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The Analysis of Electrode Combination Effect on Steel and Stainless-Steel Welding (Overview of Tensile and Metallography Test)

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Abstract— **The process of building a ship or offshore structure, proper and accurate planning and implementation is required. In the development process, it will go through a stage, namely the construction stage. At the construction stage, the construction of a ship or offshore building will go through a welding phase which functions as a connection of materials to one another. Low carbon steel and stainless steel are materials that are often used in the construction process of ships or offshore structures. In this study, an analysis of the effect of the combination of electrodes on the welding of steel and stainless-steel materials was carried out in terms of mechanical properties such as tensile strength, bending strength and metallographic shape. The materials used in this study were A36 steel and 304 stainless-steel, while the electrode combinations used were E308L and E309 electrodes. Welding variations used in this study were a combination of E308L (root) and E309 (filler) electrodes, a combination of E308L (filler) and E309 (root) electrodes, E309 electrodes, and E308L electrodes. In the tensile test results it was found that the highest tensile strength value occurred in Specimen 4 with an average value of yield strength and ultimate strength of 389.54 MPa and 522.52 MPa. The tensile strength value is influenced by the amount of chromium contained in the electrode. This is because the higher the amount of chromium causes the amount of ferrite in the material to increase so that the tensile strength value decreases.** ***In the metallographic macro testing results, the best weld profile results were obtained on specimens with the ME 4 material code because the results of the weld profile shape best met ASME Section IX standards. The results of micro metallographic testing showed that welding using the dominant E308L electrode as in Specimen 1 and Specimen 4 obtained a higher ultimate strength value compared to Specimen 2 and Specimen 3. This was due to the influence of chromium on the electrodes used, high chromium causing the formation of a ferrite phase in the microstructure of the material.***

Keywords— SMAW Method, Dissimilar Welding, Electrode, Mechanical Properties, Low Carbon Steel A36, Stainless Steel 304

I. INTRODUCTION

Metal joining techniques called welding technology from time to time have experienced rapid development and progress, especially in construction and fabrication technology. Generally, construction buildings are made of iron and steel, although there are also stainless-steel compositions in several parts of the construction [1]. In its development, many welding methods emerged using different components and functions. In practice the welding that is often used is Shielded Metal Arc Welding (SMAW). Shielded Metal Arc Welding (SMAW) or also known as Manual Metal Arc Welding (MMAW) is a method of welding that connects two or more pieces to become a fixed connection by utilizing an electric heat source and additional metal electrode wire wrapped in flux [14]. In its use, the SMAW method can be used on materials such as stainless steel, ductile iron, cast iron, carbon steel, low alloy steel and high alloy steel [3]. Welding of different materials with the SMAW method is now also often used because it is suitable for learning in the determination of electrodes used in industrial processes, besides that there are also eco-social and green technology aspects [19]. Even though when compared to other welding methods, such as TIG and MIG the mechanical strength results are not better than the two methods, they still meet the criteria in the standard [20].

As the times progress, the industrial world is also experiencing developments, one of which is in the field of welding or metal joining. From only using iron and steel, now welding with aluminium and stainless-steel materials is also being developed. Stainless steel is a metal developed by adding chromium during manufacture. This causes the character of stainless steel to be a material with a soft texture, light weight and corrosion resistance [4].

Different examples of welding in shipbuilding construction are ASTM A36 steel and Stainless steel 304. ASTM A36 steel is a material frequently used in shipbuilding, offshore structure making and the oil and gas industry [13]. The ASTM A36 steel material has a tendency that the greater the current used, the greater the tensile strength value [16]. Changes in the mechanical strength value of ASTM A36 steel are strongly influenced by the heat treatment process [18].

While Stainless Steel 304 is a material used to resist corrosion on certain parts of ships or offshore construction

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[5]. Stainless Steel 304 is a material whose mechanical strength value can be increased by the rolling process [17]. Before carrying out the welding process, it is necessary to plan so that the welding process can be carried out properly and appropriately, and makes it easier for the welder to do his job. Therefore, a Welding Procedure Specification (WPS) was made before the welding process. WPS is useful for guiding the welder so that it can save time and minimize errors [8].

