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# Underwater Welding Technology Cutting & Inspection

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# UNDERWATER WELDING TECHNOLOGY – CUTTING & INSPECTION

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**OBS.:** This is a didactic and professional course. It´s highly recommended downloading and printing the course content for your study, before answering the quiz questions.

**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.

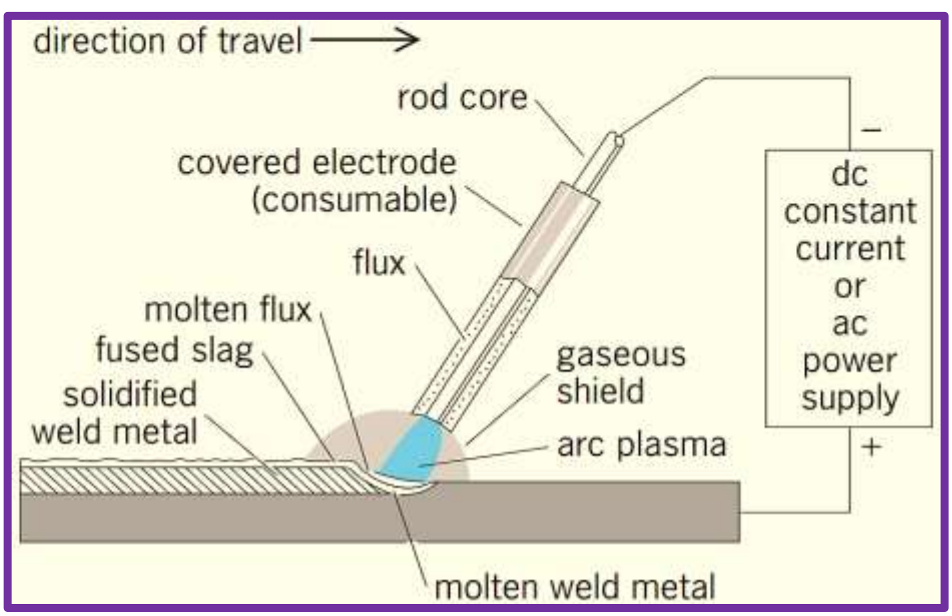
In 1957, the Flux-cored Arc Welding (FCAW) process debuted, resulting in greatly increased welding speeds, and that same year, The Plasma Arc Welding (PAW) was invented, patented in 1957 by National Cylinder Gas Company. In 1960, The Laser Beam Welding (LBW) appeared and proved to be especially useful 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.

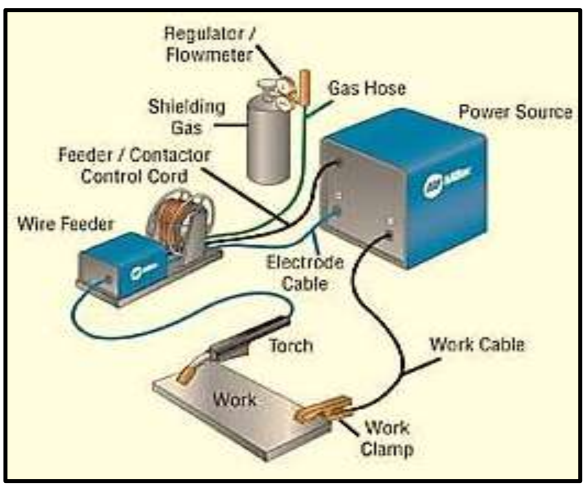


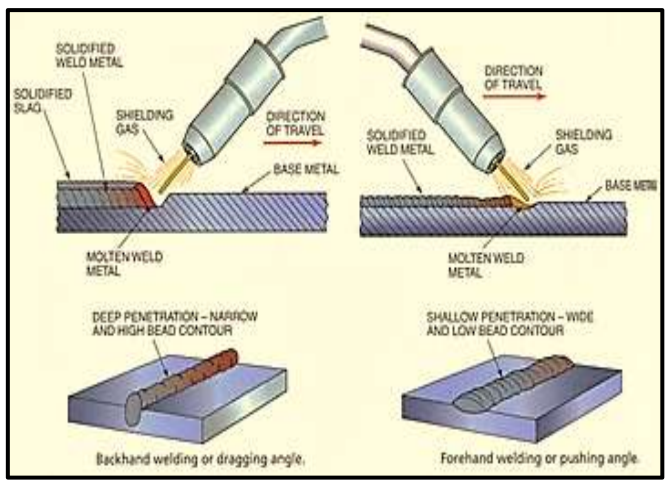
An electric current, in the form of either alternating current (AC) or direct current (DC), is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing 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 of 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.



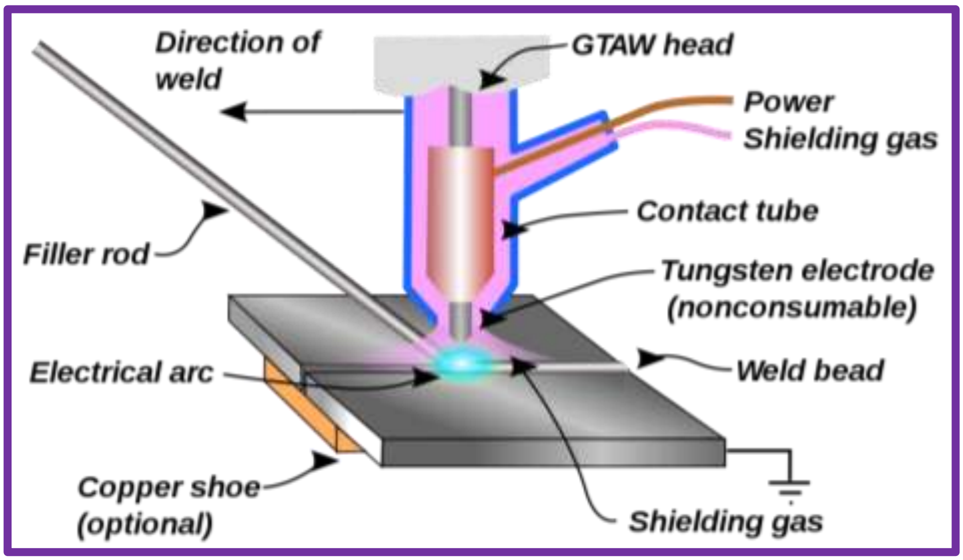




The Mig welding process operates on D.C. (direct current) usually with the wire electrode positive. This is known as “reverse” polarity. The “straight” polarity is seldom used because of the poor transfer of molten metal from the wire electrode to the workpiece. Welding currents of from 50 amperes up 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.

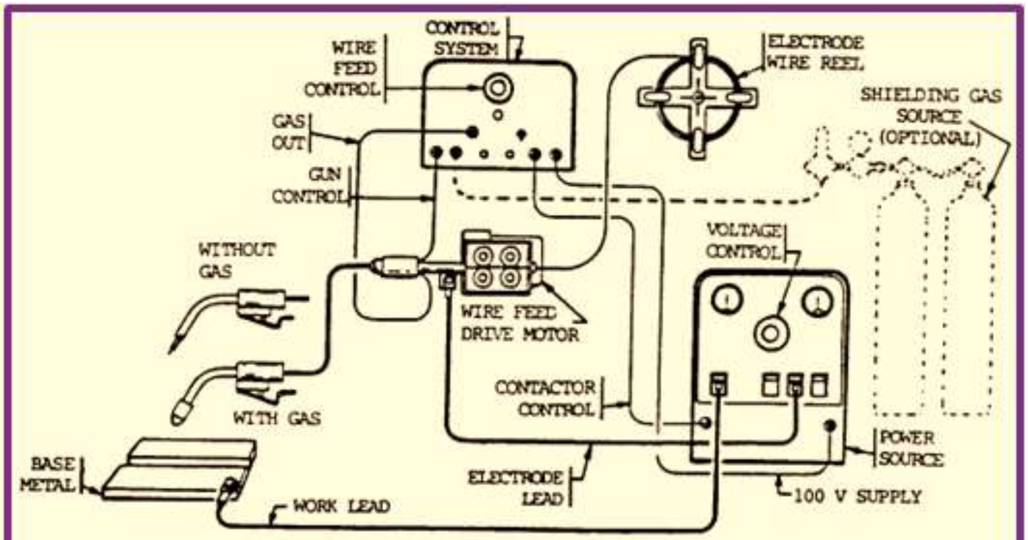
The basic GMAW process includes four distinctive process techniques: Globular Transfer, Short-Circuiting Transfer, Spray Arc Transfer, Pulsed-Spray and a special technique designated as Rotational Spray Transfer, and each of them has distinct welding properties, corresponding advantages and limitations. 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.



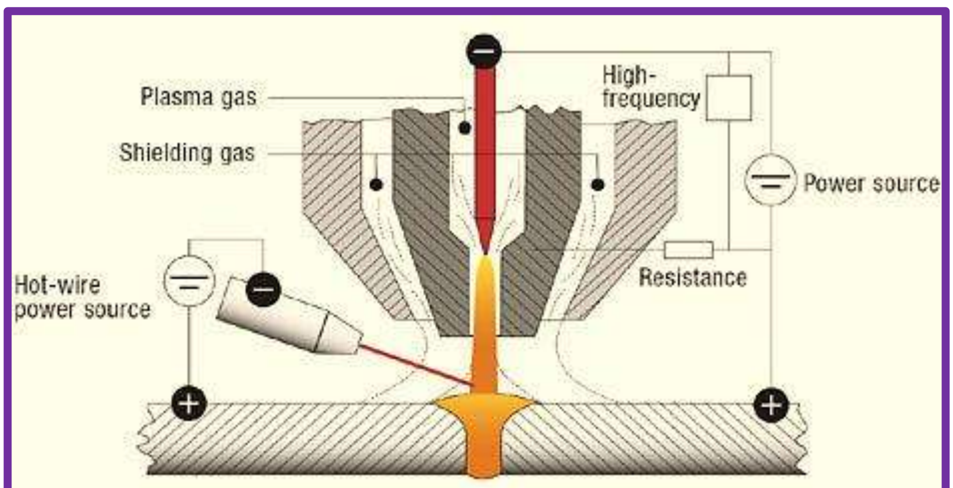

**4. FCAW (Flux Cored Arc Welding)**: Is a semi-automatic or automatic arc welding process that requires a continuously-fed consumable tubular electrode containing a flux core which is filled with a mixture of mineral flux and powder with a constant-current welding power supply. An external shielding 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.



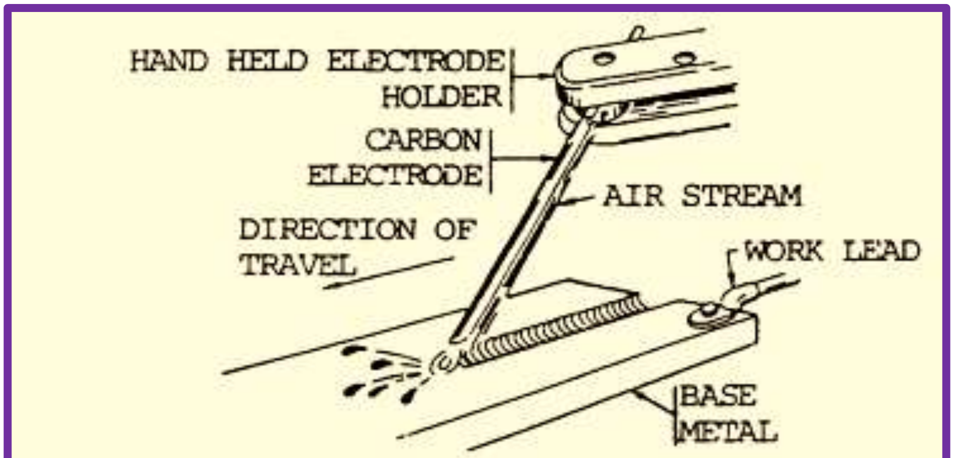

Equipment for flux-cored arc welding.

**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.




*Basic components of a plasma welding torch*

**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.



Process diagram for air carbon arc cutting.

**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.

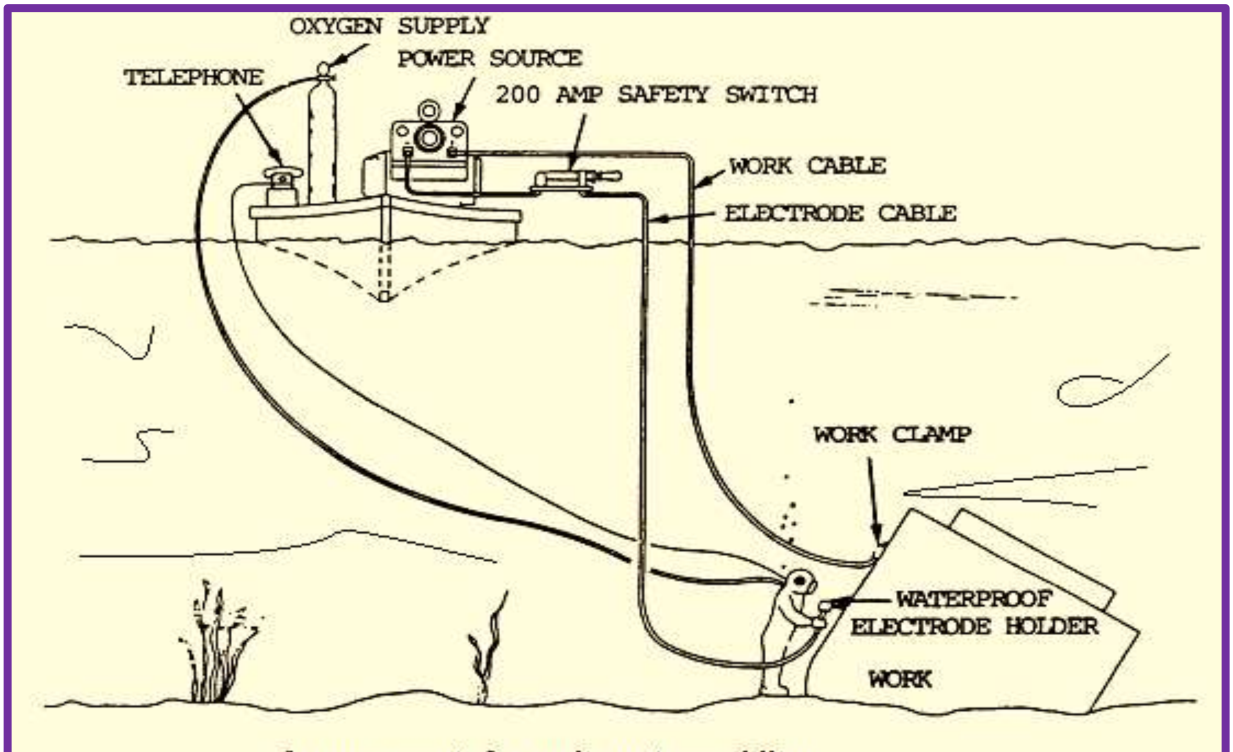
Wet underwater welding directly exposes the welder-diver and electrode to the water and surrounding elements. Welders usually use around 300-400 amps of direct current to power an electrode, using varied forms of arc welding, employing a waterproof electrode. Other processes that are used also include 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. The electric arc heats the workpiece and the welding rod, and the molten metal is transferred through the gas bubble around the arc. The gas bubble is partly formed from decomposition of the flux coating on the electrode, but it is usually contaminated to some extent by steam. Current flow induces transfer of metal droplets from the electrode to the workpiece and enables positional welding by a skilled operator. Slag deposition on the weld surface helps to slow the rate of cooling, but rapid cooling is one of the biggest problems in producing a quality weld.

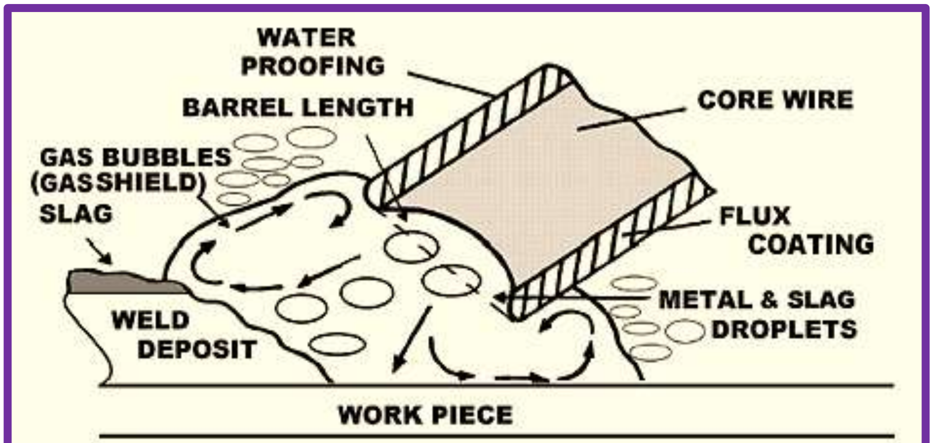
Wet welding does not need any complicated experiment set up, it's economical and can be immediately applied in case of emergency and accident, as it does not need water to be evacuated. However, difficulties in welding operation due to lack of visibility in water, presence of sea current, ground swells in shallow water and inferior weld qualities (increased porosities, reduced ductility, greater hardness in the heat affected zone (HAZ), hydrogen pick up from the environment) are the notable disadvantages of wet welding technique.

**1.1. SMAW - Wet Welding Development**: Regarding to physical principles of operation, there is no difference between common surface MMA (Manual Metal Arc) welding and underwater wet-stick welding. Both processes use basically the same equipment, with the exception of the necessary waterproof electrodes and the safety apparel. In underwater welding the arc does not behave as in the air. The activity of the gas bubbles tends to create a rather unstable arc condition, with a somewhat more confusing weld puddle, compared with surface welding, which must be mastered by the diver before successful welding can take place.



Arrangements for underwater welding

Wet welding is generally faster and less expensive than dry welding. Hyperbaric vessels, habitats and cofferdams required for most dry underwater weldings, may be difficult or impossible to install on geometrically complex structures or in physically restricted areas. However, no active thermal treatment is feasible due direct exposure to underwater environment. Friction stud welding has also been used with some considerable success to make wet spot welds.



Shielding of the welding arc and molten pool with a covered stick electrode.

**1.1.1. Technical Problems of Wet Weldings**: First of all, this technique is not as versatile as dry welding, regarding to the variety of other processes that can be performed (i.e. GMAW, GTAW, PAW). However, even in these enclosures, SMAW is the most frequently used process. Another problem is that quenching causes the formation of martensite in the Heat Affected Zone (HAZ). If the rate of cooling from the transformation temperature is too fast, a needle-like structure, called martensite may appear, and the formed crystal structure may inhibit dislocation of the electrode holder movement.

The HAZ means that the section of a weld bead, can be heated above the A1 metal transformation temperature (723 ºC), but not reaches the melting point. Consequently, there is a formation of martensite, which causes welds to be brittle, hard, and lack of toughness. Quenching also traps non-gaseous contaminants, such as oxide slags, and this entrapment further increases weld porosity. Pockets of hydrogen gas produce tensile stresses, which over time can initiate trans-granular cracks, since this phenomenon generally occurs after the weld cools too much rapidly.

**1.1.2. Material Limitations for Wet Welding**: According to some academic studies, quenching puts a lid on certain materials to be joined by wet SMAW. The most recommended to be used with this technique, are steels that derive their properties from thermal treatment (such as, quenching and tempering). Low alloy (less than 0.2% carbon), and high yield strength up to 130 ksi, quenched and tempered steels are used widely in the construction of naval surface ships and submarines. Commonly, after quenching these alloys, they are heated to a maximum temperature below A1, and gradually cooled to ambient temperature, with a process known as tempering, which causes the martensite to be softened and toughness increases.

