Underwater Welding and Cutting

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Learning Objectives

After studying this chapter, you will be able to:

- Describe developments in the field of underwater welding and requirements of AWS D3.6M *Underwater Welding Code*.
- Describe the welding equipment used for underwater welding.
- Explain the differences between wet and dry underwater welding processes.
- Describe the five habitats used for hyperbaric (dry) underwater welding.
- Describe various underwater cutting processes and explain their applications.
- Recognize the safety hazards related to underwater welding and cutting.
- Describe the recommended path toward a career in underwater welding.

The demand for welding has expanded from onshore welding jobs to the need to weld structures on or under water. Offshore oil platforms and underwater pipelines are now common around the world. These structures require maintenance, repair, and modifications. Special equipment and well-trained underwater welders are needed to address the welding demands on underwater structures.

Note

In this chapter, the terms *welder/diver* and *welder* refer to an underwater welder.

Welding methods have been developed to allow wet and dry underwater welding. ***Wet welding*** is underwater welding where the weld joint is completely surrounded by water. ***Dry welding*** is underwater welding where the water is removed from the welding area. Dry underwater welding is referred to as ***hyperbaric welding***.

Cutting is also done underwater to prepare an area for welding or for demolition of a structure. Different methods are used for these two categories of cutting.

25.1 Development of Underwater Welding

Prior to the 1960s, all underwater welding and cutting was performed as either a means of salvage or as a temporary repair. Ships and barges could be patched well enough to float and would then be taken to a dry dock for permanent repairs. Dry docks and other marine facilities were located on coastlines. These facilities could make repairs without the use of underwater welding. However, the need for underwater welding increased. Processes and equipment to allow underwater welding had to be developed.

Early oil drilling and oil platforms were in very shallow water or near land. In the 1960s, the demand for oil sent oil companies farther offshore into deeper water. Permanent platforms were put in place, and it became necessary to develop solid repair procedures to use on these structures. Repair procedures were also needed to repair the pipelines that transported the crude oil and natural gas to shore. See **Figure 25-1**.

Since all of these structures and pipelines were built to standards or codes, all repairs to them also are required to meet the same requirements.

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Figure 25-1. An oil drilling platform. The oil and gas industry drove the need for underwater welding equipment, techniques, and welders.

While the AWS already had a technical committee that addressed welding in marine construction, they needed a new subcommittee for underwater welding. The D3B Subcommittee for Underwater Welding was formed and tasked with developing a specification for underwater welding.

Commercial diving contractors saw the potential for additional work, so they began developing systems for underwater welding. The demand for offshore structures was forecast to significantly increase, and a specification was needed. One of the first companies to undertake a development program for underwater welding was Chicago Bridge and Iron. They had designed a platform for Saudi Aramco in the Persian Gulf. Before they could install the platform, they had to demonstrate that they could maintain it and repair it if required.

Chicago Bridge and Iron brought together a group of welding engineers and their top welders. This group put together an all-out effort to develop wet welding procedures that could meet the requirements of the oil company and the offshore structures. They completed the project and gave the test results to the oil company. The welding procedures they developed were accepted, and the test results from that project became the baseline for the AWS D3.6M *Underwater Welding Code*.

As the oil industry expanded exploration further offshore, it rapidly became apparent that the scope of the specification had to be broadened. Not all underwater repairs could be performed with wet welding. Wet welding could be used for structural welds but could not produce welds that were strong enough or ductile enough for repairing pressure piping or pipelines. There was a need to develop underwater welding techniques and systems that could create a dry atmosphere in which the welding could be performed.

Improvements continue today in both wet and dry underwater welding equipment, electrodes, and processes. The Ohio State University, Colorado School of Mines, and other universities and companies have programs doing research in underwater welding.

25.2 D3.6M *Underwater Welding Code*

The current AWS D3.6M *Underwater Welding Code* covers all requirements for welding structures or components under the surface of water. This code covers welding in both wet and dry environments. Clauses 1 through 8 address all of the general requirements for underwater welding. Clauses 9 through 11 contain the special requirements applicable to three specific classes of welds (A, B, and O). These classes are covered in the next section.

The D3.6M specification began as a specification for wet welding but was expanded. It now includes underwater welds made in a dry habitat (hyperbaric welding) and aligns with other specifications, such as D1.1 *Structural Welding Code—Steel*, API 1104 *Welding of Pipelines and Related Facilities*, and ASME B31-3 *Process Piping Design*. The specification was broken down into various subtypes, or classes, of welds. The class of the weld specifies a level of serviceability and a set of required properties. This allows the customer to select a repair method based on the structure's original design. The D3.6M specification also identifies essential variables for underwater welding.

Pro Tip

In industry, the term *underwater welding* usually refers to wet welding. The term *hyperbaric welding* refers to dry welding.

25.2.1 Weld Classes

The three weld classes specified in the D3.6M:2017 *Underwater Welding Code* are Class A, Class B, and Class O. The code does not specify which class is to be used for a given application. The customer must specify which class is required for a project.

Class A welds can be made in either a wet or dry environment. These welds are intended to be suitable for applications and design stresses comparable to their counterparts welded on land. This weld class is primarily based on D1.1 *Structural Welding Code—Steel*, with additional essential variables to cover the unique problems encountered in an underwater environment. Class A welds are specified for constructing or repairing main structural members.

Class B welds are normally performed in a wet environment. These welds are used for less critical applications in which lower ductility, greater porosity, and other relatively large discontinuities can be tolerated. A typical use for Class B welds is attaching nonstructural items to a structure. The welds do not carry the load of the main structure or pipe but do carry a secondary load. The welds must not weaken the main structure. In recent years, there has been a great deal of improvement in wet welding electrodes and welding machines. As a result, Class B welds are much improved. See **Figure 25-2**.

Reiner Eggendorfer for Oxylance, Inc.

Figure 25-2. A welder making a fillet weld on a pipe reinforcement, or doubler. Wet welding is a Class B weld per AWS D3.6M code.

Class O welds, used for pipelines, must meet the requirements of a designated code or specification as well as the underwater requirements of D3.6M. Using the specifications for Class O welds, new pipelines have been tied into new platforms in water depths as deep as 1100′ (335 m). These welds were made using conventional welding techniques in a dry habitat. Class O is the most demanding class of underwater welds.

Not all materials can be welded in a wet environment. However, with proper engineering and testing, most materials that can be welded above water can be welded in a dry habitat underwater.

25.2.2 Essential Variables

There are variables in all welding procedures. Some are essential variables and some are nonessential variables. An ***essential variable*** has a significant effect on the mechanical properties of a weldment if the variable is changed. A change to an essential variable requires new welding procedure specifications (WPS). A ***nonessential variable***, when changed from the approved welding procedure specification, does not require requalification of the procedure. The nonessential variable must be written on the WPS, but no additional testing is required. Procedure qualifications are discussed in Chapter 31, *Procedure and Welder Qualifications*.

One example of an essential variable is the type of electrode. A welder that is qualified to make a weld on a pipeline using E6013 electrodes cannot change to an E7018 to make a weld. The weld parameters and techniques are different.

The welder must pass an additional qualification test using an E7018 prior to welding with this electrode.

In underwater welding, there are more essential variables than for welds above water. The essential variables in underwater welding address all of the variables involved in welds made above water, as well as the unique requirements of the underwater environment. In underwater welding, nearly every variable is an essential variable.

The D3.6M specification lists all essential and nonessential variables. The following are examples of essential variables listed in D3.6M:

- Electrode type.
- Electrode coating.
- Electrode manufacturer (the coating changes).
- Electrode diameter.
- Welding current and voltage.
- Travel speed.
- Wet versus dry welding.
- Depth of welding.
- Background gas.
- Type of base metal being welded.
- An increase in the exposure time of filler metal at the qualification depth atmosphere.

An example of the effect of the depth of welding variable is that some welding rods, such as stainless steel, can be used for wet welding at 50′ (15 m) but will not weld at all at 60′ (18 m). For every procedure, depth limits must be strictly adhered to.

