmawati[2], Dioda Damai Nugroho[3], M Rizky Aji Rosyid[4], Alfi Tranggono Agus Salim[5], Mahendra Wisnu Saputra[6]
[1,2,3,4,5]Department of Engineering, Rollingstock Engineering, Madiun State Polytechnic, Madiun, Indonesia, Indonesia-63127
[6]Quality Management Department, PT INKA (Persero), Madiun, City, East Java, Indonesia-63127

***Abstract*— *The resistance spot welding time parameters that used were not in accordance with the welding current and material thickness in the process of making the K612 sidewall at PT INKA (Persero) results in welding joints that are not optimal and fail. To prevent failure in welding, appropriate parameters are needed. Resistance spot welding parameters that are considered include welding time. This research aims to analyze the effect of welding time on DIN 1.4003 material on shear strength, hardness value, nugget diameter, and microstructure after welding. This research method uses resistance spot welding with welding time variations of 11 cycles, 15 cycles, 19 cycles, and 21 cycles. The results show that the smallest welding time has the lowest nugget diameter and shear stress, and the highest hardness value. The microstructure formed in the nugget is ferrite, pearlite, and bainite. The conclusion of this research is that welding time affects the welding results as well as the mechanical and metallographic properties of DIN 1.4003 material.*

***Keywords*— *Welding Time, Resistance Spot Welding, DIN 1.4003, Mechanical Properties, Metallography*

I. INTRODUCTION

The manufacturing industry uses various types of welding processes, one of which is resistance spot welding [1]. In the process of working, resistance spot welding uses parameters, including welding current and welding time, which factors affect heat input which has an impact on the mechanical properties of the weld joint (nugget) [2]. PT INKA (Persero) as a train manufacturing industry uses the resistance spot welding method in the process of making the K612 sidewall using DIN 1.4003 material [3]. In the welding process at the PT INKA (Persero) industry, there is no use of the right parameters. The use of improper parameters will create an urgency that causes welding defects, this affecting the mechanical properties of the material and the safety and security of transportation equipment. In previous research conducted on SUS 304 (JIS G 4303) material with a thickness of 2 mm using the resistance spot welding method with a welding time variation of 0.28 seconds, 0.32 seconds, 0.36 seconds, 0.40 seconds, and 0.44 seconds [3]. The results of the research show that increasing welding time causes the diameter of the nugget to get wider and the tensile stress to increase. Another previous research was conducted on AISI 1008 low carbon steel material with welding time variations of 0.75 seconds, 1.0 seconds, and 1.25 seconds to analyze its effect on mechanical and metallographic properties [4]. The results of this research show that the highest shear strength is in the highest welding time variation because the diameter of the nugget formed is the widest and the resulting microstructure includes ferrite, pearlite, and martensite. The purpose of this research is to analyze the mechanical properties (strength and hardness) and metallography (microstructure and macrostructure) of DIN 1.4003 material after the resistance spot welding process with the target of identifying an effective welding time so as to produce benefits through solving industrial problems at PT INKA (Persero) in the use of resistance spot welding parameters in the manufacture of K612 sidewalls, as a security support for transportation equipment to maintain passenger safety and as a reference for resistance spot welding methods on stainless steel, to add insight and knowledge in engineering applied to the railway industry.

II. LITERATURE REVIEW

A. *Resistance Spot Welding (RSW)*

Resistance Spot Welding (RSW) is a welding process that is formed due to resistance heating that occurs when the current passes through the part that you want to do the welding process [5] with the type of connection is a lap joint. Spot resistance welding is found in fabrication at PT INKA (Persero) which is suitable for application to the K612 project sidewall.

B. *K612 Sidewall*

One of the main parts of the train is the sidewall, which is the object of this research. The sidewall is designed to withstand loads from components on the roof of the train. The sidewall consists of an elongated vertical steel frame and strong, rigid sidewall panels to maintain the shape of the carbody without deformation during jacking and lifting [3].

C. *DIN 1.4003 Material*

DIN 1.4003 stainless steel is a ferritic type material which is an iron-chromium alloy containing approximately 11-30 wt% chromium and low carbon content [6]. The chemical

Elza Febri Yusdetira, Ananda Nur Rahmawati, Dioda Damai Nugroho, M Rizky Aji Rosyid, Alfi Tranggono Agus Salim, and Mahendra Wisnu Saputra, "Variation of Welding Time with Resistance Spot Welding Method on Mechanical Properties and Metallographic of DIN 1.4003 Material on K612 Sidewall," *International Research Journal of Advanced Engineering and Science*, Volume 9, Issue 4, pp. 57-61, 2024.

composition of DIN 1.4003 material is shown in Table 1.

