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Underwater Welding Technology
Cutting & Inspection

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Diver inspecting platform in Gulf of Mexico

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UNDERWATER WELDING TECHNOLOGY – CUTTING & INSPECTION

CONTENTS:

I. INTRODUCTION

II. HISTORY

III. CONVENTIONAL WELDING – MAIN PROCESSES

IV. UNDERWATER WELDING
   1. Underwater Wet Welding Methods
   2. Underwater Dry Welding Methods

V. UNDERWATER ROBOTIC WELDING

VI. UNDERWATER WELDING STANDARDS

VII. WELDING PROCEDURES SPECIFICATIONS

VIII. UNDERWATER CUTTING EQUIPMENT

IX. UNDERWATER WELDING INSPECTION

X. WELDING INSPECTOR TRAINING AND CERTIFICATION

XI. WELDING INSPECTOR KNOWLEDGES

XII. ELECTRODES – BASIC CLASSIFICATION

XIII. WELDING & CONSTRUCTION – GENERAL STANDARDS

XIV. REFERENCES
I – INTRODUCTION:

This manual is intended to provide information on the use of usual techniques for cutting and welding metals onshore and offshore, mostly underwater, the main subject of this study for all those who are interested to have knowledge, or being an underwater professional welder. Welder-divers who perform underwater cutting and welding must have greater skills and stamina than those doing the same work onshore. Diving equipment, depth, adverse currents, low temperature, lack of visibility and unstable position are all factors which make underwater cutting and welding difficult.

The commercial welder-diver can also be a certified underwater welding inspector. Anyway, both the welder and the inspector are often restricted to working for only a short time on the bottom, particularly at deeper depths. The success and speed of operations depend upon the conditions under which the diver must work, because the underwater environment imposes numerous limitations and restrictions on the operator and equipment. The use of correct techniques and procedures become extremely important in terms of work accomplished per hour.

In underwater welding, both welder and inspector, wear a dive suit and use a customized equipment for underwater environments. This equipment is designed to be as safe as possible, reducing the risk of drowning, electric shock, and the development of dangerous situations. The underwater welder is always a certified skilled welding professional and a trained diver as well, with the ability to effectively prepare and understand procedures for structural welding. Thus, the welder-diver must possess both certified welding skills and commercial diving knowledge.
A number of conventional welding techniques can also be used underwater, with SMAW or stick welding being among the most common. There are numerous applications for onshore and offshore welding skills, including repairing ships, working on oil platforms, maintaining underwater pipelines, and there are many ships and steel structures that require assembly or repairs, including onshore/offshore oil rigs equipment, pressure vessels, and oil tankers. Always remember that underwater welding is very dangerous, due limitations and restrictions on the welder-diver.

Another risk is the decompression sickness due to the increased pressure inherent in saturation diving and the buildup of gas pockets and oxygen, which are potentially explosive under certain conditions. Common precautions, include a system for emergency air, a team of stand-by divers to perform a rescue, and decompression chambers to help prevent decompression sickness following saturation diving.

If a welder has no prior commercial diving experience, it is necessary to attend a recognized commercial diving school, beginning his career as a diver tender (apprentice diver). The average time that this phase takes for most candidates is two years. Most diving contractors will require the welder achieves sufficient skill in wet and/or dry underwater welding to pass qualification tests and be certified in accordance with the requirements of AWS D3.6M, Underwater Welding Code.

If a welder is certified as a "scuba diver", this sport dive training does not include the safe use of commercial diving equipment, as recommended by the Association of Diving Contractors Consensus Standards for Commercial Diving Operations. Welder-diver qualifications vary from project to project. Like many professions, work availability is subject to supply and demand, whether you are free to relocate outside your place of residence (including overseas), taking valuable considerations other related skills and certified training you have, in addition to diving and welding.

II – HISTORY:

The Middle Ages (5th to 17th century) brought a phase in welding history where forge welding was front and center. At that time, forge welding used heated metal to join two pieces together, similar to the familiar blacksmith shop. Most innovations during this time in welding history used blast furnaces. This small incremental progress lasted until the beginning of the industrial revolution.

In beginning of 1800, Sir Humphrey Davy invented the electric arc, created between two carbon electrodes that were powered by a battery. The voltaic cell was discovered by Alessandro Volta where two different metals can be connected, and become a conductor when wet. Acetylene was discovered in 1836 by Edmund Davy, but was not practical in welding until about 1900, when a suitable blowtorch was developed. In 1856, James Joule welded a bundle of wires by using an electric current and internal resistance to create heat.

