International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048
Volume 8, Issue 5, pp 99-103, May-2024
https://doi.org/10.47001/IRJIET/2024.805015

Underwater Friction Welding of Low Carbon Steel

[1]*Rusnaldy, [2]R. R. Priambadha, [3]Paryanto, [4]S. A. Widyanto

[1,2,3,4]Department of Mechanical Engineering, Diponegoro University, Jl. Prof Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia
*Corresponding Author's E-mail: rusnaldy@lecturer.undip.ac.id

***Abstract* - In this study, an attempt was made to obtain a welded joint from the underwater friction welding (UFW) process. The workpiece material used in this experiment was AISI 1018 low carbon steel. The experiment was carried out on a friction welding machine which was designed and manufactured for this purpose. The UFW process was carried out by varying the spindle rotation used to rotate one of the workpieces. The friction force was kept constant. The quality of the welded joints resulting from UFW was determined by measuring the misalignment that occurs in the weld joint, the macro and micro structures formed, as well as the mechanical properties of the welded joint. For comparison, friction welding in air (FW) was also carried out. The results obtained indicate that low spindle rotation results in high misalignment of the welded joint between the two workpieces. During the UFW process, rapid cooling occurs so that the microstructure of the weld metal, TMAZ and HAZ is dominated by a fine pearlite phase so that the hardness and strength of the weld joint are higher than those produced by FW process in air.**

Keywords: Underwater Friction Welding, Low Carbon Steel, rapid cooling, Quality of Welded Joints, Misalignment, Hardness and Tensile Strength.

I. INTRODUCTION

Underwater wet welding (UWW) is a welding technology where the metal joining process is carried out in water. The UWW process is used for the construction of offshore oil platforms, construction of mining for gas and other minerals on the seabed, ship repair, underwater pipeline installation, structural repairs in ports and bridges and many other maritime applications. Various types of welding processes that have been successfully carried out underwater are Shielded Metal Arc Welding (SMAW), Flux-cored Arc Welding (FCAW), Gas Tungsten Arc Welding (GTAW) and Friction Stir Welding [1]. In the shielded metal arc welding (SMAW) process, the arc and the heat that occurs will be in direct contact with water. There are many obstacles that must be overcome when doing underwater welding, such as high cooling rate, porosity in the weld metal, instability in the welding arc, welding defects and decreased corrosion resistance of the weld metal.

The cooling rate in the UWW process can reach 2-3 times greater than that of air welding [2]. This very high cooling rate causes high hardness in the HAZ area, porosity in the weld metal, slag inclusion, cold cracking, changes in mechanical properties and changes in the microstructure of the weld metal to marten site which will reduce the fatigue resistance of the joint [3 – 7]. The effect of rapid cooling on welded joints can be reduced, one of which is by increasing the heat input through the use of high welding speeds [2].

Porosity in the weld metal can occur when hydrogen gas is trapped in the molten metal during the welding process. Hydrogen gas around the welding arc arises due to the dissociation process of water due to heat in the welding arc [8]. During the welding process, hydrogen gas enters the molten metal and because of the high cooling rate in water, the gas does not have time to escape. The presence of porosity in the weld metal can make the weld metal brittle and cracks arise which can cause failure of the welded joint [6,9]. Porosity can also cause the tensile strength and fatigue of the weld metal to be welded under water is lower than that of welding in an ordinary atmosphere [10]. The porosity of the weld metal resulting from the UWW process can be reduced by performing multipass welding [11].

During the underwater wet welding process, water in direct contact with the welding arc causes instability in the welding arc [12]. The instability of the welding arc is caused by the hydrostatic pressure of water which varies according to the depth of the water [10]. An unstable arc causes the fusion process to be disrupted so that the quality of the weld metal becomes poor

Underwater welding process also affects the corrosion resistance of the welded joint. The corrosion resistance of welded joints is affected by the magnitude of the given heat input. Wang et al conducted a study to determine the effect of heat input on the corrosion resistance of E40 steel welded joints using underwater welding [13]. The results obtained indicate that the greater the heat input, the better the corrosion resistance. Research conducted by Sun et al also showed that the local corrosion resistance of welded joints carried out under water also increased with increasing heat input [14].

