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Analysis of welding time on microstructure, hardness, and torque of arc stud welding process

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Abstract

The manufacturing industry plays an important role in improving the national economy. One of the metal joining methods currently used is arc stud welding. Stud welding is used for welding bolts, which are useful for connecting parts in steel structures. This research was conducted with variations in current strength parameters of 200A, with welding times of 1, 2, and 3 seconds. The purpose of this research is to find the best parameters to determine the depth of penetration, heat-affected zone, and fusion zone of welding joints in A36 material. Macro testing results show that there are no defects such as cracks in the base metal, HAZ, or weld metal, meeting the ASME Sec. IX acceptance requirements. In addition, since the heat input remained within acceptable limits in the base metal areas of A36 and SS 304, the microtest results did not show significant changes. In the hardness test, the weld metal region obtained the highest value. The lowest average value was 192.85 HVN in the stud 1 specimen, while the highest average value was 195.37 HVN in the stud 3 specimen. The torque test shows that variations in welding time affect the torque strength; in specimen 3, it ranges from 50 Nm to 80 Nm.

1. Introduction

The manufacturing industry is an important key to spurring the national economy because it is more productive and provides a broad chain effect. The Indonesian government's steps to encourage national economic growth by boosting the manufacturing industry sector are also carried out by several countries in the Southeast Asian region, such as the Philippines and Vietnam [1]. The rapid development of the manufacturing industry also affects the development of the welding world in it.

The world of welding is currently growing; welding is a part that cannot be separated from industrial growth and improvement because of its very important role in metal repair, construction, and production. Welding is indispensable in various industrial work processes, such as metal cutting and construction production. Therefore, the rapid development of science and technology requires an increase in human resources in the field of welding because welding has many advantages over other methods. The welding method has advantages, including strength, ease of use, and effectiveness.

In the hopper construction project, there are several welding methods that are often used in metal connections, one of which is currently used is Arc Stud Welding (ASW). ASW is an assembly procedure consistently used for melting and joining studs to sheets or plates of various metals and thicknesses, where heat is transferred between the stud and the plate [2]. ASW process involves the same mechanical, metallurgical, and electrical principles found in other arc welding processes [3]. ASW itself is used for welding foundation bolts, which are useful for connecting parts of a steel construction. Application of ASW with ceramic ferrule has an important role in different production areas such as; steam boiler production, bridge construction, shipbuilding, automobile industry and, appliances industry [4]. ASW itself is divided into two types, namely capacitor discharge stud welding and arc stud welding. This welding process does not use additional materials or electrodes. Welding based on the classification of work methods divided into three groups, namely liquid welding, pressure welding, and soldering. Pressure welding is one way in which the two workpieces to be joined are heated using arc stud welding-type stud welding. The ASW process itself involves the use of an electric arc to connect the fastener to the base metal. The process only takes a fraction of a second.

In the hopper construction project, In the hopper construction project, A36 steel material was used which was connected to type 304 stainless steel. In ASTM standards, A36 sets specifications for structural carbon steel used in fitted, bolted, and welded structures for bridges, construction, and carbon steel parts. Welding of austenitic stainless steel to low alloy steel associated with segregation of alloying elements at grain boundaries causes a reduction in mechanical properties and corrosion resistance of the weld [5]. Welding of austenitic stainless steel to carbon steel causes migration of carbon from HAZ of carbon steel towards stainless steel melting zone that raises hardness at fusion boundary making this area considerably brittle [6] [7] [8] [9]. Arc Stud Welding results after visual testing found some welding results that are not fused due to inappropriate welding current and welding time can affect the quality of welding results.

The purpose of this study was to analyze the effects of current strength and welding time on the macrostructure, microstructure, hardness, and torsional strength of A36 material in stud welding.

