

Microstructural and Mechanical Properties of Underwater Wet Welded SS400 Steel

*N. M. L. P. K. Yasari, Nurul Muhayat, Triyono**
Mechanical Engineering Department, Sebelas Maret University

Y. C. N. Saputro
*UPTB Solo Technopark, Technical Unit on Regional Development
Planning Board Surakarta*

** triyonomesin@uns.ac.id*

ABSTRACT

Underwater wet welding is mainly used for repairing and maintenance of marine constructions. Shielded Metal Arc Welding (SMAW) is widely used in underwater wet welding. To investigate influence of welding parameters on weld joint of underwater wet shielded metal arc welding (SMAW), weld currents and electrode types were varied during welding process in the trial pool with water depth of 2.5 m. The non-destructive and destructive test including X-ray analysis, microstructure investigation, tensile, impact and hardness test were performed. The results reveal that there were a lot of defects for all specimens in the underwater wet welded joint due to the interfering environment. Due to these defects, the tensile strength was almost the same, it only increased slightly when the welding electric current increased. The increasing penetration due to increasing weld current was the main reason for this case. The highest hardness was found at Heat Affected Zone (HAZ) close to the fusion zone.

Keywords: *underwater wet welding; electrode; weld current; microstructures; mechanical properties*

Introduction

Underwater welding is a welding which mostly used to repair and maintenance of marine constructions such as submerged pipelines, offshore oil platforms, nuclear power plants, watercrafts, piers as well as harbor devices [1,2]. Rowe and Liu indicated that to fix marine constructions, particularly for the water depth less than 60 m, the technique of underwater wet shielded metal arc welding had been applied. The major advantage of underwater wet shielded metal arc welding technique is shortened duration to repair. In recent years several experimental studies have been improved and published focused on the metallurgy observations and the mechanical characteristics make a use of electrodes types with different water depths [3].

The underwater welding technique can be classified into two main kinds, wet and dry method. The collation of dry or wet method, the wet method does not need any complicated device such as a diving bell, hyperbaric vessel, drainage device, etc. The underwater wet welding process is done directly in the water and the processed is simple that makes it possible to weld even for the most complex structures. Yet, as the wet method is applied at ambient pressure with no physical barrier between the water and welding arc, the increased pressure makes welding arc unstable. Due to water dissociation, the higher amount of oxygen and hydrogen present in the weld pool, increase the porosity and hydrogen-induced cracks which are resulted in underwater wet method [4].

Underwater wet welding is a process that held in direct water without using any extra tools and has a cheaper expense compared to other underwater welding methods [6]. Another side, underwater wet welding has a deficiency on the poor arc stability and high martensite content, therefore, low tensile strength and poor bending resistance are resulted [7]. The mechanical properties deterioration of weld metal in underwater wet welding is the main problem. It is affected by the rapid cooling rate and high amount of hydrogen [8,9]. The slag-system and alloy-system of welding materials can be adjusted by deemed one of the best methods [10,11].

The previous experiments showed that Nickel was added to cover the electrode and contained about 2,5% (wt) of nickel would obtain the best mechanical characteristics [12]. The research of Rowe et al discovered the amounts of titanium and boron made the micro structures of ferrite grain size finer and decrease the capacity of oxygen in the weld metal [13]. Santos et al showed and improved an oxy rutile electrode for underwater wet welding by integrating of the good welding process and the low capacity of hydrogen [14].

Haidar and Lowke and Pires et al. have studied metal transfer process, and they said that metal transfer has affected the welding arc stability, weld formation and welding quality [15,16]. Shi et al. proposed that the good weld

joint can be obtained using appropriate of the arc voltage. They indicated that at the shallow depth, the arc stability of underwater wet welding will get worse with increasing welding current and improves with increasing welding voltage [17]. Guo et al. illustrated that the droplet transfer process using the X-ray transmission method and showed that there was a critical arc voltage that affects the stability of the underwater wet flux-cored arc welding process [18,19,20].