In the maritime industry, of course, optimization of costs and effectiveness is a very important consideration. Therefore, this research is expected to provide a reference regarding proper welding joints in the maritime industry, especially in the manufacture of chemical ships and nuclear ships. The use of the right electrodes needs to be done in order to get maximum results in the production process in the maritime industry so as to minimize the occurrence of accidents or structural failures during the operational period. The use of the E309 electrode in dissimilar welding is often used because it has a strength value that meets the standards of ASME Section IX coupled with the good corrosion resistance of this electrode [21]. While using the E308L electrode because it has a good elongation value [22].

Therefore, in this study the authors will analyse the effect of electrode variations in welding A36 Steel and Stainless Steel 304 materials on mechanical properties. The variations that will be used in this study are a combination of E308L and E309 electrodes with E309 as the root layer, a combination of E308L and E309 electrodes with E308L as the root layer, E309 electrode for all layers and E308L electrode for all layers. The tests to be carried out are tensile tests, bending tests and metallographic tests [12].

II. METHOD

A. *Welding Procedure Specification (WPS) Design*

Welding Procedure Specification (WPS) is a reference for welder when doing welding. In WPS will explain several instructions such as the type of welding, shape of the weld, welding position, electrodes and several other things. Preparation of WPS improves welding procedure, performance of individual when there is a repitative work comes at fabrication site such that the welder is selected based on performance [8].

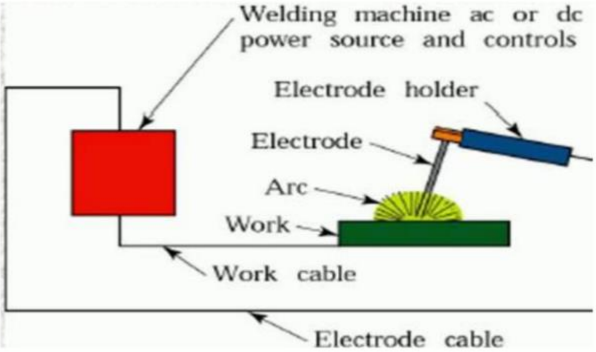


Figure 1. SMAW method [21]

B. *SMAW Method with Variation of Electrode*

Shielded Metal Arc Welding (SMAW) or also known as Manual Metal Arc Welding (MMAW) is a method of welding that connects two or more pieces to become a fixed connection by utilizing an electric heat source and additional metal electrode wire wrapped in flux [1].

As explained in the previous paragraph, that welding using the SMAW method uses filler (electrodes) wrapped in flux. In this experiment the variation used is a combination of electrodes. The electrodes used are stainless steel electrodes namely E308L and E309. The two electrodes have differences in chemical composition and material strength, as shown in the XXXXXXXXX [7].

TABLE 1. CHEMICAL COMPOSITION

AWS Classification	UNS Number	C	Cr	Ni
E308L	W30910	0.04	18.0-21.0	12.0-14.0
E309	W30813	0.15	22.0-25.0	9.0-11.0

TABLE 2. MATERIAL PROPERTIES

AWS Classification	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
E308L	520	380	30
E309	550	390	35

C. *Non-Destructive Test (NDT) with Radiography Test*

Non-Destructive Test (NDT) is a material test without damaging the test material. NDT is important in the industry because it determines the feasibility of the material to be produced [23]. In welding, NDT is used to show weld defects in the welding results. The NDT method used is a radiography test [6].

D. Tensile Test

Tensile Test is a test carried out to determine the maximum tensile strength of a material by applying an axial load (static force) and it is given quickly or slowly. In this test results will be obtained that show the mechanical properties of the material being tested, such as the strength and elasticity of the material [9]. Stress and strain values can be written using the following equation [2]:

$$\sigma_m = \frac{P_m}{A_0}$$

$$\varepsilon = \frac{L - L_0}{L_0} \text{ x } 100\%$$

With,
σ_m = Tensile Stress (MPa)
P_m = Force (kN)
A_0 = Initial area of material (mm^2)
ε = Elongation (%)
L = Initial Length (mm)
L_0 = Final Length (mm)

E. Metallography Test

Metallographic testing is a test performed to determine structural changes in the material after the welding process. In this metallographic test, the type of test is divided into two, namely micro testing and macro testing. Macro test is a material testing process with the aim of seeing the cracks and holes formed in the material by naked eye. In addition, it is also used to see HAZ changes in the weld area of the material [11]. Figure 2 is an example of the results of macro testing. Micro test is a test to determine the phase change in the material after welding. Figure 3 is an example of the results of micro testing.

