

Analysis of underwater welding in Indonesian warship using low hydrogen electrodes

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Abstract

As a security unit for the territorial waters of the Republic of Indonesia, the Indonesian Navy is required for combat readiness to carry out security operations quickly and precisely. It is very important to the readiness of the Indonesian Navy's ABK Soldiers and the Republic of Indonesia's defense equipment for warships in carrying out security activities in the territorial waters of the Republic of Indonesia. This study discusses underwater wet welding in anticipating an emergency if the ship's hull is hit by a collision so that the hull has cracks or holes. This research method uses AH36 steel plate metal. Then, underwater wet welding was carried out on the AH36 plate using a low hydrogen type electrode. Before welding, the electrodes were subjected to a drying process to a temperature of 90°C. Wet welding underwater is carried out at a depth of 5 meters in seawater. The results of underwater wet welding are NDT testing; penetrant test, radiography test, then also DT test; hardness test, tensile test, and test according to ASTM standard. Analysis of underwater wet welding results compared to atmospheric welding results as quality control, so that the percentage difference in mechanical properties can be known. The interesting thing from welding AH36 steel plate with underwater wet welding and applying low hydrogen electrodes is the minimal level of weld porosity defects in the welding results. So that the low hydrogen electrode can be used in welding AH36 steel plate in underwater welding applications.

Keywords: Low Hydrogen Electrodes; Underwater wet welding of vessels

1 Introduction

One of the main tasks of the Indonesian Navy is to defend the Unitary State of the Republic of Indonesia in the sea. When carrying out operational tasks there are several obstacles. One of these obstacles is underwater line leakage (BGA). This leak was caused by several factors, including hitting logs, hitting rocks or other ships, which caused the hull to tear, crack, and deformation which reduced the strength of the hull material. This requires fast handling because the ship must continue to carry out operations while not all bases have docking facilities that are capable of supporting the repair of the KRI. Problem-solving that can be done is by underwater wet welding.

Generally, the use of welding below the waterline is more likely to use wet welding with the Shielded Metal Arc Welding (SMAW) method. Because the SMAW method is the most popular underwater wet welding method, it is economical and efficient which is often used. However, underwater wet welding has several problems, namely; undercut defects, hardness and brittleness values in the Heat Affected Zone (HAZ), microcrack due to hydrogen embrittlement, where hydrogen embrittlement is the main factor in the failure of underwater wet welding.

According to M. Khan (2016) another factor that becomes a problem in wet underwater welding is the difficulty of obtaining electrodes made specifically for underwater wet welding. One of the most well-known types of underwater wet electrodes is the Broco Wet Welding electrode based on E7014. While the use of underwater wet welding is

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generally used to overcome emergencies that require speed for the availability of equipment including electrodes. So in this study using low hydrogen electrodes E7016 and E7018 to determine the strength of underwater wet welding according to the AWS D3.6M standard, the mechanical properties of underwater wet welding, and to find out what percentage of the quality of underwater wet welding results in atmospheric welding. In addition, it is one type of electrode that is easily found on the market. So that it can provide information to the leadership of the Indonesian Navy and the welder about the mechanical properties of underwater wet welding using low hydrogen electrodes of the types E7016 and E7018. It is hoped that in dealing with emergencies, you can use the low hydrogen electrode in underwater wet welding.

2 Literature review

2.1 The working principle of underwater wet welding

The object to be welded is connected to one side of an electrical circuit, and the metal electrode to the other. On one side there is a circuit breaker called a switch knife. When going to welding, the diver will give a signal to the operator on the surface to provide electricity, then the surface operator will provide electricity by connecting the switch knife. The electric current causes sparks that melt the base metal and form a weld pool. At the same time, the tip of the electrode melts and a drop of metal is projected into the weld pool. During this process, the flux protects the molten electrode by providing a shielding gas which is used to stabilize the weld.

Another factor that becomes a problem in wet underwater welding is the difficulty of obtaining electrodes made specifically for underwater wet welding. In terms of the price of this type of electrode, it is also an electrode that is not cheap when compared to the price of atmospheric welding electrodes in general. While the use of underwater wet welding is generally used to overcome emergencies that require speed for the availability of equipment including electrodes. A low hydrogen electrode is one type of electrode that is easily found on the market. This electrode is very commonly used in shipyards for welding structures and shipbuilding. Generally, there are two types of electrodes of this type, namely the E7016 series and the E7018 series.

According to Khan et al (2016) the low hydrogen electrodes of the E7016 and E7018 series provide arc stability when welding underwater, only before using the electrode must be dried before being coated with waterproof. If this electrode is coated directly without drying it first, the flux will be peeled out of the main wire and will not burn during the welding process, because it cannot protect a shielding gas so that the arc stability becomes weak. The use of electrodes E7016 and E7018 provides medium penetration and does not cause undercut defects when using straight polarity (DCEN). However, research from Dr. Khan is research that uses an underwater wet welding equipment system with a machine at a shallow depth.

