

Research on Fracture Failure of the Underwater Welding Joint

Xiangfeng Kong ^{1,2}, Feng Qiu ³, Jing Zhang ¹, Yan Zou ¹, Dongzhi Chu ^{1,*}

¹Institute of Oceanographic Instrumentation, Shandong Academy of Sciences, Qingdao 266000, China;

²College of Chemistry and Chemical Engineering, Ocean University of China, Qingdao 266000, China;

³Nansha Branch Center, Guangdong Entry-Exit Inspection and Quarantine Technology Center, Guangzhou 510623, China

*Corresponding author e-mail: kxf_1985@163.com

Abstract. In this paper, by testing welding joints of their metallography and hardness, we analyze the metal structure. And then, the microstructure characteristics, macro and micro fracture morphology of underwater welding joint were investigated by means of metallographical examination and SEM. The fracture failure of the underwater welding joint is discussed here. The cracks are the major factors to fracture failure. The cracks spread along with the crack of the welding line, and this expand process generates dimple. The crack continues to expand under the action of tensile and the fracture fails eventually.

1. Introduction

In recent years, with the development of marine resource exploitation and utilization, ocean industry driven by science and technology develops rapidly. Most ocean engineering structures have main components submerged in seawater, so that the research on underwater welding is crucial for the marine resource exploitation [1]. Compare with land welding, there are more pores and slag in underwater welding, while the heat affected zone (HAZ) in underwater welding is smaller. Some hardened structures like martensite are more likely to occur in welded line and the HAZ because of the quick cooling down underwater, which leads to a loss of toughness [2]. Besides, welded lines with high hydrogen content are more vulnerable hydrogen cracking. In addition, the underwater welding joint has such defects as pores and cracks, which badly affects the tensile, bending and other performances of the welded joints [3, 4]. Research on the welding joint cracks and fracture failure has been an important subject at present, which presents the theoretical support to optimize the welding rod material to obtain superior underwater welding joint. Several mechanisms for the welding joint fracture have been proposed, but none has provided a convincing explanation for the underwater welding joint's peculiarities [5, 6]. In this paper, by testing welding joints of their metallography and hardness, we analyze the metal structure. And then, the microstructure characteristics, macro and micro fracture morphology of underwater welding joint were investigated by means of metallographical examination and SEM. The fracture failure of the underwater welding joint is discussed here.



2. Experiments Material and Method

2.1. Preparation of underwater welding joint

The experiment chooses E40 steel plate as base metal, which the physical features and components of the E40 steel plate are shown in Table1, while using 359S dedicated underwater welding rods made by Institute of Oceanographic Instrumentation, Shandong Academy of Sciences. The E40 is low alloy steel, which has fine and uniform microscopic structure (Fig. 1), and there is a small amount of carbide particles precipitated out with the main precipitated phase of tin, Nb and etc, see the chemical composition in table 2-1. This E40 low alloy steel for experiment has excellent mechanical property to satisfy the performance requirement of the classification society. The experiment is carried out 3 meters under seawater at the Qingdao offshore. The welding current is 200A, and welding voltage is 30-35V

Table 1. Physical properties and Chemical composition (wt.%) of E40 Steel

Steel Type	Yield Point (σ_s , N/mm ²)	Tensile Strength (σ_b , N/mm ²)	Elongation (δ)	C %	Mn %	Si %	S %	P %
E40	390	≥ 510 -660	20	≤ 0.18	0.9-1.6	≤ 0.5	≤ 0.035	≤ 0.035

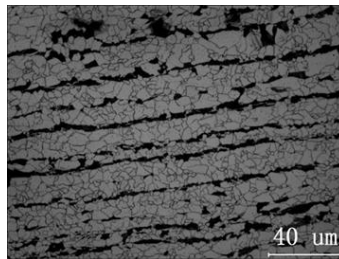


Figure 1. Metallographic structure of E40 (500×)

2.2. Experiment Method

To observe the structure faults of cracks and pores of the underwater welding joint through the metallographic test. Use the RAL microhardness tester to test the Vickers hardness of the joint line. Weld joint fracture specimen is obtained through tensile test. The fracture mode is verified by using scanning electron microscope to observe the fracture point of the welding sample under tension force, and to provide data support for researching the welding joint fracture mechanism.