In 1885, Elihu Thomson applied for two patents called "Apparatus for Electric Welding", or resistance welding (RW). In 1887/88, the Russian Nikolai Benardos and the Polish Stanislav Olszewski were granted a patent for a rudimentary electric arc welder with a carbon electrode called the Electrogefest. The primary stated use was repair welding.
In 1888, Nikolay Gavrilovich Slavyanov a Russian inventor introduced the arc welding with consumable metal electrodes, or shielded metal arc welding, considered the second historical arc welding method, after carbon arc welding, invented by Nikolay Benardos and Stanislav Olszewski. From 1889 to 1892, Charles L. Coffin, considered to be the pioneer of welding in the US, received a patent for flash-butt welding, two patents for spot welding and a patent for bare metal electrode arc welding process.

In 1895, the Niagara Falls generation project power in US, transmitted alternating current (AC), at a frequency of 25 Hz to minimize losses in transmission (changed to 60 Hz in the 1950s). The Niagara Power Station No. 1, as it was then called, could eventually generate 50,000 horsepower (37 MW) of electricity with 10 generator rated 5,000 horsepower (3.7 MW) of the outside revolving field, vertical shaft type. The output was at 2,000 volts to serve in and around Niagara Falls.

In 1907/1908, Arthur P. Strohmenger and Oscar Kjellberg released the first coated electrodes. Strohmenger used clay and lime coating to stabilize the arc, while Kjellberg dipped iron wire into mixtures of carbonates and silicates to coat the electrode. In 1912 Strohmenger released a heavily coated electrode but high cost and complex production methods prevented these early electrodes from gaining popularity. Before 1920, welding was done with D.C. current produced by batteries.

In 1925, Konstantin Khrenov, a professor soviet engineer, taught and researched welding techniques and equipment, but more than anything, Khrenov wanted to find a way to weld underwater for quicker vessel repairs. With the help of others, Khrenov devised a waterproof coating for the electrodes and stable power source. Newly equipped, he began laboratory experimentations.

In the late 1925 to early 1930s with development of AC electricity, welding machines gained in popularity. The Americans were more hesitant, but began to recognize the benefits of arc welding, instead of riveting. In 1927 the development of an extrusion process reduced the cost of coating electrodes while allowing manufacturers to produce more complex coating mixtures designed for specific applications. Lincoln Electric manufactures a variable voltage DC welding machine, and introduces the first commercial welding machines.

In 1932 after successful experimentation with coated electrodes, Konstantin Khrenov and engineers, traveled to the Black Sea for further testing. In 1936, crews performed underwater welding in the effort to lift an enormous ship called Boris out of the Black Sea. Thus, after many successful tests, underwater welding was born. The granulated flux known as “Submerged Arc Welding (SAW)”, was also developed in 1932, for construction of steel structures and pipe fabrication.

In 1940, fascinated with Khrenov’s work, Professor Cyril D. Jensen started an underwater welding program in the US. However, when the US was brought into World War II, he received a leave of absence from LeHigh University, in 1942, and traveled to Annapolis naval engineering experiment station for welding research. 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.
In 1941, Russel Meredith invented the Gas Tungsten Arc Welding (GTAW), patent issued in 1942, also called HELIARC or TIG. In 1943, the Gas Metal Arc Welding (GMAW) was introduced by C.B. Voldrich, P.J. Rieppel and Howard B. Cary, developed at Dow and Northrup Corporations and then licensed to Linde Corporation. In the 1950s manufacturers introduced iron powder into the flux coating, making it possible to increase the welding speed.

In 1957, the Flux-cored Arc Welding (FCAW) process debuted, resulting in greatly increased welding speeds, and that same year, The Plasma Arc Welding (PAW) was invented, patented in 1957 by National Cylinder Gas Company. In 1960, The Laser Beam Welding (LBW) appeared and proved to be especially useful in high-speed, automated welding. Both of these processes, however, continue to be quite expensive due the high cost of the necessary equipment.