2.2 Comparison of Atmospheric (Surface) Welding with Underwater Welding

Underwater welding requires a larger electric current when compared to surface welding, thus obtaining a higher heat input. The size of the weld bead is generally relatively the same for underwater welding and surface welding. However, wet welding has smaller weld beads and higher gain than atmospheric welding. In general, the weld form between surface welding and underwater welding is not significantly different. This means the critical effect of the water only begins when the weld pool begins to form and solidify. The HAZ in underwater welding is reduced by 30 to 50% when compared to surface welding, indicating that heat dissipates rapidly from the weld bead into the base metal. The underwater bead weld has a more diffuse shape and is less penetrating than the surface welded weld. The HAZ structure tends to change in underwater welding and unlike more homogeneous surface welding. The HAZ width for surface welding is 20 to 50% wider than wet welding according to N. Christensen (1983).

2.3 Underwater Welding Problems

The joining process using the underwater wet welding method results in lower quality and mechanical properties when compared to atmospheric welding. Because it produces weld porosity, hot and cold crack, slag inclusion, deposit different chemical composition according to N. Christensen (1983), D. Fydrych et al (2014) and S. Liu (1995). The reason for the disadvantage of this phenomenon is the cooling effect provided by the kinetic transforming water in the steel during the welding process, where a significant amount of dissolved hydrogen diffuses in the joint, the increased stress of the welding environment, and impaired visibility during the welding process according to D. Fydrych et al (2014).

In the water environment, the cooling rate for wet welding is much higher than for dry welding. In atmospheric welding, the cooling rate from 800°C to 500°C is achieved in 8 to 16 seconds, while underwater wet welding at the same temperature is achieved in 1 to 16 seconds (S. Liu, et al., 1993). This very fast cooling rate condition can give higher

microstructure results such as martensite and bainite compared to atmospheric welding, thus giving a greater brittle/brittle effect. When welding in an atmospheric environment, heat transfer occurs directly from the heat source to the base metal, but in underwater conditions, the quantity of heat is dissipated by the water environment. During wet welding, the electrode and the base metal are in direct contact with water, which significantly affects the weldability of the steel. This easily triggers hydrogen cracking according to JE Omajene et al (2014).

3 Research method

3.1 Research Flowchart

Research has the meaning of a series of activities carried out to see, seek, or observe something to improve previous research to get the desired results in the research carried out. This research was carried out systematically according to the flow chart shown in Figure 1.

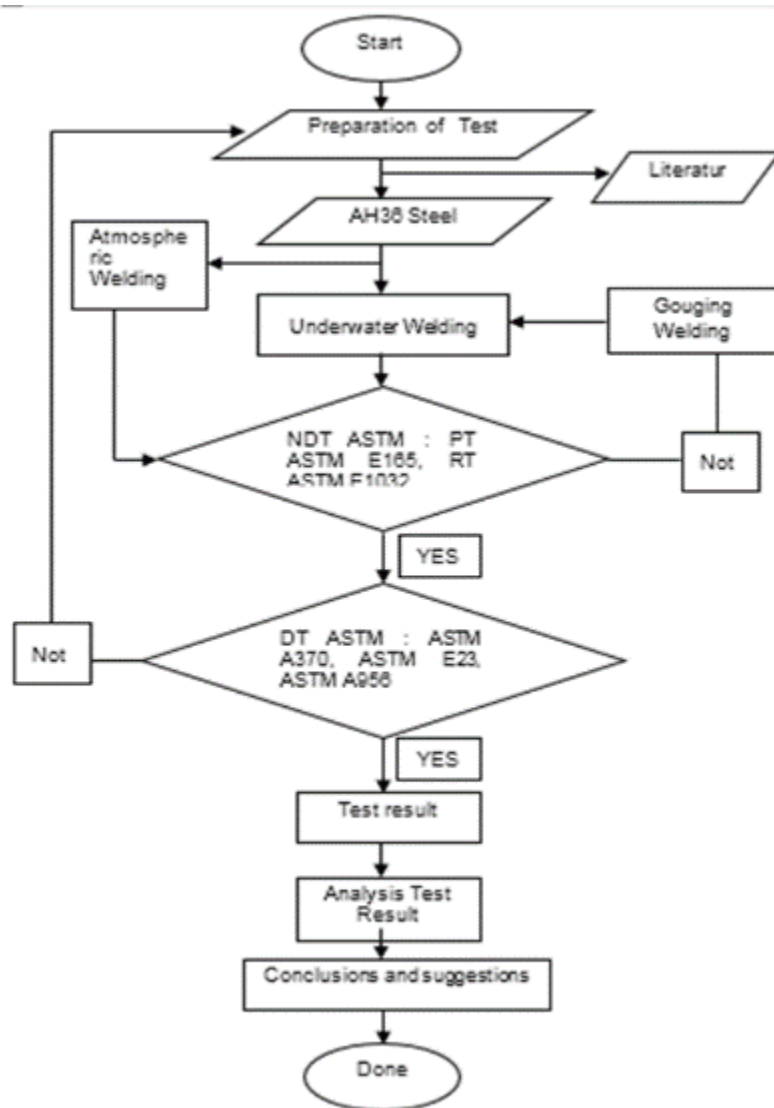


Figure 1 Research flow chart

3.2 Data Sources, Subjects, and Research Objects

The current underwater wet welding research, of course, requires data about what is being researched and what is being explained in the research. Therefore, the data sources, subjects, and objects of research in this study were determined in advance to facilitate the writing process.