A ***background gas*** is a gas mixture used to force water out of an underwater chamber and keep oxygen at a safe level. The background gas mixture changes as the depth increases. The background gas in the chamber affects the weld, so the weld must be qualified using the same background gas that will be used on the job. This means that the background gas in the chamber is an essential variable. If gas tungsten arc welding is being used, the background gas must be compatible with the shielding gas.

Essential variables for depth of welding in dry habitats are different because they address background gas. Down to 90′ (27 m), welding can be performed in a habitat with compressed air in the habitat. Air or other gases are used to force water out of an underwater chamber. The pressure used is equal to the pressure of the water outside of the chamber. Gases are compressed as the pressure increases. As the pressure increases, more gas is fit into the same volume of space, including more oxygen. At depths greater than 90′ (27 m), the amount of oxygen present increases the possibility of a fire. The allowable depth requirement for compressed air is different from the allowable depth for other gases. To summarize, depth of welding and background gas are key essential variables in underwater welding.

Warning

Compressed air at depths greater than 90′ (27 m) becomes oxygen-enriched and dangerous. For the divers' safety, the habitat is pressurized with a nonflammable or inert gas, such as nitrogen, argon, or helium.

Another essential variable that is critical to wet welding is the type and grade of steel being welded. For example, some steels that can be welded above water with an E7018 welding rod cannot be wet welded with a 70 series welding rod because of their carbon content. Rapid quenching of the welds made on higher-carbon steels causes underbead cracking. Higher-carbon steels must be wet welded with stainless steel or nickel electrodes. Stainless steel and nickel wet welding electrodes are highly sensitive to hydrostatic pressure, so they are used only in water depths to 50′ (15 m). Beyond 50′ (15 m), these rods will not weld. At depths greater than 50′ (15 m), higher-carbon steels must be dry welded.

Many welding procedure specifications (WPS), procedure qualification records (PQR), and welder performance qualification tests are required of companies performing underwater welding. These documents are explained in Chapter 31, *Procedure and Welder Qualifications*.

25.3 Welding Equipment for Underwater Welding

Most welding machines that are 300 amps or greater and have a 100% duty cycle can be used for underwater welding. Different welding machines produce different results on underwater wet welds. Welding equipment is installed on a dive barge, boat, or oil platform.

Recent advances in inverter technology have made welding power sources that produce higher-quality wet welds than older-model welding machines. These inverter machines produce a quality arc with voltage readings in the 22 to 26 volt range. This low arc voltage ensures a controlled short arc length. The combination of short arc length and the higher amperage associated with the short arc has proven to produce welds with low porosity and high ductility.

The SMAW electrode holder is a specifically designed unit that is insulated to prevent electrical shock. See **Figure 25-3**. There are no bare metal parts on an underwater SMAW electrode holder.

Broco, Inc.

Figure 25-3. An underwater SMAW electrode holder. The holder is well-insulated, with no bare metal areas.

Nonstandard Terminology

Electrode holders designed for underwater use are commonly referred to as *stingers*.

Electrodes for wet underwater welding are coated with waterproofing that prevents the flux from absorbing water. See **Figure 25-4**. The waterproofing of electrodes is so critical that the D3.6M *Underwater Welding Code* specifies that any change in waterproofing of wet welding electrodes requires that the procedure be recertified and all welder/divers also requalify.

Electrodes used in a dry habitat are the same as those used above water. E7015, E7018, and other SMAW electrodes are used in dry environments. E6010 and E7010 electrodes are not used for underwater welding in a dry habitat because their electrode coatings do not provide enough shielding gas.

GTAW and GMAW equipment, power supplies, torches, guns, shielding gas, electrodes, and filler metal are all the same as those used above water. GTAW and GMAW are done only in a dry habitat underwater. Thus, the process and equipment are the same as used above water.

As the depth of welding increases, the diameter of the electrode lead and workpiece lead must increase to minimize the cable resistance. This is the same as welding on land as the distance from the power source to the welding site increases.

25.4 Wet Welding

Wet underwater shielded metal arc welding is performed directly in the water with no barrier between the arc and the water. For the best mechanical results, wet welding SMAW electrodes should be 3/32″ (2.4 mm) or 1/8″ (3.2 mm). Larger electrodes deposit so much metal that they tend to trap more porosity and make welds that are not as ductile as welds made with smaller electrodes. Also, research and testing have found that when a weld was built-up with multiple passes, the beads on top anneal the underlying beads. This annealing softens the weld metal and makes it more ductile. Once this was discovered, the D3.6M specification made both the number of beads and the use of annealing or temper beads essential variables in the specification.

All underwater wet welds are made using the stringer bead technique. The weld pool solidifies so fast underwater that a weave bead will trap slag. For the same reason, all vertical welds are made downhill.

Greg Cain of Oxylance, Inc.

Figure 25-4. Underwater SMAW electrodes have special waterproof coatings on the electrodes. The specific coating on an underwater SMAW electrode is an essential variable.

Most underwater welds are made with DCEN. However, new electrodes, mostly stainless steel and nickel, have been developed that require DCEP.

Mild steel electrodes for wet SMAW can be used to weld all materials containing up to .40 carbon equivalent. ***Carbon equivalent (CE)*** is a formula used to quantify the weldability of a steel. The formula produces a value that takes into account many alloys found in steel. As carbon or the carbon equivalent increases, the weldability of a steel decreases. With a higher-carbon equivalent, the steel has a greater tendency for cracking. A weld in material with a carbon equivalent above .40 tends to develop underbead cracking and normally will not pass a bend test.

Stainless steel rods can be used on some material above .40 CE and on stainless base metals. Nickel welding electrodes are used on higher-carbon steel and were developed for the US Navy to weld on submarines and other ships with material up to a high-yield strength of 100,000 psi. **Figure 25-5** shows a fillet weld made with a nickel electrode.

When performing underwater welding, it is important to keep the arc length as short as possible. Arc length is critical to underwater welding. Amp and volt settings are essential variables in an underwater welding specification. A longer arc increases the arc voltage, which in turn increases the amount of porosity in the weld. The best mechanical results are achieved with arc voltage of 22 to 26 arc volts.

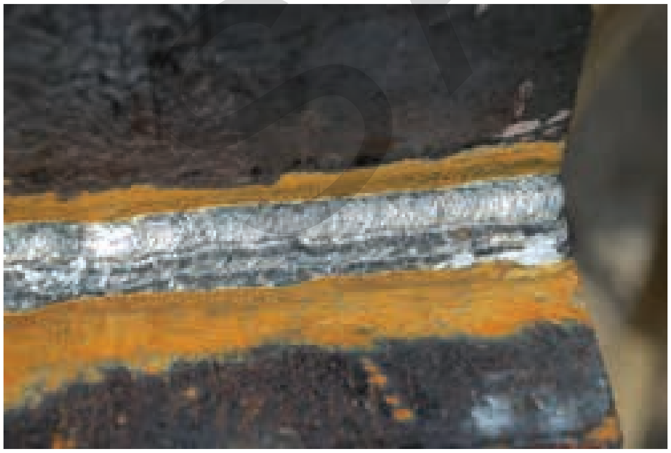
Rod angle and travel speed are critical for the welder/diver to control. The steel core of an underwater SMAW electrode melts faster than the flux and insulation coating on the electrode. This is similar to the way an E7018 electrode performs above water. The flux and insulation coating are kept in contact with the pipe or part being welded. There is a tiny gas bubble at the tip of the electrode. Too much travel angle or a travel speed that is too fast disrupts the gas bubble and causes defects in the weld.

When ready to strike the arc, the welder communicates with the dive supervisor who is in the dive station on the surface. The welder tells the supervisor or radio operator to make the knife switch hot. The ***knife switch***, **Figure 25-6**, electrically connects the welding leads to the welding power source. Making the knife switch *hot* means to connect, or close, the switch.

