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Analysis of GMAW Welding Current Variations of SS400 and SUS 201 Material Differential Joints on Mechanical Properties of Underframe Train 612

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Abstract— *The production process of the 612 train underframe assembly using dissimilar metal welding has a problem related to neglecting the welding current setting which results in defects in the weld joint. This research aims to analyze the effect of GMAW welding current on the macrostructure, microstructure, hardness, and tensile strength of the material with a thickness of 4.5 mm on SS400 and SUS 201 materials with quantitative test research methods using GMAW welding with current parameters of 80 A, 120 A, and 160 A. This research shows that the high value of welding current affects the mechanical properties of the 612 train underframe.*

Keywords— *Dissimilar Metal Welding (DMW), SS400 Material, SUS 201 Material, Mechanical Properties, GMAW Welding*.

I. Introduction

The manufacturing industry engaged in transportation uses assembly or connection with the welding process [1]. Welding carried out by PT INKA (Persero) to produce New Generation Stainless Steel trains applied to the underframe of Train 612. The underframe is the main part of the train that receives the greatest load in the train assembly process [2]. The Dissimilar Metal Welding (DMW) connection on the underframe of Train 612 uses the material type SS400 (Structural Steel 400) with SUS 201 (Stainless Austenitic Steel 201). In the welding, several welding problems were identified, including differences in melting points to welds that were not fused, this was due to current adjustments that were ignored during the welding process. Therefore, welding between different types of metals requires an appropriate welding procedure to produce a fusion connection [3]. In addition, dissimilar metal welding has the disadvantage of differences in composition between materials along the fusion line resulting in different mechanical properties of the microstructure [4]. The difference in microstructure affects the value of the mechanical properties of a material such as hardness and tensile strength [5] a). To determine the mechanical properties of a material, research was conducted on the effect of the formation of microstructure in the weld zone and base metal by considering the use of welding types and welding parameters. The type of welding to connect SS400 (Structural Steel 400) and SUS 201 (Stainless Austenitic Steel 201) at PT INKA fabrication department is GMAW (Gas Metal Arc Welding). The GMAW welding method has several advantages, such as not producing slag on the weld [6]. The GMAW welding process observes various welding parameters, inclding GMAW welding parameters to produce fusion welds, such as welding current [3], because the current affects the melting and penetration of the weld [6], increasing the welding electric current affects the penetration and melting speed [7]. The higher electric current affects the tensile strength of the connection. This is supported by research [8] that the tensile strength characteristics of welded joints are influenced by the size of the welding current. To produce the right welding current parameters in the connection of non-similar materials SS400 and SUS 201 in its determination, experimental research is carried out.

Based on the background and industrial observations, a study was conducted to determine the effect of welding current on the connection of low carbon steel (SS400) and stainless steel (SUS 201) with GMAW welding currents 80 A, 120 A, 160 A 4.5 mm thick plates implemented on the 612 train underframe at PT INKA (Persero) on tensile strength values, hardness values and microstructure. The test methods in this research are tensile test (MPa), micro vickers hardness test (HV), micro examination and macro examination.

II. Theoretical Review

A. Previous Research

- Research [3] entitled "The Effect of Current Variations on the Mechanical Properties of GMAW Welding Joints of Stainless Steel ASS 304L with Low Carbon Steel AISI 105". The results of this study show that increasing current has an effect on increasing tensile strength and yield point, the lowest tensile strength at a current of 100 A and for the highest tensile strength at a current of 120 A. This does not rule out the possibility that if the current is more than 120 A there is still an increase in tensile strength and yield strength.
- Research [8] entitled "Tensile Strength Characteristics of Stainless Steel Carbon Steel Unequal Welding Joints". The results showed that the tensile strength characteristics of welding joints were influenced by current, the higher the welding current the higher the tensile value and the weakest area occurred in the area around the HAZ of low carbon steel.

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B. Material

The material in this research object is a type of low carbon steel SS400 included in the category of steel that has a carbon content of 0.2- 0.25%. Low carbon steel has high ductility but has low hardness and wear resistance properties with a small pearlite composition, with ductile properties having the advantage that it is easier to shape [9]. SUS 201 stainless steel has low nickel content and high hardness. 201 stainless steel belongs to the austenitic category, with lower chromium, nickel and carbon content [10].