3.2.1 Research Data Sources

The research data sources used in this underwater wet welding research, for the specifications of the test objects used are as follows:

- The material used is an AH36 steel plate.
- Plate thickness 10mm, plate dimensions 300 mm x 200 mm x 10 mm.
- The electrodes used are
- The seam used is an open V type of seam, the plate gap is 2mm and the seat angle is 60°.

3.2.2 Research subject

The subject of the research on underwater wet welding is welding AH36 steel plate material using Low hydrogen electrodes. Wet welding underwater is carried out by the method of Shielded Metal Arc Welding (SMAW) and by using a V seam.

3.2.3 The object of research

The object of research on underwater wet welding is the shipbuilding in the area below the waterline (BGA) when the ship is in an emergency or emergency condition because the hull of the ship under the waterline is torn or perforated by hitting a hard object or hitting a rock so that it requires fast and precise handling, handling made by underwater wet welding using Low Hydrogen electrodes.

3.3 Welding Method

The welding method used in this study is underwater wet welding with Shielded Metal Arc Welding (SMAW), where SMAW is one of the most practical and economical underwater welding methods according to M. Khan et al (2016). This underwater welding process will be carried out in marine waters with varying depths.

The working principle of underwater wet welding is the SMAW method, where SMAW welding is electric arc welding using webbed electrodes (flux). The function of the flux in this welding is to form a slag above the weld which serves as a protection for the weld from the air during the welding process. In underwater wet welding, the coated electrode (flux) is coated again using a waterproof material (commercial electrical insulator), so that the flux does not come into direct contact with water, then the electrode is attached to a special underwater handle (underwater welding stinger).

Welding is carried out using a heat input of 1.5 kJ/mm. To obtain the heat input based on the calculation of the heat input with the parameters of current, voltage, and speed welding as follows:

heat input formula

$$HI = \frac{\text{Voltage (V)} \times \text{Current (A)} \times 60 (\text{Constanta})}{\text{Travel Speed (mm/min)}} \dots\dots\dots(1)$$

Where is the heat input value:

$$HI_{1,5} = \frac{24 (\text{Volt}) \times \text{Current (Ampere)} \times 60}{150 (\text{mm/min})} = 1,5 \frac{\text{kJ}}{\text{mm}} \dots\dots\dots(2)$$

$$1,5 \frac{\text{kJ}}{\text{mm}} \times 150 \left(\frac{\text{mm}}{\text{min}} \right) = 24 (\text{volt}) \times 60 \times \text{current (A)}$$

$$\text{current (A)} = \frac{225}{1440} \times 1000 = 156,25 \text{ A}$$

3.4 Tensile Strength Test (Tensile Test)

Tensile testing using the size of the specimen or the material of the test object being tested is shown in Figure 2. Where for the specimen size using the AWS D3.6M:2010 standard, for the standard image the specimen size is shown in Figure 3.

