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"A SYSTEMATIC REVIEW ON STRENGTH OF UNDERWATER WELDS PERFORMED THROUGH DIFFERENT WELDING METHODS"

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ABSTRACT

The basics of underwater welding are discussed in the article, along with current trends in research being done to further welding technology and the characteristics of underwater welds. Examining weld characteristics and underwater welding technologies are two of the investigations. All experiments were conducted using specially made supports that allowed welding to be done at both shallow depths and depths of up to 1000 meters. The primary inquiry lines carried out are described, including: The impact of wet welding circumstances on diffusible hydrogen quantity in the welds; The weld ability of HSLA steel and variables influencing susceptibility to cold cracking of welded joints. The impact of heat input, underwater welding depths, and shielding gas composition on the durability of welds.

Key Words: *Underwater welding, wet welding, dry welding, local cavity, weldability of steel.*

I. INTRODUCTION

Wet shielded metal arc welding and gas metal arc welding using the local cavity approach are the major research areas of the Underwater Welding Laboratory [1, 2]. Additional study is carried out using underwater cutting techniques [2, 3]. Welding activities must be carried out in a marine environment when it is not possible to dock a metal structure [2,4,5,6,7]. The following categories [2, 4, 8] can be used to group underwater welding methods: wet welding, dry welding, and local cavity welding. In the current work, an overview of contemporary underwater welding procedures is offered. Particular focus is given to local and wet cavity welding.

II. UNDERWATER WELDING TECHNIQUES

The classification of underwater welding techniques is presented in Fig. 1. There is no mechanical separation between the water and the welding arc when wet welding is carried out at ambient pressure with the welder-diver submerged. Even the most geometrically complicated objects may be welded because to the procedure' simplicity [5,6,9,10].
Wet underwater welding commonly uses a variation of SMAW, employing a waterproof electrode. Other processes used include flux-cored arc welding and friction welding. In each of these cases, the welding power supply is connected to the welding equipment through cables and hoses.

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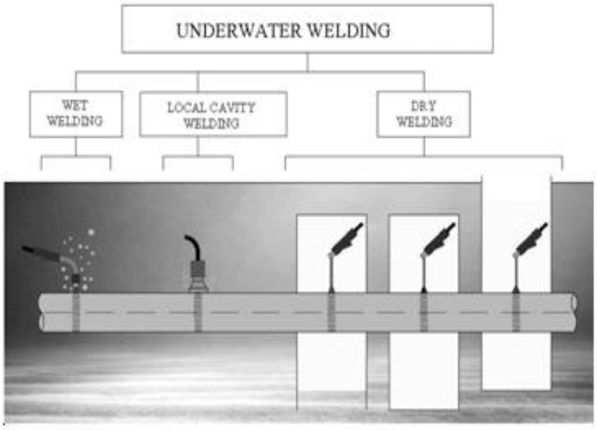

Fig. 1. Classification of underwater welding

Shielded metal arc welding (SMAW) and flux cored arc welding (FCAW), including self shielded flux cored arc welding, are the two wet welding methods most often utilized. The most affordable and adaptable way of operations in an underwater environment is wet welding with coated electrodes [5,6,9,10]. Direct welds using covered electrodes or FCAW may be made down to a depth of 100 meters [10]. Wet welding produces substantially greater cooling rates than dry welding does in a water environment. It may fluctuate from 415 to 56°C/s in the temperature range of 800 to 500°C [11]. This results in the heat affected zone (HAZ) and the weld metal losing their ductility. Porosity levels in underwater wet welds are likewise well-known to be high (Fig. 2). Molecular hydrogen, carbon monoxide, or water vapor can all create pores [12,13,14]. All wet welds have some amount of pores. The three primary variables influencing this phenomena are the water depth, electrode coverage, and arc stability [10,12,13,14].

