Jurnal Mesin Nusantara, Vol. 6, No. 1, Juni 2023, Hal. 1-11
e-ISSN : 2621-9506, p-ISSN : 2775-7390
DOI : 10.29407/jmn.v6i1.18161

Comparative Study of Conventional Underwater Electrodes and Electrodes with Additional Modification of Mg

Hindami Imam Fahrizan[1], Winarto Winarto[2] *, Dewin Purnama[3].

[1,2,3] Department of Metallurgy and Materials Engineering, University of Indonesia, Depok-16424, Indonesia

E-mail: [1]fahrizan.imamhindami@gmail.com, [2] winarto@metal.ui.ac.id

Abstract

The influence of water depth, microstructure, chemical composition, welding defects, and mechanical properties affect underwater welding. As well as, the determination of electrodes for underwater welding requires unique properties, including being able to cause arc flame bursts and slag growing on the surface of metal deposits capable of protecting from the effects of oxides and low hydrogen solubility. The electrodes must meet the AWS D3.6M underwater welding specification standard. In this study, the steel plate material used in AH-36 and implemented for underwater wet welding by comparing two electrodes, namely E6013 with additional Mg modification and Broco E70XX electrode specifically for underwater wet welding, other Mg on the E6013 rutile electrode with modification 1 (3% Mg) and Modification 2 (5% Mg). This welding method with a heat input of 1.5 kJ/mm with 130 A and 2.5 kJ/mm with 140 A is carried out at 5m depts. The radiographic test results showed that the specimens welded at a depth of 5m showed incomplete penetration defects. Perhaps due to the influence of a significant enough pressure and a higher cooling rate, the molten Weld cannot penetrate completely into the parent material. Tensile test results also showed an insignificant increase in underwater welding strength and considerable elongation. It occurs at the E6013 electrode with modification 1 (3% Mg) and Modification 2 (5% Mg), not too large an increase, with incomplete penetration. Due to the influence of a significant enough pressure and a higher cooling rate, the molten Weld cannot penetrate completely into the parent material. However, for testing the Broco E70XX electrode, there is no change in the microstructure, such as a modified electrode with magnesium. It was only grain growth.

Keywords: Underwater Welding; Wet Welding; SMAW; Electrode Development.

1. INTRODUCTION

Underwater wet welding (UWW) is gaining popularity in construction and maintenance. This manufacturing technology is starting to develop and is needed in archipelagic areas such as Indonesia; hence it is starting to be known by the public not only for welding done on land but also now being known for welding under the sea; about 62% of Indonesia's area is sea and water. As well as many offshore oil and gas drilling processes and many ships used to transport the results

Diterima 21 Juni 2022; direvisi terakhir 08 Januari 2023; diterbitkan 30 Juni 2023

of oil and gas drilling for further processing. Efforts to maintain subsea pipelines, ships, and underwater constructions by conducting regular repairs for corrosion and leakage protection facilities require activities that are conducted underwater.

The main purpose of underwater welding technology has been developed for repair, with SMAW (Shielded Metal Arc Welding) being the most straightforward technology. The welding method is divided into two ways: wet welding (underwater wet hyperbaric), which is welding on materials in direct contact with air. Also, dry welding of the hyperbaric process is not in direct contact with water and is conducted in a hyperbaric tank [1].

The method used for air-wet welding is based on the American Welding Society (AWS) standard D3.6M stipulating five basic air welding methods: air-pressure welding, welding at ambient pressure in a large dry room, welding at ambient pressure in an open dry room. Bottom welding at ambient pressure in a transparent enclosure and welding at ambient pressure. There are several class codes in underwater welding, such as type A, type B, and type O welding. Type A welding defines stand-alone requirements. For underwater welding to be suitable for application and design stresses and more accessible and applicable, type B is defined by a set of mechanical and inspection requirements. For the intended less critical application, the decreased ductility, and increased porosity, can be tolerated on the type C welds, which meet lower requirements than other types. In addition, type O meets the requirements of governing "in the air" codes, specifications, or other mandatory documents, as well as the additional requirements specified in the specifications for Underwater Welding [2]. However, to evaluate several diverse types of commercial electrodes for wet welding.

