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Underwater Welding: A Review

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Abstract: *Underwater welding is that the process of connecting two similar or different metals which are administered underwater. This process is applied in various types of construction in engineering materials both on land and underwater environments such as in ship construction, oil and gas mining in the middle of the sea and nuclear power plants. Material construction greatly effects the method suitable for the welding process. It will affect the evolution of the microstructure and mechanical properties of the fabric. So, it'll affect the results of the welded joint.*

I.INTRODUCTION

Welding may be a method of joining the method of materials, especially metal materials thatare administered for years with application, on land-marine structures **[2] [3]** and transportation modes **[4] [5]**. This process is carried out by joints two similar or dissimilar metals by heatingto melt the parts together, then allowing them to cool and may be joined together. The welding processes are often administered during a sort of engineering materials construction. Underwater welding is commonly used to repair and maintain pipeline construction on the underwater, ship components, port construction, and the structure of nuclear power plants **[6]**. The method used underwater welding consists of Shielded Metal Arc Welding (SMAW), Flux-cored Arc Welding (FCAW) and Gas Tungsten Arc Welding (GTAW) **[7] [8]**. This method is used mainlyin cases of urgent repair the structure **[9]**. Dry welding and wet welding are the working principles of underwater welding **[10] [11] [12]**. This technique has advantages and disadvantages that increase, so there is a need for attention before the welding process is carriedout. Dry welding is an underwater welding process by employing a dry chamber which serves to guard the arc welding and weld metal from the water round the welding area **[7]**. This technique can produce welding quality that is almost equal to the results of welding on land **[13]**. Dry welding uses a special chamber (dry chamber) which is trained during a dry environment in order that the arc welding is more stable **[14]**. The dry chamber in the welding process has a weakness are a space for a welder to be limited, and the cost for a dry chamber is costly. Wet welding may be a method that uses special stick electrodes because the fabricand welding electrodes must be directly contacted with water within the weld area **[10]**. Wet welding has the advantage that the operation process is moderately simple because it does not require many prepare and the motion space of the welder is unlimited. The cost required is comparatively cheaper than dry welding **[11]**.

Wet welding has many adverse effects such as reducing the mechanical properties of the material, growing the cooling rate of the underwater welding joints, growing the welding porosity slag trapped in welds, and changing within the chemical composition of weld results **[15]**. The metallic material is a material that is often used in engineering construction. If the fabric is that the process of joining by welding, the fabric will change within the microstructure and mechanical properties of the material **[6].**

[16] Observed the microstructure and mechanical performance of underwater wet welded S355 steel. It can apply to marine structures. The differences within the mechanical properties and microstructural features of both joints. the materials which is used in underwater welding specifically for metallic materials.

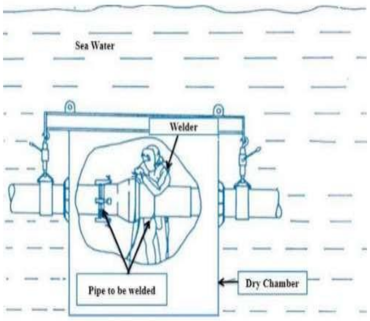
II.UNDERWATER WELDING

Underwater Welding are wet shielded metal arc welding and gas metal arc welding in local cavity method and extra works are through with the utilization of underwater cutting techniques. When it's impossible to put metal structure into a dry dock, welding operations must be performed in water environment.

Underwater welding techniques can be classified as follows
a) wet welding
b) dry welding

c) local cavity welding

Underwater welding may be a material welding technique using special equipment that's administered underwater. Underwater welding was discovered by Konstantin Khrenov in 1894. Khrenov was studying electrical welding, engineering, and mathematics. He believes that this welding technique is taken into account the foremost effective thanks to repair damage to the ship.



a.) b.)

Fig. 1. The condition of underwater welding: (a) dry welding [10], and (b) wet welding [17].

