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DETERMINATION OF THE FEASIBILITY OF SHIELDED-METAL-ARC WELDING --ETC(U)
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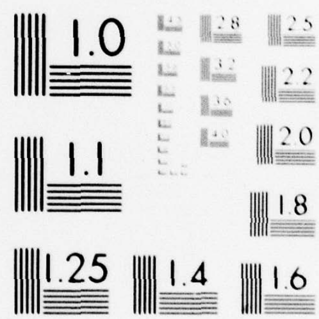

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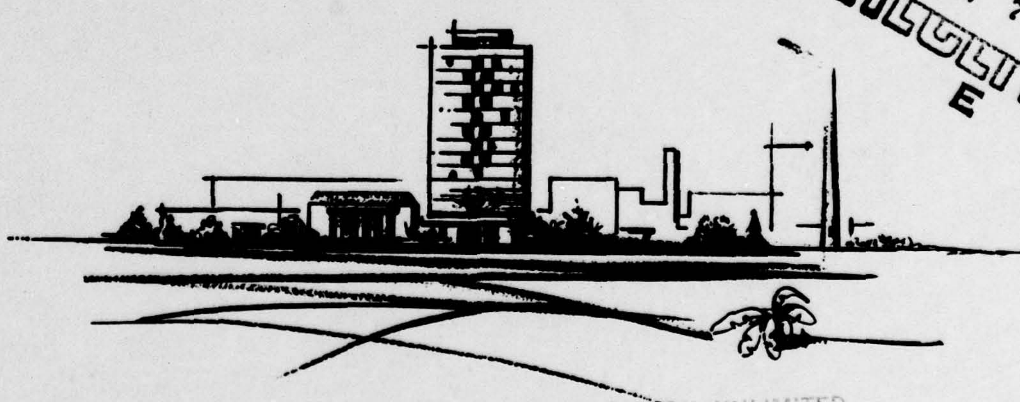

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DETERMINATION OF THE FEASIBILITY OF SHIELDED-METAL-ARC WELDING AND OXYGEN-ARC CUTTING AT A DEPTH OF 600 FEET

to

THE UNITED STATES NAVY
CONTRACT NO. N00014-66-C-0199

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July 31, 1969

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by

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F. A. DESAW, D. W. CAUDY, H. W. MISHLER [redacted] M. D. RANDALL

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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INTRODUCTION

Underwater arc welding and oxygen-arc cutting have been used in salvage and repair operations for many years. These processes have been used, however, only at shallow depths, typically less than 100 feet. Before extending the use of arc welding and cutting to significantly greater depths, the feasibility of these processes at the greater depths must be known and potential problem areas must be identified.

The task described in this report was initiated at Battelle by the Navy to meet these requirements. The specific objectives of the program were to determine:

(1) If a welding and cutting arc can be struck and maintained in seawater at depths exceeding 600 feet.

(2) The effect of voltage drop in long cables supplying the welding or cutting current.

(3) The quality of the welds and cuts made at these depths.

(4) Any problems related to the use of conventional welding cable at high pressures.

In the experimental work that was conducted in the task, use was made of a hyperbaric chamber simulating as closely as possible actual underwater welding and cutting operations and conditions. Conventional underwater welding and cutting equipment was used.

CONCLUSIONS AND RECOMMENDATIONS

Results of this program show that underwater welds and cuts can be made at extended depths by shielded-metal arc welding and oxygen-arc cutting. Weld quality was poor because of gross weld porosity; cut quality was comparable to shallow-water cuts. Welds were made at various simulated depths to 1,200 feet and cuts were made at a simulated depth of 680 feet. Standard equipment normally

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BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
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Columbus, Ohio 43201

used for underwater welding and cutting (power supply, cables, and electrode holder) was used throughout this study. This equipment performed satisfactorily for welding and cutting at the simulated water depths. A 400-ampere power source was used. While sufficient for this program because of the short arc times involved, a larger power source should be used for on-site operations. A 600-ampere power source is suggested. The amount of voltage drop in 1,200 feet of cable was about as expected and should not cause any problems. No detrimental effects of pressure on the welding cable or electrode holder were observed.