Carbon contents of steels are often compared using an index known as carbon equivalent (CE). Thus, carbon equivalent (CE) is a measure of both carbon content and, to a lesser extent, the contents of various other elements of alloy steels. In resume, positive CE coefficients generally inhibit weldability, and negative CE coefficients improve weldability. The American Welding Society (AWS) defined a specific relationship to be used when computing CE coefficients for wet SMAW using a conservative equation. Because of this relationship the US Navy has restricted the use of wet SMAW to base plates with CE coefficients of less than 0.4%, as indicated below:

$$\%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

**1.1.3. Advances in Wet SMAW Electrodes**: During World War II, Navy divers coated standard SMAW electrodes with paint to protect the flux, to be used underwater, since then, improvements have included better waterproof electrodes, designed chemical fluxes and special products to be used underwater. The water trapped can vaporize rapidly when arc is struck and explode the flux off of the electrode, leaving it unprotected.

Ferritic electrodes have the best performance and are divided into two groups: iron oxide-based (oxidizing) electrodes and rutile-based electrodes. According to tests, iron oxide-based (oxidizing) type electrodes presented inferior performance regarding to the arc stability, and rutile type electrodes presented the best results, considering mechanical properties. Then, evaluations in two or more separate wet SMAW applications, ferritic electrodes produced the highest quality welds.

Then, special chemical compositions have been formulated for wet welding fluxes, to burn more slowly than the core wire melting rate, providing a protective cavity for the arc and preventing side arcing in the contact, when SMAW electrodes. These compositions have low hydrogen content and designed to be highly exothermic, as reduced hydrogen content, limits the entrance on the weld, from the flux. Hot burning fluxes increase arc temperature and limit hydrogen input to the weld, such as rutile electrodes ($TiO_2$) and iron powder/oxidizing fluxes.

Welders were able to produce sound welds in base plates with CEs of 0.406 and below, using the prepared E7014 electrode. Other electrodes tested, as austenitic core wires stabilized by addition of alloying elements as nickel and chromium, produced the poorest weldability, and under bead cracks. A Welding Institute evaluation also concluded that ferritic electrodes, specifically those coated with an iron-oxide flux produces the best wet SMA welds.

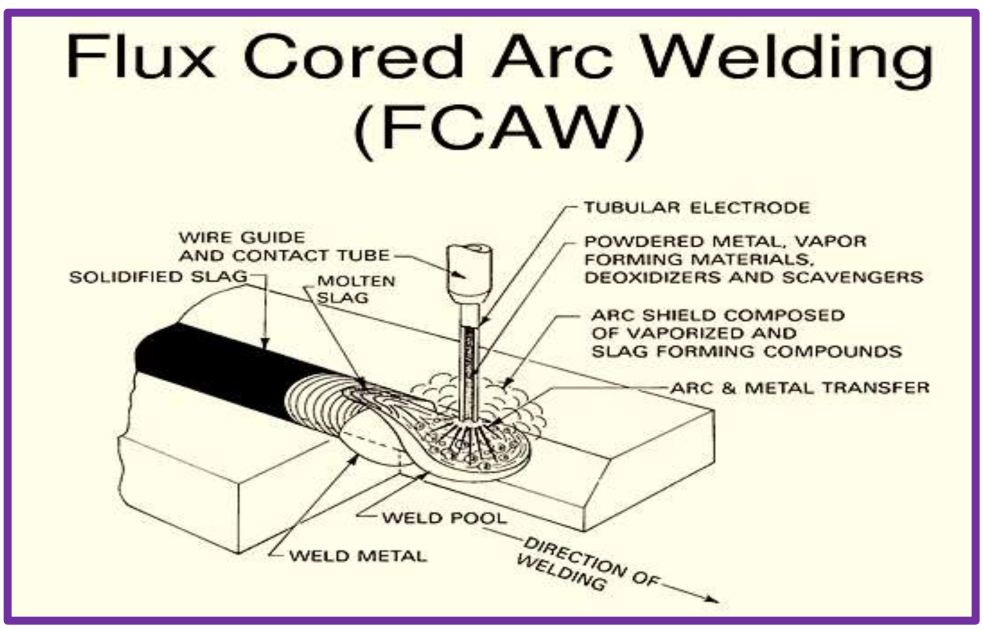
In 1990, Welding Engineering Services Inc. and the Naval Sea Systems Command conducted an evaluation of eight electrodes, specifically designed for wet SMAW at Norfolk Naval Shipyard. Fillet and butt welds were made on steel plates, with carbon equivalents ranging from 0.350 to 0.449, in a tank in the Elizabeth River. Destructive and non-destructive testing of the completed welds resulted that the E7014 ferritic electrode gave the highest weldability rating.

Improvements in wet SMAW electrodes, fluxes, and waterproof coatings, have made it possible to produce satisfactory welds, such as low carbon non-heated steel joints, not subjected to heavy environmental loads. Further improvements in wet SMA weld qualities, and broadening of materials, brought solutions to the primary problem associated with this process; rapid welding cooling. The rutile mild steel electrodes are the most widely used. The electrodes may be either carbon manganese (C/Mn) or mild steel and stainless steel (duplex).

**1.2. FCAW - Wet Welding Development**: The FCAW process utilizes a continuously fed consumable wire which consists of a metal sheath containing flux and alloying elements. The flux formulation for a self-shielding flux-cored wire is used to stabilize the welding arc, form a slag and produce shielding gas to protect the molten metal transfer and weld puddle, similar to the SMAW process. The disadvantages of typical self-shielding flux-cored wires include:

- Halogen-containing components within the flux chemistry disassociated in the arc and free ions are introduced into the water. The disassociated halogen ions may attack the passive corrosion resistant oxide layer typical of austenite stainless steel and nickel based alloys, promoting corrosion cracking.
- Self-shielding flux chemistries specifically for underwater "wet" welding of stainless steel and nickel based alloys are unavailable. Modifications to adjust for gas shielding effectiveness, slag detachability and arc stabilization must be considered.

The protective flux is inside the tubular wire (0.9 to 3.2 mm diameter), fed through the welding gun much like Gas Metal Arc Welding (GMAW). FCAW is DC only (100-500A, 16-40V, 2-20 kW). The two types of FCAW are the **gas-shielded flux-cored** arc welding (FCAW-G), which requires an auxiliary shielding gas source in addition to the flux, at the core of the wire; and the **self-shielded flux-cored** arc welding (FCAW-S), which does not require an auxiliary shielding gas. The Flux-Cored Arc Welding process was also considered a viable option for underwater development, due to the ease of automation, out of position welding proficiency, and self-shielding capabilities.




The demand for underwater welding technology is increasing because of the fast development of the exploitation of marine resources, and Flux-Cored Arc Welding (FCAW) has also been applied underwater for stainless steels, because of its high performance and efficiency. The bead geometry (including bead width, penetration and reinforcement height) of an underwater weld is an important role in determining the mechanical properties of a weld joint.

Recent developments of Ni-based flux-cored filler materials have provided improved "wet" weldability and halogen-free flux formulations, specifically designed for **wet welding** applications. Excellent results have been accomplished with cladding, fillet welds and multi-pass groove welding applications. Development has encompassed Ni-based alloy 625, 182 and 82 compositions. Alloy 625 is a Cr-Ni alloy containing 9% Mo, which provides a weld deposit highly resistant to stress-corrosion cracking, crevice corrosion and pitting. Alloy 625 was evaluated on 304 stainless steel, alloy 600 and 690 base materials, and on alloy 82 cladding material, at depths of 3 and 20 feet.

As with the Ni-based materials, improved underwater capabilities and halogen-free flux formulations have been developed with the stainless steel flux-cored wires. Excellent results have been achieved on fillet welds and multi-pass groove weld applications, at depths of 3, 20 and 50 feet. Mechanical tests of the 308L stainless steel flux-cored wires, have demonstrated the ability to exceed the acceptance criteria for ASME Section IX. The underwater welding development has resulted in code quality mechanical properties, as can be seen in Table below.

Mechanical Test Results for Stainless Steel (FCAW)

| Sample No. | Position and Joint Configuration | Qualification Test | Ultimate Stress | Comments |
|---|---|---|---|---|
| L252 | 1G, 70°included angle | Side Bends (2T) | -------- | Acceptable |
| L252 (A) | 1G, 70°included angle | Reduced Section Tensile Test | 94,000 psi | Acceptable |
| L252 (B) | 1G, 70°included angle | Reduced Section Tensile Test | 91,500 psi | Acceptable |

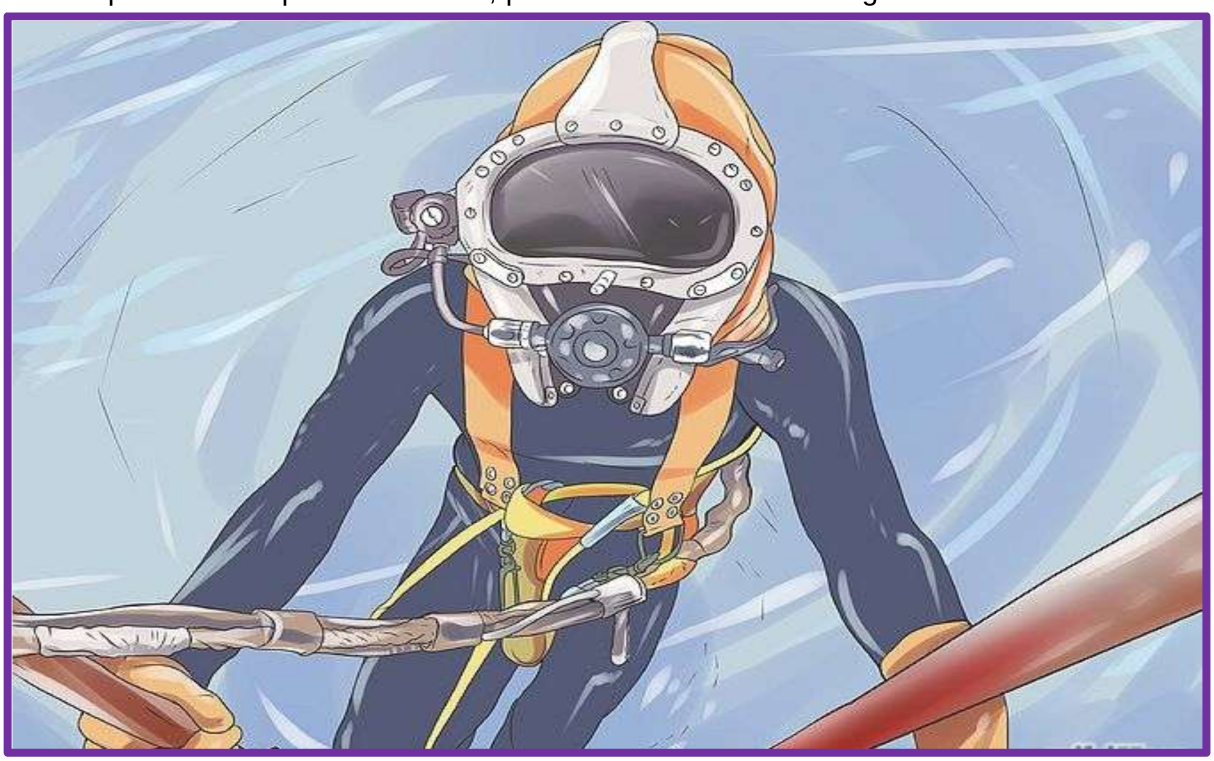
Note:
1. All test plates are 1/4-inch Alloy 600 base material welded with Alloy 625 filler material.
2. Reduced section tensile test performed by Herron Testing Labs in accordance to ASME Section IX.

Due a number of competing process parameters involved, determining optimal welding conditions in a given situation is complex. Actually, many trials are often necessary to fix the process in most cases. Therefore, if the bead geometry of an underwater FCAW joint can be predicted based on the welding parameters (e.g., arc current, voltage and travel speed) by a mathematical model, the number of trial runs would be reduced and the process of fixing schedules would be simplified.

**a.** Wet Shielded Metal Arc Welding Arc Welding (SMAW) preparation:

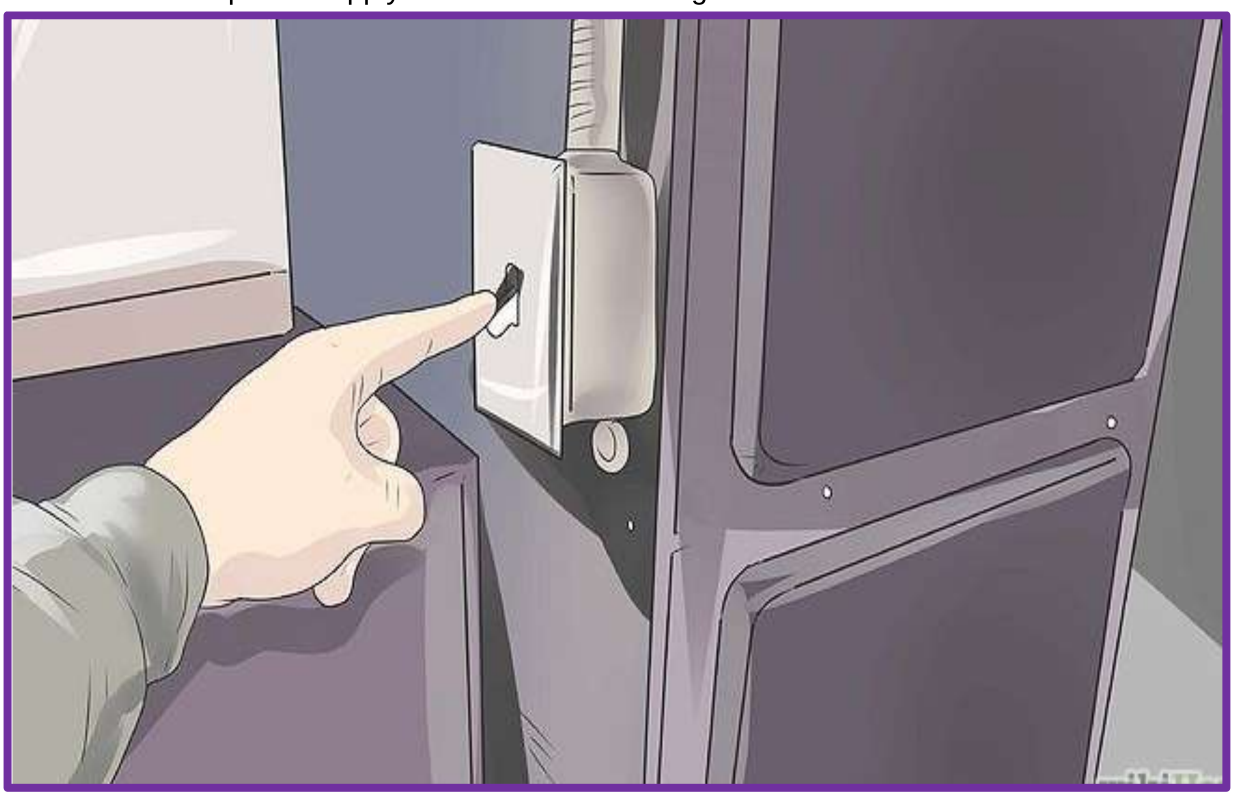
1. Investigate the joint to be welded and identify the types of metals involved:

2. Prepare the adequate electrodes, plan-out the order of welding and dive to the weld site:



3. Weld the joint, ensuring that the flux coating of the welds is coming off as expected, and that too much hydrogen is not approaching the joint:

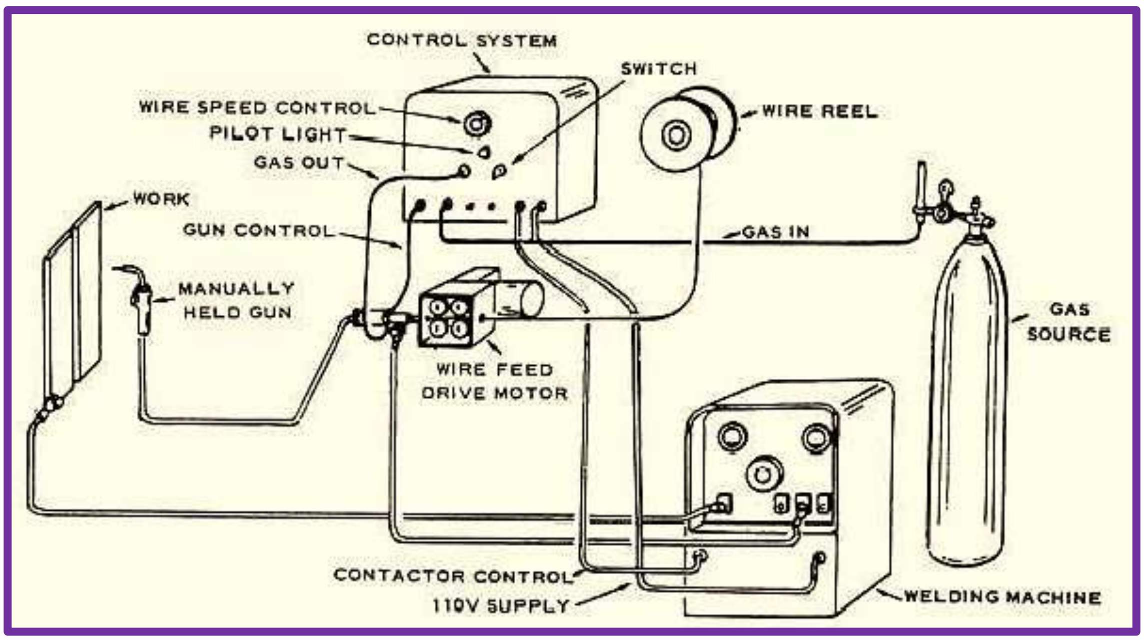
4. Turn off the power supply as soon as the welding is done:



**Filler Efficiency**: Complex factors deal with increasing material costs. Gas Tungsten Arc (TIG) and Plasma Arc Welding (PAW), can actually deposit 100% of the filler metal. Gas metal Arc Welding (GMAW) gives about 95% utilization. Flux-cored Welding (FCAW) is the lowest of the continuous wire processes, normally in the 80% plus range. Covered electrodes have the lowest utilization (SMAW) due the stub end and coating loss, which results in approximately 65% of the weight of the filler metals purchased actually being deposited in the weld joint.

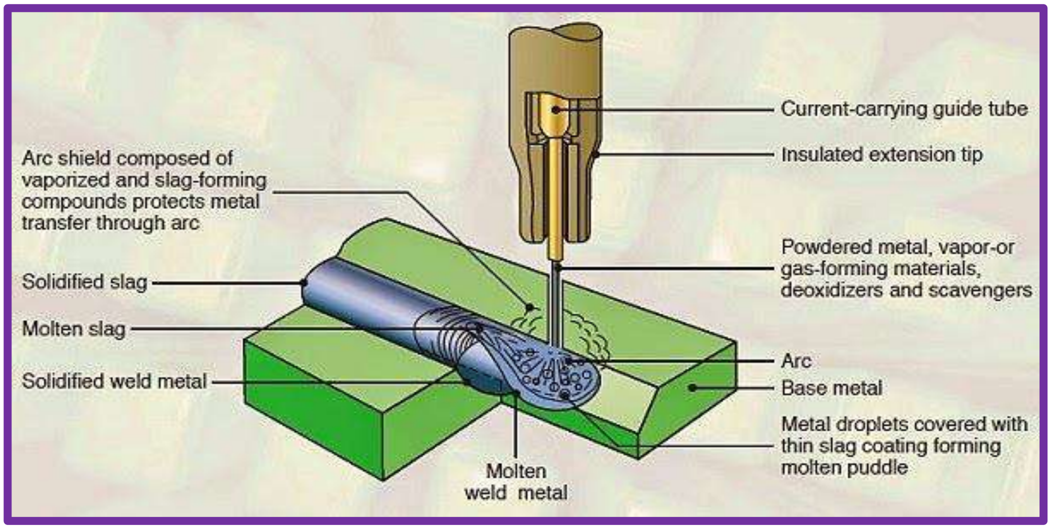
Another factor closely related to filler metal efficiency and operator factor is the total deposit of weld metal to produce a given weldment. If the amount of weld metal can be reduced to make a weld it is an economic savings, thus there is an advantage to methods such as narrow gap welding. The higher penetration characteristics of $CO_2$ welding, gives an advantage over Shielded Metal Arc Welding because fillet weld sizes can be reduced and the same weld strength retained.