The development of marine resource exploitation and utilization is driven so rapidly. Most ocean engineering structures have main components submerged in sea-water, therefore the research on underwater welding is vital for the offshore industry. Underwater welding isclassified into two based on welding techniques, dry and wet welding. The difference between dry and wet welding, which one among them is that the condition of the welding area. Dry welding is an underwater welding technique by employing a dry chamber welding component, so arc weld isn't in touch with water round the welding area. Wet welding may be a welding technique that direct contact with water within the environment around welding. Dry welding is an underwater welding process by employing a dry chamber or dry chamber.

The dry chamber is taken into account to guard the welding arc weld. If the welding arc is constant, the welding metal will increase strength and tenacity, high corrosion resistance, anda small amount of hydrogen gas produced during the welding process. But the presence of the dry chamber within the welding process features a weakness because the space for a welder to be limited, the equipment may be costly and complicated. Wet welding may be a welding process using special stick electrodes. The base metal, electrode, and welder must be contacted directly with water around welding. Wet welding conditions. Wet welding has the advantage that the operation process is straightforward because it doesn't require tons of special preparation and unlimited space for the welding operator. The cost required is comparatively cheaper than dry welding. direct contact of wet welding with water can cause some negative impacts such as the arc flame being unstable, reducing the mechanical properties of the material, and can increase the cooling rate of the welding material.

Underwater welding technique may be a suitable technique for emergency repairs within the event of structural damage within the middle of the ocean that doesn't allow dismantling to be carried inland. So that welding is taken into account to save lots of time, energy from workers, and costs **[11]**. **[18]** Argue that underwater welding can serve to repair and maintain underwater structures that are usually used in ship construction, oil, and gas piping offshore and nuclear power plants. Underwater welding can have a negative impact within the sort of defects in welding material. It caused by surrounded hydrogen gas in the weld metal, which can have a detrimental effect in the form of cracks, which can reduce the reliability of welding structures and cause steel to become brittle and broken **[15]**. **[19]** Argue that the effect of water depth on arc behavior, bubble characteristics, and welding performance on the UWW FCAW process. The results show that the depth of the water decreases the dimensions of the droplet, stabilityof arc weld, and produces tons of pores on the weld metal. This is important to consider in the selection of proper techniques for repairing underwater structures.

Table:1 Scholars, Material, Meathod & Findings

No.	Scholars	Material	Method	Findings	
				Microstructure	Mechanical Properties
1	Liu et al. (2010)	2219 Aluminum Alloy	friction stir welding	The refined grain structures, high-density displacements and enhance solid solution strength effect unnaturally led	The tensile strength of the standardized material is 315MPa, and after underwater

				to the increase of hardness of MHL, and thus improved the tensile strength of the Under water joint.	welding process is 341MPa.
2	Zhang et al. (2012)	2219-T6 Aluminum Alloy	friction stir welding	NHAZ area forms deposits with a diameter of 106 ± 28nm with a thickness of 10 ± 2.6nm while deposits in the UHAZ area have 92 ± 30 and 7±1.8nm diameters.	The minimum hardness value of UHAZ (Underwater HAZ) is 92HV, while NHAZ (Normal HAZ) is 78HV.
3	Cui et al. (2014)	S355 steel	friction taper plug welding	In the HAZ area, there are a lot of lath bainite and a few Acicular Ferrite, polygonal ferrite, and martensite.	Maximum tensile strength and impact energy at V-notch found 500MPa and 39.5J in welded joints with 45kN axial force.
4	Baillie et al. (2015)	S275 steel	friction stir welding	The underwater structure is more dominant in the form of regular Ferrite Granules. It due to the rapid cooling of UWW	Longitudinal tensile strength at the average yield strength is 475MPa, and the ultimate strength is 577MPa
5	Pedapati et al. (2017)	5052 aluminum alloy	friction stir welding	The fraction of the void area in the SZ of underwater FSW is decreases in a greater number than normal FSW. It is diminished 3.6% in the SZ of normal FSW and 1.3% in the underwater FSW stir zone.	The average hardness of underwater FSW increases 21% greater than the normal FSW, and 53% greater than its Base Material (BM)
6	Tan et al. (2017)	AA 3003 aluminum	friction stir welding	The size of recrystallized	The fracture morphology