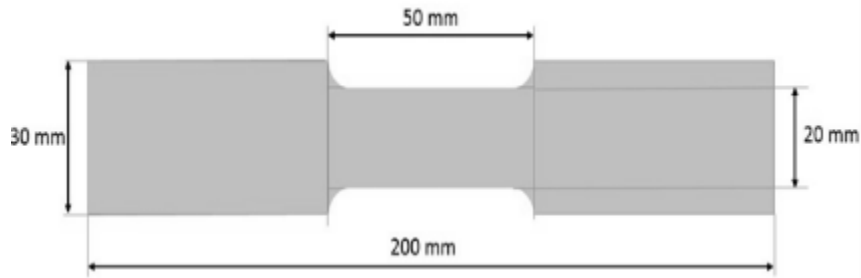


Figure 2 ASTM A370. standard tensile test sample size

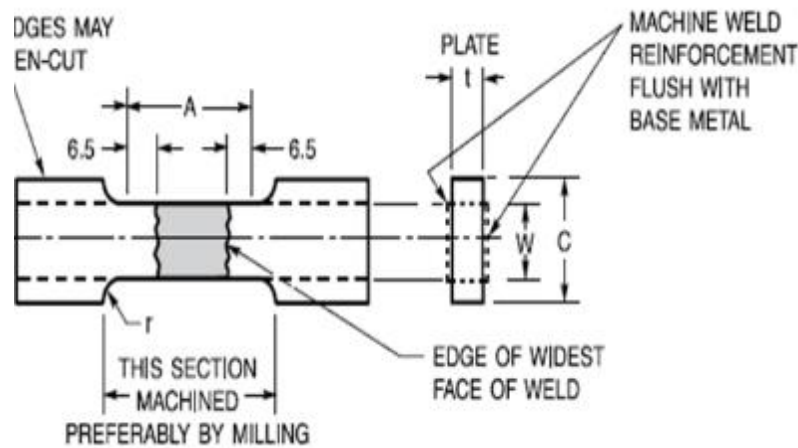


Figure 3 ASTM A370. standard plate tensile test sample

4 Results and discussion

The current research using the base metal material is AH36 type steel plate following BKI class standards. This type of steel plate is included in the HSLA plate category. The research process uses 2 methods, namely Non-Destructive Test (NDT) and Destructive Test (DT) which will be explained as follows.

4.1 Non-Destructive Testing (Non-Destructive Test)

The NDT testing process is carried out using the Penetrant Test (PT) using the dye penetrant method which aims to determine surface defects, while radiography aims to observe internal defects in the weld metal area. For the non-destructive testing process (NDT) samples were taken from atmospheric welding plates and underwater wet welding to a depth of 5 meters with a heat input (HI) of 1.5 kJ/mm.

4.1.1 The results Penetrant Test of the weld at a depth of 5 meters

While the results of underwater welding at a depth of 5 meters, welding results are shown in Figures 4 and 5. From the picture, provides information starting to show the occurrence of many surface defects, as shown in Figure 4 the results of welding at a depth of 5 meters with the E7016 electrode there are undercut defects, pores, and porosity defects. This is also found in the results of welding with the E7018 electrode (Figure 4.2) in the form of pores.

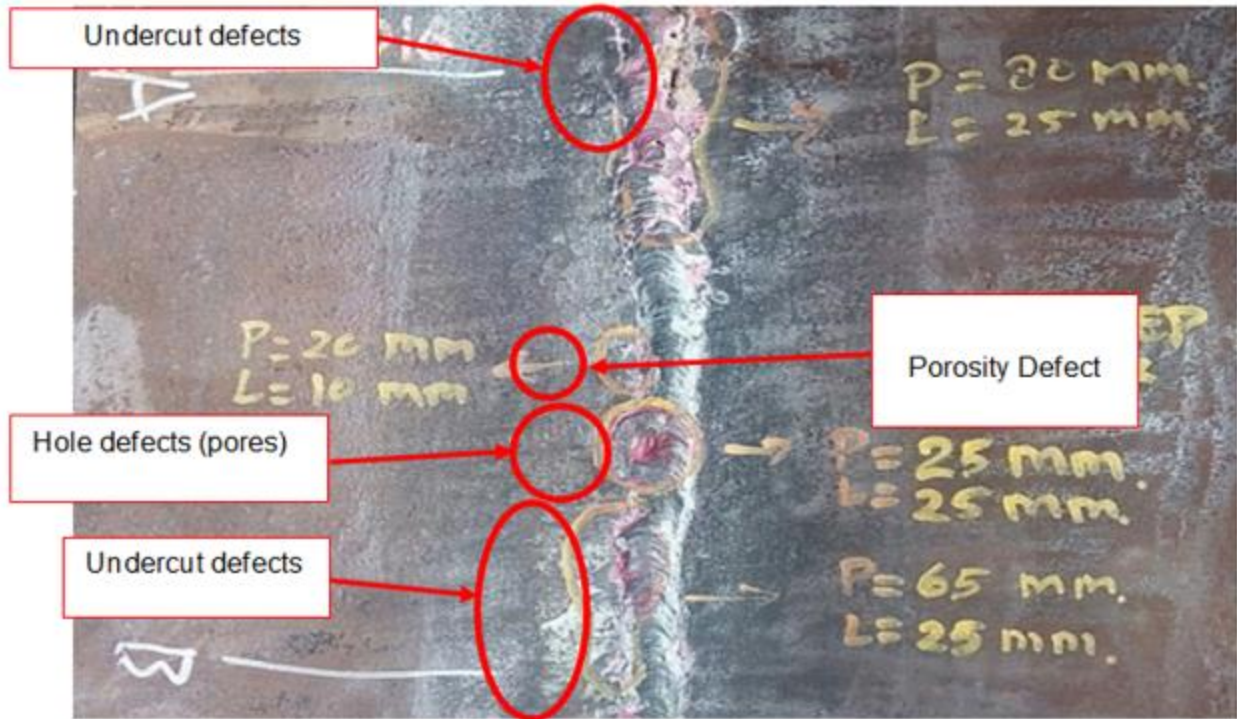


Figure 4 The results of underwater welding using E7016 electrodes at a depth of 5 meters with a heat input (HI) of 1.5 kJ/mm