Once the knife switch is made hot, the diver can start to weld. The knife switch is kept in the hot (closed) position while the diver is welding. When the diver is not welding, the knife switch is kept in the cold (open) position, cutting off electricity to the electrode. This protects the welder from accidental shocks.

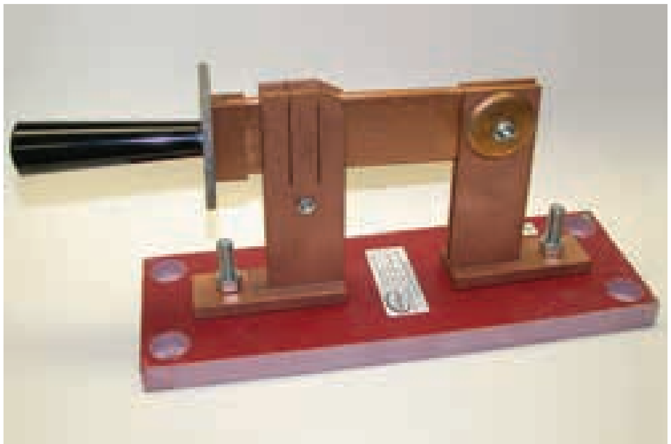
Once the arc is established, the welder must keep a slight pressure on the electrode to keep the flux and insulation coating in contact with the part being welded. This maintains a short arc and the small gas bubble at the tip of the electrode. The gas bubble keeps water away from the weld pool. The electrode should be held at a slight drag travel angle of no more than 25°. A constant travel speed must be maintained to produce a quality weld bead.

There are two ways to end a weld bead. One method is to draw the electrode away from the weld bead. The arc stops when the distance is too great for the voltage to maintain the arc. Once the arc is stopped, the diver tells the dive supervisor or radio operator to make the knife switch cold (open). This keeps the diver safe by cutting off electrical current. The problem with this method is that a long arc produces porosity in the weld.



Greg Cain of Oxylance, Inc.

Figure 25-5. Fillet weld made with the wet welding technique and nickel SMAW electrodes. Note that each pass was laid down as a stringer bead.



Bay-Tech Industries, Inc.

Figure 25-6. A knife switch is a simple and reliable type of switch. When the switch is opened, electrical power is cut off to the electrode.

The gas bubble at the end of the electrode is broken, and water quenches the weld pool. This area must be ground out prior to striking another arc to continue the weld bead.

A second method to stop a weld bead is for the diver to tell the dive supervisor or radio operator above water to make the knife switch cold when the diver nears the end of the weld or must change electrodes. The dive supervisor or radio operator opens the knife switch. This stops the welding current. No porosity is created in the weld pool. The problem with this method is that the welding circuit is still complete when the knife switch is opened. This causes an arc across the knife switch, which can damage it. Manufacturers are researching and evaluating possible solutions to the arcing problem.

When performing underwater welding, the diver must be careful not to ground the metal parts of the diving helmet to any part of the welding circuit. For this reason, the knife switch is opened whenever the welder is not welding. When the knife switch is open, no welding current is flowing, which prevents any potential shock.

A lighter value filter plate is used to protect the welder's eyes during wet underwater welding. The visibility is poorer underwater, and 90% of UV rays from the arc are filtered out by the water. A shade 5 to shade 9 filter plate is normally adequate, depending on water clarity.

Note

GTAW and GMAW are not done in a wet welding environment.

25.5 Hyperbaric (Dry) Welding Underwater

There are five basic types of dry habitats for underwater welding. Each type has its own advantages. Four of the habitats allow the welder to enter the habitat. These can be large structures. One is very small, so only the welder's arms enter the habitat. Two habitats are accessed from the surface, while the others require the welder to enter from a wet environment.

25.5.1 One-Atmosphere Pressure Vessel

In a ***one-atmosphere pressure vessel*** application, the weld project is encapsulated in a chamber with an access tunnel to the surface. This type of welding is called *one-atmosphere dry chamber welding*. Many pipeline repairs in rivers and shallow water are repaired using this method. With the dry chamber method, a chamber is lowered over a pipeline. It is sealed around the pipe and the water is pumped out. Welders enter the chamber through a trunk that extends to the surface. Any work and welding normally done in a fabrication shop can also be performed inside the chamber. See **Figure 25-7**. There is no depth limit for a one-atmosphere pressure vessel, but in practical terms, it is used in relatively shallow applications.

25.5.2 Ambient Pressure Chamber

An ***ambient pressure chamber*** can also be used to create a dry environment for welding. The chamber is set in place on the pipeline or structure and is sealed around the structure and at the high point. Air pressure or a background gas mixture is used to force the water out of the chamber. The diver enters through an entrance that is lower than the bottom of the welding chamber. Once inside, the diver removes the diving equipment and puts on regular welding clothes. He or she can then perform any task that would be done in a small, above-water welding shop.

In this type of system, the welder/diver may be required to wear a breathing mask, depending on the atmosphere in the chamber. An ambient pressure chamber can be used at depths of hundreds of feet (hundreds of meters).

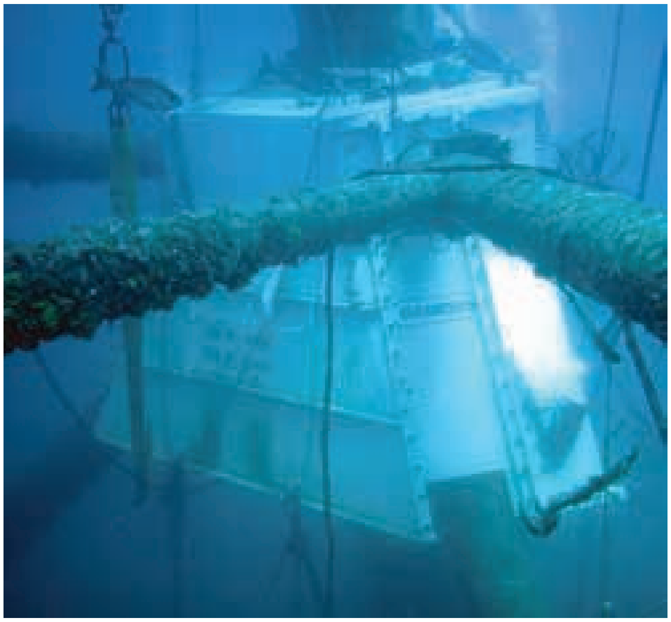
25.5.3 Open Bottom Chamber

An ***open bottom chamber*** is a simple chamber that can be set on top of a pipeline or hung on a structural member of an oil platform. See **Figure 25-8**. Once the chamber is set in place and any seals around the structure are secured, pressurized air or a background gas mixture forces water out of the chamber. The diver enters from the bottom, and the diver's upper body is in the dry area. The diver removes his or her dive helmet, puts on a welding hood, and makes the necessary welds.

25.5.4 Dry Spot Welding

Dry spot welding is an underwater welding method in which the welding takes place in a small chamber built from Lexan (a plastic), while the welder remains outside the chamber. The diver attaches the Lexan box to the weld area. It is open on the bottom for the diver to place his or her hands inside. Compressed gas is pumped into the box to displace the water. The diver stays in the water and performs the weld inside the box. Small repairs have been made in nuclear spent fuel pools using this method to perform GTAW welds.

Figure 25-7. Hyperbaric welding. A—A one-atmosphere habitat being lowered onto an underwater pipe to be repaired. B—People and equipment can enter through the two access holes to the surface. C—Inside of the habitat, an inspector examines the damaged pipe. D—Damaged areas of the pipe are documented. E—A repair sleeve is put in place. F—Welders weld the sleeve to the damaged pipe. G—Completed welds secure the repair sleeve over the existing pipe. H—Completed welds are inspected using dye penetrant.



Oceaneering International, Inc.

Figure 25-8. An open bottom chamber, or bell, has been placed around a vertical structure where a horizontal piece connects. Water is forced out using air pressure or a background gas mixture. The welder/diver enters from the bottom and welds in a dry environment.