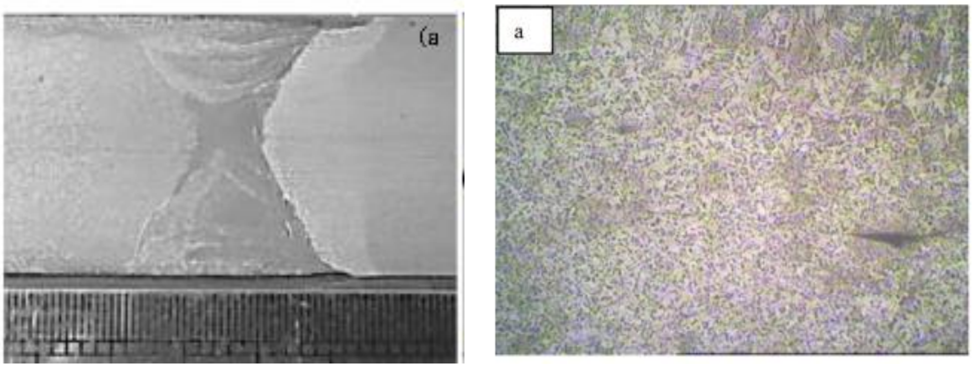
III. RESULTS AND DISCUSSION

A. Welding Procedure Specification (WPS) Design

In this study, the WPS provisions that will be used are based on ASME Section IX [8] as follows:

- Welding Process : SMAW
- Joint Design : Butt Joint
- Groove : Single V
- Base Metals : A36 to Stainless Steel 304, t:6mm, L=300, P=150
- Filler Metals : E308L and E309 diameter 3,2 mm
- Position : 1G
- Gas : N/A
- Technique : String or Weave

Table 3 is an explanation of electrode variations and Figure 3 is a welding joint design. The following Figure 4 is the result of welding for the 4 specimens.



(a) (b)

Figure 2. Illustration of (a) macro and (b) micro testing results [5] [21]

TABLE 3. CHEMICAL COMPOSITION

Number Specimen	Filler Metal (root)	Filler Metal (Filler)
1	E308L	E309
2	E309	E308L
3	E309	E309
4	E308L	E308L

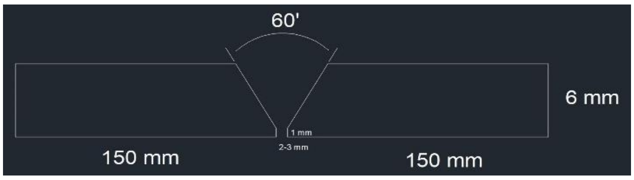


Figure 3. Welding joint design

Figure 4. Welding results

B. *NDT Radiography Test*

Radiography testing is carried out after the welding process, this testing process is carried out to determine whether there is an open defect or crack in the material. When declared passed, then the next process can be done. The following Figure 5 is of the radiographic test results.

(a) (b)

(c) (d)

Figure 5. Radiography test results (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, and (d) Specimen 4

TABLE 4. RESULT OF TENSILE TEST

Number Specimen	Average Yield Strength (MPa)	Average Ultimate Strength (MPa)
1	372,35	501,835
2	366,4	492,17
3	366,765	500,43
4	389,54	522,52

Based on the radiographic test results, all welding results are acceptable because they meet the applicable standards so that further processing can be carried out.

C. *Tensile Test*

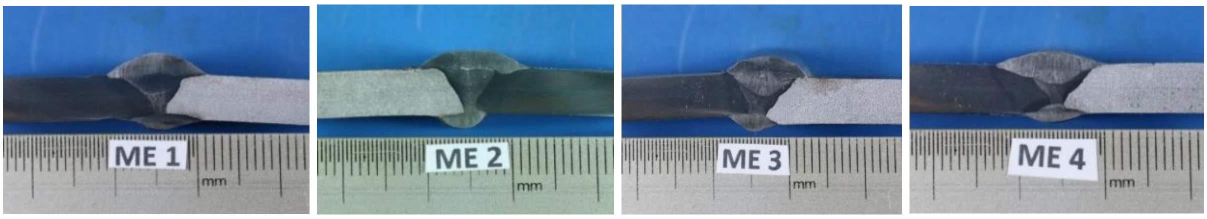
Tensile testing is carried out with the aim of obtaining yield strength and ultimate strength values of the material joints being welded. The standard used in tensile testing uses the ASME Section IX standard [9]. In the test results, all specimens must meet the tolerance limit, namely a minimum of 95% of the minimum tensile strength of the base metal. The minimum value of the A36 Steel material is 400 MPa and Stainless Steel 304 is 500 MPa. In Table 4 shows the results of tensile testing.

