Journal of Engineering Sciences and Information Technology
Volume (6), Issue (3) : 30 Jun 2022
P: 96 - 106
ISSN: 2522-3321
مجلة العلوم الهندسية وتكنولوجيا المعلومات
المجلد (6)، العدد (3) : 30 يونيو 2022م
ص: 96 - 106

Attenuating risks and difficulties in Welding pipelines and offshore structures using the underwater welding process - A Review

Aws Abbas Hussein
College of Energy & Environmental Sciences || Al-Karkh University of Science || Iraq
Fadhil K. Farhan
College of Science || Al-Karkh University of Science || Iraq

Abstract: Oil and gas pipelines, marine application, offshore structures are subjected to aggressive environment which causes corrosion and fatigue in some parts of them. Thus, they need to repair as soon as possible. Underwater welding is used for that purpose which is suitable for urgent repairs. Both types of underwater welding (wet and dry) suffer from many Risks and difficulties that affect the life of welder, on the other hand, reduce the mechanical properties of welds. In this article, the challenges associated with the underwater welding process and methods of treating them or minimizing their effects are reviewed.

Keywords: underwater welding, dry underwater welding, wet underwater welding

الحد من مخاطر وصعوبات عملية لحام الأنابيب والهياكل البحرية باستخدام عملية اللحام تحت الماء – مراجعة

أوس عباس حسين
كلية علوم الطاقة والبيئة || جامعة الكرخ للعلوم || العراق
فاضل كريم فرحان
كلية العلوم || جامعة الكرخ للعلوم || العراق

المستخلص: تَتَعرض خُطوط أنابيب اَلنِّفْط وَالْغاز اَلْمُمْتَدَّة تَحْتَ الماءِ بِالْإِضَافَةِ إلى الهياكِل اَلْبَحْرِيَّة وَالسُّفُن لِبيئةٍ عُدْوَانِيَّة تُسَبِّب تآكُل وإِجْهَاد أَجزاء مِنها مِمّا يَستَدعي عَمَلِيةَ إِصْلاحٍ سَرِيعَة وفَوريةٍ لِتَفادي تَسَرُّب اَلْمَوَادّ الكيميائية اَلْمُلَوَّثَة للبيئَة. يُستَخدمْ اَللّحَام تَحْت الْمَاءِ لِوَصْلِ الأجزاء اَلْمَعْدِنِيَّة عَنَّ طَرِيق صَهْر مَناطِق مُحَدَّدة للهياكِل وَرَبْطها عِنْدَ نُقْطَةِ اَلاِتِّصَال مِنْ أَجَّلَ إنشاء هيْكَلٍ جديدٍ أو إِصلاحِ هيكَلٍ قَدِيم. تَتَمَيز هذهِ اَلْعَمَلِيَّة بِأَنَّ هُنالِكَ اِتِّصَال مُباشِرٍ بَيْنَ عامِل اَللَّحَّام وَمَناطِق اللَّحامِ معَ الْمَاء. توجَدُ عِدَّةُ مَخَاطِر تُؤثِرُ عَلَى حَيّاةِ عامِل اللَّحامِ تَحْتَ الْمَاءِ مِثلَ اَلتَّعَرُّض للصعْقةِ اَلْكَهْرَبَائِيَّة وَالتَّخَدُّر بالنِّتْرُوجِين (نَشوَةُ اَلْأَعْمَاق) بِالْإِضَافَةِ إلى اختلاف ضَغْط الْمَاء. تنشأ التَّحدياتُ المُرافِقَةُ لهذِهِ اَلْعَمَلِيَّة من مُعَدلِ التَّبرِيدِ اَلسَّرِيع لِمِنْطَقَة اَللِّحَام بِالْإِضَافَةِ إلى اَلضَّغْط المُرتَفع تَحْت الْمَاء مِمَّا يُؤَدّي إلى تَكَون عُيوبِ مْيتالورجيّة فِي مِنْطَقَة اللّحَامِ تَضُر اَلْخَوَاصّ اَلْمِيكَانِيكِيَّة لِلوصلاتِ المَلحُومة. فِي هَذا المَقَال تَمَّ استعراض أهم اَلطُّرُق اَلْمُتَّبَعَة لِمُعالجة أو تَقليل مِنْ حِدَة المَخاطِر وَالصُّعُوبَات المُرافِقة لِعَملية اَللِّحَام تَحْت الْمَاء.