3. The Experiment Result and Analysis

3.1. The Structure and Hardness of Welding Joint

Fig.2 shows the change of metallographic structure and Vickers hardness near the fusion line. First figure show austenite weld (a), complete quenching zone martensite (b), Incomplete quenching zone martensite (c), tempered zone (d), and base metal ferrite and pearlite (e) from left to right. To verify the structures of areas, the Vickers hardness test is performed (Fig.2-2). In the pic, points 1-3 are the hardness of the base material, points 4-6 are the hardness of HAZ, and points 7-10 are the hardness of welding metal. The result is confirmed that the hardness of the heat affected area structure changes much more than that of welding line. The hardness of martensite is much higher than that of austenite, which is consistent with the previous analysis results of the joint [2].

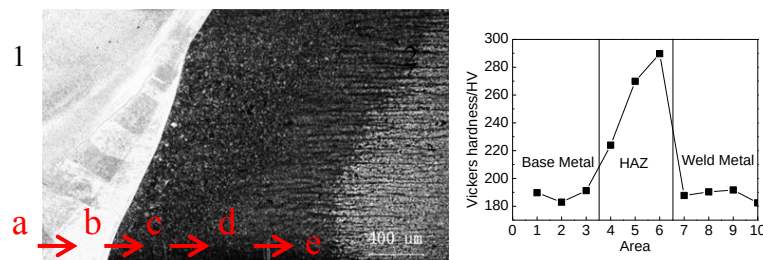


Figure 2. Metallographic structure (50×) and Vickers hardness near the fusion line

3.2. Crack and Pores of Welding Joint

According to the Fig.3, there are some pores in the welding line, which is generated in the underwater environment when welding, and the pores are cut by mechanic processing and from the bubble holes on the surface as the Fig.3 showing. The holes are smooth on the surface and glossy, which indicating that gas is gathering in the process of the pores form. The welding area is surrounding by the sea water, and the water generated a lot of hydrogen gas in high temperature, and the hydrogen gas dissolves into the metal within the welding area. When the metal solidifies, the welding line solidified rapidly due to the extremely cold temperature, and the speed of hydrogen gas gathering and floating is lower than the metal solidification speed, so as to constitute the different sizes of pores. It could be struck out that the pores are mainly found at the edge of the welding line, especially around the welding line [2].

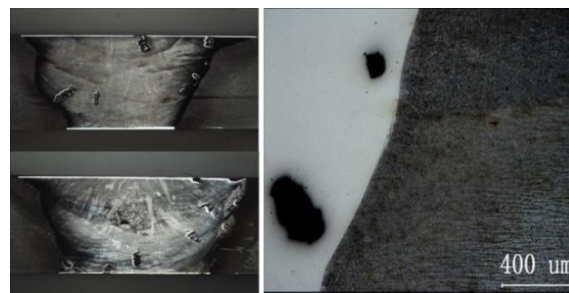


Figure 3. Pores of welding joint

3.3. The fracture point and fracture section of the welding joint sample

Fig. 4 shows two kinds of fractures on the welding joint, crack at the welding metal (a) and crack from the welding line(b). As the load increases, the crack spreads to the weld line till the joint broke down. A lot of cracks are found on the surface of the welding sample, which are generated by extension of the surface bubble holes under tension.

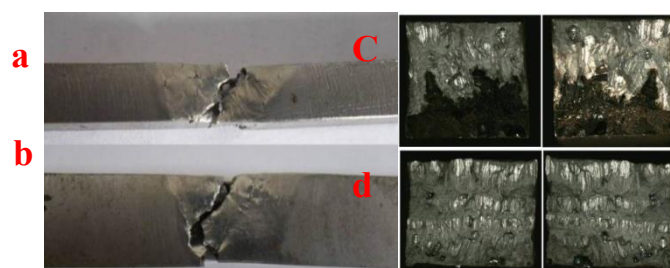


Figure 4. Crack morphology of welding joint

Many bubble holes are found exist at the fracture point with the low-magnification microscope. Numerous small bumps on the surface of the fracture points are formed from the bubble holes tension (Fig 4 a and b), and these bubble shells are not broken. The fracture point is spread out of the bubble

holes, which indicated that the bubble holes are not the cause of the fracture. Fig 4(c) sample has different structural colors at the fracture point, and the dark grey color structure found in the tension experiment is the beginning of the fracture of the welding area. Fig 4(d) sample has the same color as its fracture point, but there is no grey layer [3].