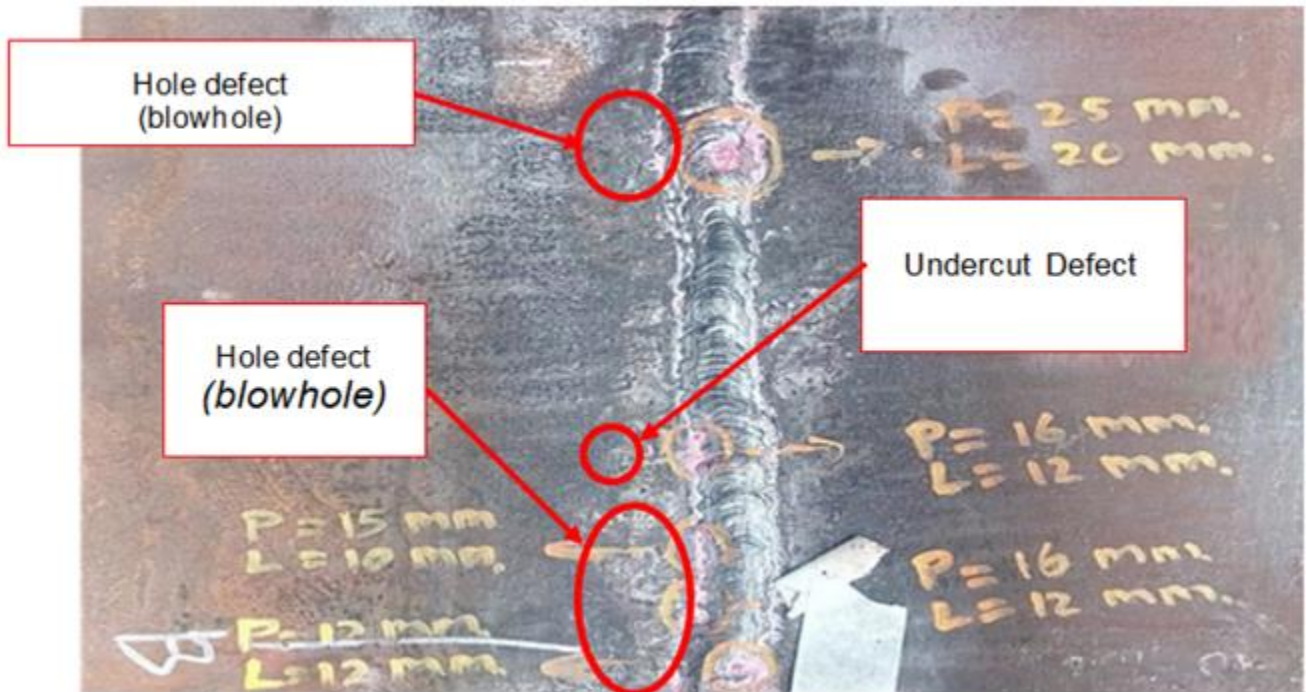


Figure 5 The results of underwater welding using the E7018 electrode at a depth of 5 meters with a heat input (HI) of 1.5 kJ/mm

For weld defects that arise due to welding conditions that are affected by stress. Where at a depth of 5 meters, the pressure exerted by the water environment becomes very large. With a very large pressure rate, it makes the low hydrogen electrode quickly become moist and the ignition is intermittent. This condition affects the arc ignition stability of the two electrodes. In this unstable condition, the heat provided by the arc electrode is uneven, so this has an impact on the occurrence of undercut and blowhole defects.

This is because the impact of water pressure is very large, where the pressure penetrates the laminate so that the electrode flux becomes impermeable which makes these two low hydrogen electrodes moist and unstable ignition. On the other hand, the depth factor which is quite far from the sun's rays has an impact on limited visibility in the water, thus affecting the welder's vision of the welding process.

4.1.2 Radiographic Test on Underwater Welding Results at a Depth of 5 Meters

For radiographic testing (RT) on underwater welding results with electrodes E7016 and E7018 are shown in Figures 6 and 7. With this picture, it can be seen that the defects that arise are incomplete penetration (IP) defects and slag inclusion (SI) defects. Such defects occur due to the effect of increasing pressure at a depth of 5 m which moves the welding molten metal unable to move through the base of the parent metal (BM). This phenomenon can be seen from the IP distance which is greater than IP as the result of underwater welding at a depth of 3 meters.

