Study of Developments in Underwater welding

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Abstract

This paper gives an overview of the principles of underwater welding, its history, classifications, requirements, applications and difficulties. A huge number of techniques are available for welding in atmosphere but when it is not possible to place metal structure on dry land in open and normal environmental conditions, welding maneuvers must be performed in water (wet conditions). Underwater welding practices are put into use in such applications.

Keywords: *Fluidization, Eulerian-Lagrangian, Combustion, Eulerian-Eulerian, Multiphase flow.*

1. Introduction

1.1 Field of Invention

Welding processes are metal joining processes that have become increasingly important in almost all manufacturing industries and structural applications. In maximum industries, welding operations are carried out in dry conditions at standard (atm.) pressure. Underwater welding practices were established for use in situations where metal joining is to be done in water i.e. wet conditions, for e.g. in submarines.

1.2 History

In the early 20th century, even though professional diving was already an established industry (and had been for hundreds of years), underwater welding was not. The Soviet engineer, Konstantin Khrenov, was the first to invent a method to join and cut metals in submerged conditions. Khrenov learnt that one of the largest hurdles to successful wet welds was the sporadic outflow of gas bubbles from the point of contact with the metal and arc. This reaction triggered major porosity in the welds. With the assistance of his peers, Khrenov developed a waterproof coating for the electrodes. He initiated experimenting and carried out underwater i.e. immersed welding in labs. In 1932, Khrenov voyaged with engineers to the Black Sea for the first successful on-field testing.

The first underwater welds left much to be wanted, but scientists logged the results in two historic articles:

a) Strains in the End Lap Welds by P.F. Papkovich (1933)
b) Design of Electric-Welded Seams for Combined Strength by Yu.A. Shimanskiy (1936)

Just several years after Khrenov's positive wet weld, the Soviets initiated to practice the use of the technology for their harbors, ships, and docks. With the commencement of WWII, many metals were in scarce supply and nothing could be wasted. In 1936, underwater welding was performed by crews as part of the effort to lift an enormous ship called Boris out of the Black Sea.

In America during the early and mid-1940's, Cyril Jensen began his private underwater welding testing. Captivated with Khrenov's work, Jensen wanted to start an underwater welding program in the US.

Later, with the US brought into WWII, he traveled to the Annapolis naval engineering experiment station for welding research. For the years that followed in the war, Jensen served in the Navy and conducted the operations for their underwater welding and cutting program. Some of his most notable underwater construction includes salvaging several of the sunken ships in Pearl Harbor.

During his life, Jensen vastly expanded the underwater welding program in the US and helped create the arc-oxygen underwater cutting process. He holds two underwater welding patents and wrote (or co-wrote) 18 research papers.

1.3 Necessity

Defects frequently form on subsea metal structures and pipes because of rigorous service conditions. Although, a large number of techniques are available for welding in atmosphere, many of them cannot be applied in offshore and marine applications where presence of water is a major concern. When it is not possible to place metal structure into a dry dock for repair or maintenance, underwater welding techniques are applied. Another advantage of underwater welding is of economical nature, because underwater welding for marine maintenance and repair jobs bypasses the need to pull the structure out of the sea and saves much valuable time. Sometimes, in case of sudden defects leading to a catastrophic accidental failure, it becomes important to carry out maintenance on site.

2. Literature Review

1. The research paper "Łabanowski, J., D. Fydrych, and G. Rogalski. "Underwater Welding-a review." Advances in Materials Sciences 8.3 (2008): 11-22." is about the research work undertaken by Department of Materials Technology and Welding at Gdansk University of Technology (GUT) in the field of underwater welding. Various classifications of underwater welding have been discussed and a description on results obtained in the lab in their tests has been presented.
2. The research paper "Cui, Lei, et al. "Friction taper plug welding for S355 steel in underwater wet conditions: Welding performance, microstructures and mechanical properties." Materials Science and Engineering: A 611 (2014): 15-28." Is about a specific advanced underwater welding technique called friction taper plug welding. Various parameters of this technique have been discussed along with the changes in the microstructure of S355 steel after this process has been carried out. The results of various tests like tensile test and their implications have also been discussed.
3. The research paper "Garašić, Ivica, Slobodan Kralj, and Zoran Kožuh." Analysis of Underwater Repair Technology on the Jack-Up Platform Spud Can" Brodo Grandja 61(2010)2, 153-160" is about a particular case of maintenance of a jack up platform that has been damaged due rocky bottom of ocean. Various techniques available for repair have been discussed along with all their pros and cons. The chain of operations to be performed for a particular type of solution is also discussed in detail.
4. The research paper "Majumdar, Jyotsna Dutta. Underwater Welding–Present status and future scope" Journal of Naval Architecture and Marine Engineering 3(2006) 39-48" is a review paper which discusses classification of underwater welding techniques along with an overview of some specific advanced welding techniques. It also discusses the scope for development in underwater welding technologies.
5. The research paper "Yoshihiro YAMASHITA , Toru KAWANO & Kurt MANN (2001) Underwater Laser Welding by 4 kW CW YAG Laser, Journal of Nuclear Science and Technology, 38:10," is about a particular case study of application of underwater laser welding used for repair work in Nuclear Power generation plants in Japan. It goes through the entire logic behind selection of a particular laser developed by Hitachi for their required application.
6. "http://waterwelders.com/" provides guidance to people looking for making a career in underwater welding.
7. "http://cdiver.net/news/application-of-underwater-welding-processes-for-subsea-pipelines/" is a link to an article that advocates the use of wet welding for repair and maintenance work of underwater pipelines.