III – CONVENTIONAL WELDING - MAIN PROCESSES:

Basically, in the electric welding processes, an arc is produced between an electrode and the work piece (base metal). The AWS D1.1 describes the welding procedures to be used with the various welding processes. To remind the concepts, the main arc welding processes used in heavy and medium carbon and alloy steel manufacturing that can be used in underwater welding, are:

- **SMAW**: Shielded Metal Arc Welding - stick welding electrode;
- **GMAW**: Gas Metal Arc Welding or MIG welding - solid wire or metal cored wire;
- **GTAW**: Gas Tungsten Arc Welding or TIG welding - rod or solid wire;
- **FCAW**: Flux Cored Arc Welding - gas-shielded flux cored wire;
- **PAW**: Plasma Arc Welding - rod or solid wire, similar to (GTAW);
- **CAW**: Carbon Arc Welding - non-consumable carbon (graphite) electrode.

1. **SMAW (Shielded Metal Arc Welding)**: Also known as Manual Metal Arc welding (MMA or MMAW), flux shielded arc welding or informally as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld.
An electric current, in the form of either alternating current (AC) or direct current (DC), is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

Once the arc has been established and the arc length adjusted, the electrode is inclined to an angle of approximately 20 degrees with the vertical. To achieve comparatively deeper penetration, electrode angle with the vertical is further reduced. The electrode is progressed along the joint at a constant speed, it is lowered, at the same time, at a rate at which it is melting.

**Welding Equipment**: AC or DC welding supply, electrode holder and welding cables. AC transformers and DC generators or rectifiers can be employed for welding with covered electrodes. The most commonly used power source for AC welding is a transformer, which may be operated with single phase, two phases or three phases. Current range up to 600A, depending on the necessary regulation, open circuit voltage between 50 to 50 volts.

2. **GMAW (Gas Metal Arc Welding)**: Is also referred to by its subtypes, Metal Inert Gas (MIG) and Metal Active Gas (MAG). GMAW is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece, which heats the workpiece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air.

The Mig welding process operates on D.C. (direct current) usually with the wire electrode positive. This is known as “reverse” polarity. The “straight” polarity is seldom used because of the poor transfer of molten metal from the wire electrode to the workpiece. Welding currents of from 50 amperes up to more than 400 amperes are commonly used at welding voltages from 15V to 32V. A stable, self-correcting arc is obtained by using the constant potential (voltage) power system and a constant wire feed speed.

Continuing developments have made the Mig process applicable to the welding of all commercially important metals such as steel, aluminum, stainless steel, copper and several others. Materials
above 0.030 in. (0.76 mm) thick can be welded in all positions, including flat, vertical and overhead. It is simple to choose the equipment, wire electrode, shielding gas, and welding conditions capable of producing high-quality welds at a low cost.

The basic GMAW process includes four distinctive process techniques: Globular Transfer, Short-Circuiting Transfer, Spray Arc Transfer, Pulsed-Spray and a special technique designated as Rotational Spray Transfer, and each of them has distinct welding properties, corresponding advantages and limitations. These techniques describe the manner in which metal is transferred from the wire to the weld pool.

3. GTAW (Gas Tungsten Arc Welding): Also known as Tungsten Inert Gas (TIG) is an arc welding process that uses a non-consumable tungsten electrode. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon). Normally a filler metal rod is used, though some welds known as autogenous welds, do not require it. A constant-current welding power supply produces energy through a column of highly ionized gas and metal vapors known as plasma.

4. FCAW (Flux Cored Arc Welding): Is a semi-automatic or automatic arc welding process that requires a continuously-fed consumable tubular electrode containing a flux core which is filled with a mixture of mineral flux and powder with a constant-current welding power supply. An external shielding gas is sometimes used, but often the flux itself is enough to generate the necessary protection from the atmosphere. The difference between FCAW and GMAW is that the flux cored wire is hollow and is filled with a flux that produces a slag to protect the weld.

There are two basic process variants; self-shielded FCAW without shielding gas and shielded FCAW with shielding gas. The difference is due to different fluxing agents in the consumables, which provide different benefits to the user. The fluxing agents in FCAW without shielding gas, are designed to not only deoxidize the weld pool, but also for shielding the weld pool, and metal droplets from the atmosphere. The flux in gas-shielded FCAW deoxidizes the weld pool and, to a
smaller degree, provides secondary shielding from the atmosphere. Usually, self-shielded FCAW is used in outdoor conditions where wind would blow away a shielding gas.