2. Research Methods

This research aims to analyze the arc stud welding method as a welding method using A36 material and SS 304 stud bolt. The variations carried out in this study is to use welding time. The Welding time is one of the most important factors resulting from the influence of the amount of heat input. [10]

The chemical composition of the A36 and SS 304 materials as shown in Tables 1 and 2:

Table 1. Chemical composition of A36 material

No	Alloying Elements	Composition
1	*Carbon*	0.25
2	*manganese*	1.20
3	*Phosphorus*	0.40
4	*Sulfur*	0.05
5	*Silicon*	0.04
6	*Cuprun*	0.2

Table 2. Chemical composition of SS 304 material

No	Alloying Elements	Composition
1	*Carbon*	0.030
2	*Nickel*	8.0
3	*Chromium*	17.5
4	*Silicon*	0.75
5	*Manganese*	2.00
6	*phosporus*	0.045
7	*Sulfur*	0.030

The welding process was used stud welding with the material used was 304 stainless steel with dimensions P = 150 mm, L = 30 mm, and t = 10 mm with a T connection design. The material design illustration is as shown in Fig. 1.

Fig. 1. The size and shape of materials

The welding parameters used in this study refer to the welding procedure. There are 3 specimens using 3 variations of welding time, namely 1, 2, and 3s, and the welding current is 200 A. The use of different current variations in the welding process produces different mechanical properties [11]. The welding process that has been carried out obtained from welding parameter record data as listed in Table 3.

Table 3. Time variation welding Process

Marking Material	Welding Process	Ampere (A)	Welding time
STUD 1	Stud Welding	200 A	1s
STUD 2	Stud Welding	200 A	2s
STUD 3	Stud Welding	200 A	3s

Following the completion of the welding process, we conducted a series of tests to evaluate the results. These tests include metallographic testing and hardness measurements. Macrostructure testing aims to observe penetration depth, fusion lines, and possible weld defects. While microtesting is carried out to see changes in the microstructure of the material due to the experimental process that has been carried out. Hardness testing aims to determine the hardness value in various areas, such as base metal, fusion line, and weld metal. Torque testing is a test to measure the amount of torque produced by a machine or system.

The locations of the hardness testing points in each area are shown in Fig. 2.

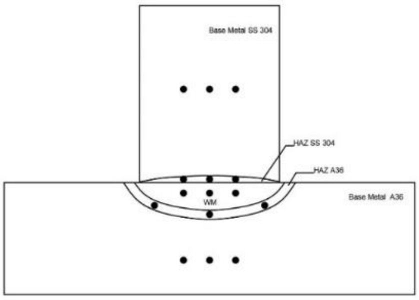


Fig. 2. Hardness test point

In the torsion test, the stud must be torsioned until a predetermined load is reached or until the stud fails, and failure occurs in the stud material itself on a thin plate, then the plug from the base metal must be removed. The tensile load is applied to the welded stud and the stud design, and a special tool is used to grip the stud properly without damage [12]. To pass the torque test, each of the five stud welds must be subjected to the required torque in the table before failure occurs in QW-192.1.3, as shown in Fig. 3.

Fig. 3. Torque Test

3. Results and Discussion.

3.1. Visual Inspection

Some things that are considered when conducting visual testing include cracks, incomplete fusion, overlap, undercut, and porosity that occur in welded specimens. The following are the results of testing specimens using the arc stud welding method with variations in welding time. From some visual test results, the weld surface shown that there are no visible defects. The standard used is ASME IX QW 194, where in the standard it is stated that the test coupon has no cracks and complete joint penetration with perfect union [13].

The following table data and documentation when visual tests are carried out shown in Table 4.

Table 4. Result Visual Inspection

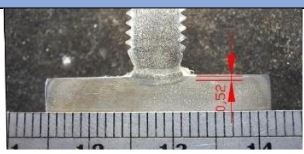
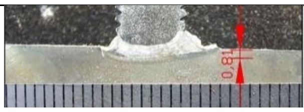
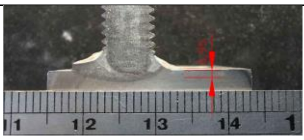
Variation	Visual Documentation
Ampere 200A *Welding time* 1s	
Ampere 200A *Welding time* 2s	
Ampere 200A *Welding time* 3s	

From the visual inspection results, no welding defects were found on the weld surface.