Moreover, the previous studies were just focused on the microstructural characterization and mechanical properties evaluation of the underwater wet welding that conducted in shallow depth. Very few publications are available on the underwater wet welding that conducts in fresh water with depth. Hence, this investigation was carried out to observe the microstructural and mechanical properties of underwater wet welding that conduct in fresh water with depth of 2.5 m with various electric currents and electrodes.

Methodology

The structural steel plate of 8 mm thick SS400 of 100 mm x 100 mm x 80 mm was selected as base metal (BM) because it is mainly used in marine constructions. The electrodes materials which used in this research is E6013 (RB 26 and RD 260) and the E7016 electrode of rutile underwater with a diameter of 3,2 mm and wax waterproofing. The chemical compositions of the base metal are shown in Table I.

Underwater wet shielded metal arc welding technique experiments were conducted in direct water with a depth of 2.5 m in the trial pool. The parameter of welding process in this research is the using of nominal electric current at 80A, 90A, 100A, 110A and various electrodes.

The X-ray test was applied by using AWS D1.1 standard to make the quality of underwater wet welding. A set of X-ray imaging system has been developed, which consists of a micro-focused X-ray tube, an image intensifier, and a high-speed camera.

The specimen for the tensile strength test is machined according to JIS 2202 shown in Figure 1 and the tensile test is conducted by a universal testing machine (UTM). The hardness distribution was conducted by micro Vickers hardness test on the cross section to study the hardness number in the microstructure of the weld joint. A diamond pyramid indenter is used with a 200 g load for 15 s.

The microstructural examinations were prepared by grinding the specimen's cross-sections using sand papers with a grade in the range from 120 to 1500 and then polished by diamond paste. Finally, the specimen was immersed in the HNO₃-alcohol solution with a ratio of 1:10 ml for less than 1

second. The microstructural investigation is performed using optical metallurgy microscope.

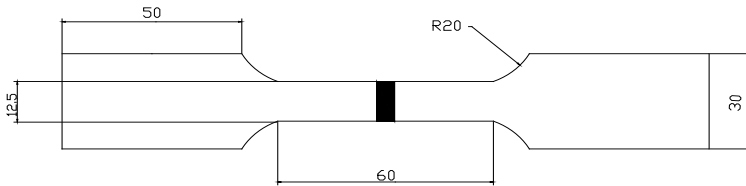


Figure 1 : Dimension the tensile test (mm)

Result and Discussion

The X-ray result shows the of quality underwater wet welding joint. All the specimen of underwater wet welding are rejected according to AWS D1.1 standard due to the defect of incomplete penetration, porosity, external undercut, irregular surface, and lack of fusion on the underwater wet welding joint. Incomplete penetration is a lack of penetration or fusion between the weld metal and the parent metal of piece. Porosity is weld contamination in the form of a trapped gas. Shielding gases or gases released as a result of the torch being applied to treated metal are absorbed into the molten metal and released as solidification takes places. However, the shielding gas doesn't perfectly reach the weld pool and the atmospheric air influences the weld bead. The defects which happened on the welding joint are usually caused by the used of too low a welding current and too slow a travel speed.

Figure 2 shows the defects on X-Ray results are a lack of fusion (V), excessive weld metal (W), external undercut (Y), and irregular surface (Z). Lack of fusion (V) occurs when there is no fusion between the weld metal and the surfaces of the base plate. Lack of fusion is commonly caused by a poor welding technique. When the weld puddle is too large (travel speed too slow), the weld metal has been allowed to occur in front of the arc. On the welding process, the arc must be kept on the leading edge of the puddle. When the arc can be kept, the weld puddle will not get too large and cannot protect the arc. Excessive weld metal (W) is a part of the face or root reinforcement which has a larger height than that specified. The defect of excessive weld metal (W) is caused by too slow electrode usage, too over root opening (root reinforcement), and too over welding amperage (root reinforcement). External undercut (Y) is a groove that is happened in the base metal close to the weld metal toe or weld root which is left unfilled by the weld metal. External undercut caused by too high welding amperage and too fast electrode manipulation. The defect of irregular surface (Z) welds

happened due to too wide or too narrow, those that have an excessively convex or concave surface, and those that have coarse, irregular ripples. Such characteristics caused by a speed of travel that is too slow and current that is too high or low.