In Specimen 1 with variations of the E308L and E309 Electrodes with the E308L Electrode as the root layer, the average yield strength and ultimate strength values were 372.35 MPa and 501.835 MPa. In Specimen 2 with variations of the E308L and E309 electrodes with the E309 electrode as the root layer, the average yield strength and ultimate strength values were 366.4 MPa and 492.17 MPa. In Specimen 3 with variations of E309 Electrodes in all layers, the average yield strength and ultimate strength values were 366.765 MPa and 500.43 MPa. In Specimen 4 with E308L Electrode variations on all layers, the average yield strength and ultimate strength values were 389.54 MPa and 522.52 MPa.

Based on the results of the tensile test it can be concluded that the welded joints in Specimens 1 and 4 have a higher tensile strength value compared to Specimens 2 and 3, this is due to the use of the dominant E308L electrode compared to the E309 electrode. If you look at the chromium (Cr) content found in the E308L electrode, the total Cr content in the E308L electrode is lower than that of the E309 electrode. From previous studies that material with a high amount of chromium will cause the value of strength and hardness to decrease. This is because chromium is a stabilizer of the ferrite phase and tends to make the ferrite phase, thereby reducing the value of hardness and tensile strength.

D. Metallography Test

In metallographic testing, two tests were carried out, namely macroscopic and microscopic tests. Macro testing is a material testing method to see metal structures using a camera. In the process, this test was carried out with a magnification of 2.25 times. The purpose of this test is to determine the HAZ area, weld metal and base metal. Meanwhile, micro testing is an observation of the metal structure that occurs in the material after the welding process to determine the phase change process in the metal. Observations in this micro test using a microscope with 100x and 400x magnification. In macro testing, we can see the weld profile and the type of discontinuity in the welds. Figure 6 is result of macro test.



(a) (b) (c) (d)

Figure 6. Macro metallographic test results (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, (d) Specimen 4

The results of the macro test show that all specimens get no imperfection results, which means that all specimens have no weld defects. In addition, the result of discontinuity type can be shown in Table 5. After checking the discontinuity type, the next step is to calculate the height of face reinforcement, height of root reinforcement and joint penetration groove weld size. Table 6 shows the weld profile from the macro test results.

TABLE 5. RESULT OF DISCONTINUITY TYPE

Discontinuity Type	
Crack	-
Lack of fusion	-
Incomplete root penetration	-
Continuous undercut	-
Intermittent undercut	-
No Imperfection	✓

In the standard used, the penetration tolerance limit in the height of face reinforcement area is 2 mm. Based on this, the results show that the material with the ME 4 material code only meets these standards, namely with a value of 1.61 mm. However, if you look at the results, the other three specimens obtained penetration results of less

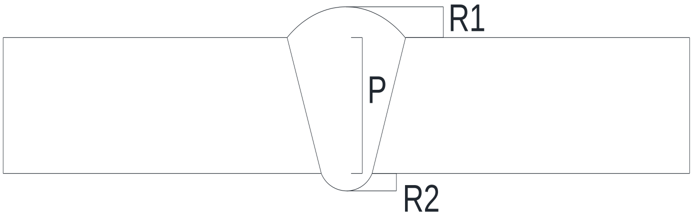


Figure 7. Illustration of weld profile

Table 7. Percentage of the number of phases on the micro photo results

Specimen	Base Metal A36		HAZ A36		Weld Metal		HAZ SS 304		Base Metal SS 304	
	Ferrite (α)	Pearlite (P)	Ferrite (α)	Pearlite (P)	Ferrite (α)	Austenite (γ)	Ferrite (α)	Austenite (γ)	Ferrite (α)	Austenite (γ)
1	60,0%	40,0%	51,5%	48,5%	32%	68%	46,5%	53,5%	40,0%	60,0%
2	60,5%	39,5%	56,0%	44,0%	39%	61%	30,5%	69,5%	41,0%	59,0%
3	59,5%	40,5%	56,0%	44,0%	34%	66%	33,5%	66,5%	43,0%	57,0%
4	59,5%	40,5%	53,5%	46,5%	24%	76%	40,0%	60,0%	40,5%	59,5%