الكلمات المفتاحية: اللحام تحت الماء، اللحام تحت الماء الجاف، اللحام تحت الماء الرطب

1. Introduction.

Underwater welding is utilized to repair marine structures, submarines pipelines and ships. It was contrived in Russia in 1932 by Konstantin. K. Khrenov (Surojo, Putri, Budiana, & Triyono, 2020). Then, it was developed by the American Cyril D. Jensen, in World War II (cDiver, 2016). Generally, two main categories of underwater welding process have been practiced which are Wet and Hyperbaric (Dry) underwater welding. In Wet underwater welding, the direct contact of welder, work pies and water are occurred. The welding process may carry out using, e.g. shielded metal arc welding (SMAW) with waterproof electrode (figure 1 and 2). Also, flux-cored arc welding (FCAW) and friction welding can be used. In Wet underwater welding, welding process can be performed directly in water down to 100 meters (Majumdar, 2006) (Łabanowski, Fydrych, & Rogalski, 2008). Wet under water welding is characterized by be cheap, rapid, good tensile strength of welds, access to weld region is easy, no construction is needed, ductility of welds is low, increase material hardness in the heat-affected zone (HAZ) area, existence of defects in the weld pool, weld arc is not stable and the presence of water waves around the welding area. In dry underwater welding, the parts to be welded must be covered and sealed by a chamber filled with a gas mixture and the process performed at the prevailing pressure (figure 3, 4). This category of welding process can be used in a depth of 300-1000 m. dry underwater welding is characterized generally of high integrity and high cost (about twice that for wet welded repairs) (wikipedia, 2021) (Surojo, et al., 2021) (Sundarapandiyan, Balamurugan, & Mohan, 2017).

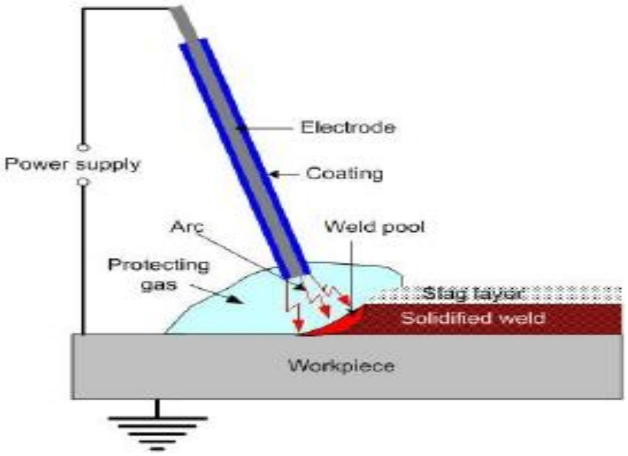

Figure (1) sheilding of the welding arc and molten pool with a coverd stick electrode (Sundarapandiyan, Balamurugan, & Mohan, 2017).

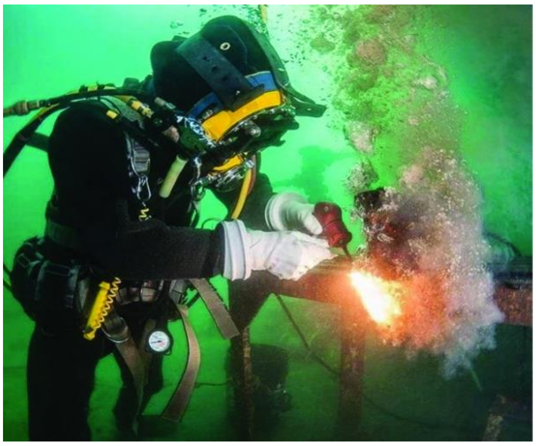

Figure (2) a diver performs wet welding process under the water (Alsayes,Y, 2020).