25.5.5 Cofferdam

A ***cofferdam*** is a structure built around the structure being welded. A cofferdam is also called a *coffer* and in some parts of the world is known as a *caisson*. A cofferdam diverts water around a construction project or keeps water out of the working area of a project.

The original use of a cofferdam was to divert water around a dam construction project. Cofferdams are used to keep water away from bridge piers, oil platform structures, or the area where a ship is being repaired. Steel or wood pillars are driven into the river bed. Sheet metal is often used and joined to the vertical pillars. The sheet metal forms a watertight seal. Larger structures use a combination of wood, sheet metal, and concrete to form the barrier. Once the cofferdam is in place, the water inside it is pumped out. The force of the water pushing on the cofferdam, which increases as the depth of the cofferdam increases, must be accurately calculated. The cofferdam must be designed to withstand these forces.

As an example, a cofferdam can be constructed on the rear of a ship so repairs can be performed on the ship while it is still afloat. A reinforced sheet metal cofferdam is constructed around the area to be repaired. Water is pumped out of the cofferdam so the area to be repaired is not in water. See **Figure 25-9**.

A Oceaneering International, Inc.

B Oceaneering International, Inc.

Figure 25-9. Cofferdam in use. A—This cofferdam built onto the rear of a ship keeps water out of the working area. The part to be welded to the ship is being lowered into the cofferdam. B—Welders are welding a part onto the ship below the waterline.

The use of cofferdams is generally not covered under the D3.6M *Underwater Welding Code*. Cofferdams are mentioned in parts of the specification for general information. In most cases, welding in a cofferdam is the same as welding above water. There may be circumstances in which the material to be welded has water on the opposite side, which can cause the weld and base metal to be rapidly cooled. In such cases, special testing techniques may be required to prove that the weld will not fail.

Welding in a one-atmosphere pressure vessel or a cofferdam habitat is the same as welding above water. The appropriate specification for the welding being performed is followed. The D3.6M code is *not* followed in these applications.

The sophisticated design of underwater welding chambers makes them essentially underwater fabrication shops. Any job that can be performed on the surface can be performed underwater, with the exception of operating cutting torches. Cutting in one-atmosphere chambers, ambient pressure chambers, and open bottom chambers is limited to cold cutting methods, like sawing or grinding, or plasma or carbon arc gouging. No flammable gases should be introduced into the atmosphere of a habitat under pressure.

The three most common welding methods used in habitats today are SMAW, GTAW, and GMAW. Welding with these three processes in a dry underwater habitat is similar to welding on the surface. The same electrodes, currents, wire feed speeds, and welding techniques are used. The helmet filter shade is the same as that used above water.

One strange phenomenon welder/divers notice in deep chamber welding with GTAW is the visible flow of argon shielding gas. At extreme depths, helium and oxygen are used to fill the welding chamber. With helium as the background gas in the chamber, the welder can see the flow of argon shielding gas. Helium is thin and light. Argon is much heavier. The argon coming out of the GTAW torch and flowing in a helium-rich environment looks like oil and water mixing or like oil and vinegar in salad dressing.

Welders with a lot of experience in deep hyperbaric welding do not adjust the flowmeter by volume. They hold the cup up to a light background and adjust the flow by visually watching how much argon shielding gas is flowing from the torch head.

25.6 Crack Repairs

Repairing cracks in steel with underwater wet welding is much more difficult than performing the same repair above water. Most small cracks are repaired by either grinding out the crack with a hydraulic grinder or chipping out the crack with an RV-4 chipping gun and a gouging chisel. The RV in the designation stands for *ring valve*. This valve type is required for use underwater. The *-4* is a size that works well and can be handled underwater.

For extensive cracks, the damaged area is removed using an underwater carbon arc gouging system. This system is similar to air carbon arc gouging, except that it uses a water jet instead of air to remove the slag. Underwater carbon arc gouging is covered later in this chapter.

Carbon arc gouging in a wet environment causes the surface of the base metal to become hard and impregnates it with carbon. When cracks are repaired using the carbon arc method, the diver has to grind anywhere from 1/16″ to 1/8″ from the surface to remove the carbon and the heat-affected zone.

When repairing cracks in a dry habitat or hyperbaric chamber, the diver uses the normal air carbon arc gouging equipment. Light grinding is required to remove the carbon from the steel surface. Heavy grinding is not required because there is no quenching effect in the dry habitat.

25.7 Underwater Cutting

Underwater cutting falls into two categories. One is cutting in preparation for welding. The second is cutting for demolition or salvage work. Cutting in preparation for welding must produce a clean cut and leave the metal ready for welding. Cutting processes used to prepare metal for welding must not create rough surfaces or a high-carbon-content surface. Demolition/salvage cutting does not have these restrictions.

Cold cutting methods are used to cut a pipeline or structural member underwater if repair welds are going to be made. Cold cutting methods do not use heat. These methods use automated saws designed for underwater use. Examples include Wachs guillotine saws, diamond saws, travel cutters, and portable hydraulic lathes. Wachs is a manufacturer of equipment; their Subsea division specializes in underwater cutting tools. These tools produce highly accurate cuts that are beveled and ready for welding.

Carbon arc gouging is a process used to remove a defect in a weld. Carbon arc gouging leaves a high-carbon deposit on the cut area. Also, the area is rough. Additional work, often grinding, must be done to remove the high carbon area and smooth rough areas to prepare the base metal for additional welding.

Underwater cutting for demolition or salvage includes exothermic cutting and oxygen arc cutting. These processes leave a very rough cut that is extremely hard and brittle, but they are effective at quickly cutting steel underwater. Since the metal will be scrapped, the hard, brittle, and rough edges left by these processes are perfectly acceptable.

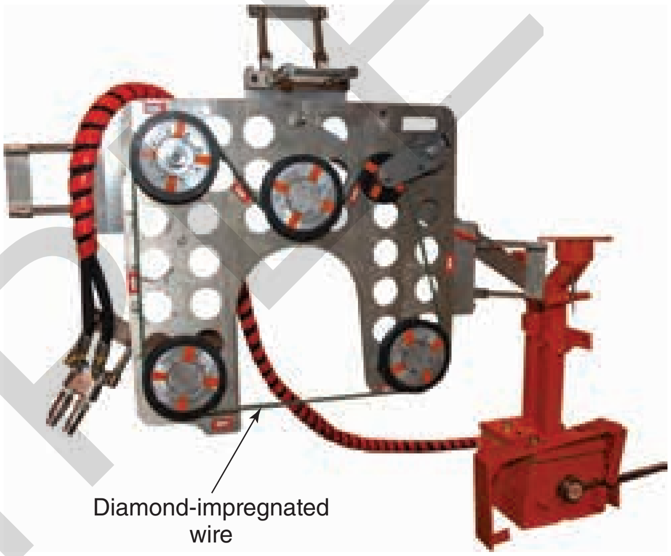
25.7.1 Mechanical Cutting

Mechanical cutting is used if the finished cut will be part of a repair or construction that requires a precise finish. Pipe or structures that are being prepared for welding need an accurate cut to allow for good part fit-up for tacking and welding.

A wide variety of mechanical cutting equipment is used in the underwater oil industry. Cutting done with this equipment is called *cold cutting* because the cut is made with saws, milling tools, or high-pressure water. Because cold cutting processes do not use heat, they do not burn the steel being cut. Cold cutting systems for underwater use are similar to systems used above water but are modified for the underwater environment. The machines are operated by hydraulic pressure. They all require a high-pressure, high-volume hydraulic pump. Any electrical controls used on the land-based versions of these units must be converted to mechanical controls for underwater use.