**b. Flux Cored Arc Welding (FCAW) Preparation**: Shown in image below, is similar to Gas Metal Arc Welding (GMAW), except that the electrode is tubular in shape and is filled with flux.



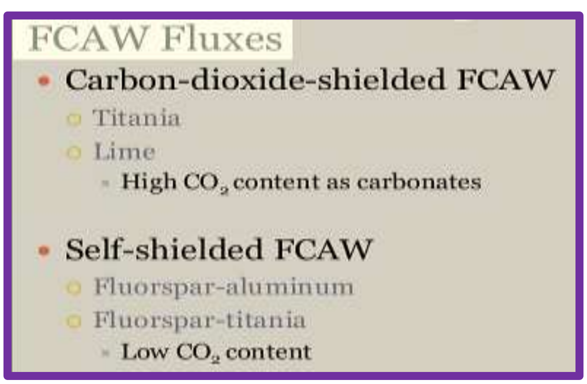

The welding zone protection from atmosphere contamination is assured by the products in the electrode's flux (designated as FCAW-S self-shielded flux cored arc welding) and sometimes by additional gaseous protection (designated as FCAW-G gas shielded flux cored arc welding). The slag created by the flux gives an additional protection during cooling time, but has to be removed after the welding.

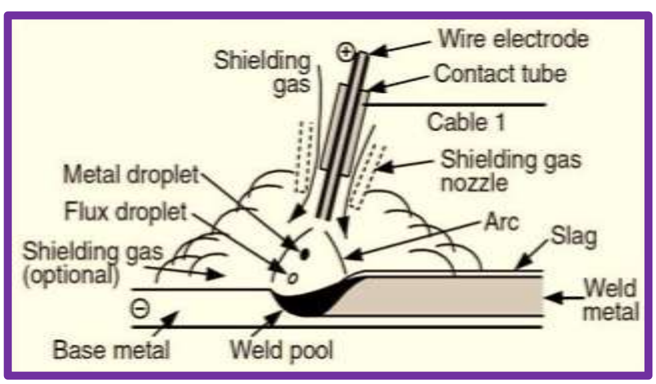
Flux-cored electrodes may be used for welding carbon steels, low alloy high strength steels, stainless steels, high strength quenched and tempered steels and abrasion resistant steels. The FCAW cored electrodes produce a more stable arc, improve weld contour, and produce better mechanical properties of the weld metal. Flux-cored tubular electrodes are provided in long coiled lengths.




**FCAW-S**: This welding pattern **does not require a shielding gas**, and is common for field or outdoor welding, where can be wind interference with gas shielded welding. Compositions of the core electrodes can be varied according to specific welding applications; however each manufacturer has own formulas for the flux ingredients. The basic functions of the flux ingredients are:

- ✓ **Deoxidizers and Denitrifiers**: Since nitrogen and oxygen can cause porosity or brittleness, deoxidizers such as **manganese and silicon** are added. In the case of self-shielded electrodes, denitrifiers such as aluminum are added, to purify the weld metal.
- ✓ **Slag Formers**: Slag formers such as **oxides of calcium, potassium, silicon or sodium** are added to protect the molten weld puddle from the atmosphere. The slag aids in improving the weld bead shape and "fast freezing" slags help hold the weld puddle for out-of-position welding. The slag also retards the cooling rate, especially important when welding the low alloy steels.
- ✓ **Arc Stabilizers**: Elements, such as **potassium and sodium**, help produce a smooth arc and reduce spatter.
- ✓ **Alloying Elements**: Elements, such as molybdenum, chromium, carbon, manganese, nickel, and vanadium, are used to increase strength, ductility, hardness and toughness.
- ✓ **Gasifiers**: Minerals, such as **fluorspar and limestone**, are usually used to form a shielding gas in the self-shielded type wires.



**FCAW-G**: This welding pattern use **gas shielded flux cored electrodes** that require an adequate gas shield be present at all times. Gas shielded flux cored electrodes are available in diameters of 0.035" to 1/8" and utilize reverse polarity (electrode positive) welding current, resulting in high deposition rates, deep penetration, and a relatively smooth arc. $CO_2$ is the most common shielding gas used; however, Argon-$CO_2$ mixtures maybe recommended for some types. The gas shield effectively protects the arc from atmospheric oxygen and nitrogen, but some oxygen may be present from the dissociation of the shielding gas.

The electrodes have a designation system that identifies the type of electrode. As an example we will use an "E71T-1" and explain what the coding system means:

- **E** - Stands for electrode.
- **7 –** Means that the filler metal has a minimum of 70,000 psi of tensile strength of weld.
- **1 –** Identifies what position the electrode is designed to weld in. There are only two designations and they are zero and one. "0" means the electrode can only weld in the flat and horizontal positions. "1" means it can weld in any position.
- **T** – Stands for "tubular" and is how you know it is a flux cored electrode. If it is a MIG electrode, it will have an "S", which stands for "solid".
- **1** – Identifies the type of flux that is inside of the electrode.

When setting your FCAW machine there are two types of transfers that can be used:

- **Globular transfer**: Is commonly used on thinner metals, not recommended for normal welding applications, where the voltage and wire feed speed produce a resulting large weld as irregularly-shaped "globs" falling into the weld pool under the action of gravity. Typically, a few pops and globs per second can be seen forming on the wire, dropping into the weld joint. To use globular you need to have a Dual-Shielding electrode, with a high percentage of Argon gas that creates a fluid arc.

- **Spray transfer**: Is the most common type used to weld and has a deep, fast, crackling sound, generally in the flat position, because of the large weld puddle. This transfer must not be confused with true spray transfer, because the used voltage and amperage, spray the metal into the joint, even though it crackles like a short circuit.

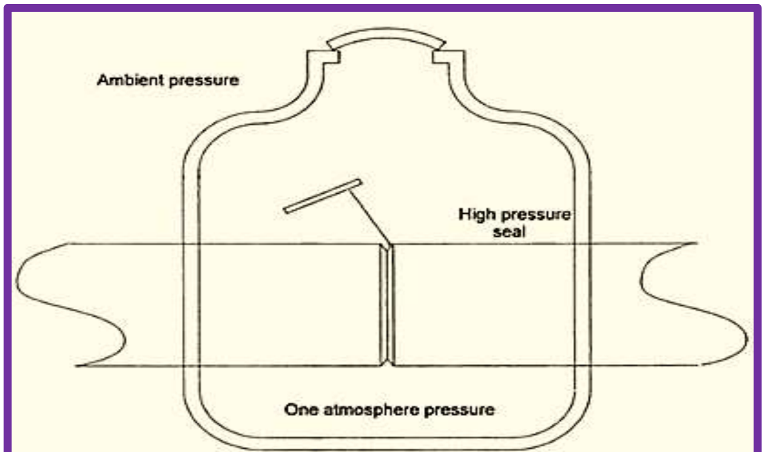
**FCAW Techniques**: The techniques used are similar to Stick and MIG welding. There are the whipping, circles and weave techniques/patterns. The first thing the welder has to know about is **forehand vs. backhand** welding. Forehand is when the welder push the puddle in the direction of the weld, which produces a shallow but wide, penetrating weld that has a low profile.

FCAW wet welding has been used in pipelines, ships, shipyards/piers, nuclear power plants, waterfront structures, platforms and in general oil and gas applications. The self-shielded FCAW in wet environment represents less than 0.5% of the total literature available for underwater welding. Handling shielding gas is always addressed, especially in offshore application.

## 2. UNDERWATER DRY WELDING METHODS:

The techniques that are physically protected from the surrounding water are classified as dry underwater welding. The dry welding processes currently in use are:

**1. One-Atmosphere Welding**: Is performed in a pressure vessel at approximately one atmosphere absolute. Welders that are not trained divers can perform this type of welding, after the device is transferred to welding position.

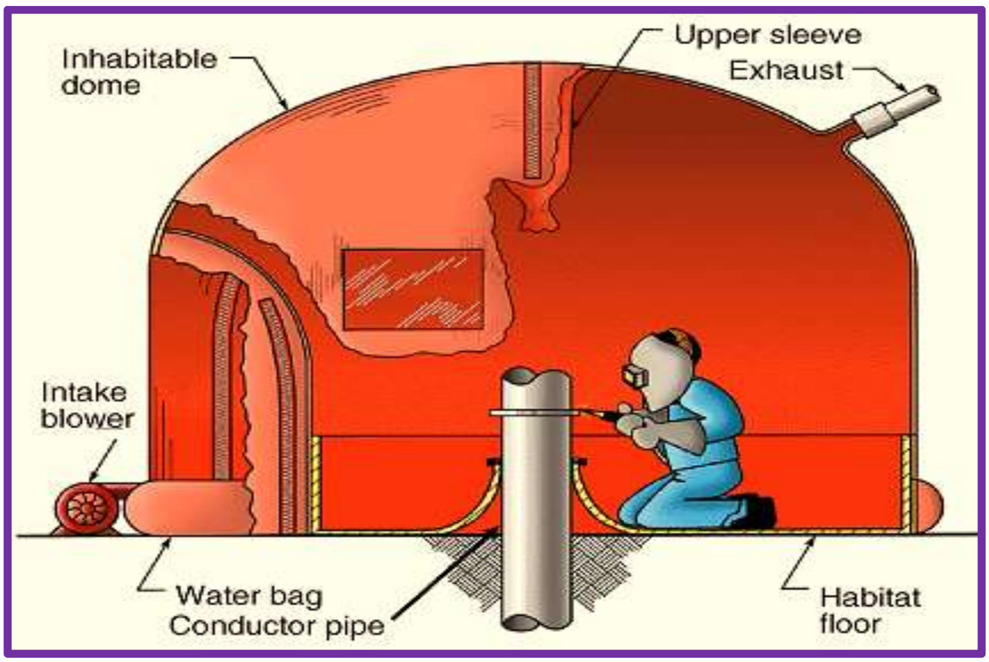


A schematic diagram of one atmosphere welding.

**2. Cofferdam Welding**: Also called a coffer, is a temporary enclosure, built like a carbon steel box to be lowered on the water surface, whose subject is creating a work environment for a safe dry welding to proceed. The cofferdam is also used on occasion in the shipbuilding and ship repair industry, when it is not practical to put a ship in drydock for repair or alteration. An example of such an application is certain ship lengthening operations.

**3. Dry Chamber or Habitat Welding**: Is a chamber used to provide a safe work environment for performing hot work in the presence of explosive gases, most often in conjunction with the need for welding, often associated with the offshore oil industry. Then, dry welding is carried out in chamber sealed around the structure to be welded. The chamber is filled with a gas (commonly helium containing 0.5 bar of oxygen) at the prevailing pressure. This positive pressure enclosure works by providing a constant inflow of breathable atmosphere, which causes gases to continuously leak out of the chamber.

This outflow of gases prevents the ingress of explosive gases or vapors, often present in such work locations. The habitat is sealed onto the pipeline and filled with a breathable mixture of helium and oxygen, at or slightly above the ambient pressure at which the welding is to take place. This method produces high-quality weld joints that meet X- ray and code requirements. The area under the floor of the habitat is open to water. Thus the welding is done in the dry, but at the hydrostatic pressure of the sea water surrounding the habitat.




**4. Mini-Habitat**: Is a process in which the water is displaced from local weld area by a transparent gas-filled box or via shielding gas surrounded by a concentric ring of water jets. The welder diver is submersed and places an enclosure around the area that needs to be welded. Then, gas is used to pump the water out of the enclosure. The welder diver performs the welding procedure by putting only his hands and welding torch in the enclosure.

The divers can move the dry box or water-jet welding apparatus along the joint as the weld is made. Dry box is inherently suited to the Gas Metal Arc (GMAW) or the Flux-Cored Arc Welding (FCAW), due the filler wire can be fed continuously through the center of the gas box or water-jet to the weld. Welds cannot be pre- or post-heated because the isolated section from the water is the only area adjacent to the arc.

**5. Hyperbaric Welding**: Is an underwater welding process at elevated pressures. The hyperbaric welding can either take place wet in the water itself or dry inside a specially constructed positive pressure enclosure, and hence a dry environment. It is referred to as "hyperbaric welding" when used in a dry environment, and "**underwater welding**" when in a wet environment. The applications of hyperbaric welding are various, often used to repair ships, offshore oil platforms, and pipelines. Carbon steel is the most common material welded.

Dry hyperbaric welding is commonly used in underwater welding when high quality welds are required because of the increased control over conditions which can be exerted, such as through application of prior and post weld heat treatments. This improved environmental control leads directly to improved process performances, and generally a much higher quality weld than a comparative wet welding. Underwater hyperbaric welding was initially developed by the Russian metallurgist Konstantin Khrenov, in 1936.

Welding in the dry environment produces high quality weld joints. It needs a pressurized steel vessel with controlled atmosphere. This method provides high quality weld joints that meet radiography and code requirements. The chamber is sealed into a structure or pipeline and filled with breathable mixture of helium and oxygen (90-95% helium and 5-10% oxygen). Therefore, welding process is not in direct contact with water. The Gas Tungsten Arc Welding (GTAW) is a common process that is largely used for underwater pipe works. This welding is used at depths of 200 ft (61 m) for pipe joining. Gas Metal Arc Welding is the best process for this welding, in all positions.

Researches using dry hyperbaric welding at depths of up to 1,000 meters (3,300 ft) is ongoing. In a control cabin, at the surface vessel, a team comprising of a welding operator and a welding engineer control the welding. All procedures are monitored by cameras giving a front and rear view of the welding arc and weld pool. The pre-programmed welding parameters can reach qualified tolerance limits be adjusted during welding. After completion of the weld, the quality can be tested by ultrasonic testing or x-rays.

Advantages of Dry Welding:

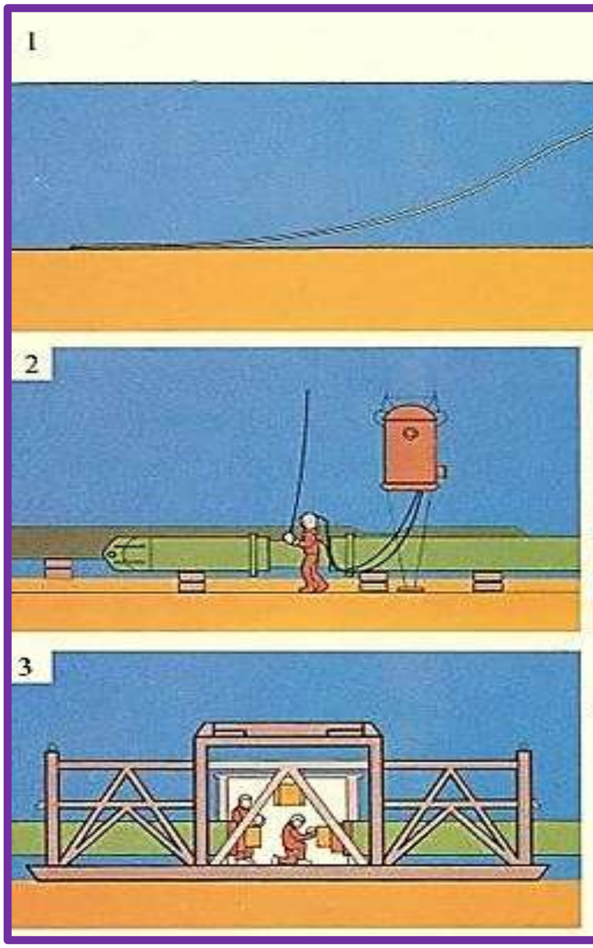
- Welder/Diver Safety. Welding is performed in a chamber, immune to ocean currents and marine animals. The warm, dry habitat is well illuminated and has its own environmental control system.
- Surface Monitoring. Good quality welds, joint preparation, pipe alignment, NDT inspection, etc. are monitored visually. The welding process is facilitated by the dry habitat environment.

Disadvantages of Dry Welding:

- The habitat welding requires large quantities of complex equipment and much support equipment on the surface. The chamber is extremely complex.
- Cost of habitat welding is extremely high and increases with depth. Work depth has an effect on habitat welding. At greater depths, the arc constricts and corresponding higher voltages are required. The process is costly, may reach $ 80000 charge for a single weld job.

Hyperbaric Vessel

The example below shows a sequence of hyperbaric welding at a high pressure water depth. The UK pipeline consisted of 361 Km (228 miles) in length and the Norwegian pipeline was 363 Km (229 miles) long. As it would be impractical raising the pipeline ends and welding them at the surface, a chamber was installed over round pipes to be welded, brought to ambient pressure by means of a mixture of helium and oxygen. Thus, the divers could work in a dry atmosphere and in relative freedom. Three-man teams did the welding work on the seabed, spending 21 days at a time living under pressure to avoid the stresses and risks of repeated pressurization and decompression.




*1 – The pipe is fed from the barge using a 'stinger' for support.*
*2 – Divers cut the two overlapping lengths to size, after which the ends are aligned.*
*3 – The hyperbaric chamber is lowered over the two ends and made watertight.*
*4 – A spool piece is welded in place to join the pipes.*

*Modified from a diagram in 'Frigg: Gas from the North Sea'.*

**6. ULBW (Underwater Laser Beam Welding)**: This process, already used at nuclear plants in Japan, made its US debut in the fall of 2013 at Progress Energy's Robinson Nuclear Plant in Hartsville, SC, to repair reactor vessel nozzles with dissimilar metal welds during the plant's scheduled outage. The ULBW process, developed jointly by Westinghouse and Toshiba, applies stress corrosion, cracking-resistant weld metal to the inside diameter surface of components, able to seal cracks up to 0.5 mm.

LBW or Laser Beam Welding is a type of radiant energy welding process that uses the laser beam to melt and vaporizes the material upon which welding is being performed. Laser beams use high electromagnetic energy density electron beams, highly coherent, monochromatic and unidirectional. By focusing the beam on a spot, beam is concentrated producing the high power density. Precise heat and dilution control of the laser beam, low-heat input of about 10% of the standard Tungsten Inert Gas (TIG) welding heat, results in consistent weld quality and high deposit purity.

The laser unit can also be located up to 1000 ft away from the actual work area. The energy produced is enough sufficient to melt & vaporizes the work metal in a very short time and thus permitting fusion with another metal. Here the lasing material used is in the form of solid ruby rod which is doped with chromium and with the end faces made parallel to each other. One end of the rod is made totally reflective and other end is made partially reflective at about 80%.