than 1 mm, this was due to a shift in the welded specimen during the welding process. Whereas at the height of root reinforcement, the penetration tolerance limit given is 1 mm. If you look at the results obtained, all test specimens do not meet the standard because they exceed the tolerance limit given. In this weld profile, specimens that are close to standard are specimens with ME 4 material code with a value of 1.06 mm.

For the weld profile of the joint penetration groove weld size, the tolerance limit given is 2 mm from the initial material thickness. Based on the existing weld profile results, all specimens meet the tolerance limit. However, in specimens with code material ME 4, the value obtained is less than the thickness of the base metal material, but still meets the standard because it is not more than 1 mm. Therefore, all specimens are declared to comply with ASME Section IX standards.

The next stage is micro metallographic testing which aims to determine the phase changes in the base metal, HAZ, and weld metal regions. This micro test was carried out with a magnification of 100x and 400x to see the microstructure of the test material. Micro test results can be seen in Figure 8, Figure 9, Figure 10 and Figure 11.

When welding using stainless steel, stainless steel has a different character from steel. Stainless steel has the property that it cannot be hardened by heat treatment, but can be hardened by cooling. The structure of stainless steel shows the presence of chromium carbide ($Cr_{23}C_6$) deposits at grain boundaries. This causes the area to experience a shortage of free chromium, which causes corrosion to occur easily due to the absence of a protective layer of chromium oxide (Cr_2O_2) [14].

On the results of microphotographs, the number of phases in each specimen is calculated using the point counting method. Point counting is a method used to determine the number of phases in micro-test specimens by dividing the micro-photo area into 100 parts. The calculation of the point counting method in calculating the number of phases is written in the equation as below:

$$\%phase = \frac{the\ calculated\ number\ of\ phases}{total\ number\ of\ points}\ x\ 100\%$$

The following is an example of calculation using the point counting method for Specimen 4 weld metal.

$$\%phase\ austenite = \frac{(52\ x\ 1) + (48\ x\ 0{,}5)}{100}\ x\ 100\%$$

$$\%phase\ austenite =\ 76{,}00\%$$

Based on the results of the phase calculation at 400x magnification for each specimen, the results are as shown in Table 7.

Based on the 400x magnification results, it can be seen that in the stainless steel HAZ area there is a change in the structural shape of the material, especially in Specimen 1, Specimen 2 and Specimen 4. In Specimen 3, the structural shape of the stainless HAZ tends to be similar to the structure of the base metal stainless steel. But overall, the material did not experience a significant phase change. In addition, the amount of austenite in Specimen 1, Specimen 2 and Specimen 4 has a higher percentage of austenite than Specimen 3. Whereas in the HAZ A36 area, there was a change in Specimen 2 and Specimen 3 in the percentage of pearlite. In Specimen 2 and Specimen 3, the E309 electrode is more dominant so that there is a change in the number of pearlite phases due to the influence of heat during welding. In Specimen 1 and Specimen 4, there was no significant change in the amount of pearlite phase [15].

TABLE 6. WELD PROFILE FROM RESULTS OF MACRO TEST

Specimen	Height of face reinforcement (R1)	Height of root reinforcement (R2)	Joint Penetration Groove Weld Size (P)
ME 1	2,89	1,24	6,08
ME 2	2,16	1,78	6,01
ME 3	2,77	1,53	6,27
ME 4	1,61	1,06	5,91