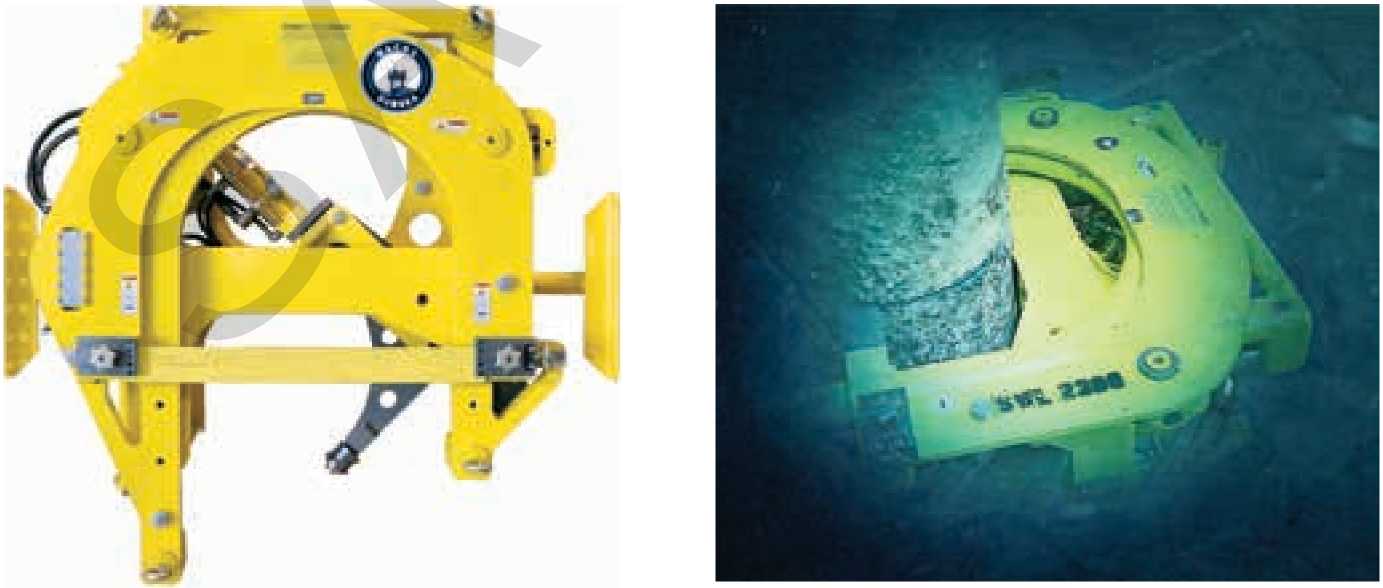
The Wachs guillotine saw is a reciprocating saw that uses a hydraulic motor to move a large saw blade back-and-forth to make a straight cut on pipe. See **Figure 25-10**. This type of saw is used for cutting a pipe so a mechanical flange can be attached to each end to repair the pipe. For example, if a pipeline is damaged over a length of 150′ (50 m), this section must be replaced. Divers will use a guillotine saw to remove the 150′ (50 m) of damaged pipe. They install a mechanical sealing flange on the ends of the remaining good pipe. Then, they weld a 150′ (50 m) piece above water and lower it into the water. They bolt the flanges on both ends of the repair section, and the repair is complete. This is not a welded repair, but a mechanical repair. The pipe could also be welded, depending on the application.

A diamond wire saw makes cuts with a wire that has commercial diamonds embedded in it. A hydraulic control unit continuously drives the wire. The diamonds do the cutting. The result is a very clean cut that is ready for welding. See **Figure 25-11**.



Wachs Subsea LLC

Figure 25-11. A diamond wire saw has industrial diamonds embedded in a wire. The diamonds cut through the pipe as the wire is continuously fed across or through the pipe.



A Wachs Subsea LLC

B Wachs Subsea LLC

Figure 25-10. Guillotine saws. A—A hydraulic reciprocating saw, called a guillotine saw, is used to cut pipe underwater. B—Guillotine reciprocating saw cutting through a vertical pipe column.

The Wachs travel cutter is a hydraulic milling machine that is clamped onto the pipe that is to be cut. It is capable of making very straight cuts and can be set up with straight saw blades or a combination of a saw blade and a beveling blade. This machine is so accurate that a finished cut can have another pipe fit up to it and welded with no additional preparation. See **Figure 25-12**.

The Wachs travel cutter is used primarily on pipelines or structural members where the repair method is a dry habitat weld and the repair is a full penetration butt joint weld. All of the cutting and fitting up of the pipe is completed in the water. A habitat is then set on the pipe, and the final weld is performed in the dry habitat.

A hydraulic lathe is another cutting tool used underwater. One ring is attached to the pipe to be cut. A second ring with a cutter attached is forced to rotate and cuts the pipe. A beveling tool can also be used. This hydraulic lathe tool can cut and bevel a pipe at the same time. The result of this lathe cutting operation is a very clean and straight cut edge ready for welding. See **Figure 25-13**. An ROV (remotely operated vehicle) version is shown in **Figure 25-14**. This unit clamps onto the pipe and then cuts and bevels the pipe. An advantage of an ROV is that it can be driven remotely. The diver does not have to be in the water to place the equipment onto the pipe.

High-pressure water jet cutting equipment is available but is not used as much as the mechanical cutting machines. These machines use water and grit that are mixed together into a slurry and pressurized to 50,000 psi (350 MPa). Water jet cutting machines can cut layers of steel with concrete between the layers. An example is cutting off jacket legs with pilings inside. There is concrete pumped in between the pile and the jacket leg. The water jet cutting system can be used in situations where it would be dangerous for divers to cut underwater.

This section lists only a few of the most common types of mechanical cutting machines. Numerous other cutting machines are used underwater.

A Wachs Subsea LLC

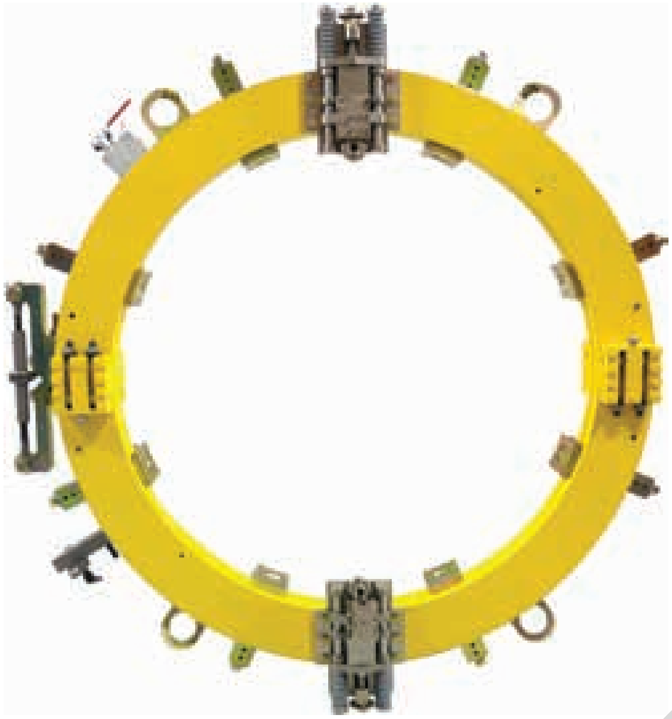
B Wachs Subsea LLC

Figure 25-12. A hydraulic milling machine. A—This machine cuts and bevels the end of a pipe in preparation for welding. B—Underwater cutter in use.

25.7.2 Thermal Cutting

Thermal underwater cutting is performed using two main processes—exothermic cutting and oxygen arc cutting. These processes are similar to those used for thermal cutting above water, but the equipment is slightly different. The cut quality is not good enough for proper fit-up prior to welding. Thermal cutting hardens the cut surfaces or makes them brittle, conditions that are not acceptable prior to welding. Most underwater thermal cutting is done for demolition, scrap, or salvage operations.

Workers should use a commercial diving helmet and related equipment when they perform underwater thermal cutting. Cutting should not be performed in SCUBA (self-contained underwater breathing apparatus) diving equipment.