The base electrode produces an unstable arc and an irregular bead appearance. The rutile electrode is the most used type for underwater wet welding because of its excellent arc stability and good bead appearance. However, the rutile electrode produces a weld metal with a highly diffusible hydrogen content of up to 80 ml/100g, making it susceptible to cold cracking. Thus, due to the low diffusing hydrogen content resulting from the development of the oxy-rutile electrode, which can give a yield as low as 20 ml/100g, these electrodes have low arc stability and lower weld bead appearance and detachability. Bad slag. From the results of the development and study of oxy-rutile electrodes that try to combine the advantages of rutile and oxidizing electrodes [3]. Therefore, the research purpose is to study the comparison between the electrodes commonly used for underwater wet welding, such as the Broco E70XX electrode with the E6013 rutile electrode by the modification with the Mg. The resulting mechanical properties of the welded material, namely the AH-36 plate, would be observed as the high-strength low-carbon steel that functions for ship hull materials.

2. EXPERIMENT METHOD

Steel plate used AH-36 as standard high-strength steel. The chemical composition is shown in Table 1.

Table 1 Chemical Composition of AH-36 Steel [4]

Material	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Cb	V
AH-36	0.18	0.10	0.90	0.035	0.035	0.020	0.08	0.40	0,35	0.02	0.05

The electrode materials used are rutile electrodes E6013+Mg and Broco E70XX electrodes with a diameter of 3.2 mm with the addition of % magnesium as shown in Table 2, and the chemical composition of Broco electrodes can be seen in Table 3.

Table 2 E6012 Modified Magnesium Electrode

Magnesium
Modification 1 (3% Mg)
Modification 2 (5% Mg)

Table 3 Chemical composition of Broco Underwater E70XX coated electrodes [5]

Designation (% wt)								
AWS E70XX	C	Si	Mn	P	S	Cu	Ai	Cr
	0.072	0.244	1.185	0.012	0.002	0.016	0.024	0.024
	Mo	Ni	V	Ti	Nb	Co	Fe	
	0.005	0.023	0.015	0.008	0.017	0.009	Bal.	

The electrodes used were modified E6013 electrodes with the addition of Mg and Broco E70XX electrodes. Before being used for underwater wet welding using the SMAW method, the E6013 electrodes were first added with modification 1 (3%

Mg) & modification 2 (5% Mg). The diameter of the electrode is 3.2 mm. In the first stages, welding was conducted using an E6013 electrode with modified Mg at a depth of 5 m using a heat input of 1.5 and 2.5 kJ/mm. Afterwards, the welding results with a modified Mg electrode were compared between the Broco E70XX electrode at the same depth and heat input as the modified E6013 electrodes.

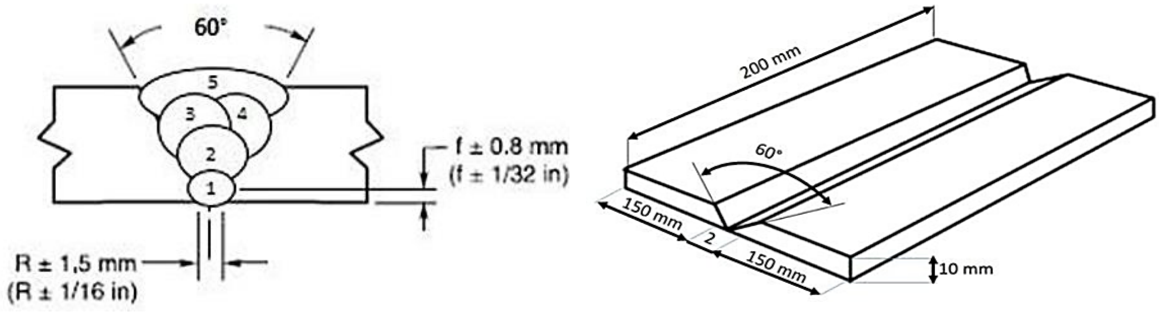


Figure 1. Preparation Welding of marine steel plate AH-36:
a) Single v-groove connection, b) welding trajectory.