3.2 Macrostructure Test

Macroscopic examination is defined as testing that done with the naked eye or with relatively low magnification aids (less than x50), which done with the etching process. Macro testing is carried out to determine the effect of strong current and welding time variations on stud welding on the depth of penetration after welding. The following macro photos on each specimen shown in Table 5 below for the Stud Welding welding process.

Table 5. Result macrostructure of variation welding time

No	Kode	Variasi Pengelasan	Hasil Makro	Kedalaman Penetrasi
1	*STUD* 1	200 A 1 second		0,52 mm
2	*STUD* 2	200 A 2 second		0,81 mm
3	*STUD* 3	200 A 3 second		0,95 mm

From the results of the macro testing above, it analyzed that the effect of welding time has an impact on the depth of penetration caused by Stud welding. in line with the research [14]. The greater the heat input will make the heat distribution area larger because there is still a large enough area for heat to expand its area as a result of the welding process taking place. The acceptance criteria listed in ASME Sec. IX include no cracks in the HAZ area. From the macrotest results above, it concluded that all specimens are declared acceptable in accordance with the acceptance criteria in ASME Sec. IX.

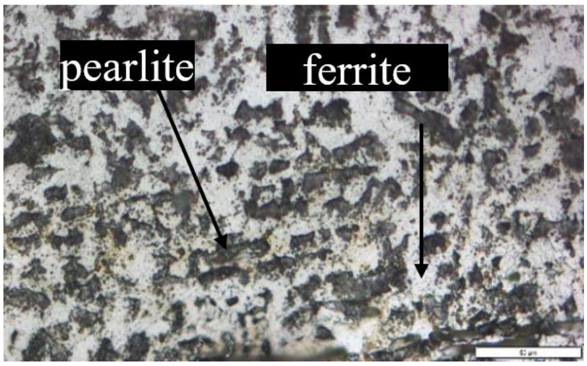
In the absence of any indication of defects, it concluded that the applied welding parameters have successfully produced solid welded joints free of structural damage. These results corroborate that the welding method used in this study is in accordance with applicable standards and relied upon to produce high quality welded joints. The lowest penetration depth was obtained in stud 1 with a welding time variation of 1 second, with a value of 0.52 mm. The highest penetration depth value is obtained in stud 3 with a welding time of 3 seconds, which is 0.95 mm. The effect of current strength has an impact on the depth of penetration, with the increase in current strength, the deeper the resulting penetration.

3.3. Micro Test

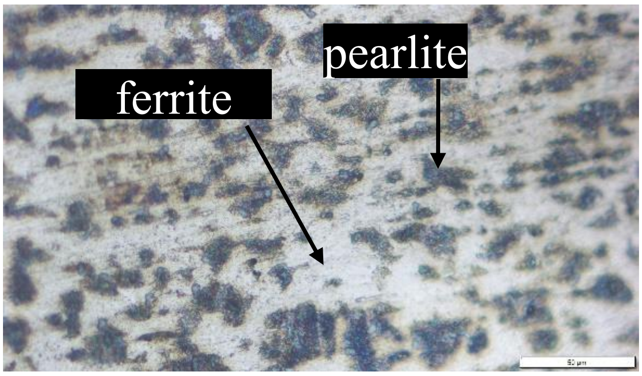
3.3.1 Base Metal A36

There are two phases in the microstructure of carbon steel, namely pearlite and ferrite. Pearlite is defined as the dark region in the microstructure. The pearlite phase is found along the ferrite grain boundary. The longer the welding time so that high heat input provides a low cooling rate, so that ferrite and pearlite will form increasingly large and coarse bonds that can produce decreased hardness in the welding results. [15]