Wachs Subsea LLC

Figure 25-13. A hydraulic lathe tool is attached to the pipe to be cut. A cutting and optional beveling tool are driven around the pipe to prepare the pipe for welding.

Wachs Subsea LLC

Figure 25-14. A remotely operated vehicle can be driven onto a pipe. This machine uses a vertical mill and other tools to cut and prepare a pipe prior to welding and to remove excess weld material from a completed weld.

Exothermic Underwater Cutting Equipment

Underwater exothermic cutting is the same process as exothermic cutting above water. The equipment is the same with a few exceptions. The cutting rod holder is designed for underwater use and is insulated to prevent electrical shock to the diver. See **Figure 25-15**. The same holder for underwater exothermic cutting is also used for oxygen arc underwater cutting. Underwater exothermic cutting rods are also insulated. Exothermic cutting can cut through steel, concrete, and any other material.

Required equipment includes the following:

- Underwater cutting rod holder.
- Welding cable (long enough to reach the job).
- Ground cable (with either a workpiece connector or a striker plate).
- Oxygen hose—3/8″ (9.6 mm) inside diameter recommended.
- Oxygen cylinders.
- High flow oxygen regulator.
- Insulated exothermic cutting rods.
- Power source—12V or 24V DC battery or a DC welding machine capable of 150 amps set on DCEN.
- Knife switch. This is above water and used to connect and disconnect the power from the rod holder.
- Commercial diving helmet.
- Dive radio for communications between the dive station on the surface and the diver.

Exothermic Underwater Cutting Process

Current is supplied to the cutting rod from a 12V or 24V battery or a welding power source. The current is needed to initiate the process.

Broco, Inc.

Figure 25-15. An exothermic underwater cutting torch and insulated rod.

It is not needed to continue the process once it has started. One advantage of exothermic underwater cutting compared to oxygen arc underwater cutting is the steel does not need to be cleaned prior to cutting.

A person on the surface of the water connects the battery or turns on the DC welding power source. The oxygen pressure is set to 100 psi (700 kPa) over the water pressure at the depth the cutting process will take place. Keep in mind that water pressure increases as the depth increases. This is due to the weight of the water above pushing down on the water below.

When ready, the diver calls for the dive station to make the knife switch hot. The term *hot* means that electrical current is flowing through it. The diver then strikes an arc and slowly opens the oxygen control valve. As soon as the rod is ignited, the diver instructs the dive station to make the knife switch cold, or turn off the electrical current. Once an exothermic cutting rod is ignited, it continues to burn as long as oxygen is flowing through the rod or until the rod is consumed. See **Figure 25-16**.

The diver keeps the tip of the rod in contact with the steel. The rod is pointed in the direction of travel. The diver pushes the rod in the direction of the cut, and the exothermic cutting rod melts the metal and blows it out of the cut. For steel thicker than 1/2″ (13 mm), the diver should reduce the angle, moving the cutting rod more toward vertical. For steel over 1″ (25 mm) thick, the rod should be almost perpendicular to the steel being cut. For steel over 2″ (50 mm) thick, the diver must move the rod into and out of the kerf, or cut in a sawing motion, in order to blow the slag out of the kerf.

Brian Derby, EPIC Divers and Marine

Figure 25-16. A diver using the exothermic cutting process. The pipe being cut does not need to be cleaned prior to cutting.

Oxygen Arc Underwater Cutting

Underwater oxygen arc cutting is the same as oxygen arc cutting above water. An arc is struck between the cutting rod and the steel to be cut. Current from a welding power source is required to maintain the arc.

The same insulated cutting rod holder used for underwater exothermic cutting is used for underwater oxygen arc cutting. The difference between the oxygen arc cutting process and the exothermic process is that the arc cutting rods are heavy-wall tubular steel. The rods may have a flux on them, similar to a welding electrode. The tubular steel rods and flux coating (if used) are insulated to prevent shock and to keep the flux dry. The rest of the equipment is the same as the underwater exothermic cutting equipment with the following exceptions:

- The power source needs to be a minimum of 350 amps and should be rated at 100% duty cycle.
- The material being cut needs to be properly grounded. The diver must ensure that the ground is tight and that he or she does not get between the ground and the cutting rod.

Oxygen Arc Underwater Cutting Process

For the oxygen arc process, the steel to be cut must be clean. Clean metal is necessary in order to maintain the arc. It is highly recommended that the base metal be properly cleaned before cutting is attempted. Steel can be cleaned using grinders, grit blasters, or a tool called a ***needle scaler***. A needle scaler is the same as an air-powered weld scaler used above water. A needle scaler has multiple small chisels or needles that impact the part to be cleaned. This tool can quickly and effectively remove barnacles and corrosion from a pipe surface.

A person on the dive tender boat sets up the welding equipment. The DC power source is turned on. The oxygen pressure is set to 100 psi (700 kPa) over the pressure at the diver's depth. The diver calls for the dive station to make the knife switch hot. The diver then strikes an arc and slowly opens the oxygen control valve. The rod begins to burn and will burn as long as the diver maintains the proper arc length.

The diver can use either a drag or push technique. Both will cut well. A drag angle of 30° to 45° works well. A typical push angle is also 30° to 45°. As with the exothermic cutting method, thicker steel requires a smaller travel angle. For very thick steel, the diver will also have to use a sawing motion, moving the cutting rod into and out of the kerf to cut through the material.

To stop the cutting process, the diver can pull the rod away from the base metal to stop the arc. **Once the arc stops, the diver must call to the surface to make the knife switch cold. This is a critical safety precaution!** No welding or cutting current flows after the knife switch is cold. Once the knife switch is cold, the diver can change position or install a new rod. When ready to cut again, the diver calls up to the surface and asks them to make the knife switch hot. The diver then strikes an arc and resumes cutting.

For both underwater exothermic and underwater oxygen arc cutting, the easiest way for a diver to adjust travel speed is by watching the kerf of the cut. If molten metal and fire is coming out on the diver's side of the cut, cutting or travel speed is too fast and the process is not cutting completely through the steel. If all of the fire and slag is going out the back side of the steel and the tip of the rod is touching the base metal, the travel speed is good.

25.7.3 Arc Water Gouging

Carbon arc gouging can be performed underwater with equipment designed specifically for this purpose. It is a similar process to air carbon arc cutting and gouging, which was covered in Chapter 24, *Special Cutting Processes*.

Carbon arc gouging underwater requires a 300A DC power source. DCEP polarity is used. The power source needs to have a 100% duty cycle. Underwater rods are shorter than the rods used above water.

Carbon arc gouging underwater uses high-pressure water instead of high-pressure air to blast the molten metal out of the cut area. The holder is designed with a tube that directs the high-pressure water. This tube is angled and directs the high-pressure water where the cutting rod arcs to the steel being cut. This high-pressure water blows the molten steel out of the gouge area.

Arc water gouging is not used as much for cutting underwater as it is for simple crack removal. Of all of the methods of cutting underwater, it is by far the slowest. Also, it causes the surface of the base metal to become very hard and brittle, and it leaves a lot of carbon in the base metal. If this method is used to prepare a crack for rewelding, a great deal of time must be spent using a hydraulic grinder to remove both the carbon and the heat-affected area.

The following equipment is required for arc water gouging:

- 300 amp 100% duty cycle DC welding machine set on DCEP.
- Arc water gouging holder.
- Arc water gouging rods.
- 3/0 welding lead.
- 3/0 ground lead.
- High-pressure water pump.

25.8 Diving Operations

Diving operations are conducted differently than land-based jobs. Most jobs on land involve anywhere from one welder to hundreds of welders working on the project at a time. In underwater welding, it is uncommon for more than one or two divers at a time to be in the water for a job. See **Figure 25-17**.

The number of divers in the water depends on the working depth and the support equipment. On shallow welding or cutting jobs, less than 33' (10 m), several divers can be in the water working at the same time because they do not require decompression. There have been jobs on docks in harbors where five or six divers are in the water working at one time; however, this is unusual.