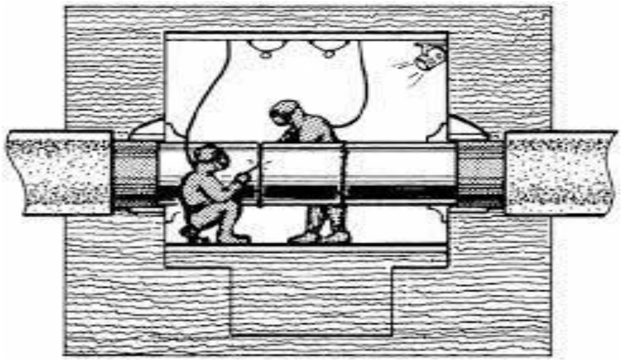

Figure (3) schematic illustration of dry under water welding (Łabanowski, Fydrych, & Rogalski, 2008) .

Figure (4) welding habitat used for performing dry underwater welding (Diving, 2021)

2. Risks associated with underwater welding process:

Generally, commercial diving considers as high hazards work according to Health and Safety Executive (HSE). The death rate of divers while performing their work is about 6- 7 per 100,000 (HSE, 2010). Underwater welding is a branch of the commercial diving where welder may expose to several risks gathered with welding process like electric shock, which is the main risk (especially in wet underwater welding), when the current can pass through the water and electrocute the welder. Nitrogen narcosis is one of the serious risks at high depth which may causes welder death. in addition, high pressure of water has a negative effect on the welder which may causes dangerous hazards due to differential pressure or what is known as "Delta P" hazards (ΔP) (Gotter, 2018) (Engineering, 2020) (Aravindhan, 2020).To avoid electric shock during dry underwater welding, proper usage of power supply is necessary and that can be obtained by adjusted the equipment voltage under the maximum safe voltage level of 30 V dc (7.5 V ac) or the operating voltage should be under the highest level of safety voltage of 250 V ac (285 V dc) and circuit breaker is fitted with a reaction time less than 20 ms. In case of wet underwater welding, direct current (DC) must be used instead of alternative current (AC) to avoid electrical shock. the persons, who desire to have this job, should be trained and qualified to weld under water and practiced in Cardiopulmonary resuscitation (CPR) and first aid. In addition, welding process must be accomplished with the presence of many trained persons to control the welding machine and cut off electrical knife switch in case of electrical leakage or in case of loose metal tools during the welding works. welders/surface helpers must have active alertness between each other to avoid all potential hazards during the welding process (Hong & Ghobakhloo, 2014) (Minstndt, 2016). Nitrogen narcosis can be avoided in several ways. Minimize of diving depth to less than 30- 50 m prevents diver from it but for diving depth over 50 m, helium or helium-nitrogen as the diluent gasses for oxygen, should be used because helium has no effect on the narcosis. In addition, diver should be well aware of narcosis symptoms, which are Laugh, garrulousness, lightheaded sensation, fatigue, hypoxia and hypothermia, and aborting diving process is necessary when those symptoms are appear (Statpearls, 2021) (Bennett, 2004). according to the Health and Safety Executive (HSE) there are 78 Fatal, Injuries and Near miss incidents of divers around the world in the years of 1854- 2009 due to differential pressure (ΔP) (figure 5-6). The highest percentage of death cases arise from diving upon dams (figure 7). Delta P occurs when the water flow moves from a region of high pressure to another of low-pressure lead to generate a considerable amount of forces cause diver at risk. So, the safety speed of water's current that allows to the diver do his duty inside the water should not exceed 0.5 m/ s. the dangerous area, where the water is flowing faster than 0.5 m/ s, must be avoided (figure 8). In case of Dams and reservoirs, the diver must avoid the opening more than 1.06 meter in diameter. Farther more, HSE, International Marine Contractors Association (IMCA) and Association of Diving Contractors (ADC) provided basic guidance and advice about how to deal with hazards of differential pressure (Fisher, Gilbert, & Anthony , 2009).