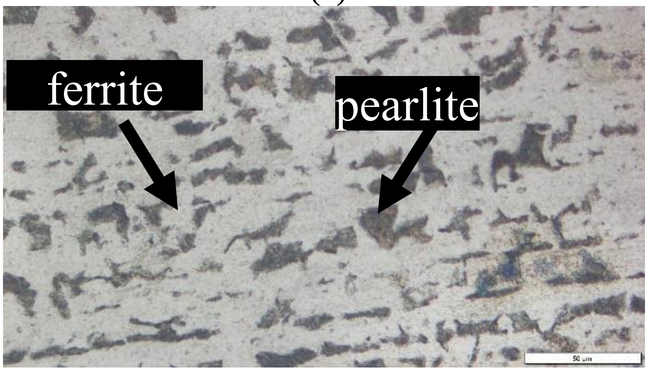
Fig. 4 shown that the microstructure of the A36 carbon steel of base metal that the phases contained in the A36 base metal area are pearlite and ferrite phases. This is because the A36 carbon steel material is not given special treatment that can change the phase in the microstructure of A36 carbon steel. In the results of the microstructure of the base metal area consists of ferrite and perlite phases where the ferrite phase has a flat, light-colored grain shape and has good ductility, while the pearlite phase has a dark grain shape and has properties that are quite hard but brittle [16]. The ferrite phase is a solid solution of pure atoms that have cube cells and have softer properties, while pearlite is also composed of fine layers and has stronger and harder properties than ferrite [17].



(a)



(b)

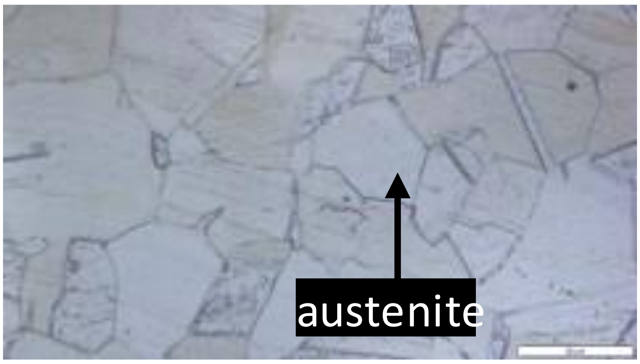


(c)

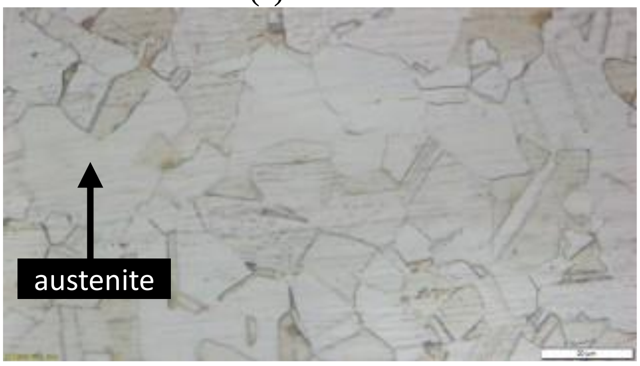
Fig. 4. Micro test base metal A36 (a) 1 second (b) 2 second (c) 3 second

3.3.2. *Base Metal* SS 304

The microstructure of the SS 304 base metal area in the specimen using 500x magnification which shown in Fig. 5:



(a)



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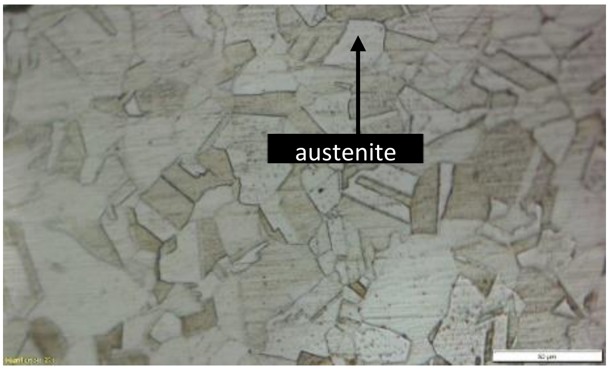