3. Classification of Underwater Welding

Underwater welding may be divided into two main types:

a) Wet welding
b) Dry welding

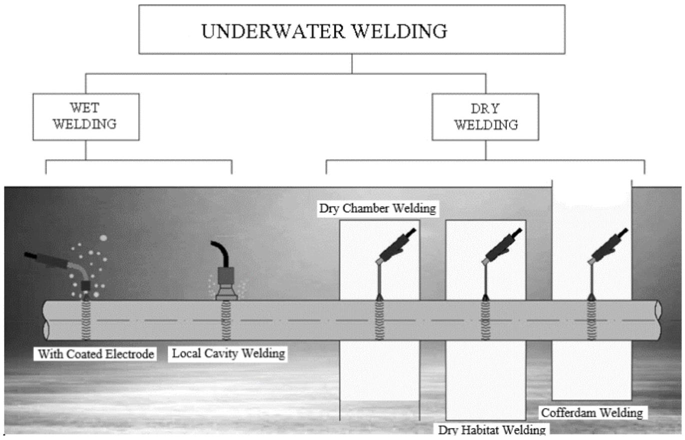

Fig. 3.1 Classification of underwater welding

3.1 Wet welding

3.1.1. Wet welding with coated electrode

Wet welding is performed at ambient pressure with the welder-diver in the water and no physical barrier between water and welding arc using water-proof stick electrode. Such electrodes are specially prepared for the specific operating conditions. Simplicity of the process makes it possible to weld even the most geometrically complex structures. The increased freedom of welder's movement makes this method very flexible compared to dry underwater welding techniques. It does not need any complicated experimental set up, is economical and can be immediately applied in case of emergencies and accidents as it does not need water to be evacuated. It is considered to be the cheapest and most versatile method of operations in underwater environment.

Although wet underwater welding is used generally at the depths of up to 50 m, tests have been done at depths greater than 100 m, but due to a high hydrostatic pressure it is difficult to maintain the electric arc, and the joint quality becomes questionable. At greater depths there are also physical restrictions which represent inevitable problems for divers.

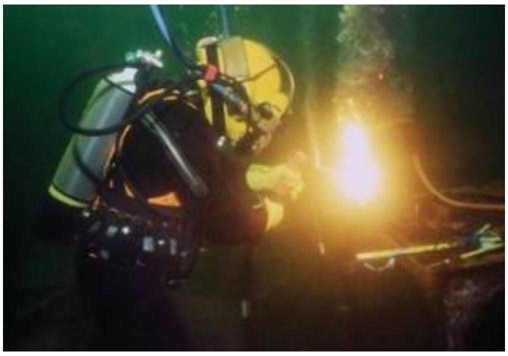
Fig. 3.2 Diver carrying out wet welding


Fig. 3.3 Specimen weld beads obtained with wet welding underwater using covered electrodes

3.1.2. Local Cavity Welding

Welding by local cavity method is possible due to utilizing standard equipment for semiautomatic or automatic gas metal arc welding (GMAW) along with special outer nozzle and elastic cover as it is shown in Fig. 3.4. In local cavity method, cooling conditions are nearly the same as those existed during welding in the air. Properties of welds performed with the use of local dry chamber are much better than properties of wet welds. View of exemplary weld beads obtained by local cavity welding is presented in Fig. 3.5. The main disadvantage of the method is the lack of possibility of welding process observations. Local cavity process can be also performed with application of laser beam as a heat source.