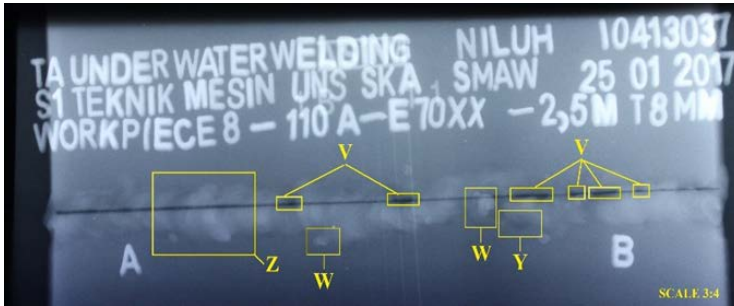


Figure 2 : X-ray result on 110A E7016

Figure 3 shows the defects on macrostructures underwater wet welding. The figure shows the defects that happened on variations of electric current and electrodes are incomplete penetration, lack of fusion, excessive weld metal, external undercut, and irregular surface. Incomplete penetration is the failure to raise the temperature of the base metal to the melting point. Incomplete penetration caused by the gap is too small. Lack of fusion happens when there is no fusion between the weld metal and the surfaces of the base metal. Lack of fusion is commonly caused by a poor welding technique. When the weld puddle is too large (travel speed too slow), the weld metal has been allowed to occur in front of the arc. In the welding process, the arc must be kept on the leading edge of the puddle. When this is controlled, the weld puddle will not get too large and cannot protect the arc. Excessive weld metal is the face or root reinforcement that has a larger height than that specified. Excessive weld metal caused by too slow electrode manipulation, too much root opening (root reinforcement), and too much welding amperage (root reinforcement). The external undercut is a groove that is gouged in the base metal adjacent to the weld metal toe or weld root and is left unfilled by the weld metal. External undercut caused by too high welding amperage and too fast electrode manipulation. Irregular surface welds are the defect due to too wide or too narrow, which has an excessively convex or concave surface, and which have coarse irregular ripples. These characteristics caused by a speed of travel that is too slow and current that is too high or low. In the welding process, the cooling rate down very quickly. The rapid cooling rate in the region led to the microstructural changes along the lines of HAZ.

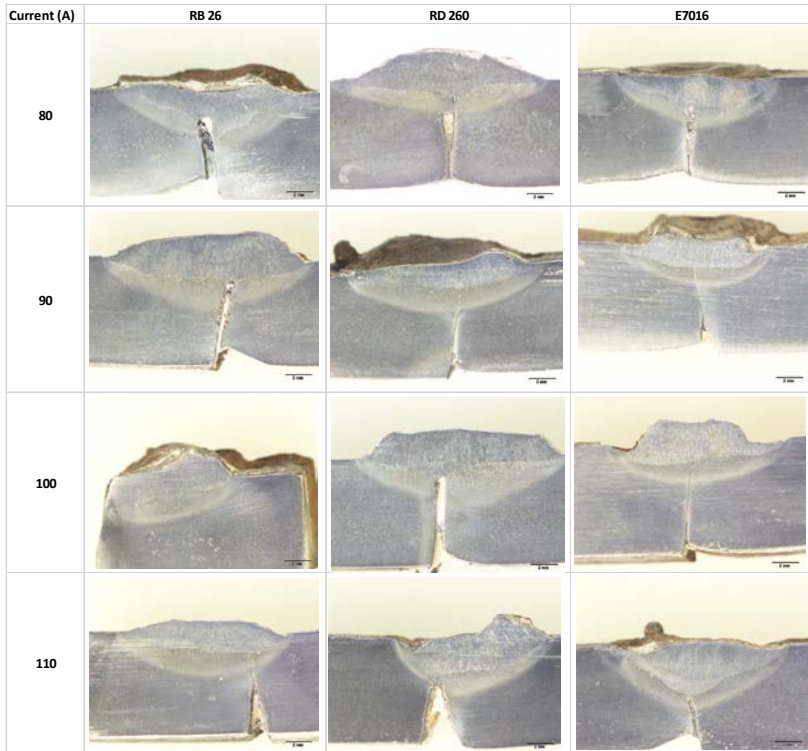


Figure 3 : Macrostructures in the underwater wet welding are using various electrodes and electric currents