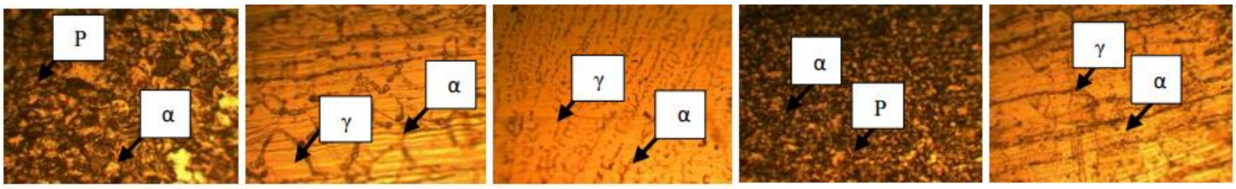


Figure 8. Micro test results with 400x magnification on Specimen 1

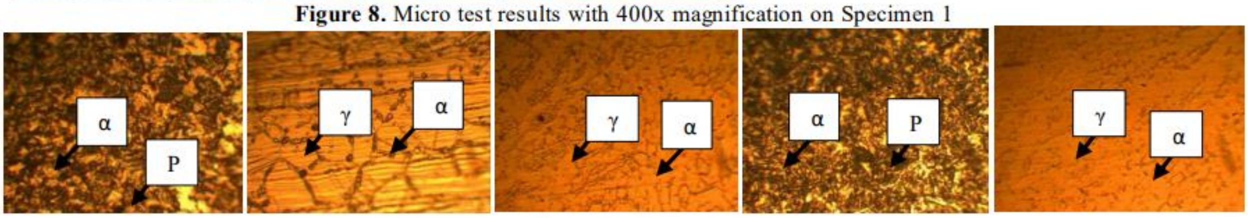


Figure 9. Micro test results with 400x magnification on Specimen 2

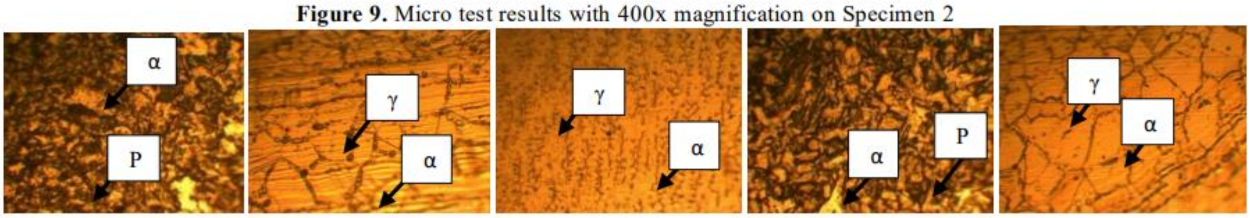
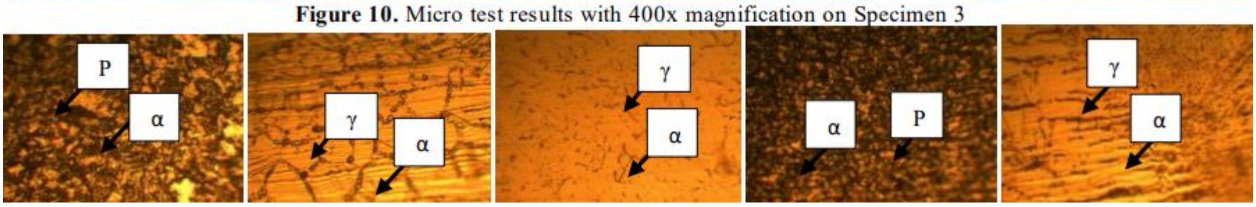


Figure 10. Micro test results with 400x magnification on Specimen 3



IV. CONCLUSION

From the results of the research that has been carried out, several conclusions were obtained:

1. Based on the results of the tensile test, the highest value occurred in Specimen 4 with the E308L Electrode variation with an average value of yield strength and ultimate strength with values of 389.54 MPa and 522.52 MPa. Based on this experiment, it was concluded that welded joints using E308L electrodes will have higher strength and hardness values compared to specimens using E309 electrodes. This is due to the influence of chromium, namely the more the amount of chromium in the electrode, the hardness and strength values will decrease.
2. In the metallographic macro testing results, the best weld profile results were obtained on specimens with the ME 4 material code because the results of the weld profile shape best met ASME Section IX standards.
3. The results of micro metallographic testing showed that welding using the dominant E308L electrode as in Specimen 1 and Specimen 4 obtained a higher ultimate strength value compared to Specimen 2 and Specimen 3. This was due to the influence of chromium on the electrodes used, high chromium causing the formation of a ferrite phase in the microstructure of the material.

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