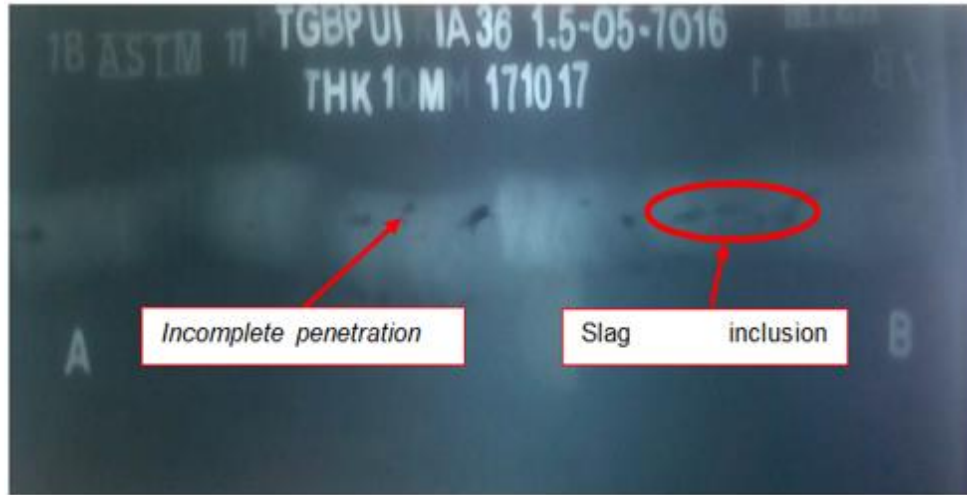


Figure 6 The results of underwater welding radiography with electrodes E7016 at a depth of 5 meters and heat input (HI) 1.5 kJ/mm



Figure 7 The results of underwater welding radiography with electrodes E7018 at a depth of 5 meters and heat input (HI) 1.5 kJ/mm

The incomplete penetration defect in the E7016 underwater welding result is lower than that of the E7018, this is due to the larger diameter of the E7018 electrode which cannot reach the root of the parent metal (BM).

Non-destructive testing (NDT) shows the types of defects that arise as a result of underwater wet welding, which affects the ability of the weld's mechanical properties. With different environmental conditions between atmospheric and in water, generally with very humid environmental conditions will cause a lot of porosity due to gas trapped due to the welding process. But based on the research results that by applying a low hydrogen electrode, it provides a low level of porosity even though there are still defects that occur in the weld metal. This type of low hydrogen electrode as long as using the right lamination method can be used in underwater wet welding.

4.2 Destructive Testing

Underwater wet welding research that is currently being carried out using the base metal material is AH36 type steel plate following BKI class standards. This type of steel plate is included in the HSLA plate category which is equivalent to steel plate according to the ASTM AH36 standard, where the chemical composition and mechanical properties of AH36 steel plate Tensile Strength Test

Tensile test results from underwater welding using low hydrogen electrodes will be compared in one step, namely, at this stage for underwater wet welding, it will be compared with atmospheric welding results where this welding is used as quality control for underwater wet welding.

4.2.1 Tensile test results on underwater welding results at a depth of 5 meters

Tensile testing of underwater welding results at a depth of 5 meters against atmospheric welding results, where welding over water as quality control for underwater wet welding is shown in Table 1.

Table 1 The results of the tensile strength of the underwater weld at a depth of 5 meters

Depth (m)	Specimen Code	Tensile strength Maximum N/mm ²	Fault Location
Atmospheric Welding Results	7016-ATM	502	BM
	7018-ATM	553	BM
Underwater Welding Results at a Depth of 5 meters	1.5-10-7016	470	HAZ
	1.5-10-7018	384	WM

For underwater welding results at a depth of 5 meters, using an E7016 electrode with a heat input (HI) of 1.5 kJ/mm provides an optimum tensile strength value of 470 N/mm² and fractures in the weld metal (WM) area. decreased strength by 9%. Electrode E7018 with heat input 1.5 kJ/mm, the tensile strength value of 384 N/mm² which is broken in the HAZ area also has a decrease in strength of 30.56%. This happens because in underwater wet welding at a depth of 5 meters, there are quite a lot of weld defects caused by an increased pressure factor (hyperbaric) at a depth of 5 meters, thus giving a weak effect on welding penetration and causing inclusions. After all, the slag in the weld metal is difficult to clean.

4.2.2 Test The results of the impact test on the results of the 5-meter depth weld

Impact testing is carried out to determine the level of the brittleness of the underwater welding results compared to the energy of impact welding. Where the test method used is the Charpy impact method which is tested on the weld metal area and HAZ at a temperature of 0°C. Impact testing for underwater wet welding at a depth of 5 meters against atmospheric welding where this welding is as quality control for underwater wet welding is shown in Table.

Table 2 Impact energy from underwater welding using low hydrogen electrodes E7016 and E7018 at a depth of 5 m in the HAZ area and weld metal (WM) at a temperature of 0°C

Depth (m)	Specimen Code	Impact Energy (Joule)	
		HAZ	WM
Atmospheric Welding Results	7016-ATM	93	82
	7018-ATM	98	86
Underwater Welding Results at a Depth of 10 meters	1.5-10-7016	86	40
	1.5-10-7018	63	43

The welding at a depth of 5 meters is shown in Table 4, where the E7016 electrode with a heat input (HI) of 1.5 kJ/mm provides an optimal impact energy value of 86 Joules in the HAZ area and 40 in the WM area. While the E7018 electrode with a heat input (HI) of 1.5 kJ/mm provides an optimum impact energy value of 70 Joules for the HAZ area and 67 Joules for the weld metal (WM) area.