(c)

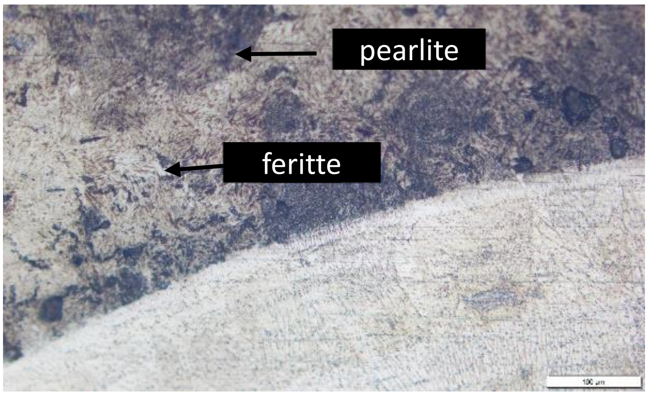
Fig. 5. Micro test base metal SS 304 (a) 1 second (b) 2 second (c) 3 second

In the microstructure of austenitic stainless steel base metal there are austenite and ferrite phases. The elements that form the austenite phase in 304 stainless steel material include carbon, manganese, nickel, and nitrogen where the austenite phase in the microstructure in Fig. 2 above is light in color. Ferrite in austenitic is formed from chromium and silicon elements. where the ferrite phase looks dark in color where the ferrite content is less than 2% of the existing phase content [18]. It shown that the base metal area does not experience changes in microstructure in the current and welding time variations because it is not affected by excessive heat input. There is no significant phase difference in the variation of current strength or welding time variation, because the base metal area of SS 304 is affected by heat due to welding but not until it passes the critical temperature so that no phase change phenomenon occurs in this area [19].

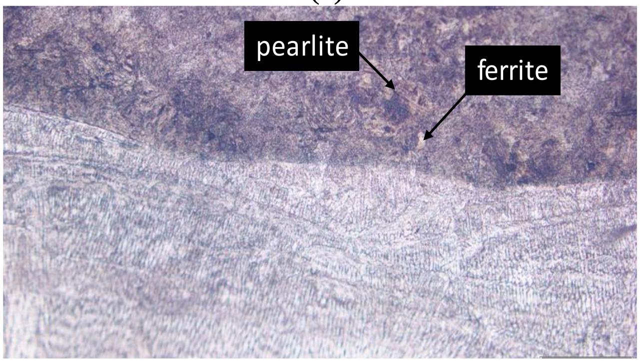
3.3.3 HAZ A36

The microstructure of the HAZ region in A36 material with variations in welding current and time shown in Fig. 6 by using a magnification of 200x. In the HAZ area of A36 material, it shown that the HAZ area in the material is dominated by pearlite and ferrite phases. This is due to the welding process where the HAZ area receives heat input or a higher temperature rise when compared to the base metal area with a fast cooling rate.

The ferrite phase, known for its soft and tough properties, is the dominant phase in low carbon steels. It is mainly formed under slow cooling conditions, where carbon diffusion can occur effectively. In contrast, paerlite is a lamellar structure consisting of distinct layers of ferrite and cementite, which provides a combination of strength and toughness. Its formation occurs at a cooling rate that allows carbon to diffuse and co-precipitate with ferrite as cementite. The chemical composition of the material, the cooling rate, and the welding parameters used, such as input heat and welding speed, greatly influence the presence of these phases in the HAZ.