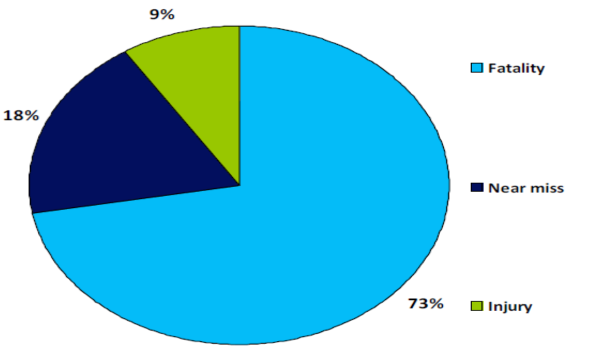

Figure (5) percentage analysis of incident classification (Fisher, Gilbert, & Anthony, 2009).

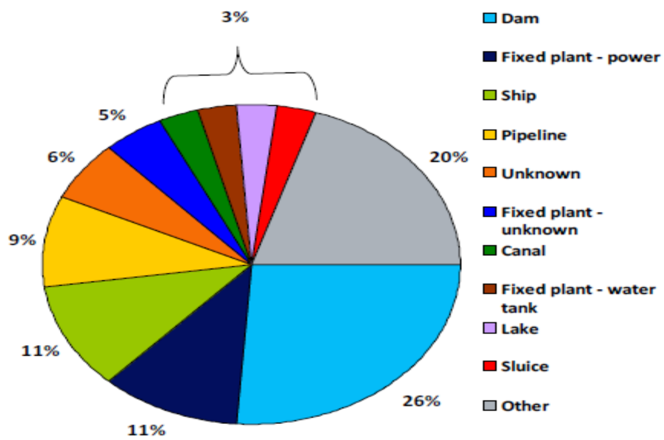

Figure (6) percentage analysis of structures dived over and divers exposed to differential pressure (Fisher, Gilbert, & Anthony, 2009).

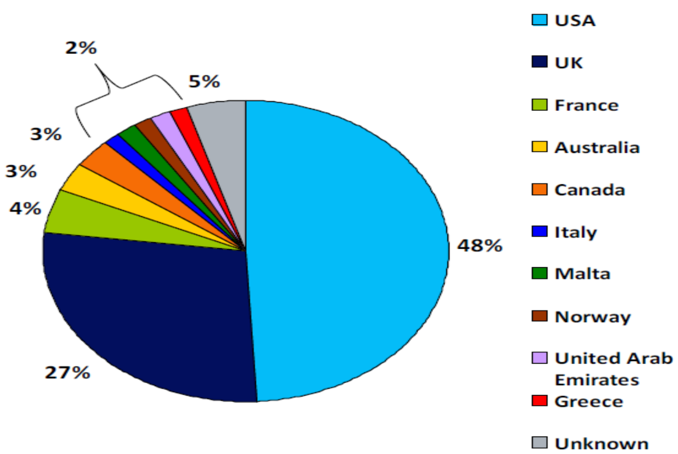

Figure (7) percentage analysis of ΔP insidents according to countries(Fisher, Gilbert, & Anthony , 2009).