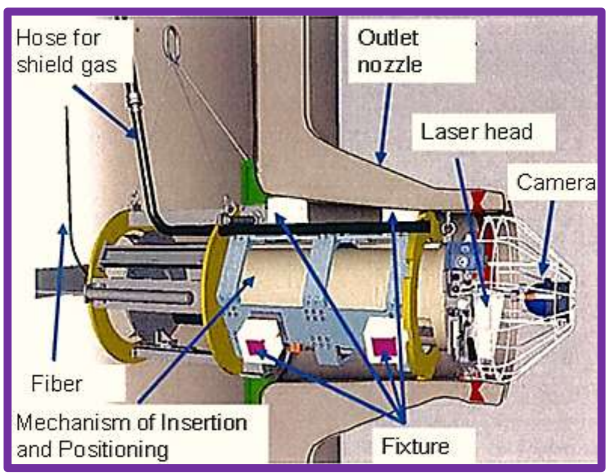
A number of xenon flash lamps are placed around laser rod for pumping it in to the excited state, and a highly reflective cylindrical enclosure surrounds both rods & flash lamps to restrict the light from pump into the rod. The action of laser is based on the following well known principle: "If an atom or molecule of lasing material is raised to high energy level by an outside source like light, heat or chemical reaction, it doesn't stay permanently over there at that state".

The frequency of light emitted will greatly depend upon the differences of the energy levels (Plank's constant). This sequence of triggering is multiplied to produce the laser beam. When this light is reflected from the end mirrors it triggers more atoms to their ground state leading to chain reaction of stimulated radiation. Some of this light escaping from partially reflecting mirror on right constitutes the laser. The great advantage of this type of welding is that the laser beam can melt & vaporizes any known metal and there is no requirement of flux or filler material.

Westinghouse and Toshiba also developed a prototype of an underwater welding machine with a mechanism of insertion and positioning, camera and welding wire, as shown below. It was confirmed that good welds were obtained in water-depth of 3 ft, with the actual nozzle. This Underwater Laser Welding (ULBW) technology was qualified by Japanese and a third party organization.

Applicable Code: ASME Code has been issued for the underwater laser welding:

ASME Code Case N-803, Similar and Dissimilar Metal Welding Using Ambient Temperature. Automatic or Machine Dry Underwater Laser Beam Welding (ULBW) - Temper Bead Technique Section XI, Division 1.





M.Yoda and M.Tamura ; "Underwater Laser Beam Welding Technology for Reactor Vessel Nozzles of PWRs", Toshiba Review, Vol.65, No.9 (2010).

**TIG Hyperbaric Orbital Robot**: Is an orbital device used where the diver performs pipe fittings, installs the track and an orbital head on the pipe and the rest of the process is totally automated. These developments of a diverless hyperbaric welding system is a great challenge and also a present trend in automation, for applications like pipe preparation and aligning, automatic electrode and wire reel changing functions, using a robot arm.

**V – UNDERWATER ROBOTIC WELDING:**

Since underwater welding is done at the elevated pressure, care must be ensured to improve the welder's safety. Hence the robotic technology is recommended to overcome the problem relating to the life threat of the welder's. Then, a brief description of the robot, designed for the underwater welding is as follows:

The recent developments in the manufacturing world have led to a revolutionary change in design and development of various systems. The welding technology is one very important change. Welding processes have been used extensively as a joining technique, used in design and fabrication of various structures like naval ships, airplanes, automobiles, bridges, pressure vessels, etc. Welding has emerged as a better option in contrast to other joining techniques in terms of joint efficiency, mechanical properties with a greater application impact.

Thus, in various intricate applications, the Robot-based welding processes have efficiently replaced human welders. Various research studies in the welding environment have shown that productivity improvement is a major thrust area of welding industry. The welders in today's world are under tremendous pressure to meet two major challenges, such as, higher weld quality, and reduced manufacturing cost.

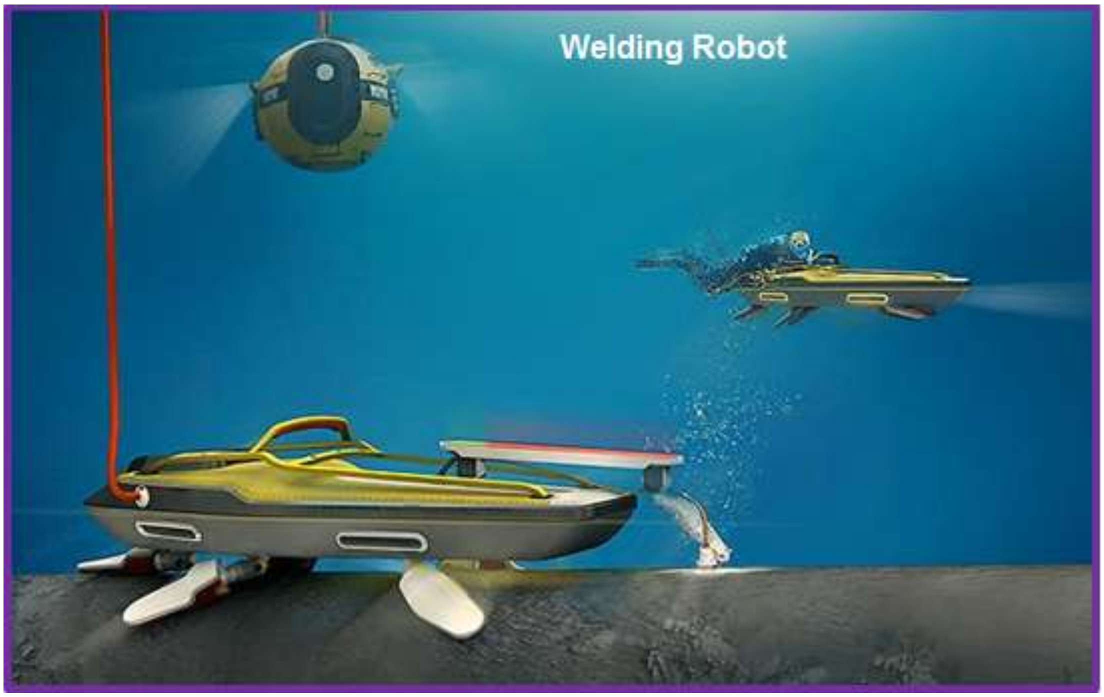
Robots are machines capable of carrying out a complex series of actions automatically, especially those that are easily programmable by a computer. The Czech writer Karel Čapek (Rossum's Universal Robots) introduced the word "robot" to the English language and to science fiction as a whole to the public theater in 1920. The play begins in a factory that makes artificial people, called roboti (robots), out of synthetic organic matter.

In the maintenance work of the nuclear power plants and facilities, there are many locations where the works by field workers are difficult or impossible due to the conditions, such as small space or narrow gap, under-water, high radiation dose rate, etc. To solve these problems, many robots are applied for the maintenance work as a means to perform these types of difficult works. Then, the welding robot was designed for underwater welding applications, based on the submarine design. The main parts of this type of robot are:

- Propeller, Electromagnetic Wheels, Welding Rod holder and Rod, Stepper Motors, Microcontroller, Camera, Lights and Propeller.

A propeller is a mechanical device for propelling a boat or aircraft, consisting of a revolving shaft with two or more broad, angled blades attached to it. Commonly, there are four propellers used in this underwater robot, showed below. Two propellers face the front side and the other two propellers face the top side. When the propellers in the front rotate clockwise the robot moves forward and vice versa for anticlockwise direction, and when the propellers at the top rotate clockwise the robot moves up and vice versa for the anticlockwise direction.

The rod used by the welding robot, is a common consumable rod, which is also flux coated with an insulated material suitable for the underwater welding. The positive side of the DC power supply is given to the welding rod holder and whereas the metal to be welded is given with the negative charge. The DC current supply is given to the wheels to magnetize and stick firmly on the metal surface. An electromagnet is a soft metal core made into a magnet by the passage of electric current through a coil surrounding it.




The operation of the welding robot is controlled by a micro-controller. When the micro-controller gets its input from the computer system, the electromagnetic wheels and propellers are actuated by the stepper motors. The camera helps to find the area of the weld and converts it into the coordinate system. This co-ordinate system helps to monitor the weld and make a weld accurately on the surface. The camera is supported by the focus light system on the either side. The welding movement is done using the propellers and the electromagnetic wheels, used to stick to the surface. The working safety is an important factor for the weld done in the underwater.

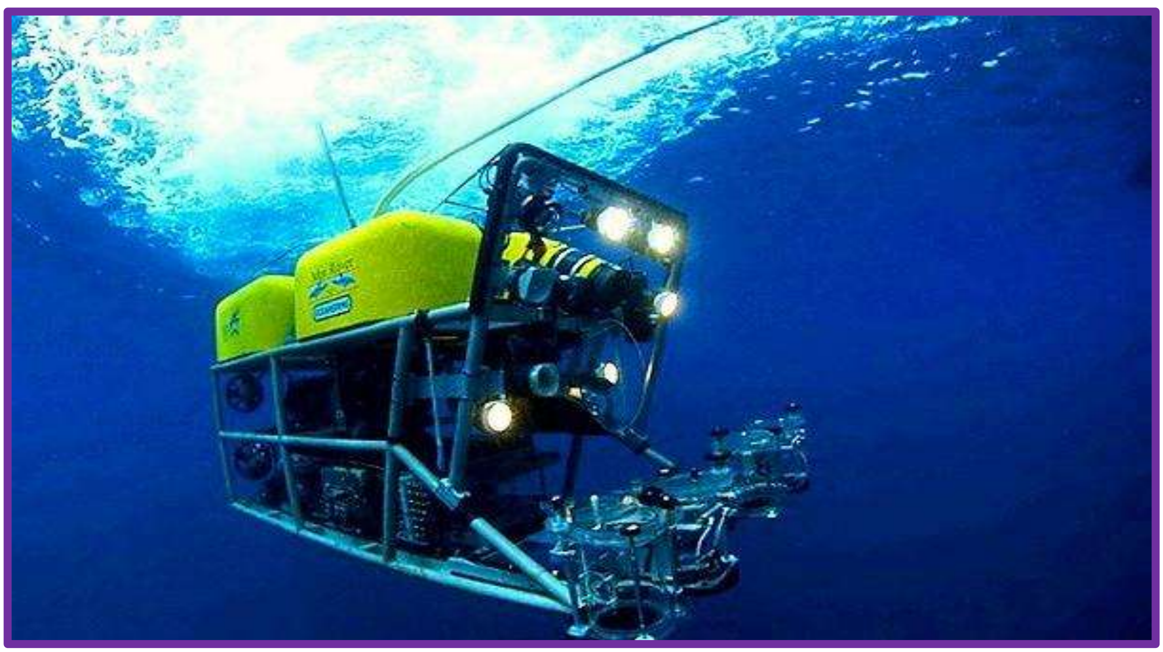
The installed camera functions as a device for recording visual images in the form of photographs, film, or video signals. The camera here converts the image to the co-ordinate system. This co-ordinate system helps to find the weld area in this context. The light here supports the camera to generate the better picture. This exclusive model of a robot will be a solution for the problems related to the underwater welding.

Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets. Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles. Hybrid stepper motors are named because they use a combination of PM and VR techniques to achieve maximum power in a small package size.

A stepper motor (or step motor) is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open loop controller), as long as the motor is carefully sized to the application. The stepper motor is connected to the H-Bridge and is interfaced to the microcontroller. There are four main types of stepper motors; permanent magnet stepper, hybrid synchronous stepper, variable reluctance stepper, Lavet type stepping motor.

**ROV (Remotely Operated Vehicles)**: Developed from technology funded by the US Navy in the 1960s, ROVs have allowed a strong capability to perform deep-sea rescue operations, recover objects from the ocean floor, beyond underwater structure inspection. The ROV, which is an underwater robot linked to a ship by a tether that transfers electrical power, video and data signals back and forth between the operator and vehicle, has become an essential part of deep water oil and gas explorations. A ROV is operated by a team, including the operations controller, submersible engineer, submersible pilot, observer, winch operator and deployment systems operator.

With the offshore industry moving into deeper waters, new challenges have arisen for the standard methods of ocean floor mapping. In deep water, ROVs have become the only method of installing hardware, performing maintenance checks and rectifying problems. These challenges are being overcome by new innovations in survey technology that aim to enhance data quality, acquisition efficiency and safety, and improve risk mitigation.



A remotely operated vehicle (ROVs) is the most widely used underwater inspection tool, ideal for serving a wide range of commercial needs. Power and control data are sent to the vehicle, and video and sensor data are returned. An umbilical cable connects the surface to the subsurface /

remote operated vehicle, enabling project owners to view a first-hand account of what the remote operated vehicle uncovers and/or records.

Another benefit of a remote operated vehicle is the virtually unlimited underwater time, and high bandwidth for high-resolution video and data transmission. ROVs offer precise navigational control and tracking, ideal for: Conducting underwater inspections; inspection of nuclear facilities; interior and exterior pipeline inspections; sensor, sampling, and monitoring platform devices; search; salvage and recovery operations; dam and tunnel inspections; damage control assessment; diver observation and management; seabed survey, etc.

**AUV (Autonomous Underwater Vehicles)**: Is a robot that travels underwater controlled and powered from the surface by an operator/pilot via an umbilical or using remote control, without requiring manual input from an operator. In military applications AUVs are more often referred to simply as “unmanned” undersea vehicles (UUVs). AUVs constitute part of a larger group of undersea systems known as underwater vehicles, a classification that also includes the Remotely Operated underwater Vehicles (ROVs),

AUVs are also remote robotic devices similar in appearance to a small submarine, fitted with all of the conventional survey sensors used to map the ocean floor. This technology continues to develop rapidly and presents more benefits, over the use of ROVs. A recent example of this, was following the failure of the drilling operations on the Deepwater Horizon drill rig in the Gulf of Mexico, where ROVs were used to examine and try to fix the mal-functioning of a Blowout Preventer (BOP), monitor and install a range of devices designed to stop the flow of oil.

Until relatively recently, AUVs have been used for a limited number of tasks dictated by the technology available. AUVs are now being used for more and more tasks with roles and missions constantly evolving. The oil and gas industry uses AUVs to make detailed maps of the seafloor before they start building subsea infrastructure; pipelines and subsea completions can be installed in the most cost effective manner with minimum disruption to the environment. The AUV allows survey companies to conduct precise surveys of areas where traditional bathymetric surveys would be less effective or too costly.

## VI - UNDERWATER WELDING STANDARDS:

Wet welding is one of the most under rated, abused and misunderstood welding processes in regular use today. Its poor reputation, developed over the years, has fuelled critical arguments that wet welding produces poor quality, hard, low ductile welds, which are prone to cracking. As an aid in providing quality assurance the American Welding Society (AWS) developed a welding standard, the AWS D3.6 Specification for Underwater Welding.

This specification, first published in 1983, was intended to provide users a choice of weld quality, with a requirement for underwater welding, on a fitness for purpose basis, taking in to consideration the state of the art of underwater welding at that time, and included both dry hyperbaric and wet welding. This specification has subsequently been revised several times but still sets out four classes of welds identified as class A, B, C or O, because the characteristics of each welding that varies due to the pressure of the cooling rate of the method used.

These classes are broadly defined as: class "A" welds are intended to be comparable with above onshore welds due specifying comparable properties and testing requirements. Class "B" welds are intended for less critical applications where lower ductility, greater porosity and larger discontinuities can be tolerated. Class "C" welds are intended for applications where load bearing is not a primary consideration and satisfy lesser requirements than class A, B and O. And finally class "O" welds must meet the requirements of another code or specification. There is also the prerequisite for trial welding, evaluated before the work commences.

Historically wet welds have lacked ductility, have high hardness values, suffered from hydrogen cracking and suffered from brittleness. Some manufactures of wet welding electrode often quote-individual properties of their electrodes as being class "A" acceptable such as a radiography report or tensile strength but are still a long way from meeting class "A" weld specification. Lack of ductility is still one of the major faults with many electrode manufactures quoting less that 9% elongation on all weld metal tensile tests and impact tests well below what is required by class "A".

Unfortunately, critics of **wet welding** can often justify their condemnation as the process is regularly abused, particularly in the onshore civil engineering industry, where weldments rarely meet any welding standard or specification. This abuse is mainly born out of ignorance, often on both sides of the contract, with the client having very little understanding of the process and relying on the diving contractor, whom may have very little understanding of wet welding himself. Understandably the contractor, not wanting to turn work away, will often bid for work on the basis that, one or two of his divers are conventional welders, and should be able to weld underwater.

This general lack of knowledge often results in projects being awarded to companies that have no wet welding procedures in place, welders with no formal or very little wet welder training and using inappropriate welding electrodes. The results are predictable with weldments having significant weld defects such as slag, gas inclusions, lack of fusion, and sometimes cracking. However, even wet welding projects also often involve a third party, like a classification society, which takes on a completely different approach, with a much higher level of quality assurance (QA).

Welds produced underwater are subjected to increased cooling rates and the process itself breaks down water into its component elements thus producing high levels of hydrogen and oxygen both of which are detrimental to the mechanical properties of the weld. Flux formulations and filler metal composition used for conventional surface electrodes may not cope with these inherent factors encountered underwater.

The resultant welds frequently exhibit unacceptable weld defects lack ductility and are likely suffer from hydrogen embrittlement which can induce toe and under-bead cracking. These cracks could, potentially, propagate into the parent metal thus causing more server damage than the repair was intended to resolve. Even some of the electrodes, commercially marketed today, as wet welding electrodes are conventional surface electrodes, covered in some sort of waterproofing and often sold as a “cheap and cheerful” option.

So, it is not surprising that even commercially available wet welding electrodes, cannot meet all the welded mechanical properties required by the specification. While many may claim they meet certain class “A” test criterion, like radiography, the overall mechanical properties of the weld are still below of what is required. The main area, in which these electrodes fail, is in the hardness and the lack of ductility. Vickers hardness testing commonly reveals hardness over 400 even on materials with a relatively low carbon equivalent CE. Typically most electrodes deliver elongation figures of between 6% and 9%, where class “A” specification requires a minimum of 14%.

Fortunately, in the offshore oil and gas and to a lesser degree the shipping and civil engineering industries, most of the wet welding projects are subjected to the same degree of QA applied to conventional dry surface welding projects. Production welding is preceded by the qualification of wet welding procedures and welder qualifications to prove the weldability of the materials, the performance of the welding consumable and the capabilities of the welder.

These procedures and qualifications are usually completed to the “AWS D3.6 Specification for Underwater Welding” which takes into consideration factors associated with the underwater environment not included in surface specifications such as water depth and or pressure. In 1999 some companies acknowledged leaders and an authority in the field of wet welding, shifted the boundaries by producing the first ever, surface quality wet welds in accordance with the “AWS D3.6M-99 Class A” welds.

The organizations that have also set the standards are; the International Institute of Welding, the American Welding Society (AWS), the American Society of Mechanical Engineers, the British Standard Institute and Bureau Veritas (BV) and Det Norske Veritas (DNV). Independent witnesses include the Lloyds Register of Shipping (LRS), American Bureau of Shipping (ABS), Det Norske Veritas (DNV), Bureau Veritas (BV), Rina and Germanisher Lloyd (GL).

Their attendance was required to ensure the welding procedures, welder qualifications and testing of the coupons complied with the AWS D3.6M-99 - Specification for Underwater Welding Class “A” weld standard. The tests provided the data from the testing and with the classification societies, confirmed that the specimens complied with, or exceeded the requirements of the AWS D3.6M: 99

for Class A welds. Another standard is the ISO 15618-2:2001: Qualification testing of welders for underwater welding - Part 2: Diver-welders and welding operators for hyperbaric dry welding. In addition, the resume for the wet welding SMAW / AWS D3.6M: 1999, underwater weld classes (A, B, C & O) are:

- ✓ **CLASS A**: Underwater welds intended to be suitable for applications and design stresses comparable to their conventional surface welding counterparts. This welding procedure is generally specified for most dry-hyperbaric welding of ferritic and austenitic base metals.
- ✓ **CLASS B**: Underwater welds intended for less critical applications where lower ductility, moderate porosity, and other limited discontinuities can be tolerated.
- ✓ **CLASS C**: Underwater welds intended for applications where load bearing is not a primary consideration and satisfy lesser requirements than class A, B and O.
- ✓ **CLASS O**: Underwater welds must meet the requirements of another designated code or standard and additional requirements, to cope with the underwater welding environment.