Underwater wet welding has also been carried out for solid state welding processes, such as the friction stir welding process, especially for joining aluminum alloys [15-18]. Underwater friction stir welding (UFSW) process is a welding process that has many benefits such as low production costs, high flexibility and does not require a highly skilled operator [19]. The UFSW process can also increase the strength and hardness of the welded joint [15-17, 20-22]. The increase in the strength of the UFSW welded joint is due to the cooling process that occurs very quickly so that the grain coarsening does not occur and the weld joint has fine grains. Dissolution of the precipitate also does not occur [23]. The heat that occurs due to friction can be absorbed by the water around the weld metal joint and affects the thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) so that in these areas there is no coarsening of the existing precipitate [23]. That is why the TMAZ and HAZ areas have high hardness values [15]. Water around the weld joint can also reduce heat input which causes fine microstructure in the weld metal area [24].

Meanwhile, to the best of our knowledge, not many research results have been reported for underwater friction welding processes. One of the research results ever published (in Japanese) is the result of a study by Sakurada et al in 2002 [25]. Information from the abstract of the paper states that the temperature that occurs in the UFW process is lower than the FW temperature in an ordinary atmospheric environment so that the area where the hardness value decreases at the weld joint is reduced and the resulting elongation is low.

There are still many technological barriers that must be overcome so that the UFW process can produce good quality welds. Considering that the application of the UFW process has good potential, such as for underwater construction and in the maritime sector, the UFW process is feasible to try.

II. EXPERIMENTAL SETUP

AISI 1018 low carbon steel was used in this experiment. For each UFW experiment, a pair of workpieces were made where each workpiece was cylindrical with a diameter of 15 mm and a length of 150 mm. Friction Welding experiments were carried out on a friction welding machine that has been designed and manufactured for this purpose (see Figure 1a). For the UFW experiment, a chamber that will be filled with water was made with dimensions of 160 mm x 110 mm x 170 mm. The first workpiece was gripped on a rotating chuck and the second workpiece was gripped on a stationary chuck. The friction pressure applied through the second workpiece was 3.5 MPa. Spindle rotations to rotate the first workpiece were400 rpm, 629 rpm and 864 rpm. The friction time used for the UFW process was 4 seconds. The UFW experiment process can be seen in Figure 1b.

Visual inspection and dimension measurement of welded joints were carried out to see the quality of the joints. The shape of the flash produced was visually observed and the alignment of the welded joints of two workpieces with the UFW process was also carried out. The macrostructure and microstructure of the areas at the weld joint were observed using a metallurgical optical microscope. Hardness testing and tensile testing were also carried out to see the mechanical properties of the resulting welded joints. As a comparison, friction welding experiments in air (FW) were also carried out.

III. RESULTS AND DISCUSSIONS

Table 1 shows the results of misalignment measurements of welded joints formed in the friction welding process, both in air and under water. Misalignment measurements were carried out and the alignment that occurs should not be greater than 1.5 mm. Alignment that occurs in the friction welding process at 400 and 629 rpm are all greater than 1.5 mm (see Figure 2a) , while at higher spindle rotations, i.e. 864 rpm, the alignments are 0.61 and 0.84 mm (see Figure 2b). This shows that the welded joint quality is influenced by friction rotation, where the higher the friction rotation, the lower the misalignment that occurs.

(a)

(b)

Figure 1: (a) Friction Welding Machine; (b) Chamber for UFS Experiments

Table 1: Misalignment

Exp. No.	Spindle Rotation (rpm)	Welding	Misalignment (mm)
1	864	Friction Welding	0,61
2	864	Underwater Friction Welding	0,84
3	629	Friction Welding	1,87
6	629	Underwater Friction Welding	2,00
7	400	Underwater Friction Welding	2,30

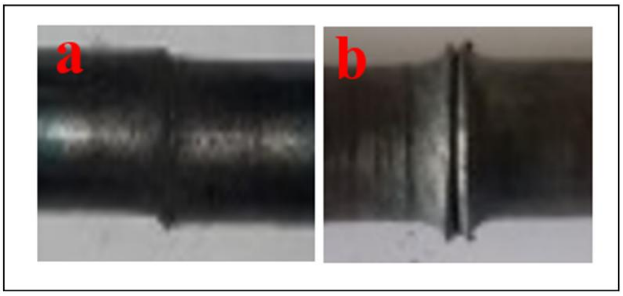
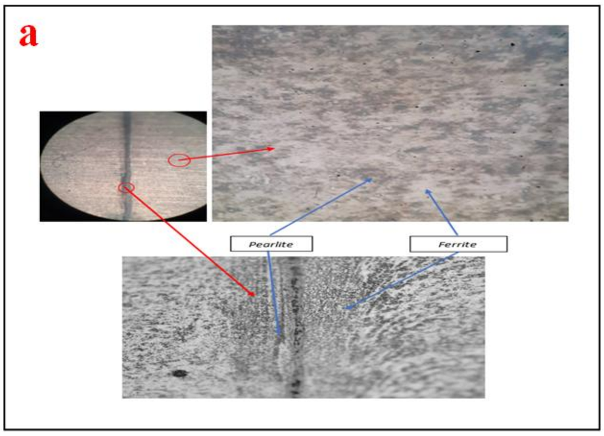