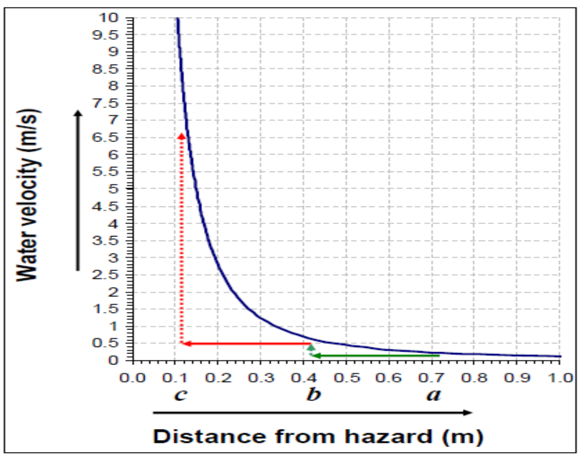

Figure (8) theoretical water velocity aganist distsnce showes the safty region of diving to avoid ΔP (Fisher, Gilbert, & Anthony , 2009).

3. The metallurgical defects of welds produced by underwater welding process:

In addition to the existence of several risks that have a fatal impact on the welders, the metallurgical defects associated with underwater welding process might have a detrimental effect on the structures and properties of welds. Welding defects are arisen from high cooling rate of welds (figure 9) which leads to demand of higher current to compensate for the quenching effect. Hight cooling rate of welding region due to water (as a welding environment) causes cold crack formation as shown in figure 10 (Tomków, Fydrych, & Wilk, 2020). the techniques used to reduce cooling rate and limiting cold crack formation through underwater welding process of steel is by using thermal insulation, which extends cooling time ($t_{8/5}$) and decreases the maximum HAZ hardness (Fydrych, Rogalski, & Łabanowski, 2014). In case of dry underwater welding, preheating of workpiece was performed before welding process which significantly reduces cooling rate of welds. Preheating process is not suitable for wet underwater welding. thus, the temper bead welding technique (TBW) was applied to minimize cooling rate of wet welding by tempering the HAZ. Then, the bead should be

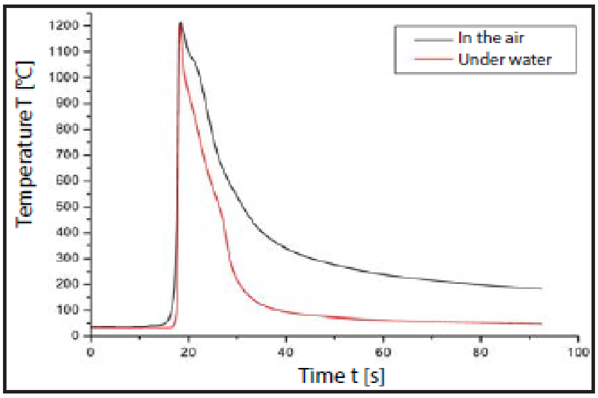

Figure (9) illustrate the thermal cycles for overlay welding in the air and underwater using the local dry chamber method (Fydrych, Rogalski, & Łabanowski, 2014).

Figure (10) Microstructure of the joint made of S420G2+M steel by local dry chamber method and arc welding with solid wire electrode; numerous cracks in the joint HAZ. Mag. 200 × (Fydrych, Rogalski, & Łabanowski, 2014)

removed after completing the welding process. It was reported that this method has ability to decrease the hardness in HAZ of S355G10+N steel joined. The hardness value achieved by this technique was below the critical value (maximum acceptable hardness value in HAZ is 380 HV10 according to the PN-EN ISO 15614-1 standard) compared with underwater welding using covered electrode method which was 459 HV10. If fact, (TBW) technique increases the ductility of HAZ by tempering the martensite (the brittle phase of steel) leads to attenuation of cold crack formation (Tomków, Fydrych, & Rogalski, 2019) (Fydrych, Łabanowsk, Tomków, & Rogalski , 2015). most of offshore structures are formed of steel alloys which should have a significant mechanical property. Yield strength of steel alloys above 350 MPa is necessary to meet the requirement of off shore structures and that achieved by controlling the cooling rate and microstructure of welds. It was found that the Realtime induction heating assisted underwater wet welding is a novel process by which induction heating was introduced to Q460 steel work pies to control of cooling rate, macro and microstructure of joints (figure 11). This novel process showed a