**VII - WELDING PROCEDURES SPECIFICATIONS:**

A Welding Procedure Specification (WPS) is a formal written document that describes welding procedures to provide direction to the welder or welding operators, for making sound and quality production welds, as per the code requirements. The purpose of the document is to guide welders to accepted procedures so that, repeatable and trusted welding techniques are used. The WPS is developed to describe each material alloy, and each welding type used. Specific codes and/or engineering standards are often the driving forces behind the development of a company's WPS.

A WPS is supported by a Procedure Qualification Record (PQR or WPQR). A PQR is a record of a test weld performed and tested (more rigorously) to ensure that the procedure will produce a good weld. Individual welders are certified with a qualification test documented in a Welder Qualification Test Record (WQTR) that shows they have the understanding and demonstrated ability to work within the specified WPS.

According to the American Welding Society (AWS), a WPS provides in detail the required welding variables for specific application to assure repeatability by properly trained welders. The AWS defines welding PQR as a record of welding variables used to produce an acceptable test weldment and the results of tests conducted on the weldment to qualify a Welding Procedure Specification.

The American Society of Mechanical Engineers (ASME) similarly defines a WPS as a written document that provides direction to the welder or welding operator for making production welds in accordance with Code requirements. ASME also defines welding PQR as a record of variables recorded during the welding of the test coupon. The record also contains the test results of the tested specimens designated as test coupons, which establish the ability of the welder.

For steel construction (civil engineering structures) the AWS D1.1 is a widely used standard. It specifies either a pre-qualification option (chapter 3) or a qualification option (chapter 4) for approval of welding processes. The Canadian Welding Bureau, through CSA Standards W47.1, W47.2 and W186, specifies both a WPS and a Welding Procedure Data Sheet (WPDS) to provide direction to the welding supervisor, welders and welding operators.

Welding procedures, which are generally completed to the AWS D3.6 - Specification for Underwater Welding, can also be qualified at one of our approved sites or at any suitable facilities requested by the client. Witnessing, testing and certification can be provided by independent classification societies including Lloyds, DNV, ABS, BV, etc. and completed coupons can be sent to independent appropriately accredited test houses. The applied welding procedures are:

- ✓ WPS (Weld Procedure Specification): This procedure details specific essential variables that instruct the welder how to weld a joint, in order to achieve a sound predetermined welding, considering intrinsic mechanical and chemical properties.

- ✓ PQR (Procedure Qualification Record): Supports the WPS and contains all information necessary to essential variables defined in the WPS including the results of NDE tests performed. Commonly used in auditing by engineers, inspectors, managers, training, etc.

- ✓ WQR (Welder Qualification Record): Is the welder performance and qualification tests, intended to establish each welder's ability to make sound welds using a qualified WPS.

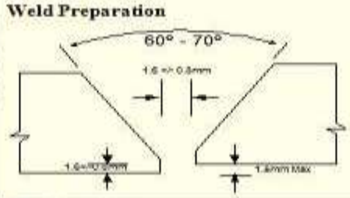
**Welding Procedure Specification**

| | | | |
|---|---|---|---|
| Client: **Mobil** | Project: **221010Goatee** | REF No. **WPS 6 R1** | |
| Procedure Description: **12" Heavy Wall Offshore Tie-in** | | 0290/1/WPS5 | |
| Material: **AS3679.1 Grade 250API 5L X65** | Diameter: **168.3** | Thickness: **18.3** | |
| Position: **6G** | Clamp Type: **Internal** | | |
| Preheat °C (Min): **100** | Interpass °C (Max): **300** | | |

| | ROOT | HOT PASS | FILL & CAP |
|---|---|---|---|
| Welding Process | SMAW | SMAW | SMAW |
| Welding Direction | Vertical Down | Vertical Down | Vertical Down |
| Filler | Lincoln SA70+ | Lincoln SA70+ | Bohler BVD90M |
| Polarity | DC +ve | DC +ve | DC +ve |
| Shielding Gas | N/A | N/A | N/A |
| Purge Gas | N/A | N/A | N/A |

| Pass No | Filler Size (mm) | Amps | Volts | Speed (mm/sec) | Heat Input (kJ/mm) |
|---|---|---|---|---|---|
| 1 | 3.2mm | 70-130 | 18-33 | 3.3-6.6 | 0.4-0.8 |
| 2 | 4.0mm | 110-210 | 18-36 | 2.9-6.8 | 0.6-1.3 |
| FILL | 4.0mm | 145-260 | 16-27 | 1.6-7.0 | 0.6-2.2 |
| CAP | 4.0mm | 130-230 | 16-26 | 1.8-5.3 | 0.6-1.7 |

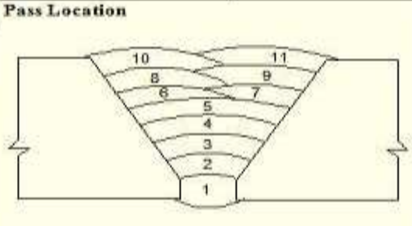
**Weld Preparation**




**NOTES**

1. API Std 1104BP3094-SP-PL-3010R1
2. Clamp removal stage : **100% completion of root (external clamp may be used in the event of a breakdown – removed after 50% minimum completion of the root.)**
3. Time lapse between root and second pass : **16 Minutes**
4. Time lapse between second pass and 1st fill : **12 Minutes**
5. Minimum number of passes before pipe movement : **2 passes**
6. Minimum number of passes before break in welding : **3 passes**
7. Minimum Number of welders- **Root & second pass: 2 , Fill & Cap : 1**
8. Method of cleaning : **Grinder / Wire brush**
9. Method of Preheat : **Gas Torch**
10. Qualification reference number : **48280/PP/WP6 R1**

**Pass Location**



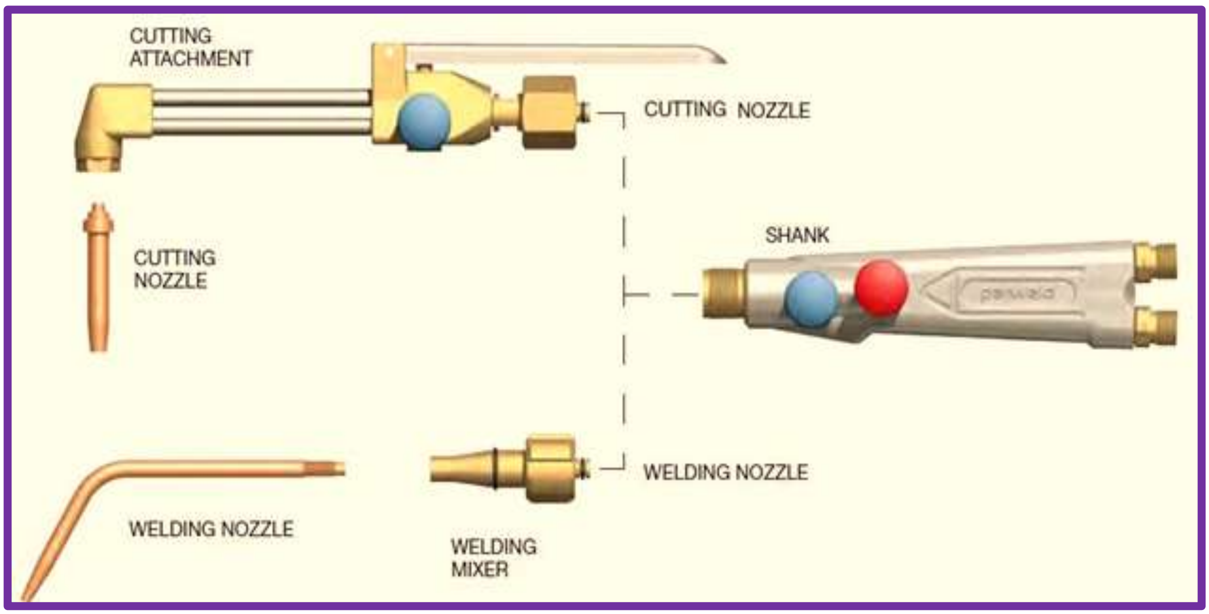

**Company Welding Engineer Approved** ..................................... **Approved for Client** .....................................

**VIII - UNDERWATER CUTTING EQUIPMENT:**

Oxy-fuel welding (commonly called oxy-acetylene welding, oxy welding, or gas welding in the U.S.) and oxy-fuel cutting are processes that use fuel gases and oxygen to weld and cut metals, respectively. French engineers Edmond Fouché and Charles Picard became the first to develop the oxygen-acetylene welding in 1903. Pure oxygen, instead of air, is used to increase the flame temperature to allow localized melting of the workpiece material (e.g. steel) in a room environment.

In conventional oxy-fuel cutting, a torch is used to heat metal to its kindling temperature. A stream of oxygen is then, entrained on the metal, burning it into a metal oxide that flows out of the kerf as slag. Torches that do not mix fuel with oxygen (combining, instead, atmospheric air) are not considered oxy-fuel torches and can typically be identified by a single tank (oxy-fuel cutting requires two isolated supplies, fuel and oxygen).

The difference between a welding torch and a cutting torch is that the welding torch head is used to weld metals. It can be **identified** by having only one or two pipes running to the nozzle and no oxygen-blast trigger and two valve knobs at the bottom of the handle letting the operator adjust the oxygen flow and fuel flow. The cutting torch head is used to cut materials, similar to a welding torch, but can be identified by the oxygen blow out trigger or lever.




Acetylene is the primary fuel for the oxy-fuel called oxy-acetylene, for general cutting and welding and is the fuel of choice for repair work. Acetylene gas is shipped in special cylinders designed to keep the gas dissolved. As acetylene is unstable at a pressure roughly equivalent to 33 feet/10 meters underwater, **submerged cutting and welding** is reserved for **hydrogen** rather than acetylene. Hydrogen has a clean flame and is good for use at a higher pressure than acetylene.

Thus, **hydrogen** fuel is therefore useful for **underwater welding and cutting** when pre-mixed in a 2:1 ratio with pure oxygen (oxy-hydrogen). The flame temperature is very high, generally about

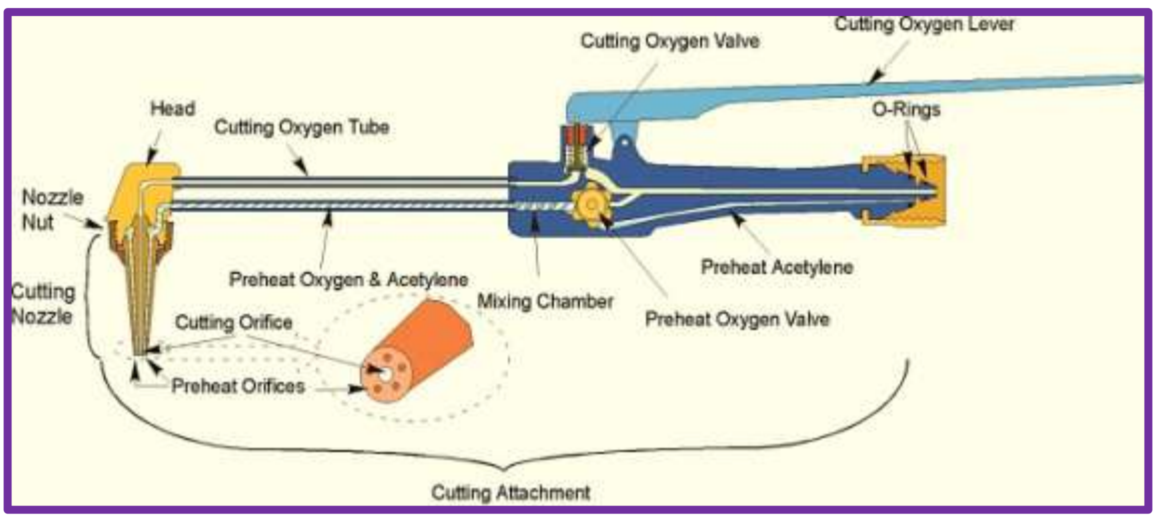
2,000 °C for hydrogen gas in air at atmospheric pressure, and up to 2800 °C. Hydrogen is **not used for welding** steels and other ferrous materials, because it causes hydrogen embrittlement.

There are two types of electrodes commonly used for oxygen-arc cutting; steel-tubular (Arcair), the exothermic types and ultrathermic. These electrodes provide excellent cutting results and can be used with a constant current DC welding generator set on straight polarity (electrode negative) supplying current to the electrode. With the work grounded, the electrode will ignite as it touches the work. Oxygen-arc is preferred because it cuts plain and low-carbon steel easily.

Propylene is also used in welding and cutting production, as it cuts similarly to propane. When propylene is used, the torch rarely needs tip cleaning. There is often a substantial advantage to cutting with an injector torch, rather than an equal-pressure torch when using propylene.

Manufacturers have developed custom tips for Mapp, propane, and polypropylene gases to optimize the flames from these alternate fuel gases. "Mapp gas" is a trademarked name, belonging to The Linde Group, and previously belonging to the Dow Chemical Company, for a fuel gas based on a stabilized mixture of methyl-acetylene (propyne) and propadiene. The name comes from the original chemical composition, methyl-acetylene-propadiene propane.

For cutting, the setup is a little different. A cutting torch has a 60 or 90º angled head with orifices placed around a central jet. The flame is not intended to melt the metal, but to bring it to its ignition temperature. The torch's trigger blows extra oxygen at higher pressures down the torch's third tube out of the central jet into the workpiece, causing the metal to burn and blowing the resulting molten oxide through to the other side.




Cutting is initiated by heating the edge or the leading face of the steel to the ignition temperature (approximately bright cherry red heat) using the pre-heat jets only, then using the separate cutting oxygen valve to release the oxygen from the central jet (as in cutting shapes). The oxygen chemically combines with the iron in the ferrous material to oxidize the iron quickly into molten iron oxide, producing the cut. Initiating a cut in the middle of a workpiece is known as piercing.

The ideal kerf is a narrow gap with a sharp edge on either side of the workpiece; overheating the workpiece and thus melting through it causes a rounded edge. The outer jets are for preheat flames of oxygen and acetylene. The central jet carries only oxygen for cutting. The use of several preheating flames rather than a single flame makes it possible to change the direction of the cut as desired without changing the position of the nozzle or the angle which the torch makes with the direction of the cut, as well as giving a better preheat balance.

**Arcwater Cutting**. Water arc cutting is essentially a melting process. The process consists of striking an arc underwater between a carbon-graphite, copper-coated, and waterproofed electrode and the workpiece. The metal is instantly transformed into a molten state and is blown away by a high-pressure jet of water, which exits the torch through an orifice located directly below the electrode opening in the torch. Since the cutting is dependent solely on the melting action of the arc, all the power available, up to 400 amps may be used. The process proves valuable when gouging out welds or cutting thin metal.

This method is particularly suited for cutting material with small cross-sections, **1.0 inch thick or less**. It does not completely eliminate the hydrogen gas build-up due to electrolysis, but the lack of pure oxygen in the process reduces the risk significantly. It also provides a very controllable cut depth and thicker cross-sections can be cut by first gouging a bevel before making the through cut. This process works well with non-ferrous metals as well.

**Arcwater Cutting Techniques**: As always, before conducting any type of electric arc cutting underwater, a ground cable must be attached to the work piece. The diver can either leave the surface with the cutting torch, ground cable and cutting electrodes or they can be lowered after arrival at the work site. The first task is to clean a spot for the ground clamp. The spot should be in a position in front of the diver and should be scraped or shiny clean wire brushed.

For diver safety, only C-type clamps should be used as grounding clamps for underwater cutting or welding operations. The clamp must be firmly secured to the work piece and the cable should have sufficient slack to prevent it from being pulled loose. The diver may first elect to lightly tack the weld, when there is a possibility of it working loose. From time to time as the cut progresses, the diver may have to reposition the ground clamp to avoid it becoming part of the electrical circuit. This process can be used for the following applications:

a. It can be used on almost all metals found in ships and underwater structures.
b. To remove defective fillet welds for re-welding.
c. To cut metal in a manner similar to the underwater oxygen-arc process.
d. Cracked butt or seam welds can be grooved for weld repair.

**Necessary Equipment**: The following equipment is required when using the arcwater underwater cutting process.

- ✓ **Power**: The DC welding generator should be capable of providing a constant open-circuit voltage of 60 volts and 350-500 amperes. This process calls for reverse polarity, that is; electrode positive (+).

- ✓ **Water**: The process requires a constant supply of sea water or fresh water supplied at a flow-rate of 3.5 gallons per minute at 90 psi over bottom pressure. A ship's fire main will normally provide sufficient pressure for this process.

- ✓ **Arcwater torch**: The arcwater torch is electrically insulated and completely waterproofed except in the area where the electrode is inserted. It is small and well balanced, designed to minimize diver fatigue.

- ✓ **Electrodes**: The arcwater torch is designed to use especially formulated, copper-coated waterproofed electrodes. Electrodes dimensions are commonly 5/16" x 9", completely waterproofed, except the end part that is inserted into the torch. The welding arc end is also waterproofed, which can be removed by lightly tapping the electrode against the work.

- ✓ **Underwater Preparations**: Insert the electrode into the collet opening until it bottoms out. Tighten the collet nut. To start cutting, hold the electrode perpendicular to the surface to be cut, place the tip of electrode against the work and call for water on and then, switch on. If necessary, withdraw the electrode slightly, and tap it against the work to start the arc.

- ✓ **Cutting**: For cutting, the torch should be held at a 75° angle with the water jet under the electrode. Care must be taken to prevent molten metal blow-back. Once a hole is pierced, proceed along the intended line of cut using a sawing motion. Holes can be pierced in the same manner and enlarged using a sawing motion.

- ✓ **Gouging**: The depth of the groove will vary with the torch angle, travel speed, amperage and pressure exerted on the electrode. For gouging and weld removal, the torch should be held at a 40° angle to the work with the water jet under the electrode. The torch should be moved forward at a speed sufficient to maintain the arc and the desired groove depth. The diver should not cut deeper than 1/4" in a single pass, to prevent molten metal from being blown back at the diver.

| Arcwater Operating Data Cutting Carbon Steel[1] | | | |
|---|---|---|---|
| Metal Thickness | Inch/min cut | Water Over Bottom pressure | Amperage Range for Cutting |
| 0.1875 | 22.0 | 90-110 psi | 475-525 |
| 0.2050 | 16.0 | 90-110 psi | 475-525 |
| 0.375 | 12.4 | 90-110 psi | 475-525 |
| 0.500 | 8.4 | 90-110 psi | 475-525 |
| 0.625 | 4.2 | 90-110 psi | 475-525 |
| 0.750 | 1.4 | 90-110 psi | 475-525 |

1. Stainless steel operating data is similar to carbon steel. Non-ferrous materials such as bronze and brass with copper content above 80% can be cut with above operating conditions.