TABLE 1. Chemical Composition of DIN 1.4003 Material

Element	C	Mn	Si	Cr	Mi	P	S	N
%	0,003	1,50	1,00	10,5 – 12,5	1,00	0,04	0,015	0,03

D. Nugget

Nugget is the result of the connection process in the spot welding process which is formed due to the pressing of the electrode and the amount of current from the electrode pressed on the metal, then melting the metal until it is fused during the weld time process due to electrical resistance and is generally round [7].

E. Mechanical Properties and Metallography

Mechanical properties are the ability of a material to receive a load without damage to the material. Some mechanical properties of materials include strength, hardness, elasticity, stiffness, plasticity, toughness, and fatigue [8]. Metallography is a method of analyzing the microstructure of a metal material with a 50-3000 times magnification microscope [9].

F. Macro Examination

Macro examination is used to determine the diameter of the nugget after the welding process. Macro examination is carried out with ASME BPVC Section IX standards to measure the diameter of spot welds with 50-500 times magnification using a digital macroscope [9].

G. Micro Examination

Micro examination serves to determine the structure of the material, to predict material properties, and to determine the correct heat treatment. Material specimens are tested at magnifications up to 3000x with a microscope [9].

H. Tensile Shear Test

Tensile shear strength is a shear stress test that is used to determine the strength of welded joints [10]. Tensile shear test refers to ASME BPVC Section IX standard to determine the value of yield strength (MPa), ultimate tensile strength (MPa), and elongation (%) seen in the resulting shear test graph [11].

I. Micro Vickers Hardness Test

Micro vickers hardness test is conducted to determine the value of vickers hardness (HVN) in the weld zone, HAZ, and base metal areas of the specimen with reference to the ASTM E92 standard [12].

III. METHODOLOGY

The process of resistance spot welding and making test specimens was carried out at PT INKA (Persero), while the testing process which includes tensile testing, hardness testing, macro and micro structure testing was carried out at the Madiun State Polytechnic Material Test Laboratory. The equipment and materials used in this research are mentioned in Table 2.

TABLE 2. Equipment and Materials

Equipment	Materials
Spot Welding Machine	DIN 1.4003
Gap shear machine	Aqua Regia Liquid
Tensile Test UTM 300kN	Polishing Paper (Grid 240- 1200)
Micro Vickers Machine Tipe TH17	Metal Polish Liquid
Macroscope Digital	Polishing Cloth
Microscope Digital	Penetrant Liquid (SKL-SP2)
CNC Miling Machine	Developer Liquid (SKD-S2)

The method used in this research is a quantitative experimental method with variations in welding time of 11 cycles, 15 cycles, 19 cycles, and 21 cycles with a welding current of 12 kA and material DIN 1.4003 thickness of 3 mm. The variables used in this research are: independent variable (welding time), dependent variable (tensile shear test, micro vickers hardness test, macro examination, and micro examination), and control variable (DIN 1.4003 material). The research results were analyzed using the Analysis of Variance (ANOVA) data analysis method to determine the accuracy of the research results. The research stages are listed in the flow chart in Figure 1.