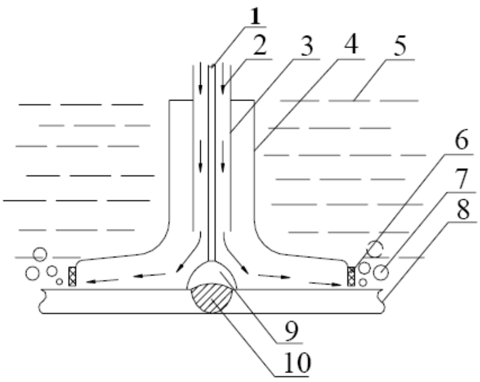

Fig. 3.4 Local Cavity Method
1 – welding nozzle, 2 – welding wire, 3 – shielding gas, 4 – outer nozzle, 5 – water, 6 – elastic cover, 7 – gas bubbles, 8 – welded element, 9 – arc, 10 – weld

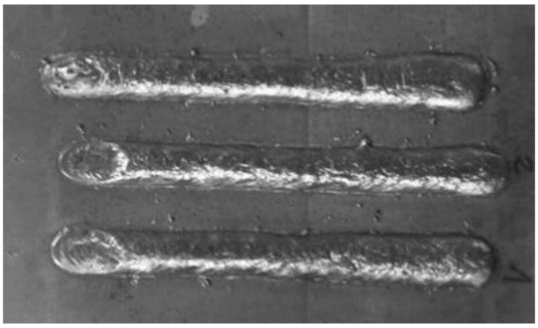
Fig. 3.5 Weld beads obtained by local cavity method

3.2 Dry Welding

Underwater welding in a dry environment is made possible by encompassing the area to be welded with a physical barrier (weld chamber) that excludes water. The chamber is usually built of steel, but plywood, rubberized canvas, or any other suitable material can be used. Size and configuration of the chamber are determined by dimensions and geometry of the area that must be encompassed and the number of welders that will be working in the chamber at the same time. Water is displaced from within the chamber by air or a suitable gas mixture, depending upon water depth and pressure at the work site. Buoyancy of the chamber is offset by ballast, by mechanical connections and chamber to the structure, or by a combination of both.

Dry welding underwater may be achieved by several ways:

3.2.1 Dry habitat welding

Welding at ambient water pressure in a large chamber from which water has been displaced, in an atmosphere such that the welder/diver does not work in diving gear. This technique may be addressed as dry habitat welding.

3.2.2 Dry chamber welding

Welding carried out at ambient water pressure in a simple open-bottom dry chamber that accommodates the head and shoulders of the welder/diver in full diving gear.

3.2.3 Dry spot welding

Welding at ambient water pressure in a small transparent, gas filled enclosure with the welder/diver in the water and no more than the welder/diver's arm in the enclosure.

3.2.4 Dry welding at one atmosphere

Welding at a pressure vessel in which the pressure is maintained at approximately one atmosphere regardless of outside ambient water pressure.

3.2.5 Cofferdam welding

Welding inside of a closed bottom, open top enclosure at one atmosphere.

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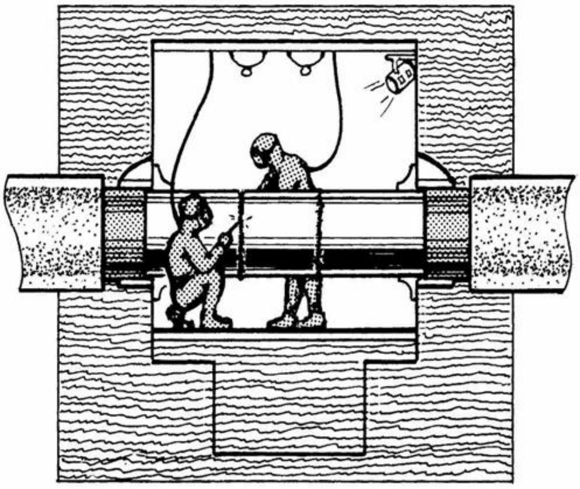

Fig. 3.6 Dry Welding

Dry welding requires a pressurized enclosure having controlled atmosphere. Weld metal is not in direct contact with water. Advantages of dry welding are improvement in stability of welding operation, reduced hydrogen problem, lower quench rate of the weld and base metal and restoration of weld strength and ductility. Dry welding may be carried out under high pressure, which consists of preparing an enclosure to be filled with gas (helium) under high pressure (hyperbaric) to push water back, and have the welder, fitted with breathing mask and other protective equipment. Limitations of hyperbaric welding are the practical difficulties in sealing the chamber and increase in pressure as weld depth increases leading to problem which affects both the weld chemistry and microstructures.