Figure 4 shows the microstructures in heat affected zone (HAZ) and weld metal (WM) corresponding to the four welding electric currents and three electrodes. As shown in Figure 4 the micro structures of HAZ show the mixture of the four types of ferrite: grain boundary ferrite (GBF), ferrite with the second phase aligned (FS (A)), acicular ferrite (AF) and polygonal ferrite (PF). When the cooling process of WM occurs, the nucleus of GBF at the major grain boundaries of austenite at high temperature turns become the nucleation sites for FS (A), that stick out from grain boundaries into the major austenite grains. When the electric current in welding process increases, the heat input will increase and affected the grain size also increases and the relative content of FS (A) and AF will decrease with increasing GBF and PF. The size of GBF and the FS (A) lath increase too with increasing welding heat input.

The structure of FS (A) is contained by low impact value and low elongation because of the arrangement along crystallographic direction and

plane. At high welding input, the columnar grain will be coarse and decrease the mechanical characteristics [21].

Figure 4 shows the micro structure of WM at electrode RB 26 and RD 260 are characterized by PF, AF, and GBF whereas the WM at electrode E7016 contain PF, GBF, AF, FS(A).

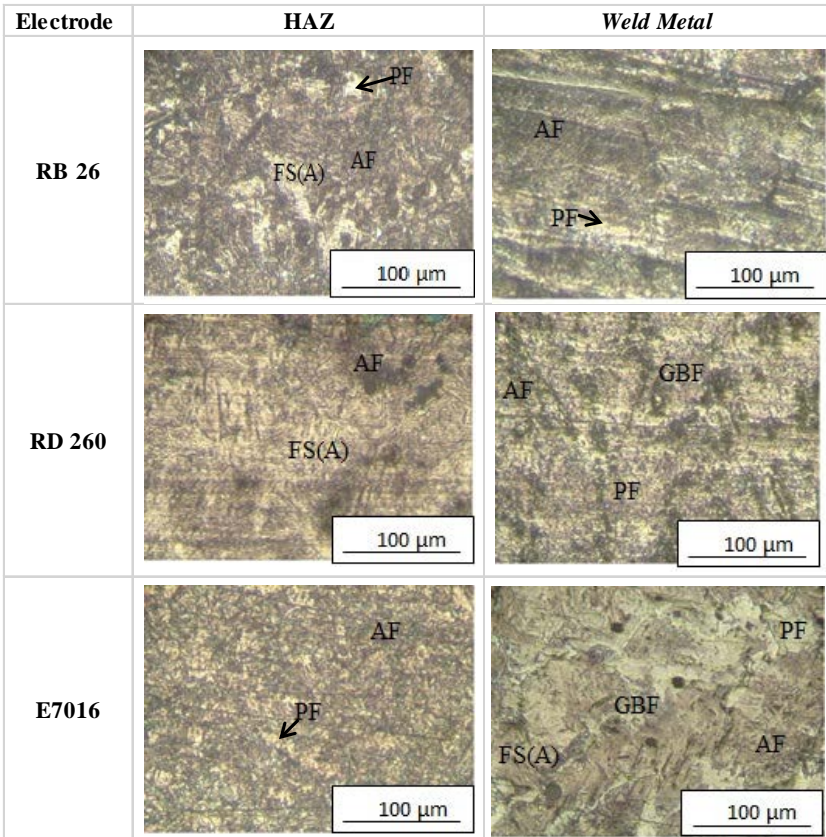


Figure 4 : Microstructures in the underwater wet welding are using various electrodes and electric currents 100A