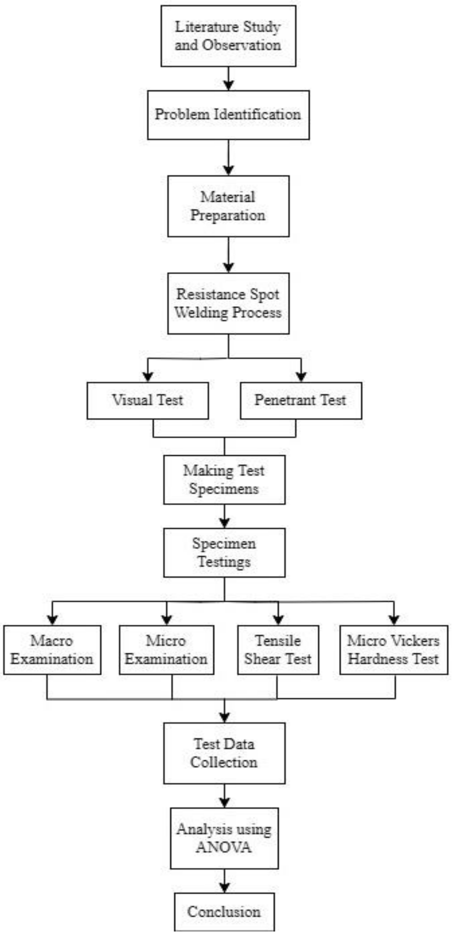

Figure 1. Research Flowchart

IV. RESULT AND DISCUSSION

A. Macro Examination

Macro examination was carried out on 12 specimens with the results of observations on nugget width and weld depth

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shown in Figure 2 and measurements shown in Table 3.

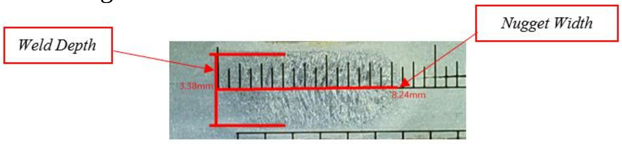


Figure 2. Weld Depth and Nugget Width

TABLE 3. Average of Nugget's Width and Weld Depth

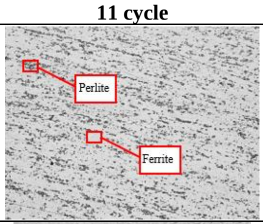
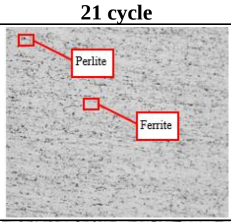
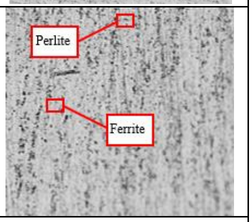
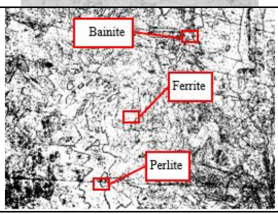
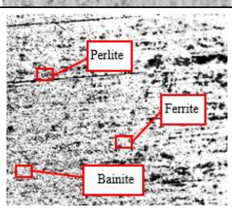
Parameters	Nugget Width (mm)	Weld Depth (mm)
11 Cycle	8,26	3.38
15 Cycle	9,66	3.68
19 Cycle	10,4	3.90
21 Cycle	11,3	4.14

Based on Table 3, the higher welding time increases the heat input rate, resulting in a wider nugget diameter and deeper weld depth [13]. This has met the acceptance requirements based on ASME BPVC Section IX DIN 1.4003 material with a thickness of 3 mm has a minimum value of 2T (2 x thickness = 6 mm) for nugget diameter and a maximum weld depth of 4.8 mm (80% x 6 mm = 4.8) [14].

B. Micro Examination

Micro examination is carried out based on ASTM E3 standards [15] to determine the microstructure formed in 3 zones in the weld metal which includes base metal, HAZ (Heat Affected Zone), and weld zone. Some samples of micro testing results are shown in Table 4.

TABLE 4. Result of Micro Structure

Welding Area	Welding Time	
	11 cycle	21 cycle
Base Metal		
HAZ		
Weld Zone		

1. Base Metal

DIN 1.4003 material has ferrite and pearlite structure, ferrite structure is characterized by bright color and relatively large grain size, no phase change occurs which makes it more difficult to refine the ferrite grain size so that the grain size becomes coarse. Thus, the ductility of the material increases after the welding process [16].

2. HAZ (Heat Affected Zone)

The results of microstructure observations in the HAZ area of DIN 1.4003 material consist of ferrite and pearlite smaller than the base metal because the longer the welding time, the greater the heat input so that the metal close to the weld zone experiences a slower cooling rate than the base metal [17].

3. Weld Zone

From the results of observations using a microscope with a magnification of 200x in the nugget area, ferrite, pearlite, and bainite microstructures were formed at each welding time variation. The addition of bainite structure is due to the thermal cycle of heating and cooling air at room temperature [18].

TABLE 5. Percentage of Ferrite and Perlite Grains

Welding Time	Percentage of Grains (%)	
	Ferrite	Perlite
11 cycle	71.90	28.10
15 cycle	77.74	22.26
19 cycle	82.10	17.90
21 cycle	84.74	15.26

Table 5 shows that welding time 11 cycle has a high percentage of ferrite worth 71.90% and low pearlite worth 28.10%. This is because the higher welding time used will produce higher heat input so that the volume of pearlite in the nugget area decreases. The growth of microstructure grains formed in the weld zone due to increased heat input generated in spot welding affects the mechanical properties of the material [19].