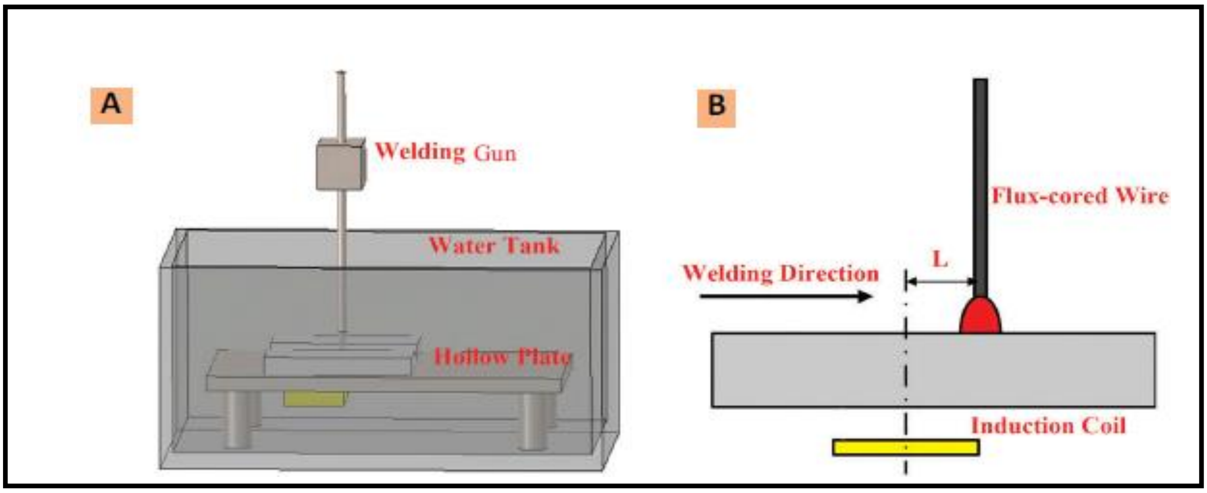

Figure (11) Schematic illustration of a novel process in underwater wet welding (Zhang, Dai, Feng, & Hu, 2015).

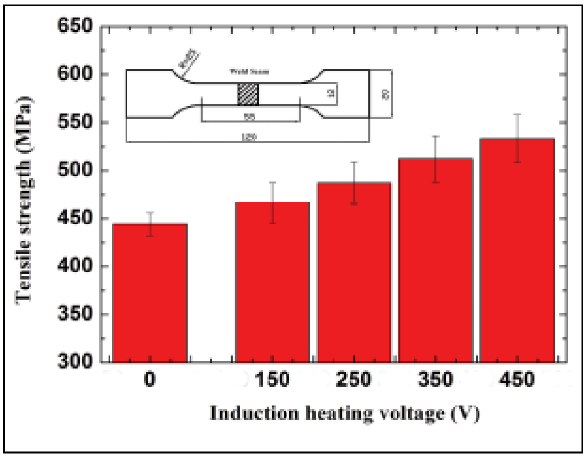

Figure (12) shows the improvement of tensile strength with increasing of heat induction (Zhang, Dai, Feng, & Hu, 2015).

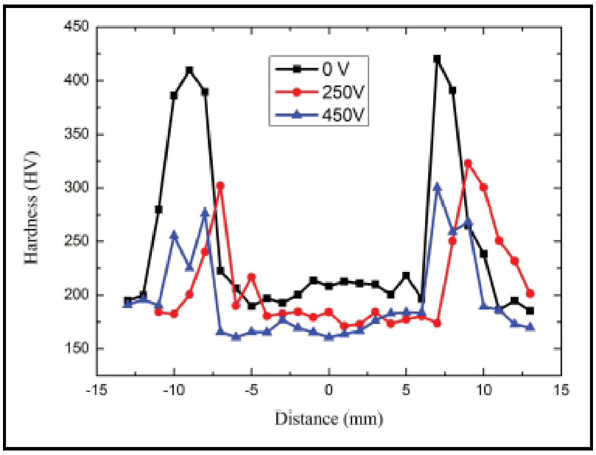

Figure (13) shows the decreasing of hardness along the joints with increasing induced heat (Zhang, Dai, Feng, & Hu, 2015).