The tensile trial for underwater wet welding joints of various electric currents and electrodes are based on JIS 2202 standard. The fracture of tensile test that all the underwater wet welding joints are a fracture in the weld metal zone. The tensile testing samples showed there are no necking happened. According to Figure 6, all the tensile specimen of underwater wet welding joint present brittle fracture. Figure 5 displays the transverse tensile

strength of the weld metal of underwater wet welding joint specimen. The increasing welding current and the decreasing welding speed causing a large amount of heat input in the welding pool and the enlargement of width and deepness of the welding pool [21,22].

Figure 5 shows that specimen underwater wet welding joint with electrode RB 26 has the highest tensile strength at 110A as 184,7 MPa. Specimen underwater wet welding joint with electrode RD 260 has the highest tensile strength at 110A as 168,6 MPa. Specimen underwater wet welding joint with electrode E7016 and weld current of 110A has the highest tensile strength of 171, 9 MPa.

Welding zone is more hard and brittle in the overheated zone when the welding current is too high [21]. However, the root of welding joint is in welded when the welding current is low so that the strength also will be low. The fracture of all specimen underwater wet welding joint included brittle fracture. Brittle fracture is the fracture of a metallic object or other material without appreciable prior plastic deformation. The fracture of all specimen underwater wet welding happened on weld metal.

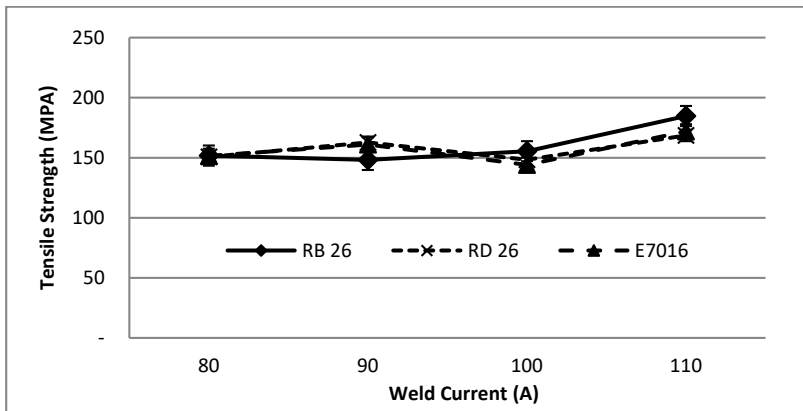


Figure 5 : The transverse tensile strength of underwater welding joint specimens

The fracture usually appeared on HAZ zone when the welding is conducted perfectly without any defects. If there are any defects on the underwater wet welding joint, the fracture conducted on weld metal.

Based on the testing results of the mechanical characteristics, micro hardness test is applied for the underwater wet welding joint. Figure 7 shows the hardness distribution data. Figure 7 shown the Vickers hardness variation along the line at the distance of 2 mm from the upper surfaces on the cross-section.

The highest hardness values are found at HAZ near to the fusion zone. The high electric current input affects to the changed of finer microstructures (GBF and PF) in HAZ when the using of electrode RB 26, the average hardness in the HAZ is 522,75 HVN corresponding to the most FS (A) microstructures and the decrease to 362,72 HVN and 350, 06 HVN at electrode E7016 and RD 260. The highest hardness value is limited to 325 HV₅ and 375 HV₅ for Class A and Class B welds according to AWS standard (AWS D3.6 :2010).