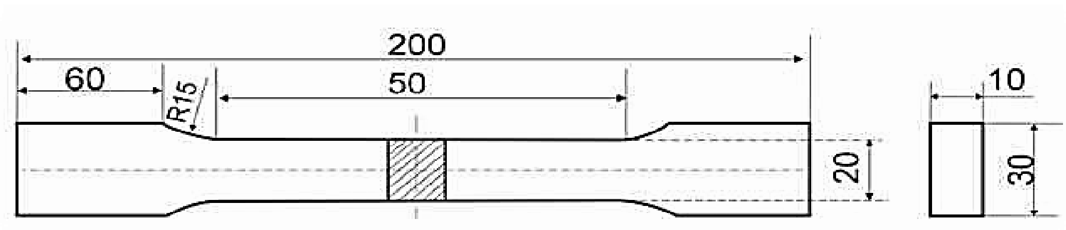


Figure 2. Tensile test sample dimensions

Welding is conducted on 200mmx150mmx10mm plates, as shown in Figure 1 a. Welding is carried out in five passes because wet underwater welding produces smaller weld beads than atmospheric welding. The first line is in the root area, followed by a fill line and completed with a cover line, as shown in Fig 1 b. Welded samples were checked with NDT; Liquid penetrant is a welding defect inspection that uses the principle of capillarity in liquids and is conducted by certified experts. This inspection is conducted two days after the underwater welding process, aiming to detect welding defects and testing. Gamma Ray Radiography detects discontinuities such as internal, surface, and subsurface defects of equipment formed from metals or alloys using light Gamma Ray. The waves from this light can penetrate solid particles. They can detect discontinuities or defects in the form of cracks, imperfect penetration, and slag inclusions in the material. These defects can be observed in IR.192 with 25Ci activity with a focal size of 3x3 and an exposure time of 2 minutes. 30 seconds. Tests in this study were conducted by following the SEC ASME standards. IX. DT Testing: Microstructure testing is taken in several parts starting from the midpoint of the weld metal so that it can display the weld metal area, the fusion area. An optical microscope magnified 100 to 500 times was used in the evaluation stage. After analyzing with an optical microscope, comparing the microstructure between welding with modified E6013 Mg and Broco Underwater E70XX electrodes and then for tensile testing conducted on the quality of tensile strength, which is intended to determine the value of its strength and where the fracture is at the Weld joint. Tensile test specimens were prepared according to the AWS D1.1 standard. The test was conducted at 25oC (room temperature) using a United SHFM 600 KN tensile testing machine at two mph/second speed. Tensile testing was conducted using two test objects. The average value was calculated, as shown in Fig 2, and the Vickers microhardness test was conducted using the Zwick Roell test equipment. Loads of 1000 of every 10 seconds, HV 10 is applied to the cross-section of the test sample consisting of BM, HAZ, and WM. The tracking point is determined 2 mm from the top surface. The hardness test in this study was conducted by following the ASTM E384 standard. The next test is impact testing. Impact testing is testing using a jolt load (sudden). The primary purpose of impact testing is to measure the brittleness or ductility of material against sudden loads. The Charpy v-notch (CVN) impact test specimen was prepared according to the ASTM E23 standard in dimensions (55 × ten × 10) mm with the notch location determined on the WM center line. The test was conducted with a Tinius Olsen Impact Tester 542 J machine. Impact at the test temperature of 25^{o}C.