Standard commercial underwater welding electrodes were used. These were AWS E-6013 electrodes obtained from the Arcair Company waterproofed for underwater use. Welds made underwater with these electrodes at 295, 680 and 1,200 feet simulated depths had excessive porosity, while welds made at sea level pressure (but underwater) were sound. Welding with reverse polarity appeared to reduce the size and amount of porosity although sufficient welds were not made to verify this performance. The cause of this porosity is not known although it probably is related to more rapid freezing of the weld metal at the greater depths.

Cuts were made underwater at 680 feet. No problems were encountered and the cutting operation performed satisfactorily.

The results of this study indicate that arc welds and oxygen-arc cuts can be made underwater at extended depths. The quality of the welds made at these depths probably will be much poorer than similar welds made at shallow depths. Some improvement in weld quality might be achieved through further efforts to optimize welding operations. It is expected, though, that the ability to make sound welds will be achieved only through the development of new welding electrodes or procedures. The direction of such a program cannot be stated at this time because the causes of the poor weld quality are not known. Therefore, it is recommended that a program be initiated to examine the behavior of the welding arc and gas bubble in underwater welding at extended depths. This program also should include a more thorough investigation of the effects on weld quality of variations in welding parameters and the use of other welding electrodes having different flux coating compositions for underwater welding.

EQUIPMENT AND TOOLING

The underwater welding and cutting operations were conducted in a hyperbaric chamber 18 inches in diameter by 39 inches long (Figure 1). This chamber has a maximum pressure rating of 1000 psi. The chamber is equipped with two viewing ports located at approximately the 1 o'clock and 11 o'clock positions. One of these ports is visible in the illustration.

The welding torch and the workpiece were mounted on a fixture contained within the chamber. This fixture is shown in Figures 2 and 3 and positioned in the chamber in Figure 4. The workpiece was contained within the bucket which could move horizontally on the fixture track. During welding or cutting, the electrode was held in a fixed position and the workpiece moved horizontally under the electrode. The electrode was held in a commercial electrode holder which could move vertically as the cutting or welding electrode melted. Thus, a relatively constant arc length could be maintained between the end of the electrode and the workpiece.

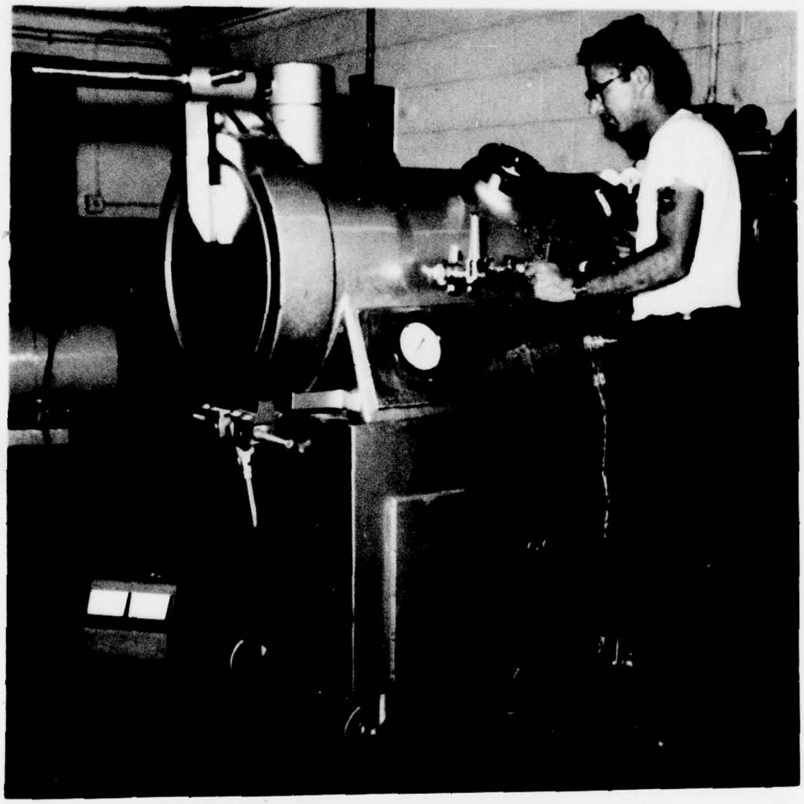


FIGURE 1. HYPERBARIC CHAMBER USED FOR UNDERWATER WELDING AND CUTTING STUDIES.