3.4. The morphology analysis of the welding joint fracture point.

To confirm the fracture form, the electron scanning microscope is used to observe the microtopography of the fracture point, so as to verify the form of the fracture.

3.4.1. Dimple Morphology Fig.5a shows that the macroscopic shape of the fracture is fibrous, the color is gray, and the edge is under a shearing lip with a plastic deformation and a slip line. From Fig. 5b, it can be seen that there are a large number of honeycomb morphologies in the broken gap, which are composed of concave pits formed by many plastic deformations forming pores, these pits are dimple, and the bottom of the dimple contains the second phase particles or inclusions (Fig.5c). The fracture form is plastic fracture. Plastic fracture occurs after a large number of plastic deformations, the structure fracture in the direction of stress will leave a larger residual deformation, there are naked eye visible deflections, thickened, necking etc. in the vicinity of the fracture gap Plastic deformation often makes container diameter increased and shell thickness reduced. Because of the formation, growth and aggregation of microscopic cavities, the saw tooth-shaped fibrous fracture is definitely formed. The majority of this type of fracture is the wear-crystal fracture, so the fracture gap is not flashing metallic luster but dark gray. Because plastic fracture is slipping first and then fracture, the fracture mode cut off in the larger sense and the fracture is uneven [2, 4].

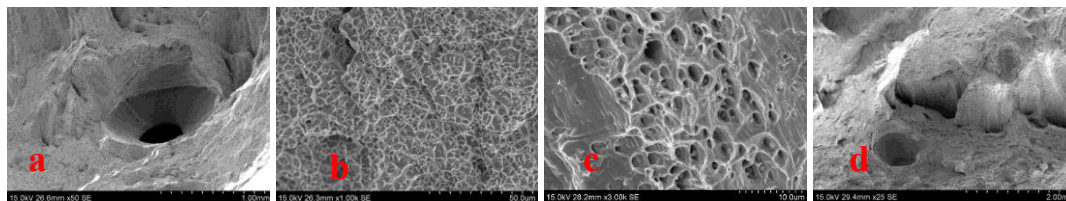


Figure 5. SEM of dimple cleavage

The edge has a shearing lip with 45° angle in the direction of main stress in which the dimple is formed. Fig. 5d shows the shape of the plastic fracture step, in the process of stretching, the plastic fracture is produced in many directions along with the crack propagation in each direction, and when the vertical cracks are intersected, the crack is combined and the step is formed in this place. The crack will continue to expand along the direction perpendicular to the tensile, and the intersecting crack can produce the step again until it breaks.

3.4.2. Lamellar Tearing Fig. 6 shows that the fracture is flat, the crack platform area is flat, the boundary is clear, the plastic deformation is almost few, it is a kind of cleavage plane formed by the sheet inclusions and the matrix under tensile stress, and the platform is separated by ridge tearing. There are low melting point non-metallic sundries such as sulfide, oxide and silicate existed in rolled steel plates, especially the role of sulfide, in the rolling process was extended in a flake, distributed in parallel with the surface of each layer, in the perpendicular to the thickness of the direction of the welding stress, the sundries first crack and expand, In the future, this kind of cracking occurs successively between the layers and forming a layer tearing. The morphology of the image is mainly because there is layered tearing crack in the connection, when the tensile test is done on the specimen, the layered tearing crack expands under the action of tensile force and the shape of Fig. 6b is formed in the process of expansion with plastic fracture [5, 6].