(a)



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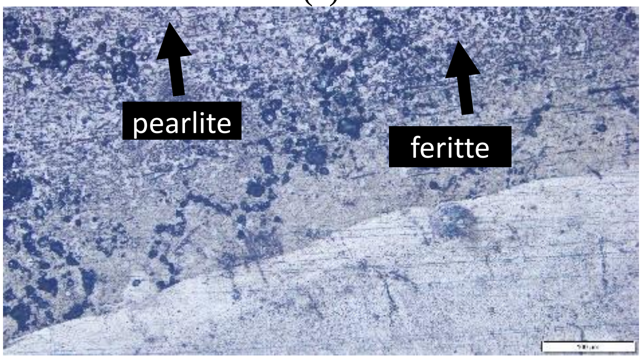
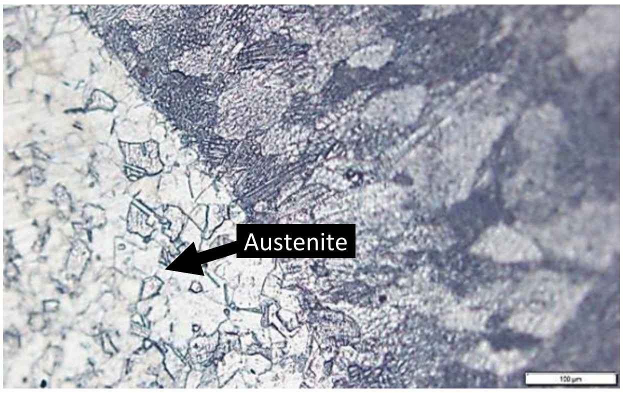


(c)

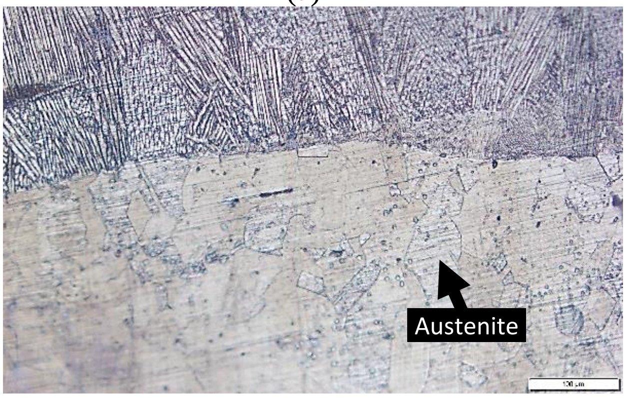
Fig. 6. Microstructure of HAZ A36 (a) 1 second (b) 2 second (c) 3 second

3.3.4 HAZ SS 304

The following are the results of microstructure testing in the HAZ area of austesnitic stainless steel. Fig. 7 shows the microstructure of each variation and phase in the HAZ microstructure of austesnitic stainless steel. In the 9 specimens below, it shown that there are only austenite and ferrite phases which are the most common phases in austenitic stainless steel type materials. There is no difference in microstructure in different HAZ areas because it is only affected by heat in the welding process.



(a)



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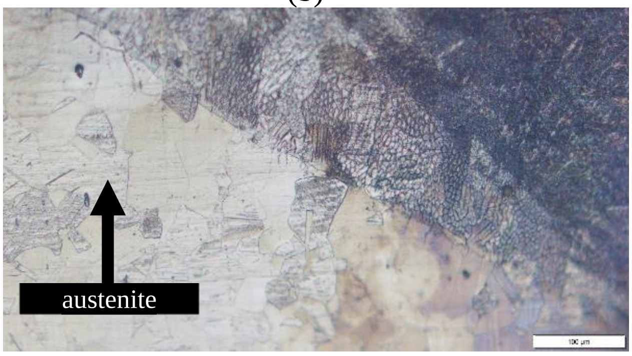


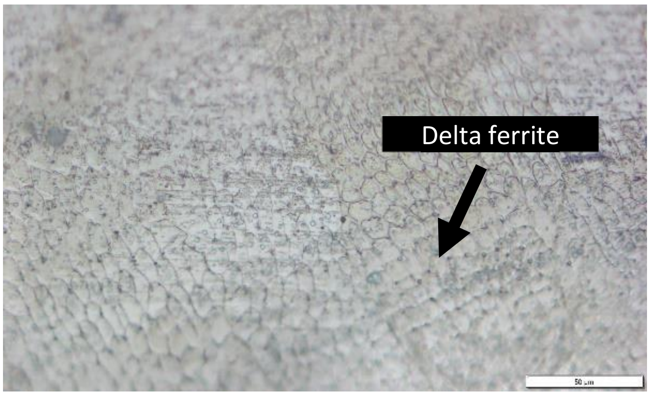
(c)