4. Applications

In recent years, the number of offshore structures, pipelines, and platforms being installed in deeper waters has increased. Some of these pipelines and structures will experience failures. Various applications of underwater welding include:

- Maintenance of oil rigs
- Salvaging of vessels sunk in sea
- Construction of large ships beyond capacity of existing docks
- Off-shore construction for tapping sea resources
- Temporary repair work caused by ship collisions or unexpected accidents
- Repair of subsea pipelines

4.1 Subsea Pipelines

Pipeline damage after installation may be caused by internal and external corrosion, hydrogen-induced stress cracking, unstable seabed conditions, anchors, and dropped objects from the surface. The risk of damage depends on the intensity of surface activities such as ship transport and offshore operations, depth, seabed conditions and the design of the pipeline itself. The extent of possible damage will vary from insignificant to a fully buckled or parted pipeline. Any repair for these on location will require the use of underwater welding. Typical repair methods are to use fittings for repairs and tie-in of submarine pipelines. These fittings include: couplings, clamps, T-branch connections and isolation plugs. Mechanical means are used to connect these fittings to the pipeline and welding subsequently used to make the repair permanent.

5. Challenges in Underwater Welding

The main difficulties in underwater welding are the presence of a higher pressure due to the water head under which welding takes place, chilling action of the water on the weld metal (which might change the metallurgical structures and properties), the possibility of producing the arc mixtures of hydrogen and oxygen in pockets, which might set up an explosion, and the common danger sustained by divers, of having nitrogen diffused in the blood in dangerous proportions. Furthermore, complete insulation of the welding circuit is an essential requirement of underwater welding. In practice, the use of underwater wet welding for offshore repairs has been limited mainly because of porosity and low toughness in the resulting welds. With appropriate consumable design, however, it is possible to reduce porosity and to enhance weld-metal toughness through microstructural refinement.

Test welds were performed in lab for conditions of welding at low depths with application of various welding conditions like - welding current, painting of electrode, electrodes polarity, thickness of flux covering electrodes core, salinity of water, contamination of electrode (carbohydrates) and time of wetting of electrode in water; it was found that the most relevant variables for quality of weld were as shown in following Pareto chart:

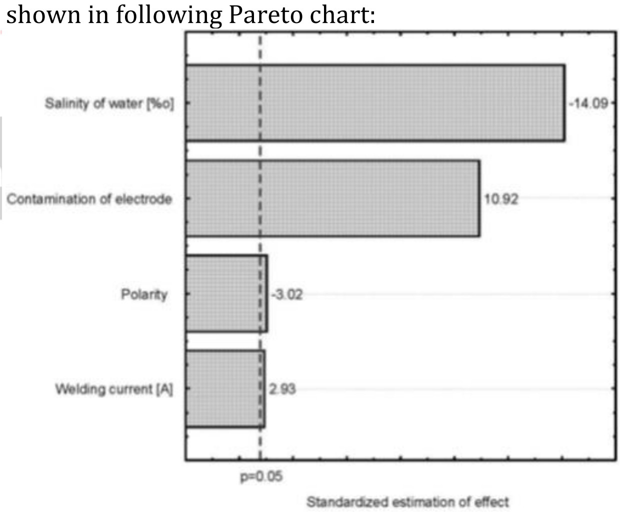

Fig 7.1 Pareto chart of standardize effects

These factors must be taken into account while selecting parameters to ensure good quality welds.

Underwater dry welds are of better quality in comparison with those obtained in wet conditions, but large support equipment is required and involved costs are relatively high. In dry conditions, there is a possibility to use almost all standard methods of welding. In many cases, dry welds have mechanical properties equal to similar welds performed above water. Estimated cost and time for dry welded repairs are twice that for wet welded repairs. The maximum depth for using manual hyperbaric welding is 300 m.

6. Discussion

Modern underwater welding techniques make it possible to obtain joints with sound welds that meet various requirements. Recent improvements in underwater welding have led to the increased use of wet and dry hyperbaric welding for marine applications. But more wide-spread application of wet welding methods is limited due to the higher technical expertise required. The general acceptance of underwater welding processes has been further advanced by the standardization of methods, procedures, and certification requirements provided by the American National Standards Institute and American Welding Society.

7. Future Scope

In spite of many successful applications and results of investigations, underwater welding requires new research and development to achieve its full potential. There is scope for research in the following areas:

1. Automation of the underwater joining and inspection of the welded structures.
2. Application of advanced welding techniques like friction, laser welding
3. Understanding the behavior of materials after the welding
4. Generation of research data book on weld ability of materials during underwater welding.
5. Process optimization.
6. Invention of new welding techniques and exploration of possibilities of in underwater welding.

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