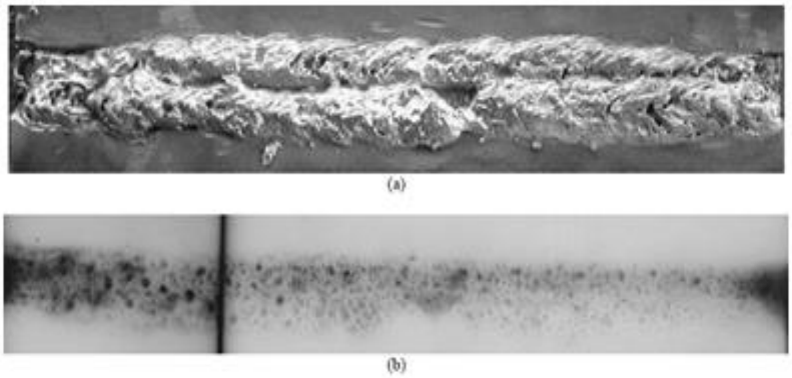

Fig. 2. V-groove wet weld deposited at 100 m depth (a) and its radiographic image (b) [15]

The quality of wet welds has increased during the past few years. Modern electrodes that are readily accessible on the open market and unique flux-cored wires guarantee high-quality welded junctions [6,16,17]. Utilizing normal gas metal arc welding (GMAW) equipment that is additionally instrumented with a specific outer nozzle and elastic cover, as illustrated in Fig. 3, makes it feasible to weld using the local cavity approach. The cooling conditions for the local cavity approach are almost identical to those experienced during air welding [20]. The quantity of hydrogen in weld metal is between 5 and 21 ml/100g Fe, according to the results of studies to determine diffusible hydrogen [18, 19]. It depends on welding conditions, particularly the flow rate of shielding gas. Properties of welds completed using a local dry chamber are much superior to those of wet welds and satisfy classification society standards for depths up to 200 m [21,22]. Figure 4 shows a view of some sample weld beads produced by local cavity welding. The method's biggest drawback is the inability to see the welding process. Application of a laser beam as a heat source may also be used to carry out local cavity processes [23].

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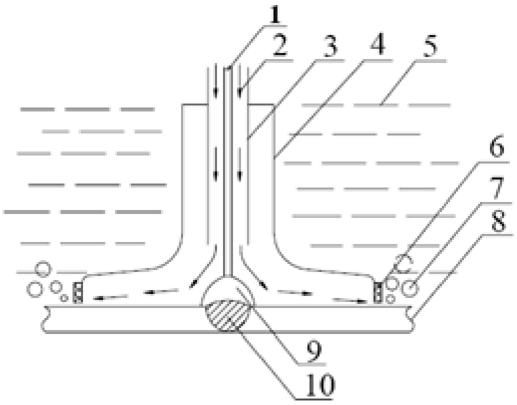

Fig. 3. Welding by local cavity method. 1 – welding nozzle, 2 – welding wire, 3 – shielding gas, 4 – outernozzle, 5 – water, 6 – elastic cover, 7 – gas bubbles, 8 – welded element, 9 – arc, 10 – weld

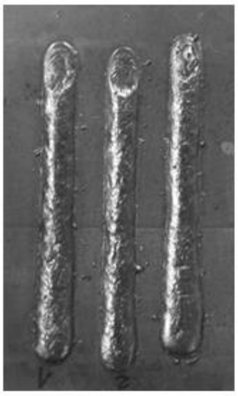

Fig. 4. Weld beads obtained by local cavity welding

In a chamber where water has been replaced with air or a gas combination, depending on depth, dry hyperbaric welding is done at atmospheric pressure. The quality of underwater dry welds is higher than that of wet welds, but significant support equipment is needed, and the associated expenses are quite expensive [4,7,24]. Dry welds frequently exhibit mechanical characteristics that are on par with those of comparable welds done above water. Dry welding repairs are expected to cost and take twice as long as wet welding repairs [5]. It is possible to employ practically all common welding techniques in dry environments. The most popular welding methods are SMAW, GMAW, FCAW, and tungsten inert gas (TIG) welding [4,7,25]. 300 m is the highest depth at which hand hyperbaric welding may be done.