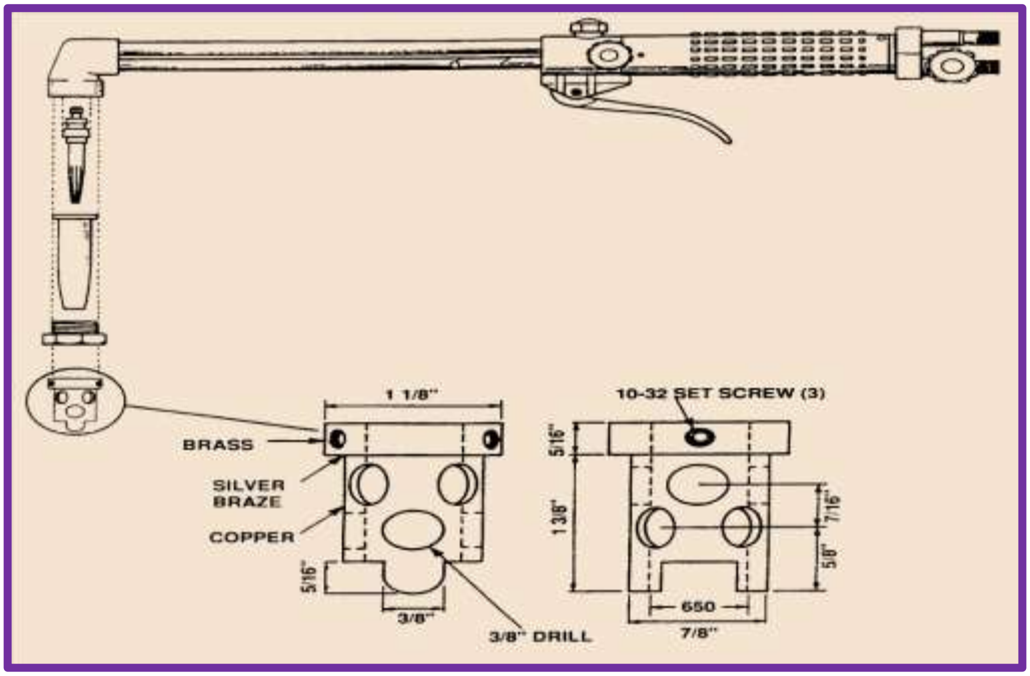
**Important Note**: Acetylene is very unstable at pressures above 15 psi and is NOT used for underwater cutting.

**Underwater MAPP Gas Cutting**: MAPP gas is a mixture of stabilized methyl-acetylene propidene, colorless, odorless combustible fuel gas. Like all fuel gases which are odorless by nature, a chemical has been added to aid in detecting leaks by smell. Like any other combustible gas, MAPP gas forms explosive mixtures with air or oxygen. MAPP gas cutting **is the only oxygen-fuel underwater cutting process** approved for use by the Navy. It is used only when oxy-arc cutting equipment is not available or when there is an absence of sufficient electric power to conduct oxy-arc cutting.

The principle of cutting metal underwater with a gas torch is virtually the same as that employed topside, except that the **acetylene has been replaced by MAPP gas**, performed with a gas torch rather than with a cutting electrode. The technique for underwater cutting is exactly the same as oxygen-acetylene cutting topside. However, a great deal more skill is required using the MAPP gas process as opposed to oxy-arc underwater cutting.

The torch **mixes the MAPP gas and oxygen**, which burns and generates sufficient heat to melt the metal to be cut. A small area on the metal is heated to a molten puddle and then oxygen is directed at that point. The oxygen instantly converts the molten puddle into a gaseous and chemical state, while simultaneously blowing it away. The flame is angled slightly in order to preheat the metal ahead of the cut, thus allowing the cut to continue. The following precautions are:

1. A standard oxy-acetylene oxygen cutting torch can be used for cutting with MAPP gas underwater, as shown below. A standard surface cutting torch with the underwater spacer sleeve controls the oxygen and the MAPP gas, cutting the oxygen and regulating the FS or stinger cutting tip. The torch must be attached to hoses, which carry the gases, and the torch should be clearly marked, so that the oxygen hose and the MAPP gas hose can be connected with the proper gas passages within the torch.

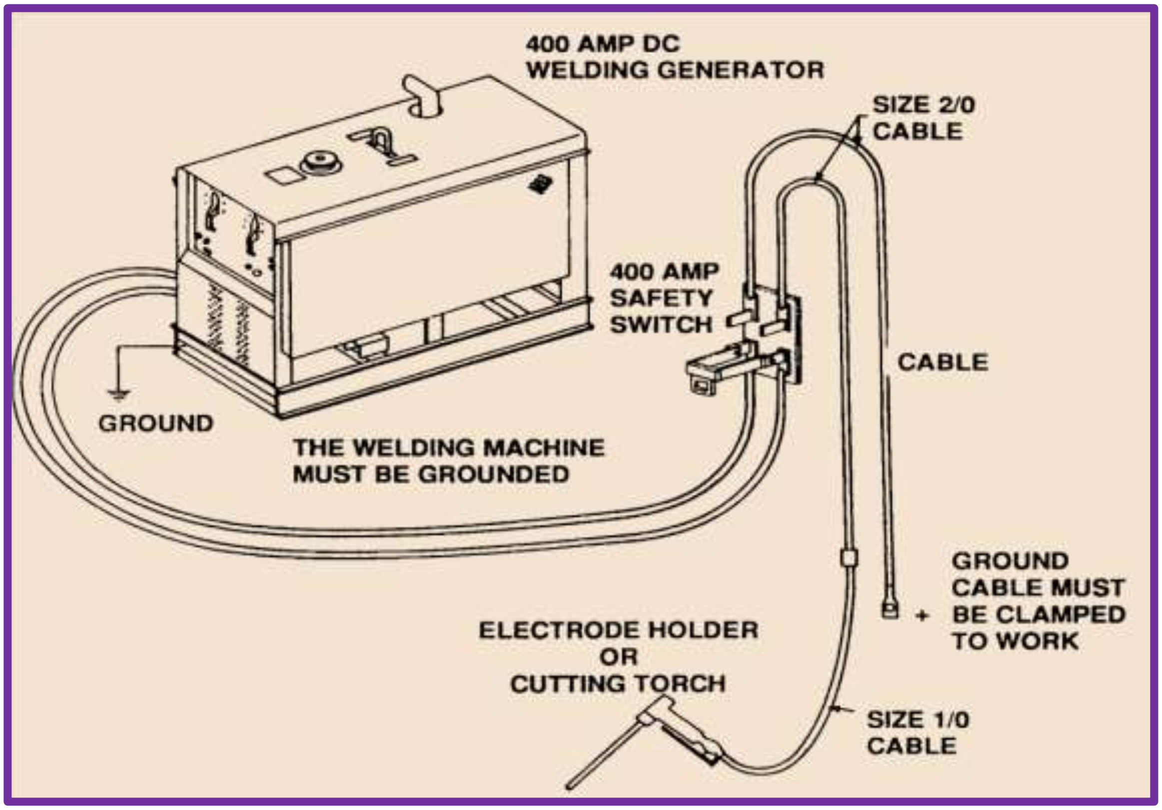



2. The cutting tip is a two-piece standard pressure tip, with a fine spline, which fits on a standard acetylene oxygen cutting torch. Selection of the proper tip size depends on the thickness of the metal; then, refer to a standard table for the proper size to be used with various plate thicknesses. The cutting tip has a preheat perimeter, which is equally divided into 18 to 26 milled slots and displaces water more evenly than the 8 holes of the standard pressure tip. This cutting tip preheats faster and gives quicker starts and is especially recommended, when cutting is to be done with a tip spacer sleeve.

3. It is the responsibility of the diver's tender to see that the correct pressures are maintained at the regulators. When the job has been completed, the diver should shut off the MAPP gas valve first and release the oxygen trigger; however, let preheat oxygen blow until the torch is removed from the water. This will keep the preheat parts from becoming clogged with foreign matter. Clean the torch and tips if it is suspected that clogging may have occurred. The ignited torch may be lowered to the working location in one of two ways:

- **Carrying the Torch Below**: In moderate or shallow depths and easily accessible locations, the ignited torch may be carried below by hand. The diver should be prepared to make adjustments to the flame to compensate increased hydrostatic pressure during descent.

- **Lowering the Ignited Torch**: In shallow depths and locations, where it is absolutely certain that the flame can be kept clear of all hoses, lines, diver's dress, helmet and other equipment or personnel, the ignited torch may be lowered directly to a point, to be near the diver. The welder must never lower an ignited torch, until it is certain that the diver is ready and watching for it. The welder should choose an ideal position where the torch flame cannot possibly strike his helmet, suit, hose or an umbilical.




**Dive Supervisor**: Is responsible for the diver's overall safety and ensures that all control measures identified through the risk assessment process are implemented. If a diving superintendent is present on the job, he should also be involved in this hand-over and ensure that control measures are being complied with. It shall be determined in the risk assessment process whether a second diving supervisor is required on each shift. If there is only one supervisor per shift no burning will be performed during shift handover. They should:

- Be competent in the management of burning operations; including knowledge of the primary risks, their controls and compliance with this *Recommended Practice*.
- Be familiar with the worksite, through procedural review, diver inspection and assessment.
- Maintain physical control of the dive, burning operations and management control over the knife switch or circuit breaker, controlling the electrical current to the burning torch. The circuit breaker/safety switch shall be in easy reach of the supervisor.
- Participate in the risk assessment specific to the burning operation. Shall not take over, or handover, an operation to the next shift supervisor without a thorough exchange of information as entered in the operational log, equipment status, and location of diver and earthing/grounding point prior to leaving the radio or assuming control of the diver.

The following commentaries represent the best industry practice and safety warnings regarding to using the oxy-arc underwater cutting process. Many of these comments are very important to all dive supervisors and underwater welders, within the body of this work.

- ✓ One experienced member of the crew shall be designated by the diving supervisor for burning equipment oversight and to monitor equipment while in use.

- ✓ Verify that tools are available to assess electrical current and gas pressure/flow during the burning operation. Verify the diving project procedures detailing the operational work scope and how it will progress from start to finish.
- ✓ Participate in the risk assessment process and ensure that mitigation measures are implemented during the operation. The HAZID (Hazard Identification) and risk assessment should be specific to underwater burning (provide documentation of the trained and qualified divers identified for the operation.
- ✓ Be familiar with the worksite location, either through drawing review or diver inspection and assessment.
- ✓ Underwater burning produces a combination of pure oxygen and hydrogen gases as a by-product of electrolysis and heat generated over 2000°F. When trapped in a confined or un-vented area, this gas mixture will produce a serious explosion when ignited.
- ✓ Holes in the outer insulation cover of a burning lead may "bleed" a red copper oxide from the electrolysis in the wire core if the lead has been submerged in water.
- ✓ Never burn where there is a pressure differential from one side of the cut to the other. A differential that causes either a pressure release or a vacuum is an extreme danger to a diver.
- ✓ The diver must ensure that there are no hydrocarbons present that can ignite during the burning process. Never burn into an area that is not vented.
- ✓ In order to flush out any hydrogen gas pockets in the equipment, oxygen must be flowed through the torch and rod prior to energizing the circuit. Always follow the manufacturer's instructions when using oxy-arc cutting equipment.

**Cutting Torches**: Torch heads require regular maintenance and shall be marked with an identification number. Maintenance should be logged in the Equipment Maintenance System (EMS) to track the life of the torch and its burning umbilical. The torches should be inspected following the manufacturer´s recommendation prior to use, before and after each burning operation. A checklist of inspection is as follows:

- Check all threaded pieces for contamination or slag in the threads; clean accordingly. Check electrode collet for electrolysis erosion or arc damage. Replace as required, for tight electrode fit. The welding cables or torch leads should be inspected at the connection to the torch body.
- Electrolysis can result that this connection may become loose over time. It should be re-tensioned according to manufacturer's specification. Electrolysis can produce hydrogen as a by-product of the process. This hydrogen may build up in the torch head voids if dead space exists.

**Risk Mitigation**: The decision to use arcwater cutting should always be considered against other methods and the risks identified, assessed and controlled. The use of unmanned submersibles or ROVs with power-operated saws can also be considered and the choice to use a diver in an oxy-arc burning scenario should be balanced, with alternative methods. The ROV can also be used to assist in oxy-arc cutting by monitoring hoses, vent paths and the operation; this should be identified in the risk assessment.

**Preparation for Underwater Shielded Metal Arc Welding**: Standard electrode holders designed for surface use, may also be used when underwater holders are not available, but **only** in an extreme emergency situation. It must be realized that these holders are never intended to be used underwater, and therefore, standard surface holders are not adequately insulated. The importance of fully insulating for all current-carrying parts cannot be over-emphasized. See the table below for common electrodes and amperage settings to depths up to 50 FSW (Feet of Sea Water).

| Recommended Amperage Settings for Wet Welding to Depths of 50 FSW | | | | | |
|---|---|---|---|---|---|
| Electrode | | Welding Position | | | |
| Type | Size inch | Horizontal Amps | Vertical Amps | Overhead Amps | Arc[1] Voltage |
| E6013 | 1/8 | 130-140 | 130-140 | 130-135 | 25-35 |
| | 5/32 | 150-180 | 150-180 | 150-170 | 26-36 |
| E7016 | 1/8 | 140-150 | 140-150 | 130-140 | 25-35 |
| | 5/32 | 160-200 | 160-200 | 160-180 | 26-36 |
| E7014 | 1/8 | 140-150 | 140-150 | 130-145 | 25-35 |
| | 5/32 | 170-200 | 170-200 | 170-190 | 26-36 |
| | 3/16 | 190-240 | 190-240 | 190-230 | 28-38 |

When preparing for underwater welding operations, several factors must be considered before welding actually begins. Adequate electrode preparations must be made. Lack of attention to detail here may well result in wasted diving time. For best results, follow the guidelines below:

- ✓ Avoid handling the flux coating with fingers. It is important that the work be accomplished in an area of low humidity.
- ✓ Before the dipping process, E7014 and E7016 electrodes shall be removed from their containers and placed into an oven and heated to 300°F and held at this temperature for 4 hours. After this time, the oven temperature shall be reduced to 150°F. The electrodes must remain in the oven until dipping operation takes place.
- ✓ Dip warm electrodes vertically into the waterproofing solution. Wait until no more gas bubbles generated by the electrode appear in the dipping container. Then, remove the electrodes from the container, to ensure a uniform waterproof coating on the flux covering.
- ✓ Dip electrodes once or twice as desired, covering all of the flux coating each time. If dipping more than one electrode at a time, do not allow their surfaces to touch each other.
- ✓ Hang electrodes vertically in a warm, dry area. This allows excess waterproofing, not absorbed into the flux coating, to run off evenly and form a slight bubble on the electrode tip. Leave the bubble attached. This will be removed when the diver strikes the arc.
- ✓ Allow electrodes to fully dry before re-dipping. Follow the same procedure for E308 and E310 electrodes. Do not heat E6013 electrodes prior to dipping. To do so would dry out the water-based flux adhesive rendering the flux useless.
- ✓ Mix the waterproofing according to the manufacturer's instructions in a clean container. Attach handling clips to the bare metal end of the electrode before dipping. Suitable clips can be fashioned using alligator clips, with holes drilled into one end, or "S" hooks can be made from small wires.

**IX - UNDERWATER WELDING INSPECTION:**

The welding inspector should be knowledgeable concerning each of the procedures, standards and methods required for general welding examination. It is the responsibility of those in charge of the project administration and inspection supervision to make certain that the principles and methods set forth, are properly understood and uniformly applied. This responsibility includes the qualification and certification of welders and inspectors, where such certifications are required by codes, procedures or civil laws.

Personnel performing welding examination also include welders, welding supervisors, the contractor's welding inspector, the purchaser's examiner or the regulatory controller. Fabrication documents, contract specifications and regulatory agencies, as well, may specify who performs final inspections. When technical documents do not address safety and health hazards concerning welding and cutting procedures, pertinent information can be found in OSHA (Occupational Safety & Health Administration) and ASME/ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes, and other safety-related documents including fe-deral, state, and local regulations.


The standard AWS D3.6M:1999 covers the requirements for welding structures or components under the surface of water using dry spot welding, habitat welding, one atmosphere welding, wet welding, and hyperbaric welding. It includes welding in both *dry and wet* environments. Sections 1 through 6 constitute the general requirements for underwater welding, while sections 7 through 10 contain the special requirements applicable to four individual classes of weld:

**Class A** - Comparable to above-water welding;
**Class B** - For less critical applications;
**Class C** - Where load bearing is not a primary consideration;
**Class O** - To meet the requirements of another designated code or specification.

The Section IX of the ASME - American Society of Mechanical Engineers relates to the qualification of welders, welding operators, brazing operators, and the procedures to be employed in welding and brazing according to the ASME I Power Boilers, ASME VIII Pressure Vessels, ASME

B31.1 and ASME B31.3 for Pressure Piping. The rules also apply to the preparation of the Welding Procedure Specifications (WPS) and the qualification of welding procedures, welders, and welding operators for all types of manual and machine welding processes. It is divided into two parts: Part QW gives requirements for welding and Part QB contains requirements for brazing.

AWS has chosen nondestructive examination (NDE) as the preferred terminology for these inspection methods. In other standards, literature, and industry usage, other expressions are commonly used and among these are; nondestructive evaluation (NDE), nondestructive inspection (NDI), and nondestructive testing (NDT). It must be emphasized that all of these expressions are commonly used, and may be considered equivalent.

Onshore inspection of welded joints may be also performed by conventional nondestructive methods, such as radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection. The radiographic or ultrasonic inspections, or both, are commonly used when the overall soundness of the weld cross section is to be evaluated. The introduction of nondestructive test methods began in the later part of the 1970's, and is still very much an integral part of inspecting offshore oil rigs.

Some of underwater inspections of bridges, piers, and cargo cranes that require extensive inspections to determine their structural integrity consist of a "swim by" only, but in most cases, this inspection is supplemented with underwater video or still photographic documentation. In many cases, the underwater visual inspection is supplemented by nondestructive testing of critical welds or selected areas of the structure. Radiographic testing, ultrasonics and magnetic particle are routinely used to determine wall thickness and weld integrity on inland, as well as, offshore structures.

The AWS B1.10 standard provides a reference guide for nondestructive examination methods, to be used to verify weldments, and to meet the requirements of a code or specification. The most common nondestructive examination methods described in AWS B1.10 are: Visual (VT); Liquid Penetrant (PT); Magnetic Particle (MT); Radiographic (RT); Ultrasonic (UT); Electromagnetic (Eddy Current) (ET); Leak (LT).

The AWS B1.11 standard essentially provides an introduction to visual examination (VT) of weldments. These examinations fall into three categories based on the time they are performed, as follows: (1) prior to welding, (2) during welding, and (3) after welding. An extensive treatment is provided on weld surface conditions, including reference to frequently used terminologies associated with preferred and non-preferred conditions. Visual examination may be performed by different inspectors or organizations.

The general requirements for welding, fabrication, brazing, inspection, and associated processes for naval sea systems and military vessels and equipment may also be under rules or in accordance with the standards, NAVSEA S9074-AR-GIB-010/278, MIL-STD-1689, and NAVSEA 0900-LP-001-7000. Underwater welding and cutting may also be constructed and inspected in accordance with NAVSEA S0300-BB-MAN-010 handbook. The main two types of weldings to be covered in this manual are:

- Wet welding: The work is done completely submerged, accomplished with both divers. Shielded metal-arc welding is the most widely used process for wet welding.

- Dry welding at the “splash zone”: Is generally conducted in a dry box, hyperbaric vessel, habitat, or a cofferdam at atmospheric pressure.

Welding and inspection for naval sea systems, such as machinery, piping, pressure vessels and components may also comply with the requirements of the technical manual NAVSEA S9074-AR-GIB-010/278, the Naval Ship’s Technical Manual NAVSHIPS 59086-AA-STM-010, and NAVSEA S0600-AA-PRO-010 standards. Fabrication, brazing procedures and weld operators can also be qualified in accordance with NAVEA 0900-LP-001-7000, except as amended by any appendix.