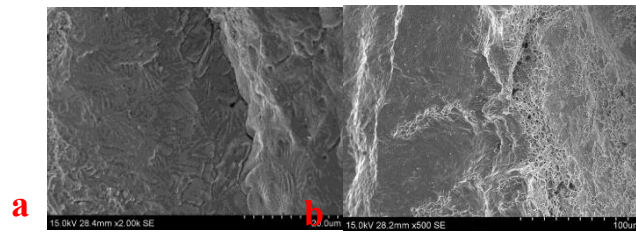


Figure 6. SEM of lamellar tearing

3.4.3. *Fracture Inclusions* The small particles are the impurities in the weld(Fig. 7), it is the residue of the welding or the metal-oxygen complex by energy spectrum test.

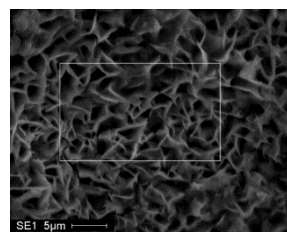


Figure 7. Fracture Inclusions **Figure 8.** Fracture grey fault zones

3.4.4. *Fracture grey fault zones* the substance in Fig.8 is a pine needle shape which is determined by composition analysis as a mixture of iron oxides and carbides. Energy spectrum test shows that the oxygen content is very high in the fracture grey fault zones.

3.5. Analysis on crack of welded joint

Through the observation and analysis fracture of underwater welding specimen, the main form of fracture is plastic fracture and the existence of layered tearing can be found in some areas. The source of the fracture is the crystallization crack on the fusion line. In the tensile test, although the crack has expansion trend under the tensile force in the initial tension increasing, because the tension does not reach the crack instability expansion of the critical tension, then the joint will have plastic deformation under the tensile effect, the joints will produce plastic shrinkage. With increasing of the tensile force, the crack instability expands when the critical tensile strength of the crack is reached. At first, the crack expands along the fusion line because there are more cracks in the fusion zone and the crack growth consumes less energy. But with the growth of crack, the crack in the weld seam decreases and the crack growth energy increases. Since the weld strength of austenitic organization is lower than that of completely quenching martensite strength, plastic deformation is larger under tension, and a certain amount of crystallization crack formed in high temperature and spread under tension force. The cracks within the welding area meet with them and combined together, and the cracks spread along with the crack of the welding line, and this expansion process generates dimple. The crack continues to expand under the action of tensile and the fracture fails eventually [6,7].

4. Conclusion

The primary results obtained from the research provide some clues for the study on the mechanism of fracture failure on the underwater welding joint. The main results obtained were as following:

- (1) The structure of welding metal is austenite and HAZ is mainly composed of martensite, while base metal is composed of ferrite and pearlite the hardness of the HAZ structure changes much more than that of the welding line.
- (2) The cracks are the major factors to fracture failure. The cracks spread along with the crack of the welding line, and this expand process generates dimple. The crack continues to expand under the action of tensile and the fracture fails eventually.

Acknowledgments

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References

- [1] Omajene J E, Martikainen J, Kah P, et al. Fundamental difficulties associated with underwater wet welding[J]. Journal of Engineering Research and Applications, 2014, 4(6): 26-31.
- [2] Guo N, Yang Z, Wang M, et al. Microstructure and Mechanical Properties of an Underwater Wet Welded Dissimilar Ferritic/Austenitic Steel Joint[J]. Strength of Materials, 2015, 47(1):12-18.
- [3] Kong X, Li C, Zou Y, et al. Measurement and analysis of the diffusible hydrogen in underwater wet welding joint[C]//MATEC Web of Conferences. EDP Sciences, 2016, 39.
- [4] Guo N, Xu C, Guo W, et al. Characterization of spatter in underwater wet welding by X-ray transmission method[J]. Materials & Design, 2015, 85: 156-161.
- [5] Li H L, Liu D, Song Y Y, et al. Microstructure and mechanical properties of underwater wet welded high-carbon-equivalent steel Q460 using austenitic consumables[J]. Journal of Materials Processing Technology, 2017, 249:149-157.
- [6] Gao W, Wang D, Cheng F, et al. Enhancement of the fatigue strength of underwater wet welds by grinding and ultrasonic impact treatment[J]. Journal of Materials Processing Technology, 2015, 223: 305-312.
- [7] Li H L, Liu D, Yan Y T, et al. Microstructural characteristics and mechanical properties of underwater wet flux-cored wire welded 316L stainless steel joints[J]. Journal of Materials Processing Technology, 2016, 238: 423-430.