III. Weldability of Stell in water Environment

Due to increased pressure, hydrogen concentration in the welded metal, and faster cooling rates, underwater welding is more challenging than welding done outside [2,4,8,11,26]. The presence of diffusible hydrogen and brittle microstructures in the welds might be grounds for crack development, and it has been demonstrated that increasing pressure renders welding arcs unstable [4,8,10].
Carbon steels, low alloy steels, austenitic steels, and duplex stainless steels are often joined by underwater welding [2,4,12]. Steel's propensity for cold or hot breaking influences its weldability in aqueous environments [28,29,27,30]. The fundamental issue in welding high strength low alloy steels (HSLA) and creating dissimilar connections is their susceptibility to cold cracking (Fig. 5). The majority of the time, completely austenitic stainless steel weld metal exhibits hot fractures (Fig. 6). This topic has been covered in a fair number of papers [4, 9, 18,27,28,31,13].

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Fig. 5. Microphotograph of the cold crack in the bainite structure of heat affected zone [18]

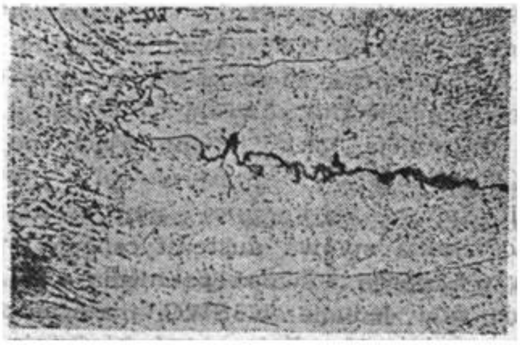

Fig. 6. Microphotograph of the hot crack in austenitic weld metal [30]

High strength steel weld joints that are completed in humid underwater circumstances are extremely prone to cold cracking (hydrogen cracking) [27,28,30]. Reduce the effects of three elements to prevent cracking: the quantity of diffusible hydrogen, the hard microstructures in the HAZ, and the high residual stresses in the weld joint [33,34,35]. Utilizing consumables that contribute less hydrogen to welds or choosing welding conditions that reduce hydrogen pickup in the weld pool are two ways to reduce the hydrogen concentration [19,36].
Unfavorable structural changes in HAZ can be prevented by limiting the rate of cooling of the welded joint and applying high heat inputs to the welded plate's surface [11,36]. Use of tiny weld deposits, consumables with base material-compatible coefficients of thermal expansion, and the use of edge preparations that minimize weld deposit are all welding techniques that reduce residual stresses in the joints.
Because high strength steel (yield strength exceeding 350 MPa) is needed at increasing depths, the steel's strength is a crucial component of deep-water constructions. The weldability of high strength steels is often poorer and they typically have carbon equivalents above 0.4%.

IV. Investigations Performed on Underwatwer Welds

Cold cracks can form in high strength steel welded joints, even though underwater welding using the local cavity approach assures cooling conditions that are substantially identical to those experienced when welding in the air [2,8]. Therefore, the goal of the study project was to determine the joints' sensitivity to cold cracking in underwater settings using the local cavity approach. For that reason, HSLA S355 (18G2A) steel and complementary filler materials were used for the GMAW process. There aren't many articles on this topic, and the conclusions reached by writers don't always agree [2,8,18,20]. Table 1 provides the material's chemical composition.

Table 1. Chemical composition of S355 (18G2A) steel, wt %

C	Mn	Si	Cr	Ni	Cu	Al
0.17	1.44	0.35	0.04	0.077	0.30	0.027

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At the underwater welding platform, test welds were created using the GMAW method and IS-10S wire (1.2 mm). Testing for susceptibility to cold cracking was done using implants. The following parameters were used to produce implant specimens: heat input eL=10–20 kJ/cm and shielding gas (CO_2) flow rate Wg=20–50 l/min [18]. A backing plate's borehole was filled with a cylindrical notched specimen of the test material, which was then joined to it by one bead of welding. On the "Implant 02" platform depicted in Fig. 8, the specimen was exposed to a static tensile force. It was noted when the fracture occurred. If the specimen hadn't already failed, the tensile force was kept in place for 16 hours [18].