C. Gas Metal Arc Welding

To produce maximum welding and fusion things to consider when doing the welding process as follows:

- Welding Current (Weld Current), the selection of current must be considered properly in the welding process of different types of materials because they have different melting points, thus affecting the melting rate of the parent metal [3].
- Voltage (welding voltage) is related to the length of the welding arc or the distance between the electrode and the workpiece during the welding process, if when welding there is an increase in arc height, the welding voltage increases and the current decreases [4].
- Travel speed in welding affects the amount of welding current. If the current increases, the welding speed increases, because the high current causes the electrode to melt quickly [4].

D. Destructive Test

- Macrostructure Examination, to determine the macro structure and welding penetration of a material such as weld zone, HAZ and base metal [11].
- Microstructure Examination, to identify the structural grains of metal in the weld zone, HAZ, and base metal areas so that the mechanical properties are known by showing a comparison of tensile strength values, hardness, and comparing changes in metal microstructure [3].
- Tensile Test, tensile testing process aims to determine the tensile strength of the welding area and the location of the break of a welding joint with the resulting value of ultimate tensile strength (MPa), yield strength (MPa) and elongation (%) data [12].
- Micro Vickers Hardness Test aims to determine the resistance of a material to friction and impact [9]. This test uses a diamond indenter with a pyramid shape with a diagonal measured to determine the hardness value (HV). The time to indent the test is 10-15 seconds.

III. Methodology

The research methodology includes information about the research stages to achieve the research objectives, as follows:

A. Equipment and Materials

In the research, several pieces of equipment and materials used are:

TABLE 1. Equipment & Materials

Equipment	Materials
Gas Metal Arc Welding Machine	SUS 201 Material with 4.5 mm Thickness
Macro Test Machine	SS400 Material with 4.5 mm Thickness
Microscope Digital Series Olympus	Electrode ER 309 L
Tensile Test Machine	Polishing Paper
Micro Vickers Hardness Test Machine	Polishing Cloth
Polishing Machine	Mounting Resin
Ruler	Etching Reagent
Cutting machine	Polishing Paste

B. Preparation Specimen

The process of making test specimens takes into account the number of tests and follows the standard. Specimens were cut using a gap shear machine with dimensions of 150×300×4.5 mm.

C. Welding Process

The welding process uses Gas Metal Arc Welding (GMAW) using current variations of 80 A, 120A, and 160 A. The next stage is visual testing and penetrant tests that refer to the AWS D1.1 standard. Visual test and penetrant test are non destructive tests [13]. After passing the visual test and penetrant test, the tensile test, micro vickers hardness test, micro and macro examination are carried out.

IV. Result

A. Macrostructure Examination

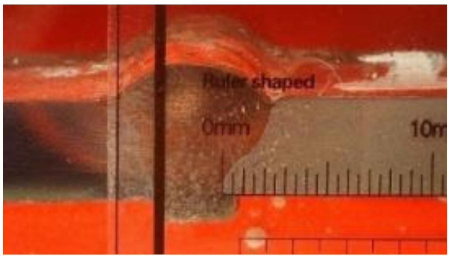

Fig. 1. Macrostructure Current 80 A

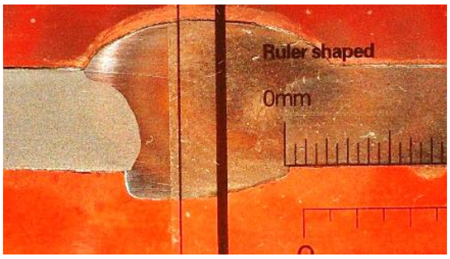

Fig. 2. Macrostructure Current 120 A

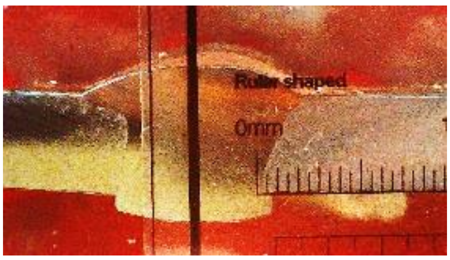

Fig. 3. Macrostructure Current 160 A

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TABLE 2. Result Macrostructure Examination

Weld Zone	Current 80 A	Current 120 A	Current 160 A
HAZ SS400	6,5 mm	6,5 mm	7 mm
HAZ SUS 201	0,5 mm	1 mm	1 mm

The results of macro testing show that the width of the HAZ area of SS400 material is widest in the current variation of 160 A compared to the currents of 80 A and 120 A which is 6.5 mm. This shows that the wider the HAZ area, the greater the tensile and hardness test results [14].