FIGURE 2. OVERALL VIEW OF THE WELDING AND CUTTING FIXTURE.

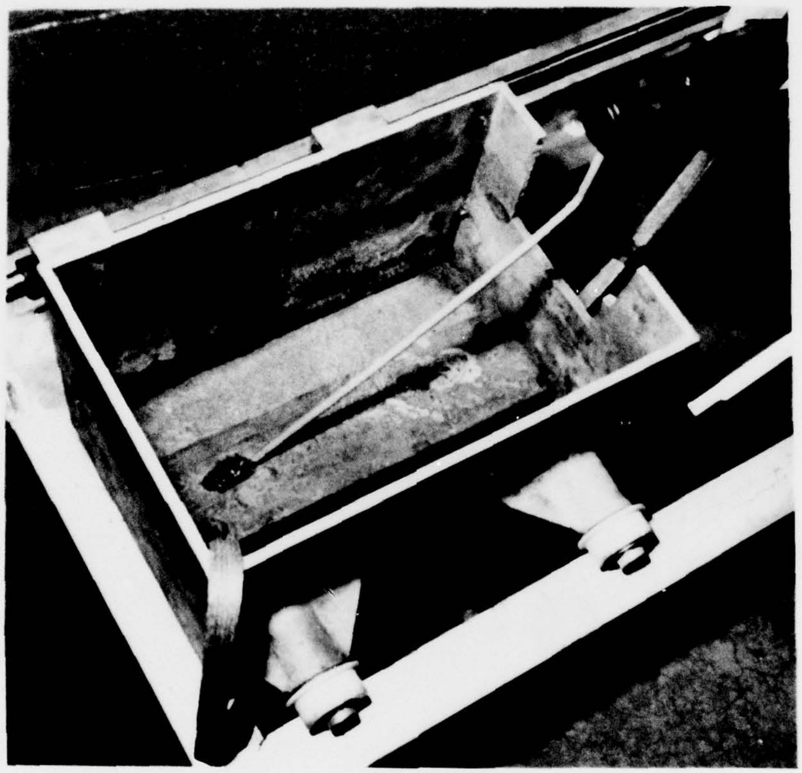


FIGURE 3. MOVABLE BUCKET OF THE WELDING AND CUTTING FIXTURE.