Deeper dives require more people and equipment to support the diver. There are time limits for how long a diver can be at a given depth. ***Bottom time*** starts when a dive begins and ends when the diver begins to ascend, or come back up.

Oceaneering International, Inc.

Figure 25-17. Diver wet welding on an underwater structure.

Time requirements and depths for decompression must be followed. Additional equipment to support the diving operation and emergency equipment is also required. When diving operations are launched from boats or oil rigs, there is limited space for support equipment and personnel. These are additional reasons why typically only two or three welder/divers work at a time.

For the safety of the diver, multiple people are required to tend to the diver's needs. One person above water must have voice communication with the diver at all times. For each diver in the water, the following support people are needed:

- Dive supervisor.
- Communication (radio) operator.
- Tender to watch breathing hose and to send down any tools or supplies needed.
- Standby diver in case a diver gets in trouble.

The deeper the dive, the shorter time the diver can remain at the working depth. A ***dive table*** dictates the maximum time a diver can stay at a given depth (bottom time).

Divers must also ascend to the surface slowly, spending a specific amount of time at different depths specified in the dive tables. These are referred to as *water stops*. Gases, such as oxygen, nitrogen, and helium, dissolve in the bloodstream differently under high pressure than they do at atmospheric pressure. These stops and times in a dive table are to prevent the diver from getting the bends. The ***bends*** occur when gases dissolved in the diver's blood are not allowed to return to normal prior to returning to atmospheric pressure at the surface. Returning the body to the proper gas mixture and the process of the body getting rid of excess and non-normal gases is called *off-gassing*. If a diver returns to the surface too quickly, the gases dissolved in the blood can form bubbles. The results can be fatal. Divers must be well-trained and understand and follow dive tables for safety.

Divers working at depths between 170′ and 300′ (50 m and 90 m) and using surface-supplied mixed breathing gas (helium and oxygen) can stay at full depth for only 50 to 80 minutes, depending on the depth and the gas mixture. Divers must spend two to three hours in the water at various depths (water stops) to gradually decrease the inert gas in their tissues and reestablish proper absorption of gases. This controlled ascent is followed by two to three hours in a decompression chamber to complete the decompression process. This requires a larger crew with a lot of support equipment. Because of the decompression time and equipment required, only two or three welder/divers at a time are working in the water on most jobs.

Saturation diving is the preferred method of most dive companies for working deeper than 170′ (50 m). Even work in shallower water is now being accomplished with saturation dives. The ***saturation diving*** technique is based on the fact that after a given time, the diver's body and blood will not absorb any more gases. The body becomes saturated. Divers can remain under pressure, either underwater at great depths or in a pressure chamber, for days or weeks.

During a saturation dive, the welder/divers live in a pressurized living chamber called a *saturation chamber*. This chamber is on a ship or platform. The pressure in the chamber is the same as the pressure at the depth where the work is performed each day. When it is time to work, the welders exit the saturation chamber and enter a pressurized bell. The bell is sealed. A ***bell*** is the chamber used to lower and raise the welders into the water. The bell is large enough for two or three divers. The divers in the bell are lowered to an ambient hyperbaric pressure chamber or to the depth where the work will be performed. The welders leave the bell, swim to and enter the dry welding habitat, or remain in the water if wet welding. The welders work their shifts in the hyperbaric pressure chamber or the water.

When the day's work is complete, the welders leave the hyperbaric chamber, enter the bell, seal the bell, and are raised to the surface ship. The welders leave the bell and enter the saturation chamber on the ship. There is no decompression cycle because the welders remain under the same pressure they experienced at the working depth. The gases the welders breathe are the same in the chamber on the ship and in the underwater working chamber.

The entire process can go on for days or weeks. The welder/divers are at the same pressure and breathing the same gases in the living chamber, in the bell, and in the working hyperbaric pressure chamber or underwater worksite.

Once the project is completed, only one decompression cycle is required. The decompression cycle or process is completed in the saturation chamber on the ship. Decompression time is required to allow the body to eliminate dissolved gases in the body tissues, to return to normal pressure, and to return the air to normal nitrogen and oxygen levels. This process can take days. Approximate decompression time is 24 hours per 100 feet (30 m). As the pressure in the chamber is lowered, the gas mixture is changed. The decompression cycle, which is done gradually and in stages, returns the mix of gases in the body to normal. Only after complete decompression are the welder/divers able to safely leave the pressurized chamber on the ship.

Another use of a bell is as a staging area near a wet welding area. Two or three divers are lowered in the bell to the working depth. One diver leaves the bell to perform the welding, cutting, or other required work, while the others stay in the bell as standbys. The welder/divers take turns performing the required work. When the work is complete, all welder/divers enter and seal the bell, and are raised to the surface where they live in the pressurized habitat.

Saturation diving is dangerous. The dive supervisor and multiple support personnel are necessary. A welder/diver must completely understand dive tables and decompression cycles. All proper safety equipment must be available and used properly.

Saturation diving is conducted from a dive boat designed for this type of operation. The saturation chamber can be installed on a large boat or barge or set up on a platform. Saturation chambers may be permanent or portable. A permanent saturation chamber is built into a dive boat. It is often large and can hold up to 16 divers. It cannot be removed from the dive boat. A portable saturation chamber can be moved by truck and set up on a dive boat, barge, or platform. It can be removed after the project is complete.

Diving is a skill. Not everyone is comfortable in diving equipment and working underwater. It takes time to learn proper diving techniques and to become knowledgeable in all the safety precautions required. Deep diving is a team effort, and everyone must do their job properly.

25.9 Jobs in Underwater Welding

Underwater welding is an interesting career. Many years ago, dive companies found that it is much easier to teach a welder how to dive than it is to teach a diver how to weld. After completing welding school, it is best to get two or three years of practical welding experience, especially in structural or pressure pipe welding, before pursuing an underwater welding career. Once a welder develops a strong welding background, he or she should attend a commercial dive school that teaches underwater welding and cutting. Another option after completing welding training is to work as a fabricator with one of the larger dive companies. This provides first-hand knowledge of the diving industry before time and money are invested in attending a dive school.

Underwater welders can make an excellent salary. Working as a welder/diver is a challenging job. There are two career options—diver and welder/diver. A diver performs all underwater tasks needed to set up and complete a job, except for welding and cutting. The diver's responsibilities include moving and setting pipe, inspecting pipe and structures, preventing corrosion, doing maintenance, and many other jobs on underwater structures and pipes. Because of the broad responsibilities of the job, there is typically more work for a diver than a welder/diver. However, welder/divers are also called on to perform many tasks in addition to welding and cutting.

There is also the job of an underwater inspector. Becoming an inspector requires training in the various inspection methods. These include eddy current, magnetic particle, and ultrasonic testing, which are discussed in Chapter 30, *Inspecting and Testing Welds*. Often the welder/diver inspects the weld. Photos or data are sent to an inspector, who may be on the dive boat or platform or in an office on land. The inspector evaluates the photos and data to determine the quality of the weld. In this way, the requirements of the inspector are the same as for inspecting welds on above-water welding jobs.

Some schools specialize in teaching people to become underwater welders. A lot of training is required. See **Figure 25-18**.

Navy Joining Center

Figure 25-18. A student welder practices wet welding an overhead butt joint.

The welder/diver must practice to develop the skills needed to produce high-quality welds that meet the code requirements. See **Figure 25-19** and **Figure 25-20**. Having prior experience as a welder will speed up the process of becoming an underwater welder.

25.10 Safety

Safety is extremely important when underwater welding and cutting. Underwater welding and cutting combines two dangerous operations—welding and diving. Safety issues with welding and cutting include hot molten metal, intense light, high currents, shielding gases, and high-pressure gases used for oxygen cutting.

Underwater cutting with mechanical cutting equipment is straightforward. Machines have moving parts, and the diver must keep hands and dive equipment, such as the dive hose, out of the machine. Underwater burning, oxygen arc cutting, and arc water gouging require many more safety precautions than mechanical cutting.