Table 3 The use of heat input (HI) 1.5 kJ/mm in underwater welding from the results of impact testing at a temperature of 0°C

Electrode	Energy Impact in the HAZ (J) region	Impact Energy in the WM (J) region
E7016	77	41
E7018	77	62

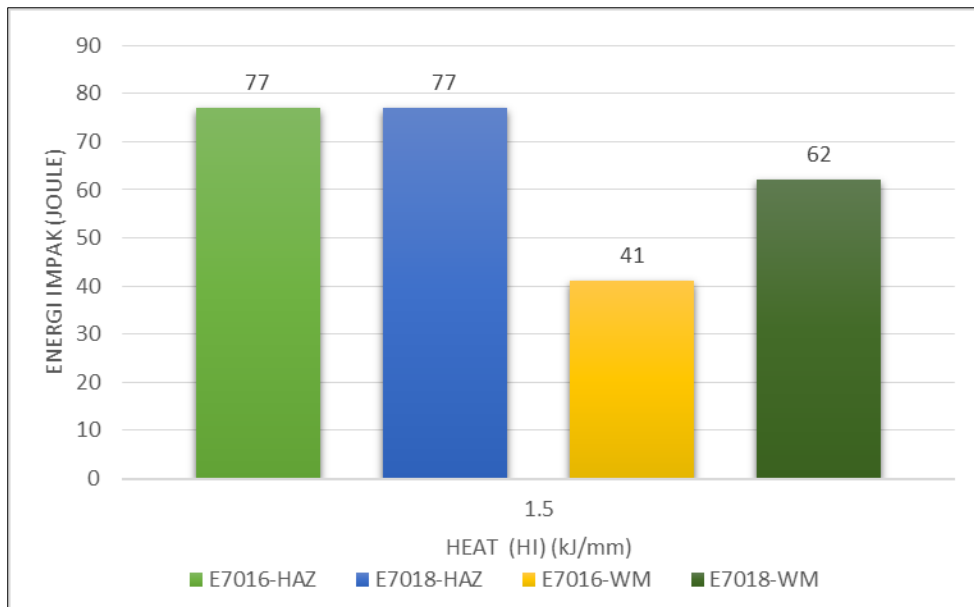


Figure 8 Graph of heat input (HI) in underwater welding on temperature impact energy of 0°C in the HAZ and weld metal (WM) area

Based on Figure 8, the use of heat input (HI) 1.5 kJ/mm gives a good average value of impact energy in the HAZ area on both electrodes with an average value of impact energy of 77 Joules. While in the WM area the best value is 62 Joules using the amount of heat input (HI) 1.5 kJ/mm for the low hydrogen electrode E7018 and the low hydrogen electrode E7016 the average value of the WM impact is 45 Joules smaller than the low hydrogen electrode E7018.

Then for the use of a sufficiently high head input or heat input, it will increase the heat input lost due to the resistance of the water environment and the pressure effect from the depth, so that it gives the microstructure less time to diffuse compared to the low heat input (JE Omajene, et al., 2014). In general, the use of low hydrogen electrodes (low hydrogen) provides optimal energy values.

4.2.3 Hardness Test on the result of the 5-meter depth weld

In the hardness test, the results of welding the AH-36 marine plate steel using the Equotip hardness test tool calibrated to the Rockwell B (HRB) Hardness standard. For hardness point sampling, the test sample is carried out in the base metal area (BM), HAZ area, and weld metal area (WM) three times the data is taken in one hardness test sample, then the test material data that has been obtained is taken on average from each point area.

Hardness testing for underwater wet welding at a depth of 5 meters against atmospheric welding results, where for welding over water (atmospheric welding) is as quality control for underwater wet welding, and the results of hardness testing are shown in Table 4.

Table 4 Hardness values in the area of the base metal (BM), HAZ, and weld metal (WM) from underwater welding at a depth of 5 m

Depth (m)	Code Specimen	Hardness (HRB)		
		Base Metal (BM)	Heat Affected Zone (HAZ)	Weld Metal (WM)
Atmospheric Welding Results	E7016-Atm	60	73	70
	E7018-Atm	64	78	73
Underwater Welding Results at a Depth of 5 meters	1.5-10-7016	49	53	61
	1.5-10-7018	72	77	74

From Table 4. data obtained from hardness tests on AH36 steel plate material on welding results at a depth of 5 meters, where the results of underwater wet welding at a depth of 5 meters with E7016 electrodes are compared with atmospheric welding results as quality control, there will be a percentage, difference The hardness test value will occur in the base metal (BM) and HAZ regions. In that area, there will be a decrease in the value of hardness with a percentage decrease of 3% and 2.7%, while in the weld metal (WM) area there will be an increase in the value of hardness of 1.4%. In the results of underwater welding with the E7018 electrode, the hardness values in the base metal (BM) and welding metal (WM) areas increased by 1.6% and 3%, respectively.