Figure 2: Misalignment of Welded Joints

Figure 3 shows the macro structures and micro structures of the welded joints resulting from the UFW (3a) and FW (3b) processes at a spindle rotation of 864 rpm. From the figure it can be seen that the welded joint on the UFW is well formed, while the welded joint on the FW is not well formed. It can be seen that there are voids in the FW weld joint. Meanwhile, the microstructure of the UFW welded joint shows elongated grains, which indicates plastic deformation of the grains due to large friction forces. The pearlite phase with a fine size is visible in the HAZ area which indicates a rapid heat treatment cycle of heating and cooling due to the weld joint being in direct contact with water during the UFW process. The large heat input and rapid cooling are thought to be the cause of the formation of more fine pearlite phases and the absence of grain coarsening.



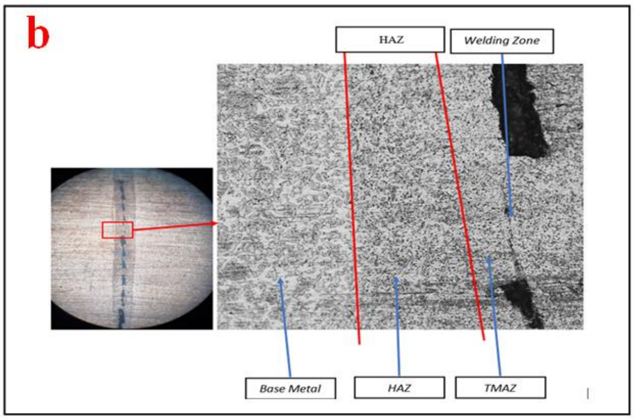


Figure 3: Macrostructures and Microstructures of Welded Joints, (a) UFW; (b) FW

Figure 4 shows the results of tensile testing of welded joints using the UFW and FW processes. The tensile test results show that the strengths of the welded joints from UFW and FW are much smaller than the tensile strength of the base metal. The tensile strength of the UFW welded joint is 230 MPa and the tensile strength of the FW welded joint is 140 MPa, while the tensile strength of the base metal is 404 MPA. This much lower tensile strength is due to the welding joint being formed imperfectly. This can be seen on the fracture surface of the tensile specimen after the tensile testing process (see Figure 5). From the fracture surface on the workpiece, it is clear that a perfect weld joint was not formed. This is due to the lack of friction pressure and spindle rotation so that the friction that occurs does not result in a good welded joint due to the limitations of the machine used. In the future, adequate friction welding machines need to be designed and manufactured, especially to obtain better quality of UFW process welded joints.

The distribution of hardness in the welded joint can be seen in Figure 6. The hardness value produced in the welded joint in the UFW process is higher than the hardness value produced in the FW process. This is in line with the resulting microstructure, where the microstructure of the UFW welded joint has a large amount of fine pearlite phase compared to the microstructure of the FW welded joint.

IV. CONCLUSION

The Underwater Friction Welding (UFW) experiment has been carried out well. From the results of misalignment measurements, friction welding carried out at low spindle rotation produces large misalignments. From the tensile test results, it can be seen that the workpiece breaks at the welded joint with a lower tensile strength than the strength of the base metal. From observing the fracture surface, it can be seen that the welded joint is not fully formed so the strength is low.