B. Microstructure Examination

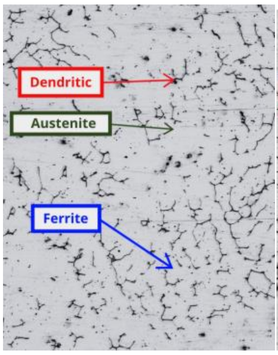

Fig. 4. Microstructure Current 80 A

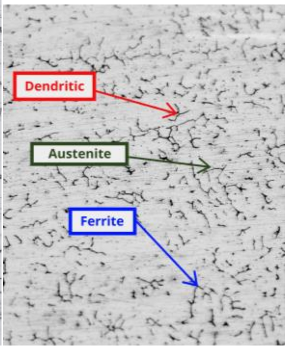

Fig. 5. Microstructure Current 120 A

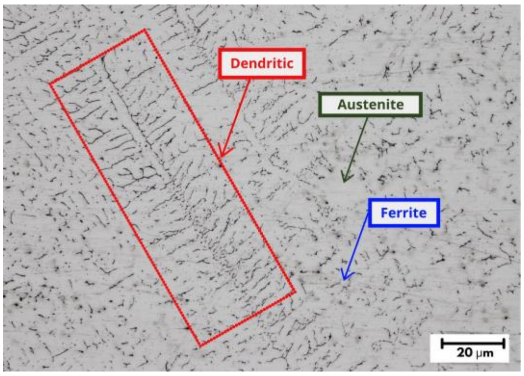

Fig. 6. Microstructure Current 160 A

The base metal area of the material used is different types (dissimilar), namely SUS 201 (austenite type stainless steel) and SS400 (low carbon steel). The following are the results of observations made using the Olympus BX53M Series Microscope with a magnification of 200x [15], [16]. The weld zone has the structure of austenite, ferrite, and dendritic formed with different current variations [17]. Hardness rises as dendritic structure is dominant [18], [19].

TABLE 3. Result Microstructure Examination

No	Specimen	Ferit (%)	Austenit (%)
1.	80 A	38.07	61.93
2.	120 A	30.21	69.97
3.	160 A	27.51	72.49

C. Tensile Test

The Tensile Test produces data in the form of Yield Strength (Y.S), Ultimate Tensile Test (U.T.S.), and Elongation (%) values [8]. In each current variation, the tensile test is carried out by testing as many as three test specimens that have been profiled in accordance with ASTM E8 standards.

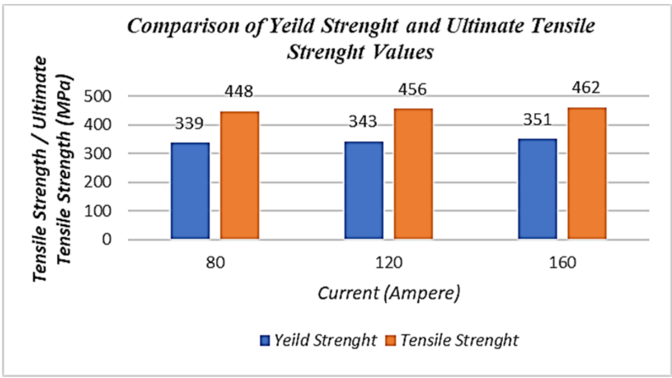

Fig. 7. Tensile Test Chart Current 80 A, 120 A, and 160 A

The comparison results of the three variations seen in the figure, the phenomenon shows that the yield strength and Ultimate Tensile Strength values increase as the welding current variation increases and the tensile test results show that the fracture always occurs around the HAZ area in carbon steel, so it can be concluded that the tensile strength of the welded joint is higher than the tensile strength of the lower carbon steel raw material [8].