continuous improvement in both microstructure and mechanical properties of joints with increasing voltage of heat induction (figure 12, 13) (Zhang, Dai, Feng, & Hu, 2015). Hight pressure of water considers as a main challenge in underwater welding which leads to decrease melting efficiency, influence welding stability, decrease the arc diameter, increase the number of short circuits, deposit the chemical composition and increase hydrogen diffusion. It was stated that using of modification method for electrode and core by adding alloying element reduces the effect of water depth. the electrode core with Nickel and Molybdenum, as alloying elements, can delimiting solidification cracking of weld region and reduces brittle cracking sensitivity (Fydrych, Rogalski, & Łabanowski, 2014). Wet welding of different alloy steels by laser welding method under the water condition was carried out to study effect of water depth on the arc disturbing generated from pressure of water (Zhang, Ashida, Shono, & Matsuda, 2006) (fu, Guo, Cheng, Zhang, & Feng, 2020) (Sakate, Mullick, & Gopinath, 2021). the influence of water depth on laser beam welding (ULBW) was investigated by using a camera. The results showed that there was no negative effect of water on the laser beam at depth less than 3 mm, but the failure of (ULBW) occurs when the depth of water reaches of 7mm (Guo, et al., 2017). the challenge of getting joints by wet underwear welding characterized by being free cold cracks is arisen from hydrogen diffusion at high water depth. The hydrogen and oxygen transform to the ionic state around the welding arc which lead to diffuse hydrogen inside weld pool. SMAW process used to join S235 JR steel at different water depths using rutile-based flux coated stick with 20% $CaCO_3$, 53% TiO2, 12% SiO2, 10% FeMn (figure 14). The process was performed inside pressure chamber to simulate welding under deep water. All tasted samples showed increasing of residual hydrogen and decreasing of the diffusible hydrogen in the welds with increasing depth of water (figure 15). It was found that there is no wet welding method can limit the diffusion of hydrogen inside welds yet. during underwater wet welding process, the vapor and gas bubbles around arc contain 85–96% of diffusible hydrogen which responsible for [H] content inside molten metal and causes porosity, cold crack and hydrogen embrittlement which deteriorate the mechanical properties of joint (Klett, et al., 2020). Thus, many systems of gas and slag were designed for flux-cored consumables to minimize the partial pressure of H_2 and H_2O vapor in the vapor and gas bubble. The dissociation of carbonates (like, $CaCO_3$ and $MgCO_3$) in the coating of flux cored wire can decreasing porosity. the vapor and gas bubble react with $CaCO_3$ and $MgCO_3$ lead to formation of carbon dioxide and Carbon monoxide which decrease the H_2 partial pressure near the weld pool (the amount of [H] is 54 cm3 /100 g when 20% of calcium carbonate is added at depth of 12 m). Also, the florid (like, CaF2) can be dissociated in the coating of flux cored consumable to stimulate a reaction of H_2 and fluorine and the result is HF

Figure (14) influence of water depth on weld beads quality (200 A, 22 V) (Klett, et al., 2020).