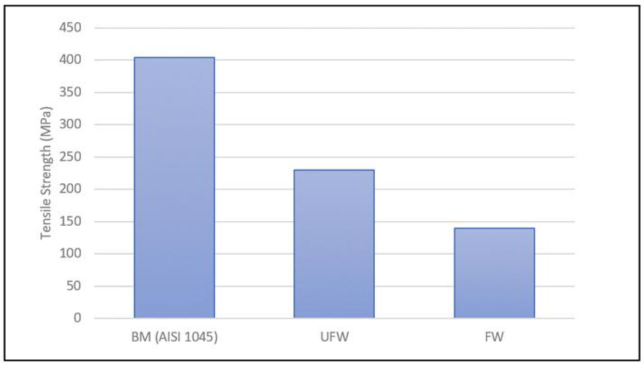


Figure 4: Tensile Test Results

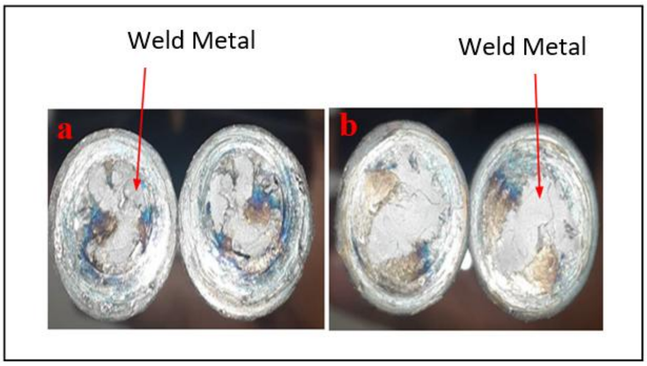


Figure 5: The Fracture Surfaces of weld joints, (a) UFW; (b) FW

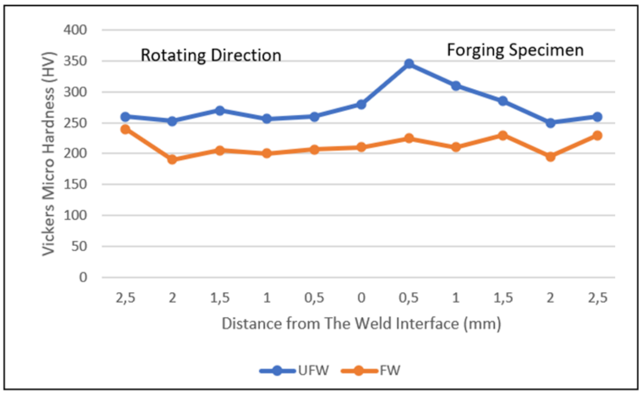


Figure 6: Vickers Hardness Distribution of Welded Joints

Meanwhile, from observing the microstructure, it can be seen that the weld metal resulting from UFW has more pearlite phases with a finer size than the microstructure resulting from the FW process. This can explain why the tensile strength and hardness of the workpiece produced by UFW are higher than FW.

REFERENCES

[1] E. Surojo, E.D.W.S. Putri, E.P. Budiana, “Recent development on underwater welding of metallic material”, Procedia Structural Integrity, 27, pp. 14-21, 2020.

[2] P. Vashishtha, R. Wattal, S. Pandey, N. Bhadauria, “Problems encountered in underwater welding and remedies- a review”, Materials Today: Proceeding, 64, pp. 1433-1439, 2022.

[3] J. Klett, V. Hecht, O. Grunzel, E. Schmidt, H.J. Maier, T. Hassel, “Effect of the water depth on the hydrogen content in SMAW wet welded joints”, SN Applied Science, 2 (7), pp. 1-14, 2020.

[4] J. Tomków, G. Rogalski, D. Fydrych, J. Łabanowski, “Improvement of S355G10+N steel weld ability in water environment by Temper Bead Welding”, Journal of Materials Processing Technology, 262, pp. 372–381, 2018.

[5] G. Terán, R. Cuamatzi-Meléndez, A. Albiter, C. Maldonado, A.Q.Bracarense, “Characterization of the mechanical properties and structural integrity of T-welded connections repaired by grinding and wet welding” Materials Science & Engineering A, 599, pp. 05–115, 2014.

[6] H. Chen, N. Guo, X. Zhang, L. Zhou, G. Wang, “Effect of water flow on the microstructure, mechanical performance, and cracking susceptibility of underwater wet welded Q235 and E40 steel”, Journal of Materials Processing Technology, 277, pp. 103-115, 2020.

[7] Y. Zhang, C. Jia, B. Zhao, J. Hu, C. Wu, “Heat input and metal transfer influences on the weld geometry and microstructure during underwater wet FCAW”, Journal of Materials Processing Technology, 238, pp. 373–382, 2016.

[8] D. Fydrych, J. Łabanowski, “An experimental study of high-hydrogen welding processes”, REVISTA DE METALURGIA, 51, 4, pp. 51-55, 2015.

[9] A.Swierczynska, D. Fydrych, G. Rogalski, “Diffusible hydrogen management in underwater wet self-shielded flux cored arc welding”, International Journal of Hydrogen Energy, 42, pp. 24532–24540, 2017.