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Yeild Strenght	Between Groups	470.889	2	235.444	8.544	.018
	Within Groups	165.333	6	27.556		
	Total	636.222	8			
Tensile Strenght	Between Groups	310.889	2	155.444	8.854	.016
	Within Groups	105.333	6	17.556		
	Total	416.222	8			
Elongation	Between Groups	15.472	2	7.736	4.756	.050
	Within Groups	9.760	6	1.627		
	Total	25.232	8			

Fig. 8. Statistical Analysis Data ANOVA Tensile Test

From the ANOVA test results, it can be concluded that the Sig value is 0.018, 0.016, 0.050 <0.05, then the variation of GMAW welding current on different types of materials has a significant effect on tensile strength, yield strength and elongation.

D. Micro Vickers Hardness Test

The micro vickers hardness test uses the ASTM E92 standard with a distance between points of 300 µm and the load used is 1000 Kgf. Data was taken from two sides considering that the materials used were different types of SS400 and SUS 201 to compare the hardness distribution of each material.

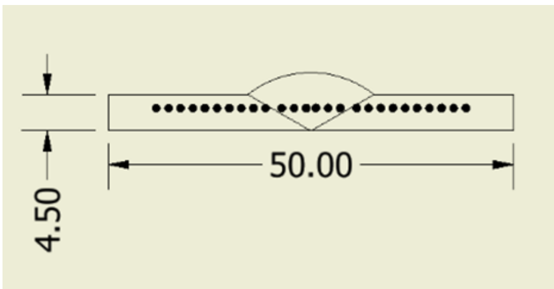

Fig. 9. Test Point on Micro Vickers Hardness Test Specimen

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The indentation result of micro vickers hardness testing is a hardness value with micro vickers hardness units (HV).

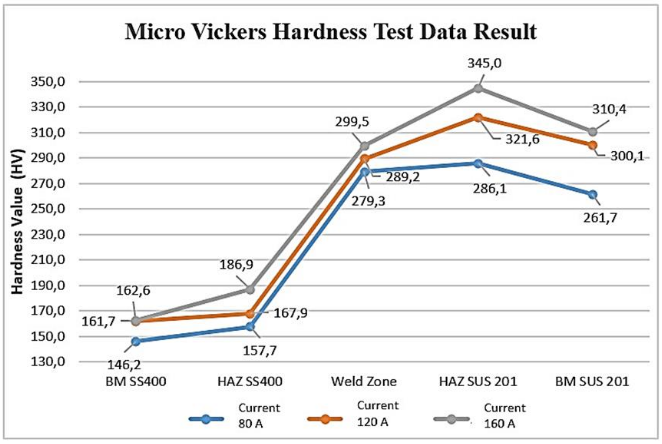

Fig. 10. Hardness Test Chart Current 80 A, 120 A, and 160 A

Based on the graph, it is known that the phenomenon that occurs is that the higher the welding current, the more the resulting hardness value increases[17], [18]. This phenomenon is due to the influence of local heating and different cooling rates and different characteristics of the two materials so that the difference in hardness values for each region and the highest hardness value is in the HAZ SUS 201 region.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Base Metal SS400	Between Groups	638.167	2	319.083	13.514	.002
	Within Groups	212.500	9	23.611		
	Total	850.667	11			
HAZ SS400	Between Groups	1794.500	2	897.250	14.851	.001
	Within Groups	543.750	9	60.417		
	Total	2338.250	11			
Weldzone	Between Groups	1800.667	2	900.333	18.800	<,001
	Within Groups	431.000	9	47.889		
	Total	2231.667	11			
HAZ SUS 201	Between Groups	6840.667	2	3420.333	138.506	<,001
	Within Groups	222.250	9	24.694		
	Total	7062.917	11			
Base Metal SUS 201	Between Groups	6373.167	2	3186.583	45.924	<,001
	Within Groups	624.500	9	69.389		
	Total	6997.667	11			

Fig. 11. Statistical Analysis Data ANOVA Micro Vickers Hardness Test

From the ANOVA test results, it can be concluded that the data is normally distributed because it has a significance value of $p < 0.05$, so the variation of GMAW welding current on different types of materials has a significant effect on the hardness value of the material.

V. Conclusion

The width of the HAZ area of the SS400 material is widest in the 160 A current variation compared to the 80 A and 120 A currents. Welding current affects the distribution of structures, the higher the welding current, the grain structure will be smooth and flat and each region has a different structure. Welding current affects the value of hardness & tensile strength.

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