4. **PAW (Plasma Arc Welding):** Is an arc welding process similar to Gas Tungsten Arc Welding (GTAW) using a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle. The main difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 20,000°C. Plasma Arc Welding is advanced in relation to GTAW process.

5. **CAW (Carbon Arc Welding):** Is a process which produces coalescence of metals by heating them with an arc between a non-consumable carbon (graphite) electrode and the work-piece. It
was the first arc-welding process ever developed, but today it is not used for many applications, having been replaced by Twin Carbon Arc Welding, SMAW and other variations. The Carbon Arc Welding electrode is used to produce an electric arc between the electrode and the materials being welded. This arc produces extreme temperatures in up to 3,000°C. At this temperature the separate metals form a bond and become welded together.

**Shielding Gases:** The primary purpose of a shielding gas is to protect the arc and weld puddle from contaminating effects of the atmosphere, such as oxygen and water vapor. The nitrogen and oxygen of the atmosphere, if allowed to come in contact with the molten weld metal, cause porosity and brittleness. The choice of the proper shielding gas for a specific application is based on the type of metal to be welded, arc characteristics and metal transfer, availability, cost of the gas, mechanical property requirements, and penetration and weld bead shape.

1. **Carbon dioxide:** Carbon dioxide is manufactured from fuel gases which are given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a by-product of calcination operation in lime kilns, from the manufacturing of ammonia and from the fermentation of alcohol, which is almost 100 percent pure. Used in GMAW, GTAW (more popularly known as MIG and TIG, respectively) and FCAW.

2. **Argon and carbon dioxide:** Are sometimes mixed for use with flux-cored arc welding. A high percentage of argon gas in the mixture tends to promote a higher deposition efficiency due to the creation of less spatter. The most commonly used gas mixture in GMAW, GTAW and FCAW is a 75 percent argon-25 percent carbon dioxide mixture. The gas mixture produces a fine globular metal transfer that approaches a spray. It also reduces the amount of oxidation that occurs, compared to pure carbon dioxide.

3. **Argon-oxygen mixtures:** Argon-oxygen mixtures containing 1 or 2 percent oxygen are used for some applications either in GMAW, GTAW and FCAW. Argon-oxygen mixtures tend to promote a spray transfer which reduces the amount of spatter produced. A major application of these mixtures is the welding of stainless steel where carbon dioxide can cause corrosion problems.
IV – UNDERWATER WELDING:

The underwater welding process came into existence after the development of waterproof electrodes by Konstantin Khrenov, a soviet engineer, who performed underwater welding on a ship in the Black Sea, in 1936. The main difficulties in underwater welding are the presence of a higher pressure due to the water head, chilling action of the water on the weld metal (change of 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.

Underwater welding processes are classified as wet or dry based on exposure conditions of the ambient environment. 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. However, with appropriate consumable design, it is possible to reduce porosity and to enhance the metal toughness through microstructural refinement. Furthermore, complete insulation of the welding circuit is an essential requirement for underwater welding.

1. UNDERWATER WET WELDING METHODS:

In wet welding technique, even a complex structure may be welded. The most commonly used wet welding technique is the Shielded Metal Arc Welding process (SMAW) and the Flux Cored Arc Welding (FCAW), using the self-shielded flux cored arc welding. However, from an economic point of view, the wet welding technique with coated electrodes (SMAW) comes as the first consideration for general underwater welding. This is carried out by means of special waterproof stick electrodes, with no physical barrier between water and welding arc.

Wet underwater welding directly exposes the welder-diver and electrode to the water and surrounding elements. Welders usually use around 300-400 amps of direct current to power an electrode, using varied forms of arc welding, employing a waterproof electrode. Other processes that are used also include the Flux-cored Arc Welding (FCAW). In each of these cases, the welding power supply is connected to the welding equipment by specially isolated cables, installed from topside or platforms above the water.

The welder instructs the surface operator to make and break the contact, as required, during the procedure. The contacts should only be closed during actual welding, and opened at other times, particularly when changing electrodes. Direct current is used, and a heavy duty isolation switch is installed in the welding cable at the surface control position, so that the welding current can be disconnected when not in use. Wet welding with a stick electrode is done with similar equipment to that used for dry welding, but the electrode holders are designed for water cooling and are more heavily insulated. A constant current welding machine is used for Manual Metal Arc welding.

The process is generally limited to low carbon equivalent steels, especially at greater depths, because of hydrogen formation, which is a strong cause of cracking.