Greg Cain of Oxylance, Inc.

Figure 25-19. Bend test specimen of a butt joint that was welded underwater.

Greg Cain of Oxylance, Inc.

Figure 25-20. Polished cross section of a multiple pass butt joint weld made with a nickel SMAW electrode underwater.

Water is made up of hydrogen and oxygen. The high temperatures required to thermally cut steel underwater causes the oxygen and hydrogen to disassociate (break apart) from each other. Hydrogen gas is produced during thermal cutting. In most cases, the gas rises away from the cutting area and travels through the water until it reaches the surface. There is a risk that if the hydrogen gas accumulates, it could ignite.

In addition to all of the safety requirements for welding, welder/divers have the added burden of all of the safety requirements associated with diving. There are dangers at every depth. As the dive depth increases, so does the potential danger. Divers must know and understand dive tables. When not using a hyperbaric chamber and a bell for saturation diving (as presented under section 25.8), it is critical that welder/divers carefully follow dive tables that specify how to safely rise to the surface. If dive tables or saturation tables are not followed, the bends will result, which can be fatal if the proper emergency equipment is not immediately available. For precaution, additional safety equipment and decompression chambers must be kept on the dive boat.

Divers must never allow any of the metal components of their dive gear to become part of the circuit. Metal parts, including the dive helmet, bail out bottle (SCUBA bottle used for emergency air), and weight belt, must be kept out of the welding circuit.

Divers must ensure that they do not get in a position where they are between the arc and the ground. The knife switch, which opens and closes the electrical path to the electrode, should be made cold (opened) whenever welding is not taking place.

Divers must ensure that the workpiece connector is either welded to the structure they are welding on or is tightly clamped in place. **A workpiece connector that is loose causes the water to become the ground, which diminishes the arc strength and could shock the welder.**

Underwater welding or cutting should never be performed in scuba diving equipment. The welder/diver must have the proper commercial diving gear, including a commercial diving helmet. It is critical that the diver has support people above water and that they maintain voice communication with the diver.

All underwater welding systems must have a knife switch in line to break the current when the diver is not welding. The electrode holder must not have power going to it when the diver is not welding. This is one reason there must be communication between the surface and the diver.

Welding leads and electrode holders must be inspected before each dive. **All bare spots in a welding cable must be located and properly insulated or they can cause electrical shock.**

Summary

- There are two types of underwater welding. In wet welding, the weld joint is completely surrounded by water. In dry (hyperbaric) welding, the water is removed from the welding area.
- The AWS D3.6M *Underwater Welding Code* covers requirements for welding structures or components under the surface of water.
- Class A welds can be either wet or dry and are specified for constructing or repairing main structural members.
- Class B welds are normally performed in a wet environment and are used for applications in which lower ductility, greater porosity, and discontinuities are tolerated.
- Class O welds are used for pipelines. These welds are made in a dry habitat.
- In underwater welding, nearly every variable is an essential variable, which means it has a significant effect on the mechanical properties of a weldment if the variable is changed.
- A background gas is a gas mixture used to force water out of an underwater chamber and keep oxygen at a safe level.
- Special SMAW electrodes and electrode holders are required for wet welding.
- All underwater wet welds are made using the stringer bead technique. All vertical welds are made downhill.
- During underwater welding, the arc length must be kept as short as possible.
- The five basic types of dry habitats for underwater welding are a one-atmosphere pressure vessel, ambient pressure chamber, open bottom chamber, Lexan chamber (dry spot welding), and cofferdam.
- A cofferdam is a barrier built around the structure being welded to keep water out of the work area.
- Cold cutting methods are used to cut a pipeline or structural member underwater if repair welds are going to be made.
- Most underwater thermal cutting is for demolition, scrap, or salvage operations.
- The two main thermal underwater cutting processes—exothermic and oxygen arc cutting—are similar to land-based thermal cutting, but the equipment is slightly different.
- There are time limits for how long a diver can be at a given depth. Divers must ascend to the surface slowly, spending a specific amount of time at different depths as specified in the dive tables.
- In saturation diving, the welder/divers are at the same pressure and breathing the same gases in the living chamber, in the bell, and in the working hyperbaric pressure chamber or underwater worksite.
- Two career options are diver and welder/diver. A diver performs all underwater tasks needed to set up and complete a job, except for welding and cutting.
- In addition to welding safety requirements, welder/divers must adhere to all of the safety requirements associated with diving.
- If dive tables or saturation tables are not followed, the bends will result, which can be fatal if the proper emergency equipment is not immediately available.
- Underwater welding systems must have a knife switch in line to break the current when the diver is not welding.

Technical Terms

ambient pressure chamber
background gas
bell
bends
bottom time
carbon equivalent (CE)
cofferdam
dive table
dry spot welding
dry welding
essential variable
hyperbaric welding
knife switch
needle scaler
nonessential variable
one-atmosphere pressure vessel
open bottom chamber
saturation diving
wet welding

Review Questions

Answer the following questions using the information provided in this chapter.

Know and Understand

1. The term *hyperbaric welding* refers to _____.
   A. welding that is performed on land
   B. underwater welding where the water is removed from the welding area
   C. underwater welding where the weld joint is completely surrounded by water
   D. welding that is done under very high pressure
2. *True or False?* The AWS D3.6M *Underwater Welding Code* covers requirements for welding structures or components under the surface of water.

3. Which class of welds are normally performed in a wet environment for less critical applications?
   A. Class A.
   B. Class B.
   C. Class O.
   D. All of the above.
4. Which class of welds are specified for constructing or repairing main structural members?
   A. Class A.
   B. Class B.
   C. Class O.
   D. All of the above.
5. Which class of welds is used on pipelines?
   A. Class A.
   B. Class B.
   C. Class O.
   D. All of the above.
6. Which is the most demanding class of underwater welds?
   A. Class A.
   B. Class B.
   C. Class O.
   D. They are equally demanding.
7. Which class of welds is used for applications in which lower ductility and greater porosity can be tolerated?
   A. Class A.
   B. Class B.
   C. Class O.
   D. All of the above.
8. The purpose of a knife switch is to _____.
   A. keep the flux and insulation coating in contact with the part being welded
   B. open and close the welding chamber
   C. control the operation of the cutting equipment
   D. electrically connect the welding leads to the welding power source
9. A structure that is built around the structure being welded to keep water out of the work area of a project is called a(n) _____.
   A. bell
   B. ROV
   C. cofferdam
   D. hyperbaric chamber
10. *True or False?* It is easier to teach a diver how to weld than it is to teach a welder how to dive.

Apply and Analyze

1. In the 1960s, what industry drove the initial demand for underwater welding and repair welding?
2. List five essential variables in underwater welding.
3. Why must higher-carbon steels be dry welded at depths greater than 50′ (15 m)?
4. Why do newer inverter welding power sources produce higher-quality wet welds than older welding machines?
5. When is a weave bead used in wet underwater welding?
6. What is the purpose of the small gas bubble at the end of the electrode?
7. Briefly describe the wet welding technique that keeps a small gas bubble at the end of the SMAW electrode.
8. What is the disadvantage of ending a weld bead by drawing the electrode away from the weld bead?
9. What type of cutting is done to prepare for underwater welding?
10. What type of cutting is done during underwater salvage operations?
11. In which thermal cutting process should the steel be cleaned before it is cut?
12. What causes the bends?
13. What are water stops and what purpose do they serve?
14. Why is only one decompression cycle required in saturation diving?
15. What is the purpose of a dive table?

Critical Thinking

1. Suppose your goal is to become a welder/diver after completion of your current welding program. What would be a reasonable three-to-five-year plan to achieve your goal?
2. The best mechanical quality welds are produced using 22–26 volts. Why does higher voltage produce poorer mechanical properties?

Experiment

1. Research at least two underwater welding schools online. Determine the entrance requirements, location, tuition costs, and length of the programs offered by each.