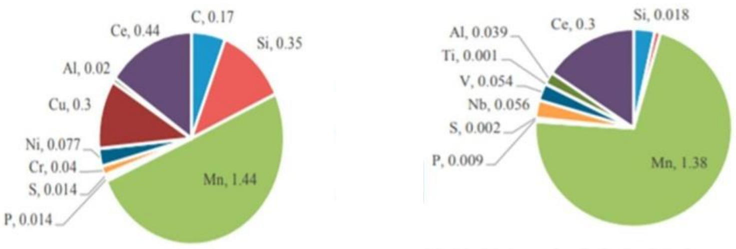
		alloyAA 3003 aluminum alloy		grains was nearly 2.26µm and 2.33µm, in 0°C water, the size of recrystallized grains decreased to 1.20µm and 1.23µm for the hot band and annealed hot band.	was constituted of a large number of deep dimples. When the annealed hot band was welded in 0°C water, the fracture morphology was a large number of shallow dimples, in air condition, the depth of the dimples regularly increased.
7	Li et al. (2018)	E40 Steel	flux-cored arc welding	There are many microstructures of Lath Martensite with different types that dominate the CGHAZ area.	Ultimate tensile strength and impact strength increase during the process of a solid solution, due to many alloying elements
8	Muhayat et al. (2020)	Low carbon steel SS400	shielded metal arc welding	Air welding is presented by Polygonal Ferrite (PF) and grain boundary ferrite (GBF) phases. UWW with a depth of 2.5m is dominated by GBF and PF, while depths of 5and 10m are dominated by AF and FSP (Ferrite with Second Phase-aligned).	Weld metal on UWW joints at a depth of 10m has a higher hardness value of around 365HV. There are many structures of AF (Accicular Ferrite) caused by rapid cooling.
9	Chen et al. (2020)	Low carbon Q235 steel	self-shielded	In the CGHAZ area, there are	High strength low alloy

		and high	flux-cored	some LM (Lath	E40 steel
		strength low alloy E40 steel plate	wire	Martensite) and AM (acicular martensite) in the Low carbon Q235 steel while in the high strength low alloy E40 steel plate, there are some SPF (side plate ferrite) and AF (Acicular Ferrite).	plate has a higher crack warmth value than low carbon Q235 steel material.

III.METALLIC MATERIAL

The metallic material may be a material that has special properties that engineers usually use for engineering. Metallic materials are classified into two, ferrous and nonferrous metal **[20]**. Ferrous metal is a metal that has the central element in the form of iron (Fe). This material is mainly used in the construction of engineering, powerplant equipment, shipbuilding, bridge construction, and other apparatuses. Nonferrous metal is a metal that contains little or no important elements in the form of iron (Fe). Alloy elements from nonferrous metal materials are Copper (Cu), Aluminum (Al), Magnesium (Mg), Titanium (Ti), and others **[21]**. Thealloying elements can affect the resulting weldability. If the elements are added to nonferrous materials, special methods are required for the welding process.

[22] research on weldability for ferrous metal. A material S355J2G3 in water condition while S500M steel in air and water condition. The welding process with MMA Process. A mixtureof chemicals contained in material S355J2G3 and S500M steel. The S355J2G3 steel consistsof various Ferrite and Pearlite structures, while the S500M steel structure consists of several Ferrite grains of very different sizes and Pearlite structures



(a) (b)

Fig. 2. Composition of chemical contained on S355J2G3 and S500M steel (weight %)[22].