C. Tensile Shear Test

Tensile shear tests were conducted based on ASME BPVC Section IX standard to determine the strength of the welded joints to withstand the applied load. This test resulted in the peak load and fusion fracture values shown in Table 6.

TABLE 6. Peak Load and Fusion Fracture Value

Welding Time	Peak Load (kN)	Fusion Fracture (mm)
11 cycle	32.35	8.14
15 cycle	33.42	8.22
19 cycle	34.66	8.30
21 cycle	35.19	8.34

Table 6 shows that welding time has a significant effect on the load given during the testing process, so that the higher the time variation given, the higher the peak load value and the resulting fusion fracture [20]. Where τ is the shear stress value (N/mm^2), F is the maximum load (N), A is the cross-sectional area of the specimen (mm^2), and d is the average diameter of the broken nugget (mm).

$$\tau = \frac{F}{A} = \frac{F}{\frac{1}{4} . \pi . d^2}$$

The calculation of shear stress increases with the increase of welding time enabled. The increase in shear stress is due to the increase in the peak load value resulting from the test. From the calculations performed, it is known that the shear strength value is directly proportional to the peak load value and the resulting fusion fault [21]. The results of the shear stress calculation are shown in Table 7.

TABLE 7. Result of Shear Strength

Welding Time	Shear Strength (N/mm^2)
11 cycle	621.99
15 cycle	630.09
19 cycle	641.02
21 cycle	644.50

The higher the weld time, the higher the peak load and the higher the fusion fracture, thus affecting the increasing shear stress [22]. The increase in peak load value that affects the shear stress strength is due to the increase in the diameter value of the nugget formed which is getting bigger as the welding time variation increases [23].

TABLE 8. Analysis of Variance (ANOVA)

		Sum of Squares	df	Mean Square	F	Sig.
Nugget Width	Between Groups	14.796	3	4.932	39.720	<.001
	Within Groups	.993	8	.124		
	Total	15.789	11			
Peak Load	Between Groups	14.690	3	4.897	60.872	<.001
	Within Groups	.644	8	.080		
	Total	15.333	11			
Fusion Fracture	Between Groups	.060	3	.020	17.805	<.001
	Within Groups	.009	8	.001		
	Total	.069	11			

ANOVA analysis in Table 8 shown that the variation of welding time has an influence on peak load, fusion fracture, and shear stress of the material [24]. The test results show that as the welding time increases, there is an increase in the peak load value and the area of the fusion fracture so that the shear stress increases [25].

D. *Micro Vickers Hardness Test*

Micro vickers hardness test was conducted based on ASTM E92 [26] standard to determine the vickers hardness value (HVN) of the weld zone, HAZ, and base metal areas of the specimens in each variation as described in Table 7.

TABLE 9. Hardness Vickers Number

Welding Time	Hardness Vickers Number (HVN)		
	Base Metal	HAZ	Weld Zone
11 cycle	190.05	335.72	354.42
15 cycle	178.35	310.27	342.87
19 cycle	175.40	300.27	335.05
21 cycle	171.47	295.05	323.77

The micro vickers hardness test then produces the value of vickers hardness (HVN) in the weld zone area which is the largest in the 11 cycle variation and the smallest in the 21 cycle variation with its hardness value and in the weld zone area there is the highest hardness value compared to the HAZ and base metal areas. This is because the higher the time variation given, the higher the heat input rate which affects the higher microstructure grains so that there is a decrease in hardness value [27]. The hardness value in the base metal area when compared to the HAZ and weld zone area is the smallest because it is not exposed to heat from welding [28]. The decrease in hardness value is still within the limit of using DIN 1.4003 material as the sidewall of K612.

V. Conclusion

Based on the tests that have been carried out, the microstructure produced in the results of this welding is ferrite, pearlite, and bainite. Shear stress is directly proportional to welding time, while the material hardness value (HVN) is inversely proportional to welding time. Nevertheless, the strength of the material is still within the limit of using DIN 1.4003 material as the sidewall of K612. All welding time variations are optimal enough to be applied in solving industrial problems.

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