Fig. 7. Microstructure of HAZ SS 304 (a) 1 second (b) 2 second (c) 3 second

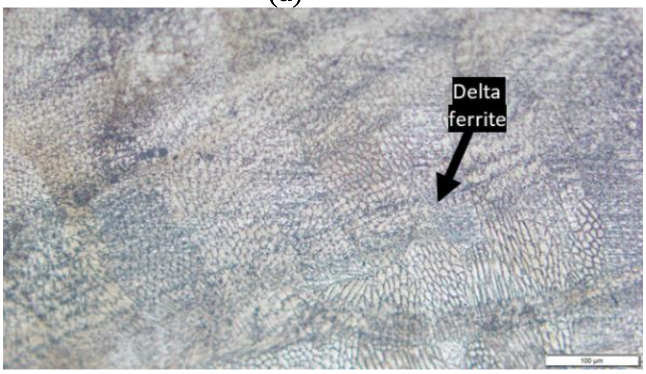
From the results of micro observations in the HAZ area of SS 304, it shown that the phases formed are Austenite and ferrite phases. Austenite and ferrite phases which are the most common phases found in austenite steinless steel type materials. No significant difference was found in the HAZ area of stainless steel due to this area only being affected by heat from the welding process.

3.3.5 *Weld Metal*

The results of microstructure observations in the weld metal area with current and welding time variations using 500x magnification shown in Fig. 8.



(a)



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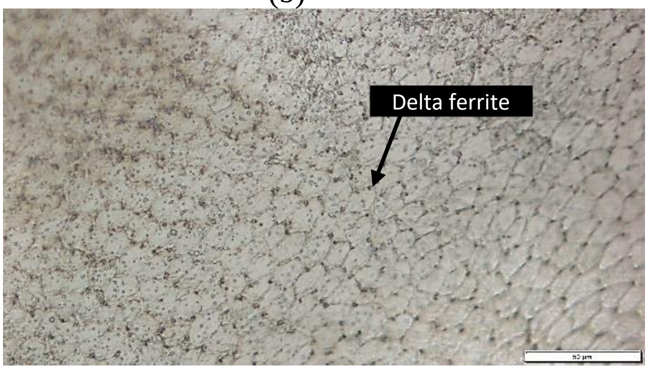

(c)

Fig. 8. Microstructure of weld metal SS 304 (a) 1 second (b) 2 second (c) 3 second

From the above documentation for micro testing in the weld metal area for variations in current strength and welding time, it observed that there is one type of phase formed in the weld metal area. Delta ferrite is a phase formed in the weld metal area which is darker in color. Basically, delta ferrite is formed due to an increase in the Cr_{eq} / Ni_{eq} ratio in the weld metal area [20]. The presence of delta ferrite phase in the weld metal region of austenitic stainless steel is very important, because too much delta ferrite will tend to reduce the ductility but high hardness value, as well as the corrosion resistance of a weld joint, while too little delta ferrite can cause solidification cracks [21].

3.3. *Hardness Test*

Hardness test is one type of destructive test that has the aim of knowing the hardness value of a material as a result of a welding process and other treatments. This vickers hardness test is carried out on the base metal, heat affected zone and weld metal in each variation, namely welding time 1.00s, 2.00s, and 3.00s. 3 specimens were tested using the vickers hardness testing method with a loading of 2 kgf / mm² and 10 seconds of dwell time used. The test results shown in Fig. 9.