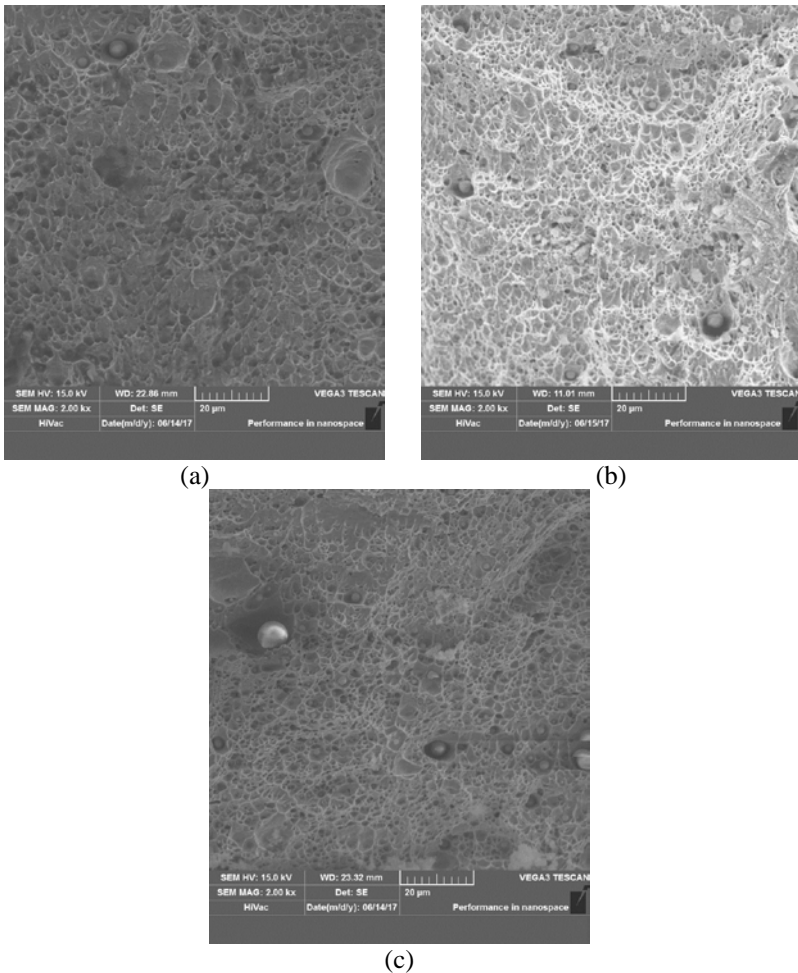


Figure 6: The brittle fracture a) RB 26 Electrode, b) RD 260 Electrode, c) E7016 Electrode on tensile strength test by SEM

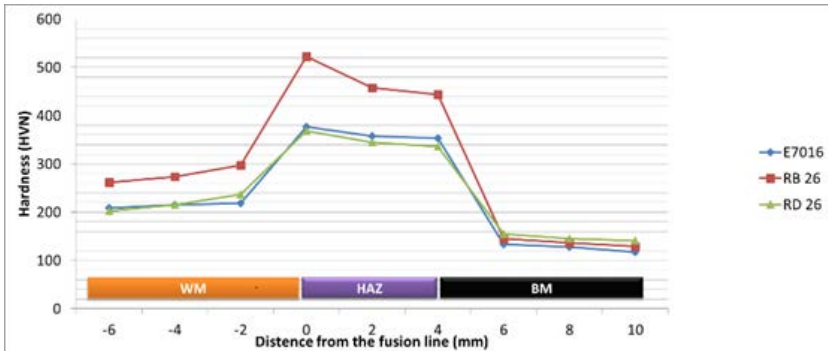


Figure 7 : Vickers hardness distribution of the underwater wet welding joint

Conclusions

Based on the discussion, it can be concluded that the X-ray results show the defect on all of the underwater wet welding joint. As the welding electric current increases, the heat input increases, then the grain size increases and the relative content of FS (A) and AF decrease with increasing content of GBF and PF. The size of GBF and the FS (A) lath also increase with increasing welding heat input. The fracture of the tensile test exhibited that the weld joint is a brittle fracture. The highest hardness was found at Heat Affected Zone (HAZ) close to the fusion zone. The high electric current input affects to the changed of finer microstructures (GBF and PF) in HAZ. When using electrode RB 26, the average hardness in the HAZ was 522,75 HVN corresponding to the most FS (A) microstructures.

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