3. RESULTS AND DISCUSSIONS

a. Non-Destructive Test (NDT) of Welding

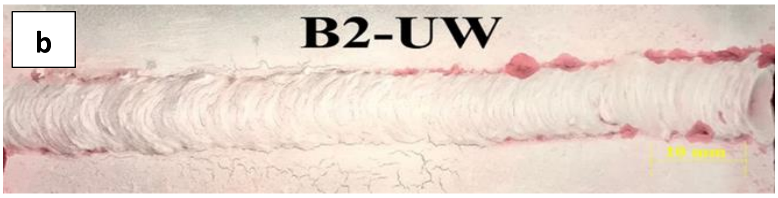


Figure 3. Samples of test results with liquid penetrant
(a) B1-UW and (b) B2-UW

Figure 3 shows the test results using liquid penetrant on the underwater welding sample, which was welded using the Broco E70XX Special Underwater electrode with a heat input of 1.5 kJ and 2.5 kJ in samples B1 and B2, respectively. Cause defects on the surface because it is welded by a professional welder and with a particular electrode for underwater

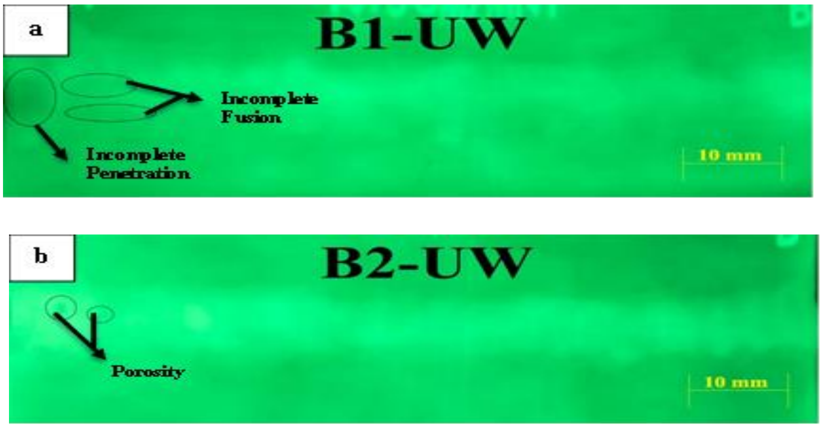
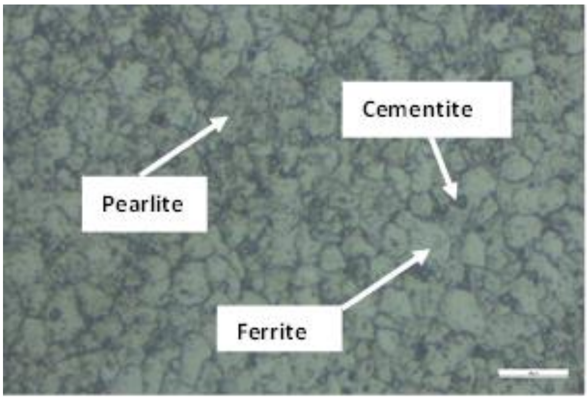


Figure 4. Results of testing with gamma-ray radiography:
(a) BI-UW and (b) B2-UW

Figure 4. is the result of testing through Gamma-ray radiography. The welded sample B1 using 1.5 kJ/mm heat input showed the weld defects. It is namely the incomplete penetration of 28 mm, and the incomplete fusion of 25 mm. It is due to travel speed being too high, the gap or root opening being too wide, the electrode distance or the welding arc being too high, the electrode angle being wrong, and the welding amperage being too small. Meanwhile, sample B2, which was welded using a heat input of 2.5 kJ/mm, had defects in the form of porosity 4 mm + 5 mm due to the welding current being too low, travel speed too high, the presence of impurities in the workpiece (such as rust, oil, water).

According to the AWS standard D3.6M:2010 class B at point 8.10.1 regarding radiographic acceptance criteria, the existing defects still meet the weld soundness requirements [6].