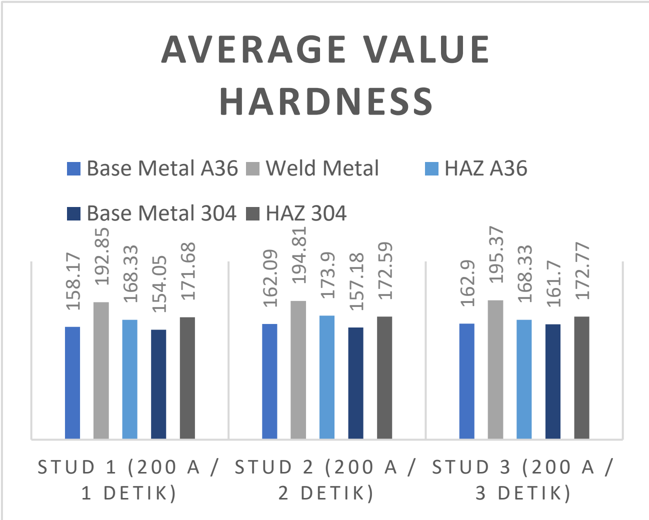

Fig. 9. Graph of Hardness Test Results

Hardness value is the resistance of a material against another object pressed against the material against plastic deformation [22]. The hardness value in the base metal area is not too significant, because the base metal area is not too affected by heat from the welding process. In the HAZ area, it is narrowed due to high thermal diffusion so that the value in the HAZ area increases with each increase in the variation used. The hardness value in the weld metal area with the lowest value in the welding time variation of 1 second, the hardness value in the weld metal area with the highest value in the welding time variation of 3 seconds. The weld metal area has a high value due to the delta ferrite phase which has high strength properties. Based on the hardness test results displayed on the graph, it shown that the difference in hardness values for each variation does not show a significant difference. This indicates that the hardness values of each variation are almost the same, with only slight changes or variations between the values.

Welding time affects the hardness value. Based on the hardness test results shown in the graph, it shown that the difference in hardness values for each variation does not show a significant difference. This indicates that the hardness value of each variation is almost the same, there is only a slight change or variation in value.

3.4 Torque Test

Torque testing aims to measure the strength and resistance of an object to a rotating force. In a torque test, the stud must be torqued until a predetermined load is reached or until the bolt breaks. In this test, a sleeve, washer, and nut of the appropriate size are attached to the bolt. The nut is tightened with a torque wrench against the washer on the sleeve by applying a predetermined load according to the strength of the bolt itself. Variations in torque values observed in different welding currents as shown in Table 7 below.

Table 7. Torque Test Value

NO	KODE	Torque Test Value (Nm)
1	*STUD 1*	50
2	*STUD 2*	60
3	*STUD 3*	80

In ASME sec. IX to fulfill the torque test, each of the stud welding must be carried out with a required torque of 10.8 Nm for stud bolt material SS 304 diameter M8. Based on the results in Table 7, the torque values for all variations are greater than the value specified in ASME sec. IX. It concluded that the welding parameters used in this study have successfully achieved strength and exceeded the minimum specifications that have been set.

4. Conclusions.

The results of the study showed that the results of macro testing at welding time showed differences in penetration depth in each specimen. Stud 1 variation had the lowest penetration depth with a value of 0.52 mm and optimal results were obtained in stud 3 variation with a welding time variation of 3 seconds getting a value of 1.04 mm. The results of micro testing on current strength variations in the base metal area do not have significant changes because in the base metal area A36 and SS 304 there is no maximum heat input, the phases found in the base metal area are ferrite phase, pearlite phase and austenite phase. While in the weld metal area a delta ferrite phase is formed due to an increase in the Cr_{eq} / Ni_{eq} ratio. In hardness testing with variations in welding time in the weld metal area, the lowest average value is 192, 85 HVN in stud 1 specimens with a welding time variation of 1 second, while the highest value in the weld metal area is obtained in stud 3 specimens with a welding time variation of 3 seconds with an average value of 195.37 HVN. The results of the torque test on the variation of welding time showed that the welding time affected the torque test value. This is evidenced by the increase in the torque test value which is in line with the increase in the welding time variation.

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