Welding, brazing and inspection for piping systems may also comply with the requirements of NAVSEA 0900-LP-001-7000 except as amended by any appendix. Welding procedure qualifications previously prepared for other agencies, such as, AWS, ABS, ASME, or other established regulatory codes may be submitted for approval to the NAVSEA authorized representative in accordance with limitations of NAVSEA S9074-AQ-GIB-010/248.

Welding and inspection of ship structures for military systems may comply with the requirements of MIL-STD-1689. All references to weld joint symbols shall be interpreted in accordance with MIL-STD-22 and AWS A2.4. Welding nomenclature and definitions shall be interpreted in accordance with AWS A3.0. Base materials shall meet the requirements of the applicable material specification listed in NAVSEA S9074-AR-GIB-010/278, MIL-STD-777, or MIL-STD-1689. Weld operators may also be qualified in accordance with these requirements.

Argon gas shall conform to the requirements of MIL-A-18455. Helium gas shall conform to the requirements of Fed Spec BB-H-1168 Grade A. Carbon dioxide gas shall conform to the requirements of Fed Spec BB-C-101. Tungsten electrodes shall conform to the requirements of AWS A5.12, EWTH-2 - 2% thoriated. Underwater welding and cutting inspection may be in accordance with NAVSEA S0300-BB-MAN-010.

All inspections of welded joints in machinery, piping and pressure vessels can also be performed in accordance with NAVSEA S9074-AR-GIB-010/278. All inspections of welded joints may be conducted in accordance with NAVSEA 0900-LP-001-7000, unless otherwise stated by NAVSEA S9074-AR-GIB-010/278. Repairs to base materials or welds are to be inspected to the same requirements as the original base material or weld. Unless otherwise specified all acceptance criteria shall be in accordance with MIL-STD-2035 Class 3 acceptance standards.

**ROV and AUV Inspection**: The term ROV means Remotely Operated Vehicle and AUV is Autonomous Underwater Vehicles. ROV’s and AUV´s are popularly used for underwater projects, where they are tethered to the surface, and controlled by a remote pilot. ROV’s are particularly useful because they have no depth restrictions which may limit divers, no depth time limitations, ability to enter dangerous and small spaces or contaminated water, and very good quality video.

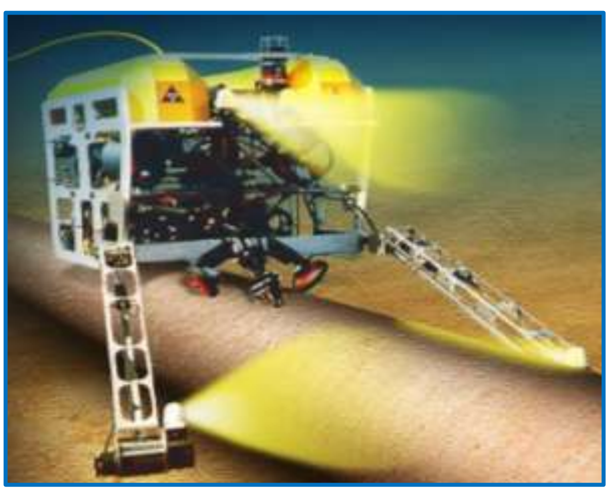
The ROV´s inspection tasks have been generally limited to corrosion monitoring utilizing cathodic potential metering devices, visual assessment via video or photographic means, and limited Ultrasonic techniques to provide wall thickness measurements or a flooded member detection capability. This presentation traces the development and successful utilization of advanced NDT techniques to inspect circumferential butt welds in deep water, using a ROV system.

Since statutory regulations require that saturation and surface orientated mixed gas diving techniques be utilized in water depths greater than 50 meters, there has been a concomitant increase in the development and utilization of Remotely Operated Vehicles to perform deep water cleaning and inspection tasks.

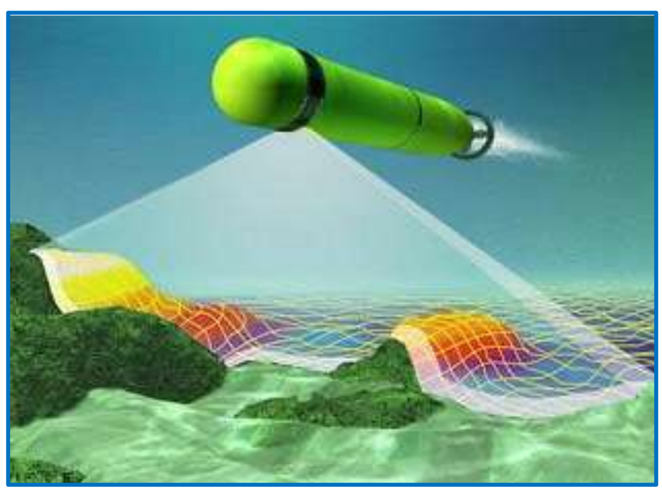
Waters Marine has been using a Video Ray Pro 4 unit for the past two years, to inspect pipes, water tanks and other structures in dams and rivers throughout Queensland and New South Wales. We can provide a DVD of the inspection as soon as the inspection is complete for the client's records. Waters Marine's ROV can reach depths of 300 meters.

It has two high quality video cameras with still capability, adjustable lighting, two forward thrusters and one depth thruster. A manipulator arm at the front of the ROV can hold small items when found on the sea bed, or attach tools such as probes and metal thickness gauges. Sonar can also be fitted for low visibility water.

**Remote Underwater Vehicles)**: *ROVs (Remote Operated Vehicles)* and *AUVs (Autonomous Underwater Vehicles)* are commonly used to make general inspections, maps, information transmissions, subsea maintenance evaluation, such as structures, umbilicals, pipelines and seafloor completions, in a manner with minimum disruption to the environment. Systems include communication module applications, high current, hydraulic power units (HPUs), optical fibers, UTPs, coaxial cables for video, phone, radio and computer communication, or a combination of all.



ROV (Remote Operated Vehicle)



AUV (Autonomous Underwater Vehicle)

ROVs and AUVs are unoccupied, operated by a crew aboard a vessel. These vehicles can be linked to the ship by either a neutrally buoyant tether or, often when working in rough conditions or in deeper water, a load-carrying umbilical cable is used along with a TMS (Tether Management

System). The TMS is a garage-like device, which contains the ROV during lowering through the splash zone or, on larger work-class ROVs.

The purpose of the TMS is to lengthen and shorten the tether by cable drags, where underwater currents can be minimized. The umbilical cable is an armored cable that contains a group of electrical conductors and fiber optics that carry electrical power, video, and data signals between the operator and the TMS. Where used, the TMS then relays the signals and power for the ROV down the tether cable. Once at the ROV, the electrical power is distributed between its components.

Most ROVs are equipped with at least a video camera and lights, but additional equipment is commonly added to expand the vehicle's capabilities. These may include sonars, magnetometers, a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, water temperature, water density, sound velocity, light penetration, and temperature. Experienced inspectors and commercial divers can operate an extensive array of underwater ROVs, including film work, military and construction.

Water metallic reservoirs may also be inspected and cleaned using ROVs, since from a small 30 metre (10 ft) high elevated tower, to larger reservoirs up to 10,000 m² with an experienced team of trained divers, including confined space to carry out these operations that can be conducted even the reservoir remains full, thus preventing the waste of water.

## X - WELDING INSPECTOR TRAINING AND CERTIFICATION:

Underwater inspector skills and training include the basics of salvaging oilfield equipment, vessels, shipwrecks and anything else lost on the seabed. Training includes search and rescue techniques, underwater cutting and explosives safety, lifting techniques using cranes, lifting bags and improvisation, excavation using air lifts and suction pumps, coffer dams, concreting, standard rigging practices and engineering drawing interpretation. It also covers electricity and computer skills, risk assessment for inflammable, contaminant & corrosive chemical exposure and trapping hazards.

**CSWIP (Certification Scheme for Welding and Inspection Personnel):** Provides internationally recognized, role-specific competence for people engaged in welding, joining, materials integrity and inspection in manufacturing, construction, operation or repair of high integrity structures, plant or machinery. The scope of CSWIP includes, among others, Welding Inspectors, Welding Supervisors, Welding Instructors, Cathodic Inspection personnel, Drilling Inspectors, Plant Inspectors, Underwater Inspectors, Plastics Welders and NDT personnel. CSWIP is managed by the Certification Management Board, which acts as the Governing Board for Certification in keeping with the requirements of the industries served by the scheme.

The CSWIP certification schemes are UKAS-accredited to ISO/IEC 17024, the international standard for personnel certification. In 2012, the bridging agreement between the AWS CWI and the TWI CSWIP was defined. Individuals holding CSWIP credentials must fill out all standard applications to register for CWI examinations, and must take and pass all three components of the examination to earn CWI credentials. All CSWIP Boards and Committees comprise member representatives of relevant industrial and other interests (TWI Training & Examination Services, Cambridge, United Kingdom).

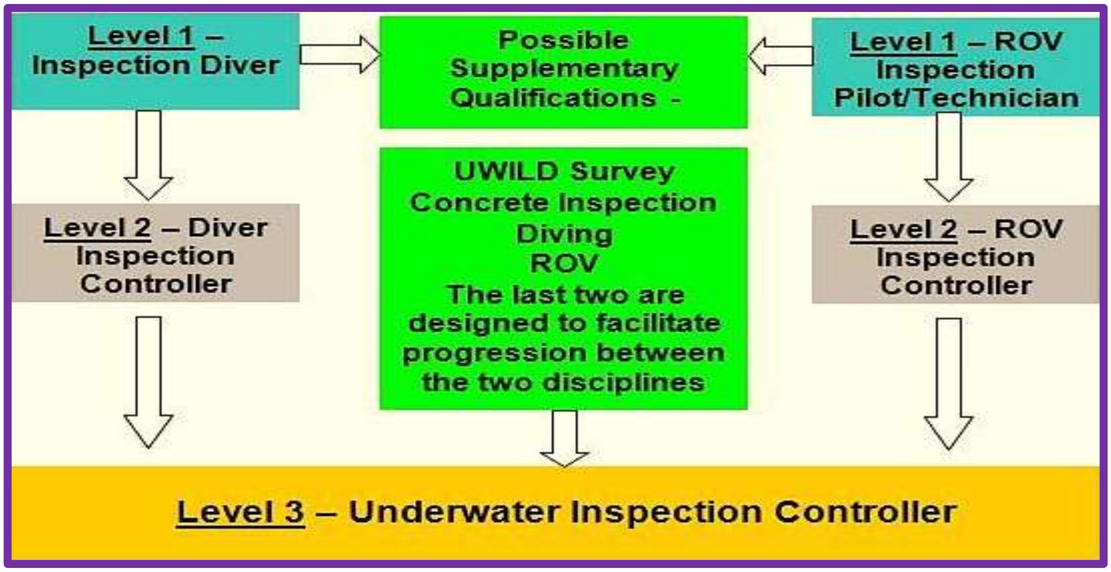
TWI Training & Examination Services deliver internationally recognized CSWIP, BGAS-CSWIP, EWF/IIW, PCN, ASNT, SNT-TC-1A, NEBOSH certification and more. Courses include NDT training, welding inspection, plant inspection and welding procedures, practical welding, health and safety and specialist diver training for underwater inspection. TWI-CSWIP covers available courses, entry requirements and career progression opportunities, and also features footage of students in a TWI's custom-built dive tank.


**CSWIP 3.1U Underwater Inspection Course**: This preparatory course is widely regarded by industry as one of the key aspects of training, whether working in onshore or offshore. The skills and techniques taught on this course provide a career as a commercial diver. As a commercial diver, subsea inspection is almost certainly going to be an important and regular part of your job. The CSWIP certification is currently the only certification for underwater visual inspection, throughout the world. The CSWIP courses are divided in three parts, according to qualification needed:

**CSWIP 3.0 Visual Welding Inspector - Level 1:** The Level 1 qualification covers all the practical aspects of the discipline, actually getting down and doing the job. They will know how to follow a specified procedure and why it is important to do so, but they will not be expected to design, develop, write or administer that procedure; they will know how to do the job.

**CSWIP 3.1 Welding Inspector - Level 2:** The Level 2 qualification is intended to be supervisory and will cover the procedural and control aspects of underwater inspection. This course can ensure that the all correct methods will be applied to the proper standards. In common with other PCN qualifications, Level 2 people will have a proven practical background in all the skills they are expected to supervise and control.

**CSWIP 3.2 Senior Welding Inspector - Level 3:** The Level 3 qualification covers both diving and ROV inspection, with all methods of underwater inspection. The Level 3 Inspectors will be proficient in various methods used to record and process inspection data. They will also be familiar with the considerations relevant to multi-role work scheduling when divers, air and saturation, and ROV operations are required simultaneously. Inspectors that have been qualified to Level 2 in either diving or ROV may also go to the Level 3 qualification.




**Note**: PCN is a personnel certification scheme in NDT methods, welding inspection and condition monitoring, which is accredited by UKAS according to ISO 17024. PCN certification schemes for the major NDT methods conform to BS EN ISO 9712 (2012).

**CSWIP 3.1U - NDT Inspection Diver:** This underwater NDT inspection course covers: theoretical instruction to CSWIP approved syllabus; general underwater and close visual inspection; recording by video and photography; cathodic protection measurements; ultrasonic digital thickness measurements; end-of-course assessment.

**CSWIP 3.2U - NDT Inspection Diver:** This underwater NDT inspection course covers: theoretical instruction to CSWIP approved syllabus; advanced underwater NDT techniques; magnetic particle inspection; weld grinding; overview of electro-magnetic techniques.

**CSWIP 3.3U Grade**: Applies to ROV Inspectors who carry out inspections, using a ROV or an autonomous submersible vehicle using visual and selected NDT techniques. The Inspector will be expected to be able to demonstrate his/her ability to carry out inspections by means of a ROV or unmanned submersible, using visual and selected NDT techniques.

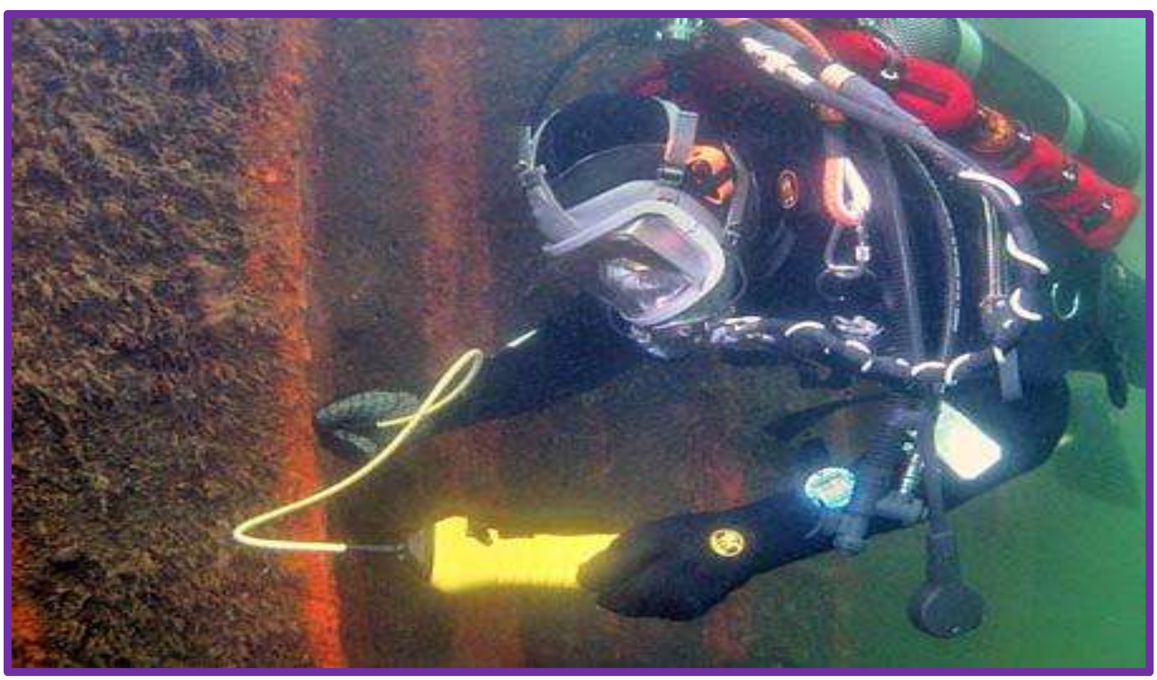
**CSWIP 3.4U Grade:** Applies to underwater inspection controller, as well as to a subsea inspection coordinator and subsea project manager. The Coordinator will be responsible for all planning and briefing of operations, including general inspections and NDT (non-destructive testing).

The initial two grades of activities that apply to divers who are involved in underwater structural inspections are CSWIP 3.1U and 3.2U, and a concrete examination is also available for all holders of these underwater inspection certifications. Inspectors who hold these grades are expected to be able to apply appropriate inspection methods and techniques underwater. They should be capable of maintaining appropriate job records, of preparing written reports and of producing an adequate oral commentary on their work as and when required.

The 3.3U grade Inspectors should have knowledge of QA relevant to underwater inspection and an appreciation of the abilities and limitations of remotely applied inspection systems, ROV's and submersibles. They should be capable of maintaining appropriate job records, of preparing written reports, and producing of an adequate oral commentary on their work, as and when required.

The 3.3U grade Inspectors must have an appreciation of the roles and responsibilities of other personnel and organizations, and will be expected to have knowledge of all aspects of the ROV inspections and testing methods included in the 3.2U examination and must have the skills and limitations of diving, ROV's, and submersibles, with optimum understanding of inspection planning and briefing.

**Practical Examination:** Underwater practical examinations will be conducted in either a tank or open water, but no more than three hours in water will be allowed for underwater tests. As part of the examination an adequate oral commentary by the candidate during underwater work may be required. All candidates must provide evidence of unaided or corrected near visual acuity in at least one eye, capable of reading N4.5 Times Roman type at a distance of not less than 30 cm on a standard reading test chart. There is a comprehensive list of approved commercial diving qualifications that can be found on the Internet at http://www.hse.gov.uk/diving/qualifications.



**AWS – Inspector Certification Levels:** According to AWS B5.1-2003, the three levels of qualifications for welding inspection personnel are:

- ✓ **AWI** - Associate Welding Inspector;
- ✓ **WI** - Welding Inspector;
- ✓ **SWI** - Senior Welding Inspector.

**Associate Welding Inspector (AWI):** Shall be a high school graduate, or hold a state or military approved high school equivalency diploma. Shall have a minimum of two years' experience in an occupational function with a direct relationship to weldments fabricated to national or international standards and directly involved in one or more of the areas.

**Welding Inspector (WI):** Shall be a high school graduate, or hold a state or military approved high school equivalency diploma. Shall have a minimum of 5 years' experience in an occupational function with a direct relationship to welded assemblies fabricated to national or international standards and be directly involved in one or more of the areas.

**Senior Welding Inspector (SWI):** Shall be a high school graduate, or hold a state or military approved high school equivalency diploma. Shall have a minimum of 15 years' experience in an occupational function with a direct relationship to welded assemblies fabricated to national or international standards and be directly involved in one or more of the areas.

**Written Test Requirements:** Is performed an applicable **AWI, WI, or SWI** examination. Individuals failing one part of the examination shall have to retest on all parts. The examination includes:

- A test on the requirements of a code, standard or specification. A test on fundamental principles including, but not limited to: welding processes, NDT examination, safety, quality assurance, inspector's duties, weld discontinuities, welding symbols, joint design, mechanical properties of metals, and basic on-the-job mathematics.

- A test on practical application of welding inspection knowledge including, but not limited to: welding procedure qualification, welder qualification, mechanical testing, drawing and specification compliance, welding examination, and nondestructive testing processes.