The test results obtained, shows that the distribution of hardness is relatively not much different, in this case by applying a low hydrogen electrode E7016 and a low hydrogen electrode E7018 in underwater wet welding, the hardness value does not cause high numbers from the analysis of the hardness test results. This condition occurs because of the use of the parent metal (BM) with very low carbon content. According to JE Omajene et al (2014) In wet underwater welding applications, it is recommended to use a type of steel with a low % carbon content ($C < 0.4$), because at a very fast cooling rate it will create a medium hardness level and reduce the occurrence of hydrogen cracking according to JE Omajene et al (2014).

For a comparison of the hardness values between the low hydrogen electrode E7016 and the low hydrogen electrode E7018, the graph is shown in Figure 9.

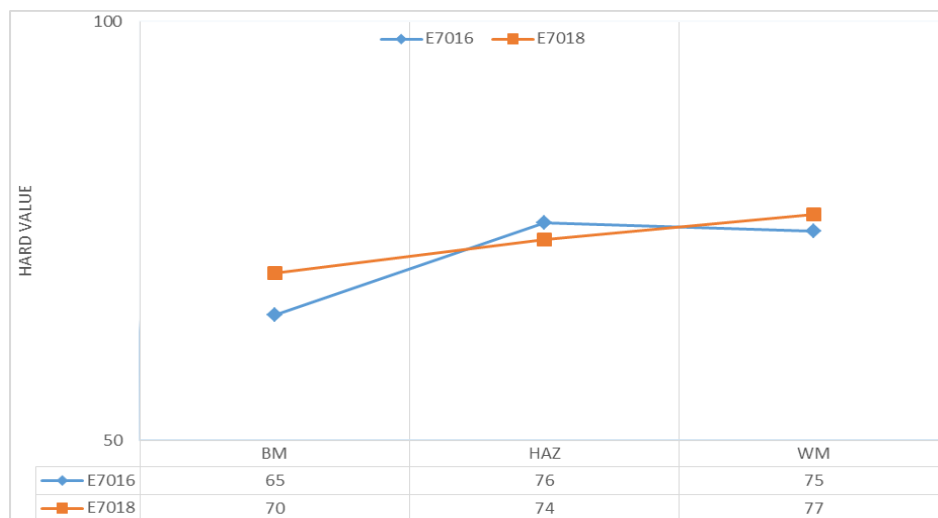


Figure 9 The graph of the comparison of the hardness of the low hydrogen electrode welds taken based on the BM, HAZ, and WM areas

Based on Figure 9 shows the hardness value between the electrodes there is no significant difference. Although the comparison results did not show a significant difference, the two low hydrogen electrodes could give slightly higher hardness values. So that the use of low hydrogen electrodes can be applied for underwater wet welding.

5 Conclusions

Analytical data from the results of testing and analysis of underwater wet welding using low hydrogen electrodes have been described in the previous chapter so that conclusions can be drawn.

- From the test results using the NDT method, then followed by the DT test showing the character and mechanical properties of the underwater welding to atmospheric welding. The NDT test shows defects that occur from the results of the penetrant test (PT) and radiographic test (RT). Atmospheric welding using low hydrogen electrodes shows porosity hole defects, incomplete penetration, and more defects. Whereas in underwater welding using low hydrogen electrodes, the occurrence of porosity defects is minimal. Then from the results of the DT test based on the depth and the electrodes used with a heat input (HI) of 1.5 kJ/mm, the following conclusions were obtained:
 - The tensile test results from the depth factor indicate a decrease in strength for underwater wet welding against atmospheric welding (quality control). Based on the heat input (HI) of 1.5 kJ/mm low hydrogen electrode, the average strength value is 465 N/mm².
 - The data on impact testing can explain that underwater wet welding is very susceptible to shock loads, but when compared with the material standards issued by the class (AWS), the results of the impact tests that have been carried out on the test samples are still included in the criteria. The use of heat input (HI) of 1.5 kJ/mm can optimize the value of the impact energy in the HAZ and weld metal (WM) areas as shown in the test results both at room temperature and 0°C.
 - The results of the hardness tests carried out showed that there was a difference in the hardness value between the results of underwater wet welding and the results of atmospheric welding.
- From the results of the NDT and DT tests described in the previous chapter for underwater welding results when compared with atmospheric welding as quality control, there was a decrease in tensile strength by 30.56%, a decrease in impact energy by 40%, and for defects that arise in underwater welding. increases gradually as the depth of the weld area increases. From research with insignificant percentage figures, low hydrogen electrodes can be applied in underwater welding of ships in emergency conditions, especially for Bottom of Waterline (BGA) leaks.
- From the data of tensile strength test results and impact test results, the recommended electrode is the low hydrogen electrode E7018 because the flux composition contains potassium, iron powder with stable ignition to a depth of 5m. The E7016 electrode contains calcium carbonate (easy to absorb water) so that the ignition is unstable or intermittent with increasing welding depth.

Future Work

The research that has been carried out is still lacking in test data so that further research is needed for the type of electrode protection through a laminate (coating) that protects a flux membrane made of low hydrogen to be more resistant to moisture in the water environment. Because there are several obstacles or problems in carrying out the underwater wet welding process.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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