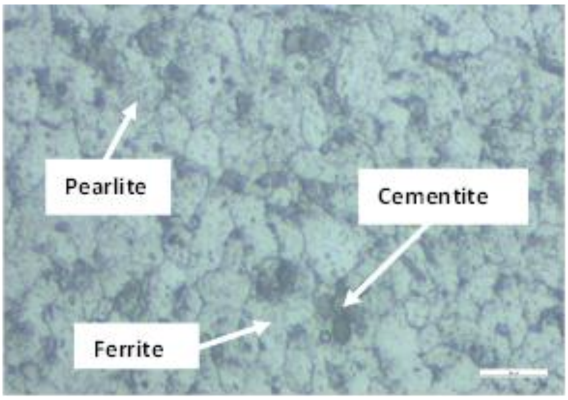


Figure 5. Weld metal microstructure (a) B1-UW heat input 1.5 kJ/mm 500x magnification, (b) B2-UW heat input 2.5 kJ/mm 500x magnification

There was no phase change in samples B1 and B2 with broco E70XX electrodes. Only cementite was formed where other micro constituents, such as pearlite, cementite, and martensite, could also occur. At faster cooling rates, the formation of bainite or ferrite with aligned carbides (AC) and martensite is possible [7]. is shown in Figure 5. One of the differences in heat input between 1.5 kJ/mm and 2.5 kJ/mm can be seen in the size of the austenite grains. The grain size of B2 is larger than the grain size of B1. The higher heat input causes the cooling process in the weld metal to be slower even though it is conditioned in water so that the grain size is still coarse. In addition, higher heat input can also increase grain size, which can contribute to reducing hardness. It is similar to the study reported by previous researchers [8].

b. Destructive Test (DT) of Welding

The value of tensile strength with a heat input of 1.5 kJ/mm (B1-UW) using electrode Broco E70XX has a value of 527 MPa. However, the tensile strength for heat input of 2.5 kJ/mm (B2-UW) using electrode Broco E70XX has a value of 533 MPa. The Broco E70XX electrode, specifically for underwater application, has different weld properties with the electrode E6013 + Mg. The ductility of the weld metal increases with increasing heat input [8].

Table 4 Tensile test results for AH-36. steel underwater welding

Sample	Tensile Strength (MPa)	Broken location
Base metal	**550**	
A1-UW	545	*Base metal*
A2-UW	544	*Base metal*
A3-UW	548	*Base metal*
A4-UW	541	*Weld metal*
B1-UW	527	*Weld metal*
B2-UW	533	*Weld metal*

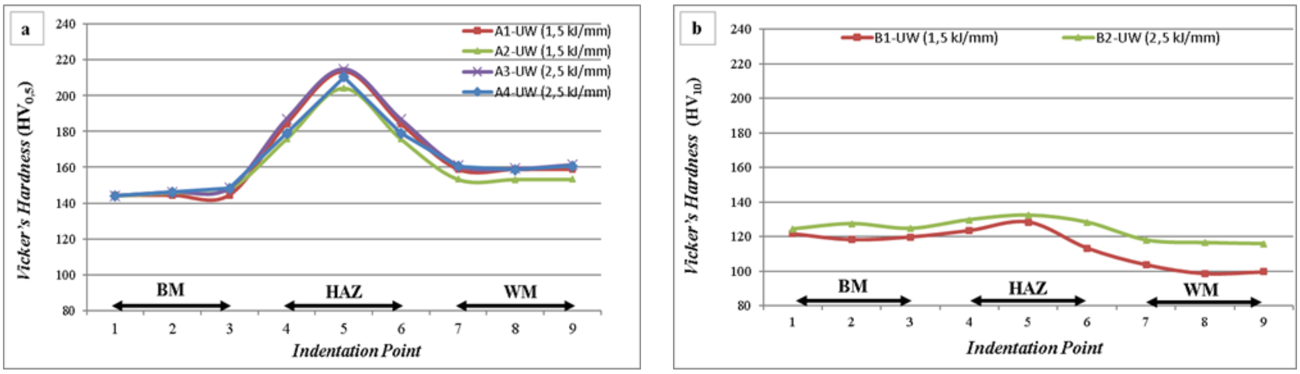


Figure 6. The results of the Vickers hardness test at a depth of 2 mm with electrodes (a) electrodes E6013 modified Mg (b) Broco E70XX