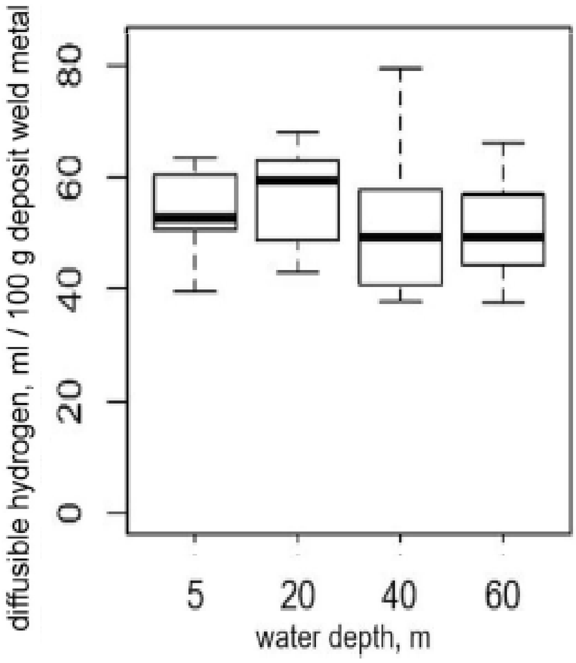

Figure (15) illustrate [H] content in weld pool verses depth of water using rutile-based flux coated stick with 20% $CaCO_3$, 53% TiO2, 12% SiO2 and 10% FeMn at (200 A, 22 V) (Klett, et al., 2020).

compounds. This reaction reduces [H] content near of weld pool of 39 cm3 /100 g when 20% of calcium florid is added. Thus, the florid is must useful than carbonate as a coating material. Also, a system consists of TiO2–CaF2–Na3AlF6 used with flux-cored wire shows decreasing of [H] content inside weld pool of 27.1 mL/100 g (Parshin, Levchenko , & Maystro, 2020). even in case of local cavity method, when the weld's region is dry by using shielding gas gathered with GMAW process, microscopic investigations of S355J2G3 steel welds exhibited presence of cold cracking due to [H] content (Fydrych & Kozak, Underwater welded joint properties investigation, 2009). joints welded by this method demonstrated [H] content from 4.73 to 17.49 ml/100 g Fe. It was found that many parameters increase diffusible hydrogen content in local cavity method which are voltage of arc, salinity of water, speed of welding and welding current. Whereases, the increase in the length of the free consumables, shielding gas flow rate and the number of coiled forms of the elastic band can reduce it (e.g., joins with low [H] content, similar to welding in air, can be achieved when the flow rate of gas shielding is more than 501/min[5]) (Fydrych & Rogalski, Effect of underwater local cavity welding method conditions on diffusible hydrogen content in deposited metal, 2013). at Hight water depth, dry underwater welding may carry out with a chamber covers the welding region. This chamber is filled with mixture of gases (He, Ar and CO_2) to keep the pressure inside it identical to water depth or equal to atmospheric pressure (Shi, et al., 2018). existence of height pressure through welding process declines arc stability. with attendance of diffusible hydrogen, crack formation could be occurring in weld region (Yusof & Jamaluddin, 2014). many methods were used to join steel alloys in hyperbaric underwater welding like, GTAW and GMAW. An improvement in the mechanical properties and quality of joints was reported when FCAW method was applied with hyperbaric underwater welding. it was found that using cored consumables with fluoride flux, to join API X70 steel pipes, produced welds which classified as class A according to American National Standards Institute/ American welding society D3.6M: 2010 when the pressure inside hyperbaric chamber was up to 0.6 MPa. In case of bainitic X70 steel welding at pressure exceeds 0.6 MPa, Hight percentage of deoxidizers and fluorides content should be used with consumables, as a metallurgical treatment, to improve the microstructure of weld pool by minimalizing O2 and N2 content (Parshin & Levchenko, Underwater hyperbaric dry welding of high strength steel arctic oil and gas pipelines, 2020). farther studies should be established to develop wet and dry underwater welding process and to overcome the difficulties arising from diffusible hydrogen and high pressure (water depth) for getting joints with long-term performance.

4. Future developments:

The development in modern underwater welding techniques, e.g., laser beam welding, friction stir welding, alignment by automatic pie, automatic welding and non-submersible Hyperbaric welding process, is necessary to reduce the metallurgical defects of the welding regions and improve the properties of joints. Furthermore, automation of welding process should be deeply studied due to control on welding parameters especially at high depth. Also, explosive welding should be tasted in deep sea and study the extent of its metallurgical potential on welds.

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