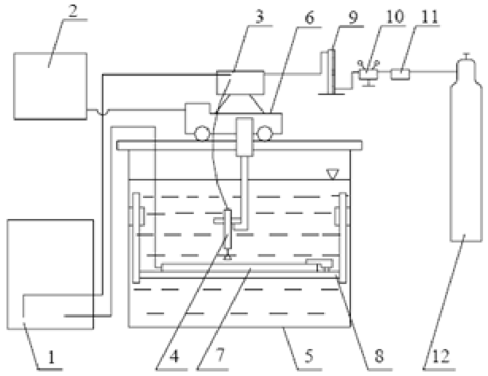

Fig. 7. Test stand for underwater welding
1 – power source, 2 – track feeder, 3 – engine, 4 – head, 5 – water container,6 – welding track, 7 – specimen, 8 – work piece holder, 9 – flow meter, 10 – reducer, 11 – preheater, 12 – gas cylinder

Fig. 8. Test stand "Implant 02" [37]

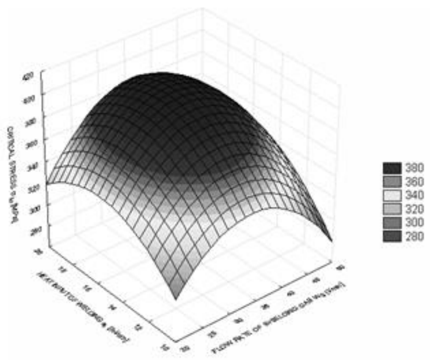

Fig. 9. Relationship between critical stress σ_{cr} and flow rate of shielding gas Wg and heat input e_L for underwater welds [18]

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Other studies used covered electrodes to measure the amount of diffusible hydrogen in the metal that had undergone wet underwater welding [36]. Utilizing the Plackett-Burman design process, the issue has been resolved. At the welding stand for low depths, test welds were carried out under a variety of welding conditions, including welding current, electrode painting, electrode polarity, thickness of flux covering the electrode core, salinity of the water, electrode contamination (carbohydrates), and electrode wetting time. The weld metal glycerin technique was employed to assess the diffusible hydrogen concentration [38]. Table 2 compiles the findings of various investigations. The range of hydrogen content was found to be between 45.90 and 87.40 ml/100g Fe.

Fig. 10. Specimens with test beads obtained by wet underwater welding conditions with the use of coveredelectrodes

The results of analysis performed in Statistica software show that the most relevant variables are: salinity of water, contamination of electrode, electrode polarity and welding current [36].

Table 2. Conditions and results of diffusible hydrogen measurements [36]

No	Welding current [A]	Thickness of covering [mm]	State of electrode	Painting	Salinity of water [‰]	Polarity	Time in water [min]	Average hydrogen amount H_D [ml/100 g Fe]
1	240	0.90	pure	yes	10	+	5	45.90
2	292	0.90	pure	no	0	+	0	70.46
3	240	1.35	pure	no	10	-	0	47.27
4	292	1.35	pure	yes	0	-	5	74.17
5	240	0.90	oil	yes	0	-	0	87.40
6	292	0.90	oil	no	10	-	5	71.11
7	240	1.35	oil	no	0	+	5	83.98
8	292	1.35	oil	yes	10	+	0	63.95
9	240	1.35	oil	no	0	+	5	79.48

The subsequent research attempted to measure the impact strength of joints produced underwater using the local cavity method on shielding gas and water depth. On a test stand designed for underwater welding at great depths, test welds were produced using the GMAW method and CO2 and Ar+CO2 shielding gases [39].

Fig. 13. Test facility for simulating underwater welding on high depths

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Samples were taken from test joints created under the following conditions: heat input ranging from 1.53 to 4.38 kJ/mm and water depth up to 200 m. At room temperature, Charpy V specimens were used to test impact strength. Figure 14 shows that the variation in impact strength values up to 60 meters of water depth is rather small, however for welding in mixed gas Ar+CO2, the impact strength decreases between 60 and 100 meters. According to the findings of these tests, it is advised to only utilize pure argon as a shielding gas when welding at depths lower than 60 m [39].

V. Conclusion

Modern underwater welding methods make it possible to create connections with strong welds that satisfy classification society standards. The usage of wet and dry hyperbaric welding for marine applications has expanded as a result of recent advancements in underwater welding. However, the widespread use of wet welding techniques is constrained by perceptions of the poor quality of the welds produced by this technique [2,4,8,10,11,24]. The American National Standards Institute and American Welding Society's standardized methodologies, processes, and certification criteria have helped enhance the widespread acceptability of underwater welding operations [40]. Despite several successful applications and study findings, further research and development are needed for underwater welding to reach its full potential.

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