**Practical Test Requirements:** Covers welding procedures, welder qualification, mechanical tests and properties, welding inspection and flaws, and nondestructive tests. Test candidates should be familiar with fillet and groove weld gauges, micrometers, dial calipers, and machinist's scales. Part C - Open Book Code. This portion consists of questions on the code the individual has selected for this part of the examination. The following codes are applicable to this portion of the examination:

- AWS D1.1: Structural Welding Code Steel, examination covers the following subject areas: general requirements, design of welded connections, prequalification of WPS, welder qualification, fabrication, inspection, stud welding and annexes.

- API 1104: Welding of Pipelines and Related Facilities, examination covers the following subject areas: general, qualification of welding procedures, welder qualification, design and preparation of a joint for production welding, inspection and testing of production welds, standards of acceptability NDT, repair or removal of defects, radiographic procedure, and automatic welding.

- AWS D1.5: Bridge Welding Code, examination covers the following subject areas: general provisions, design of welded connections, workmanship, technique, qualification, inspection, stud welding for welded steel bridges, fracture control plan for non-redundant members and annexes.

- AWS D15.1: Railroad Welding Specification for Cars and Locomotives examination covers: welding of metal at least 1/8 in thick, specific requirements for welding railroad cars, and the requirements for the manufacturing and reconditioning of locomotives and passenger train vehicles.

- The examination according to ASME Section IX, ASME B31.1, ASME B31.3: The ASME Section IX covers the qualification of Welding and Brazing Procedures, and Welders/Brazers. The ASME B31.1 is the Power Piping code and ASME B31.3 the Process Piping Code.

- The examination according to ASME Section VIII covers the material, design, fabrication, inspection and qualification requirements for pressure vessel construction and welding and brazing qualifications. ASME B31.1 and ASME B31.3 also covers the material, design, fabrication, inspection and qualification requirements and welding and brazing qualifications for power and process piping.

In Australia and New Zealand the qualification/certification of welding inspectors is a common question from people looking to develop their careers. For the structural steel industry, most welding is required according to AS/NZS 1554.1:2011 Structural Steel Welding. Typical acceptable qualifications include:

a) An International Institute of Welding diploma as an IIW Welding Inspector, at the appropriate level.
b) A Welding Technology Institute of Australia Certificate as a Welding Inspector, at the appropriate level.
c) A Certification Board of Inspection Personnel (CBIP) New Zealand Welding Inspector.
d) A certificate as a structural welding supervisor in accordance with AS 2214.

Then, qualifications for examiners are set out in AS/NZS 1554, which defines the CBIP Certified Welding Inspector (CWI) or a person with at least the qualifications of a welding supervisor, such as IIW International Welding Specialist or AS 2214 Certification of welding supervisors - structural steel welding, or a NZIW Welding Supervisor Certificate.

The Welding Technology Institute of Australia (WTIA) has produced a guideline (GN12) on welding inspector qualifications and certifications, and summarized this in table form. This is a guideline only, and as such it is offered as fair comparison to assist employers and individual personnel. The table below is a summary and the guideline should be consulted in full before it is used for any decision making purposes.

| | *1. IIW International Institute of Welding Qualification* | *2. Australia (prior to 2008) WTIA Certification* | *3. Australia (Current) WTIA Certification* | *4. South Africa SAIW Qualification* | *5. USA AWS Certification* | *6. UK CSWIP Certification* | *7. NZ CBIP Certification* |
|---|---|---|---|---|---|---|---|
| 4 | International Welding Inspector Comprehensive (IWI C) | No equivalent existed at this level | WTIA Certified Comprehensive Welding Inspector (CCWI) Based on IWI C | SAIW Level 3 Welding Fabrication Inspector | No AWS equivalent exists at this higher level | No UK equivalent exists at this higher level | No NZ equivalent exists at this higher level |
| 3 | International Welding Inspector Standard (IWI S) | WTIA Certified Welding Inspector | WTIA Certified Senior Welding Inspector (CSWI) Based on IWI S | SAIW Level 2 Welding Fabrication Inspector | Certified Senior Welding Inspector (CSWI) | CSWIP 3.2 Senior Welding Inspector Level 3 | CBIP Senior Welding Inspector |
| 2 | International Welding Inspector Basic (IWI B) | No equivalent existed at this level | WTIA Certified Welding Inspector (CWI) Based on IWI B | SAIW Level 1 Welding Fabrication Inspector | Certified Welding Inspector (CWI) | CSWIP 3.1 Welding Inspector Level 2 | CBIP Welding Inspector |
| 1 | No qualification at this lowest level | No equivalent existed at this level | No equivalent exists at this level | No equivalent exists at this level | Certified Associate Welding Inspector (CAWI) | CSWIP 3.0 Visual Welding Inspector Level 1 | No equivalent exists at this level |

**XI - WELDING INSPECTOR KNOWLEDGES:**

The welding inspector is a responsible person, involved in the determination of weld quality according to applicable codes and/or specifications. In the performance of inspection tasks, welding inspectors operate in many different circumstances, depending primarily for whom they are working. Welding experience is valuable to an inspector but not the only one of the necessary. The inspector should have sufficient knowledge of the welding process to enable him/her to know what defects are most likely to occur.

Thus, there is a special need for job specifications due to the complexity of some components and structures. The Welding Inspector should be familiar with procedure specifications, and know how to apply, and must be a high skilled technician or engineer with a good knowledge of general industry manufacture, materials, quality systems, inspection procedures and standards as:

- ✓ Standard organizations as ASTM, SAE, AISI, AWS, ASME and other institutions;
- ✓ Metals metallurgy, hardness tests and heat treatment;
- ✓ Materials properties, destructive testing and NDT methods;
- ✓ Terminology, weld joint geometry and welding symbols;
- ✓ Welding equipment, metal joining and cutting processes;
- ✓ Application of procedures, records, welding inspection and qualifications;
- ✓ Evaluation of weld and base metal discontinuities;
- ✓ Metric and conversion practices and safe welding practices.

**1. Certification and Test Methods:** It is essential that the inspector have some knowledge of the test methods to a better understanding of why one welder may be qualified to weld and another welder is not. This knowledge also enables the inspector to understand the limitations that may be imposed on some welders.

**2. Welding Processes and Quality:** Prepare reports and understand what is SMAW, SAW, OFW, RW, GTAW, FCAW, GMAW, PAW, SW, ESW, Thermal Spraying, Soldering, Mechanical Cutting, Thermal Cutting/Gouging, Brazing Welding. Understand VT, MT, AET, UT, PT, ET, RT, and LT, quality procedures, quality audits and surveillance, fundamentals of welding metallurgy, welding symbols, drawings and related documents.

**3. National and International Standards:** Verify base material, verify filler metal, verify filler metal storage/handling, verify inspection records, verify proper documentation, verify base material and filler metal compatibility, certify documented results, verify procedure qualification records, verify welding procedure, and verify NDE procedures.

**4. Welder Qualifications:** Verify welding equipment appropriateness, edge preparations, joint geometry, witness procedure qualification, verify welder procedure qualifications, (review and approve), develop welding procedures, verify welder safety procedures.

**5. General Inspection:** Perform visual examinations, verify examination procedure, review examination results, develop visual inspection procedures (before, during, and after welding), provide NDT inspection planning and scheduling (before, during, and after a project).

**6. NDT Requirements:** Review welding inspection reports, verify implementation of nondestructive and destructive methods, visual inspection requirements, prepare NDT requirements, report results of quality inspection, prepare destructive testing procedures.

**7. Records and Reports:** The inspector should have the skills required to review a Procedure Qualification Record (PQR) and a Welding Procedure Specification (WPS) and to be able to determine if procedure and qualification records are in compliance with applicable ASME IX, ASME Boiler and Pressure Vessel Code and additional requirements of API 570.

**8. Welding Procedures:** Determine that the number and type of mechanical tests that are listed on PQR are the proper tests, and whether the results are acceptable. Filler metals will be limited to one per process for SMAW, GTAW, GMAW, or SAW. The PQR will be the supporting PQR for the WPS. Special weld processes such as corrosion resistant weld metal overlay, hard facing overlay, and dissimilar metal welds with buttering of ferritic member will be excluded.

**9. Safety and Quality Assurance:** Verify safety requirements compliance, develop safety procedures and policies. Perform audits and surveillance, develop quality assurance plans, prepare base material control requirements, prepare weld consumable, prepare audit and surveillance plans, prepare documentation control requirements.

**9. Project Management:** Review contract requirements, review vendor proposal compliance, prepare weld inspection, bid specifications, prepare purchase specifications, determine vendor capacity and capability, select vendors, verify and inspect products storage.

**10. Training:** Develop and provide a training program, develop visual inspection training, verify implementation of visual inspection training, develop quality assurance program, verify implementation of quality assurance training, provide guidance to inspectors for maintaining their individual qualifications.

**11. Inspector Duties:** Witness welder performance qualification, verify welder qualification, verify welder qualification records and request welder performance requalification. The inspector duties will follow the general headings below:

1. Interpretation of the Plans and Specifications;
2. Verification of Welder Records and Welding Procedures;
3. Verification of Written Welding Procedures;
4. Production Welding Checks;
5. Keeping Records and Reporting;
6. Selection of Test Samples.

**XII - ELECTRODES - BASIC CLASSIFICATION:**

Classification consists of a prefix letter "E" specifying an electrode, a group of two or three digits specifying weld metal strength in ksi in the 'as-weld' or stress relieved condition, and a final two digits specifying type of covering, weld position and current characteristics. The nomenclatures of electrode specifications are:

E60xx - 60ksi (420 MPa);
E70xx - 70ksi (490 MPa);
E80xx - 80ksi (560 MPa);
E90xx - 90ksi (630 MPa);
E100xx - 100 ksi (700 MPa);
Exx10 - Cellulosic covering for the use with DC reversed polarity;
(E6010) - Deep penetration and all positions electrode for general purpose;
Exx11 - Cellulosic covering for AC or DC, all position;
(E6011) - Deep Penetration and thin slag, X-ray quality weld;
Exx12 - Rutile covering AC or DC, all positions;
(E6012) - Medium penetration, good choice for fit-up work;
Exx13 - Rutile electrodes AC or DC, all position;
(E6013) - Good performance in sheet metal welding;
Exx14 - Iron powder rutile same characteristic as Exx 13, but with a higher welding speed;
Exx15 - Basic low hydrogen covering requiring use of DC only, all positions for steel welds;
(E7015) - Good for high sulfur steels;
Exx16 - Basic low hydrogen covering as Exx15 but with addition of potassium;

(E7016) - Salts to allow operation with AC;
Exx18 - Low hydrogen electrode as Exx 16, but with 30% iron powder to give (E7018);
Exx20 - Typical mineral (iron oxide/silicate) covering for use in flat and (E6020);
Exx24 - Rutile and 50 per cent iron powder covering similar to Exx12, with (E7024);
Exx27 - Mineral plus 50 iron powder covering with similar (E6027) characteristics to Exx20;
Exx28 - Low hydrogen plus 50 per cent iron powder covering with high (E7028) deposition rate;
Exx30 - Mineral covering similar to Exx20 but high deposition rates. F positions only.

**Note:** Typical electrodes in brackets are most widely used. The use of mineral or iron oxide/silicate covered electrodes is decreasing in the USA and UK.

**Electrode Designations:** Electrode types EX XXXX. For example, ER 4211, EA 4214.

The **first letter** "E" indicates a covered electrode for SMAW, manufactured by extrusion process. The **second letter** "R" indicates type of covering e.g., R = Rutile, A = Acid, B = Basic, C = Cellulosic, RR = Rutile heavy coated, S = any other type not mentioned here.

The **first numerical** "4" indicates strength (UTS = 410-510 MPa) in combination with the yield strength of the weld metal deposit YS = 330 MPa. The **second numerical digit** indicates percent elongation in combination with the impact value of the weld metal deposited. Thus "2" means 22% of minimum elongation with an impact test of 47J at zero °C. The **third numerical digit** "1" shows the welding position in which the electrode may be used.

1 = means all positions;
2 = all position except vertical;
3 = flat butt weld horizontal/vertical fillet weld;
4 = flat butt and fillet weld;
5 = vertical down and flat butt;
6 = any position not mentioned here.

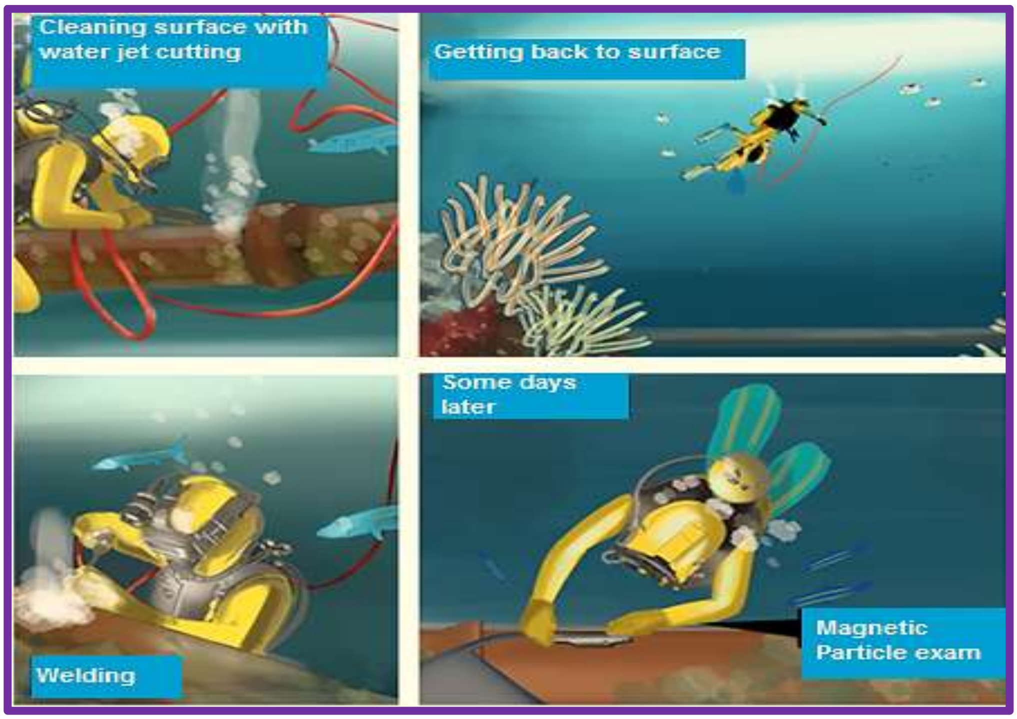
**Water-proofed Electrodes:** Consist of steel-tubular electrodes with a special polymer waterproofed flux coating, which is applied during the manufacturing process, commonly used for underwater welding. These electrodes commonly have 14 inches long with a 5/32" outer diameter and a bore diameter slightly less than 1/8 inch. The waterproof flux coating is similar in composition to the coating on welding electrodes. The flux coating serves the following purposes:

- a. It promotes easy starting and maintenance of the arc;
- b. It liberates gases, thus forming a protective bubble around the arc.

These electrodes have a special rutile flux coated welding electrode with added nickel, to be used for all structural steels. It has a special formulated clear polymer based waterproof coating, to ensure the maximum resistance to water and moisture penetration. The electrodes allow higher levels of misuse in handling and care, and are provided with electrical insulation for improved welder/diver safety. These electrodes are commonly available in 3.2mm and 4.0mm (1/8" and 5/32"), boxed in plastic telescopic containers, and should exceed AWS D3.6M-99 Class “B” quality.

Although there is not yet a defined standard/specification for underwater welding electrodes, the nearest equivalent may be taken from BSEN ISO 499: 1995 for covered welding electrodes. For example, the nearest code is E4221NiRR (AWS E7014). According to manufacturer (Barracuda) the Gold electrodes should exceed the specification criteria as stated under BSEN ISO 15618-1:2002 and AWS D3.6M-99 for underwater class “B” welds.

Testings were made with electrodes submerged up to a 90 minute period without any undue interference or loss of performance, although it is always recommended electrodes that should be used within a 30-45 minute period, where possible. These electrodes are designed to be used in all positions, making welding very easy, for both experienced and inexperienced divers.




**Underwater Cutting Electrodes**: The oxygen-arc cutting is defined as oxygen-cutting process in which metal is severed by means of the chemical reaction of oxygen with the base metal at elevated temperatures. The heat of the arc brings the metal to its kindling temperature, and a high velocity jet of pure oxygen is directed through a tubular cutting electrode at the heated spot. The metal oxidizes and is blown away. The tip of the electrode, which is exposed to both heat and oxidation, is consumed in the process and must be replaced frequently.

Currently there are many manufactures for underwater cutting electrodes such as, exothermic, tubular steel and water-arc cutting electrodes that can easily burn after it is ignited. These electrodes are commonly available in a 4.0 mm (5/32”) diameter and can cut a wide range of materials; including steel, stainless steel, cast-iron, bronze and copper alloys, and aluminum and its alloys, both above and below the waterline. Cutting electrodes require no special equipment since a 300-400 Amp., DC welding power source will do the job.

According to manufacturer, the prothermic underwater cutting rods can be used up to 1000 ft below the surface of the sea. The prothermic rod burns at an approximate temperature of 10,000º F, and will continue to burn even when the power supply is turned off. The rods can be used on the following types of materials; carbon steel, cast iron, stainless steel, non-ferrous metals, concrete, rock, rope and wood.

**XIII - WELDING & CONSTRUCTION - GENERAL STANDARDS:**

**American Bureau of Shipping (ABS):** Is a classification society, with a mission to promote the security of life, property and the natural environment, primarily through the development and verification of standards for the design, construction and operational maintenance of marine-related facilities. The ABS main operation is the provision of classification services through the development of standards called ABS Rules. These Rules form the basis for assessing the design and construction of new vessels and the integrity of existing vessels and marine structures.

ABS also develops standards for the design, construction and operational maintenance of offshore drilling and production units and for gas carriers of all types. These standards cover mobile offshore drilling units (such as jackup rigs, semisubmersible rigs, and drill ships), floating offshore production installations (spars, tension leg platforms, semisubmersibles and FPSOs/FSOs), fixed offshore installations, pipelines, risers, and single point moorings. The most common standards for welding and general construction are:

AWS D3.6M - Specification for Underwater Welding;
AWS D1.1 – Structural Welding Code
AWS A2.4 - Standard Symbols for Welding, Brazing, and Nondestructive Examination;
AWS A3.0 - Standard Welding Terms and Definitions;
AWS B1.10 - Guide for the Nondestructive Examination of Welds;
AWS B1.11 - Guide for the Visual Inspection of Welds;
AWS B2.1 - Specification for Welding Procedure and Performance Qualification;
AWS B4.0 - Standard Methods for Mechanical Testing of Welds;
AWS B5.1 - Specification for the Qualification of Welding Inspectors;
AWS QC1 - Standard for AWS Certification of Welding Inspectors;
ANSI/ASME B31.1 - Power Piping;
ANSI/ASME B31.3 - Process Piping
ANSI/ASME B16.5 - Pipe flanges and flanged fittings.
ASME VIII - Pressure Vessels, Division 1, Division 2 and Division 3;
ASME V - Non-destructive examination;
ASME IX - Welding and Brazing Qualifications;
API 510 - Maintenance inspections, repair, alteration, and procedures for pressure vessels;
API 570 - Performs visual, baseline and in-service corrosion inspections on piping systems;

API 653 - Specific inspection and techniques that apply to above ground storage tanks; API 570 - Piping inspection code;
API RP 574 - Inspection practices for piping system components;
API RP 577 - Welding and metallurgy;
API RP 578 - Material verification program for new and existing alloy piping systems;

**XIV - REFERENCES:**

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