The hardness value between the heat input of 1.5 kJ/mm and 2.5 kJ/mm has the Vickers hardness value, which tends to be the same. With a higher heat input, the cooling rate can be slower, allowing carbon atoms to diffuse so that martensite may reduce [9]. That the maximum hardness value occurs in HAZ followed by WM and BM. The hardness value in HAZ is highest compared to WM and BM because the HAZ microstructure has a large amount of martensite. When compared to atmospheric welding, underwater welding has a higher hardness value [10]. Another thing is that the low heat input will cause the cooling rate to be faster when compared to the high heat input, so it tends to form a more complex phase in the microstructure, but this is not following the data in almost all test samples show in Figure 6.

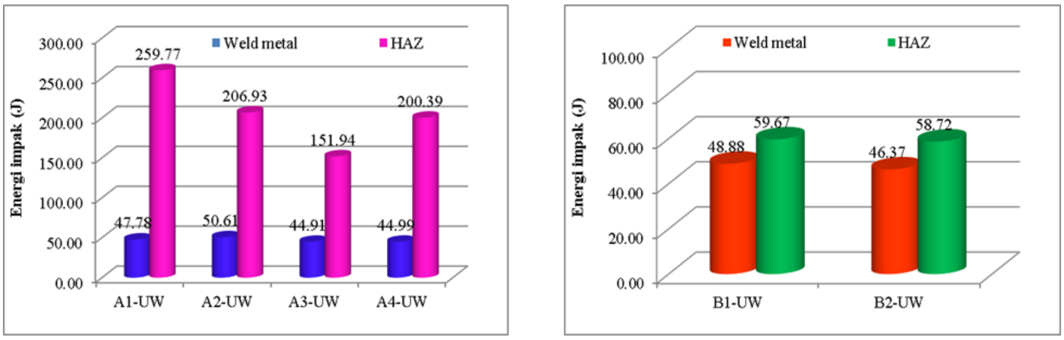


Figure 7. Comparison of impact toughness values of WM and HAZ steel AH-36 with Electrode (a) E6013 Modified Magnesium and (b) Broco E70XX.

Figure 7 compares the impact toughness values between HAZ and WM with a heat input of 1.5 and 2.5 kJ/mm on the modified E6013 electrode with magnesium and the Broco E70XX electrode. The impact energy on the HAZ in all samples has a higher value when compared to WM because, in underwater welding, there is a rapid cooling process so that the width of the HAZ formed is narrower when compared to welding on land. Because the width of the HAZ created is limited, the determination of the notch in the impact test may already be in the base metal (BM) area, so the location of the fracture is in the base metal. The rupture in BM may result in a higher impact toughness value on the welded specimens because the area on the base metal (BM) is not exposed to heat, so BM does not undergo a grain structure transformation which can reduce the toughness of a material [9]. However, when compared to the E6013 modified magnesium electrode, it is better than the Broco E70XX electrode because the Broco electrode does not change the microstructure, there is only grain growth, and there is no Acicular ferrite (AF) formation which is a ductile microstructure and can increase the toughness value of a welded joint.

4. CONCLUSION

a. Underwater welded steel AH-35 with a heat input of 1.5 kJ/mm using the modified electrode of 5% Mg shows a little weld defect such as porosity, slag inclusions, and a little undercut in the weld metal. However, those defects still meet the specification for AWS D3-6M:2010 class B.
b. In the microstructure with Broco E70XX electrodes, there is no significant phase change, only grain growth, and there is a cementite phase.