[10] N. Muhayat, Y.A. Matien, H. Sukanto, Y.C.N. Saputro, Triyono, “Fatigue life of underwater wet welded low carbon steel SS400”, Heliyon, 6, e03366, 2020.

[11] R. Wattal, S. Pandey, N. Bhadauria, “Problems encountered in underwater welding and remedies- a review”, Materials Today: Proceedings, 64, pp. 1433-1439, 2022.

[12] X. Di, S. Ji, F. Cheng, D. Wang, J. Cao, “Effect of cooling rate on microstructure, inclusions and mechanical properties of weld metal in simulated local dry underwater welding”, Materials &Design, 88, pp. 505–513, 2015.

[13] J. Wang, J. Ma, Y. Liu, T. Zhang, S.Wu, and Q. Sun, “Influence of Heat Input on Microstructure and Corrosion Resistance of Underwater Wet-Welded E40

Steel Joints", Journal of Materials Engineering and Performance, Vol. 29(11), 6987–6996, 2020.

[14] K. Suna, M. Zenga, Y. Shia, Y. Hua, X. Shen, "Microstructure and corrosion behavior of S32101 stainless steel underwater dry and wet welded joints", Journal of Materials Processing Technology, 256, pp. 190–201, 2018.

[15] H.J. Liu, H.J. Zhang, Y.X. Huang, L. Yu, "Mechanical properties of underwater friction stir welded 2219 aluminum alloy", Trans. Nonferrous Met. Soc. China, 20, pp. 1387−1391, 2010.

[16] J. Zhang, Y. Shen, X. Yao, H. Xu, B. Li, "Investigation on dissimilar underwater friction stir lap welding of 6061-T6 aluminum alloy to pure copper", Materials and Design, 64, pp. 74–80, 2014.

[17] H.J. Liu, H.J. Zhang, L. Yu, "Homogeneity of Mechanical Properties of Underwater Friction Stir Welded 2219-T6 Aluminum Alloy", Journal of Materials Engineering and Performance, Vol. 20(8), pp. 1419-1422, 2011.

[18] Y. Zhang, C. Jia, B. Zhao, J. Hu, C. Wu, "Heat input and metal transfer influences on the weld geometry and microstructure during underwater wet FCAW". Journal of Materials Processing Technology, 238, pp. 373–382, 2016.

[19] H.A. Derazkola, F. Khodabakhshi, "Underwater submerged dissimilar friction-stir welding of AA5083 aluminum alloy and A441 AISI steel", International Journal of Advanced Manufacturing Technology, 102(9), pp. 4383–4395, 2019.

[20] H.J. Liu, H.J. Zhang, L. Yu, "Effect of welding speed on microstructures and mechanical properties of underwater friction stir welded 2219 aluminum alloy", Materials and Design, 32, pp. 1548–1553, 2011.

[21] M.A. Wahid, Z.A. Khan, A.N. Siddiquee, "Review on underwater friction stir welding: A variant of friction stir welding with great potential of improving joint properties", Trans. Nonferrous Met. Soc. China, 28, pp. 193−219, 2018.

[22] R. SaravanaKumar, T. Rajasekaran, "Optimizing the underwater friction stir welding parameters to enhance the joint strength of armour grade aluminium alloy AA5083 butt joints", Materials Today: Proceedings, 47, pp. 6999–7005, 2021.

[23] H.J. Zhang, H.J. Liu, L. Yu, "Microstructure and mechanical properties as a function of rotation speed in underwater friction stir welded aluminum alloy joints", Materials & Design, 32, pp. 4402−4407, 2011.

[24] F. Heirani, A. Abbasi, M. Ardestani, "Effects of processing parameters on microstructure and mechanical behaviors of underwater friction stir welding of Al5083 alloy", Journal of Manufacturing Process, 25, pp. 77–84. 2017.

[25] D. Sakurada, K. Katoh, H. Tokisue, "Underwater friction welding of 6061 aluminum alloy", Journal of Japan Institute of Light Metals, Vol. 52, No. 2, pp. 2-6, 2002.

Citation of this Article:

Rusnaldy, R. R. Priambadha, Paryanto, S. A. Widyanto, "Underwater Friction Welding of Low Carbon Steel", Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 8, Issue 5, pp 99-103, May 2024. Article DOI https://doi.org/10.47001/IRJIET/2024.805015

****