The result of this research is the hardness value of underwater welding S355J2G3 steel jointsup to 400 HV10. Higher carbon content in this steel in association with an increased cooling rate of the joints resulted in the HAZ area **[23]**. At the carbon equivalent Ce = 0.44% for S355J2G3 steel, led to forming quench structures. Specimen of S355J2G3 steel has a characteristic for starting cracks in the fusion line, which is confirmed by the presence of brittle structures in this area. The hardness value in base metal S500M is 200 HV10. After the weldingprocess in the air environment, the hardness value on the HAZ at the S500M welded joint increased to 240HV10 while the hardness value of the underwater welding joint of this material increased by 40%. The low carbon content in the steel as well as carbon equivalent (Ce = 0.30%). This situation can indicate that low-carbon steels after thermo-mechanical processing is applicable for marine and offshore engineering structures when underwater welding is required.

(c) (d)

Fig. 3. Microstructure from S355J2G3 and S500M steel [22].

Shnavas et al. (2018) **[24]** investigated the weld ability of marine grade AA 5052 aluminum alloy by underwater friction stir welding. Marine-grade aluminum alloys are used in the aerospace, marine, and automobile industries. This material can use an alternative to steel because the characteristics are lightweight, good formability, functional strength, and high corrosion resistance. This used high-strength aluminum-magnesium alloy AA 5052-H32. The welding equipment and the process parameters used both for underwater FSW and normal FSW. Photographs of the fabricated with different tool rotational speed for underwater FSW joints are shown in Table 2.

Table 2. Process parameters of fabricated [24].

Process	1	2	3	4	5
Tool rotational speed (rpm)	500	600	700	800	900

The appropriate heat input at FSW is necessary for dynamic recrystallization. The strain rate controls the grain size at lower rotational speed or higher welding speed, heat input controlsthe grain size at higher rotational speed or lower welding speed. The results of grain size increased. Grain size will affect the value of maximum tensile. Based on the welding results,

The optimum process parameters for achieving maximum tensile strength by normal FSW compared with underwater. The maximum tensile strength both underwater and normal FSW at tool rotational speed of 700rpm produced 208.9 MPa and at 600 rpm produced 200.3 MPa.It means the maximum tensile strength obtained by underwater FSW is about 2% greater thannormal FSW. The absence of the HAZ region found in the underwater FSW process, which might be due to water cooling.

If the water cooling increases, the ultimate tensile strength will increase. It found finer equiaxed grains at Stir Zone (SZ) of the welded plates by underwater FSW process than the normal FSW process. HAZ is an area where crack propagates in high-strength welded joints.

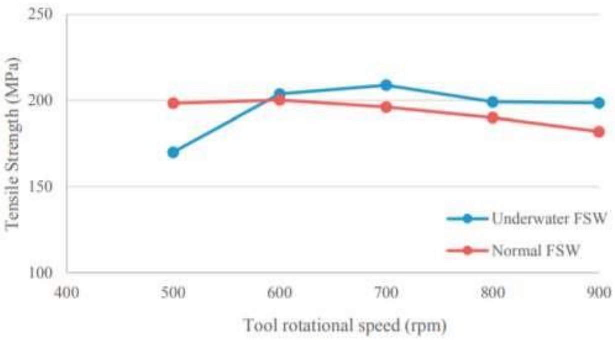


Fig. 4. The comparison of tensile strength of underwater FS and normal FSW [24].

The absence of this area found in the underwater FS welded plates due to faster heat dissipation during water cooling. The plates welded by the underwater FSW process showed high resistance to fracture compared to the normal FSW process.

IV.CONCLUSION

The application of material uses in marine, and offshore engineering structures. The underwater welding process can affect the base metal composition and mechanical properties that occur at the joint of the weld metal. The chemical composition that changes can affect the welding capability in underwater welding, as an additional carbon content. If the carbon in the material grow, so the weldability will reduce. The highcarbon content in the material will cause the mechanical properties of the material to become hard and brittle.

water temperature produces high cooling rates and finer microstructures with high hardness. If the hardness and tensile strength of the material increase, so the material crack increase too. Crack in the material can reduce the reliability of the underwater welding structure because the welding material becomes brittle and fracture.

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