c. All the tensile properties on the Mg modification of the E6013 electrode and the Broco E70XX electrode have shown more ductile properties except for the welded steel of 2.5 kJ/mm heat input with the modified electrodes of 5% Mg. The welded steel with an Mg-modified electrode with a heat input of 1.5 kJ/mm has a higher average tensile strength value than the welded steel with a heat input of 2.5 kJ/mm. In contrast to the Broco E70XX electrode, the average value with a heat input of 2.5 kJ/mm has a higher average tensile strength value than the welded steel with a heat input of 1.5 kJ/mm.
d. The welded steel using an Mg modified E6013 electrode with a heat input of 1.5 kJ/mm is a higher impact toughness value when compared to a heat input of 2.5 kJ/mm. The optimum impact energy is 50.61 J, and it is occurred on the welded steel with the heat input of 1.5 kJ/mm using 5% Mg modified of the E6013 electrodes

5. ACKNOWLEDGMENTS

The authors would like to acknowledge the Directorate of Research and Public Services, Universitas Indonesia (DRPM-UI), for the financial support for this study through the PUTI Doctor Grant in 2020 with the contract number of NKB-673/UN2.RST/HKP.05.00/2020.

6. DAFTAR PUSTAKA

[1] D. Purnama, W. Winarto, N. Sofyan, A. Prihastomo, and K. Ito, “Microstructure and mechanical properties of ah-36 steel weldment welded using magnesium modified E6013 electrode,” Int. J. Technol., vol. 11, no. 1, pp. 48–59, 2020, doi: 10.14716/ijtech.v11i1.2737.

[2] R. P. Campos, A. C. Cuevas, and R. A. Esparza Muñoz, “Characterization of metals and alloys,” Charact. Met. Alloy., pp. 1–255, 2016, doi: 10.1007/978-3-319-31694-9.

[3] C. E. Grubbs, M. F. Bluem, and P. T. Delaune, “Overview of ‘Specifications for Underwater Welding’ Aws D3. 6.,” pp. 221–226, 1983, doi: 10.1016/b978-0-08-030537-0.50023-5.

[4] H. Ozaki, J. Naiman, and K. Masubuchi, “Study of Hydrogen Cracking in Underwater Steel Welds.,” Weld. J. (Miami, Fla), vol. 56, no. 8, pp. 231–237, 1977.

[5] A. Sanchez-Osio, S. Liu, D. L. Olson, and S. Ibarra, “Designing Shielded Metal Arc Consumables for Underwater Wet Welding in Offshore Applications,” J. Offshore Mech. Arct. Eng., vol. 117, no. 3, pp. 212–220, Aug. 1995, doi: 10.1115/1.2827092.

[6] X. Guirong, G. Xuesong, Q. Yuliang, and G. Yan, “Analysis and Innovation for Penetrant Testing for Airplane Parts,” Procedia Eng., vol. 99, pp. 1438–1442, 2015, doi: 10.1016/j.proeng.2014.12.681.

[7] D. L. Olson, T. A. Siewert, S. Liu, and G. R. Edwards, “Welding, Brazing, and Soldering Volume 6 of the Asm Handbook.,” Asm Int., vol. 74, no. 8, pp. 269–278, 1993.

[8] D. Fydrych et al., “Weldability of S500MC Steel in Underwater Conditions,” Adv. Mater. Sci., vol. 14, no. 2, pp. 37–45, 2014, doi: 10.2478/adms-2014-0008.

[9] K. R. Manikandan, P. Ashwin Sivagurunathan, S. S. Ananthan, A. Arul Marcel Moshi, and S. R. Sundara Bharathi, “Study on the influence of temperature and vibration on indications of liquid penetrant testing of A516 low carbon steel,” Mater. Today Proc., vol. 39, no. xxxx, pp. 1559–1564, 2020, doi: 10.1016/j.matpr.2020.05.572.

[10] W. Gao, D. Wang, F. Cheng, X. Di, C. Deng, and W. Xu, “Microstructural and mechanical performance of underwater wet welded S355 steel,” J. Mater. Process. Technol., vol. 238, pp. 333–340, 2016, doi: 10.1016/j.jmatprotec.2016.07.039.