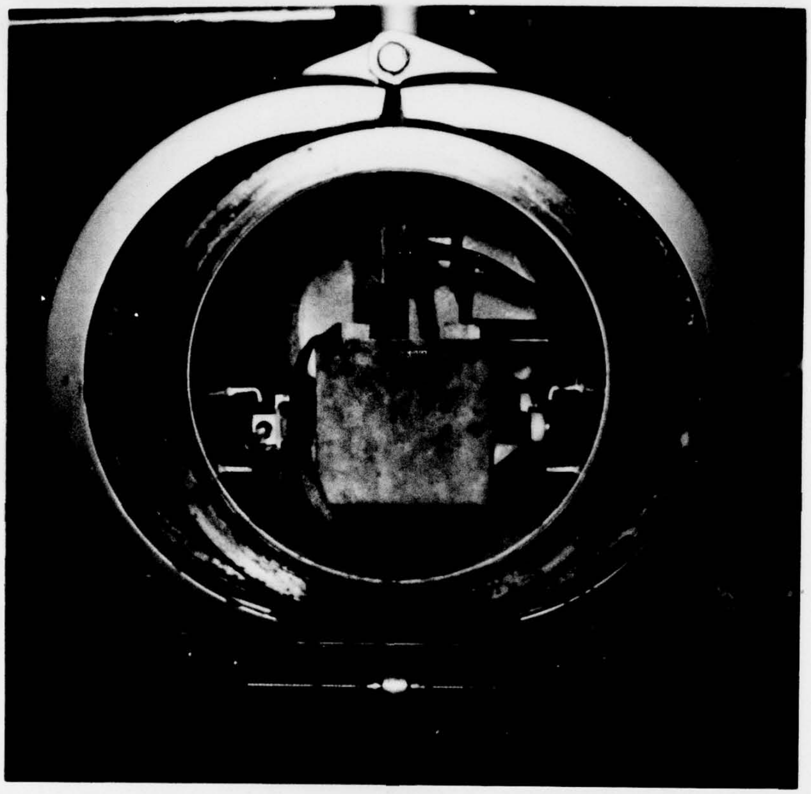


FIGURE 4. WELDING AND CUTTING FIXTURE POSITIONED IN CHAMBER.

Horizontal movement of the bucket and workpiece, and vertical movement of the electrode holder, were controlled by bell crank-slide mechanisms operated by rods extending through the chamber walls. Rotation of these rods by the operator imparted horizontal and vertical linear motion respectively to the bucket and electrode holder. The control rods penetrated the chamber walls through rotating pressure seals.

The electrode holder used in these studies was an Arcair Underwater Torch (Catalog No. 14-050-101). This torch can be used for both welding and cutting underwater and accommodates either type of electrode.

The bottom of the bucket was covered with a 1/4-inch-thick layer of asbestos and a 1/8-inch-thick layer of sand to protect the bucket bottom from the heat of the welding or cutting operation. The workpiece was mounted in the bucket on 1-inch legs. Before welding or cutting, the bucket was filled with a salt-water solution prepared with tap water and Instant Ocean salt to a specific gravity of 1.02. The workpiece was about 2 inches beneath the surface of the water. Thus, the welding or cutting was performed underwater although the entire electrode and the electrode holder were not underwater. During welding and cutting, the chamber was pressurized with nitrogen to a pressure level corresponding to the desired water depth. The welding or cutting electrode and the electrode holder were under pressure throughout the welding or cutting operation.

The power supply was a commercial 400-ampere Lincoln motor-generator. It was connected to the workpiece and electrode holder by two 3/0 cables 600-feet long. Cables of this length were used to simulate an on-site equipment set up where welding and cutting was being done in 600 feet of water. The cables were attached to electrical lead-throughs in the chamber wall. Short (3 to 4 feet) lengths of cable led from the lead-throughs to the workpiece and electrode holder inside of the chamber. Because of lack of space, the two 600-foot long cables were coiled on a reel. It is realized that inductive losses are present when the cable is coiled; however, for the purpose of this program this was not considered serious.

Figure 5 shows the electrical connections of the equipment. The location of the meters for measuring voltage and current also are shown.

The welding and cutting electrodes that were used were commercial electrodes especially designed for underwater use. The welding electrodes were Arcair underwater welding electrodes, Catalog No. 42-034-000, 3/16-inch diameter by 14-inches long. These are AWS Class E-6013 electrodes purchased by Arcair and waterproofed. The cutting electrodes were Arcair underwater oxygen-arc cutting electrodes, Catalog No. 42-059-001, 5/16-inch diameter by 14-inches long.

Oxygen is required in the cutting operation. It flows through the hollow cutting electrode to burn away the metal heated by the arc. The oxygen was fed from tanks through a stainless steel tube through a pressure fitting in the chamber wall. The oxygen hose of the torch was connected to the pressure fitting inside of the tank. The oxygen pressure that was used was the chamber pressure plus 30 psi. The stainless steel tube was required between the oxygen tank and chamber since this line would be under the full pressure. A hose would not be strong enough to contain the full pressure. A hose was used inside the tank since the pressure differential in this hose

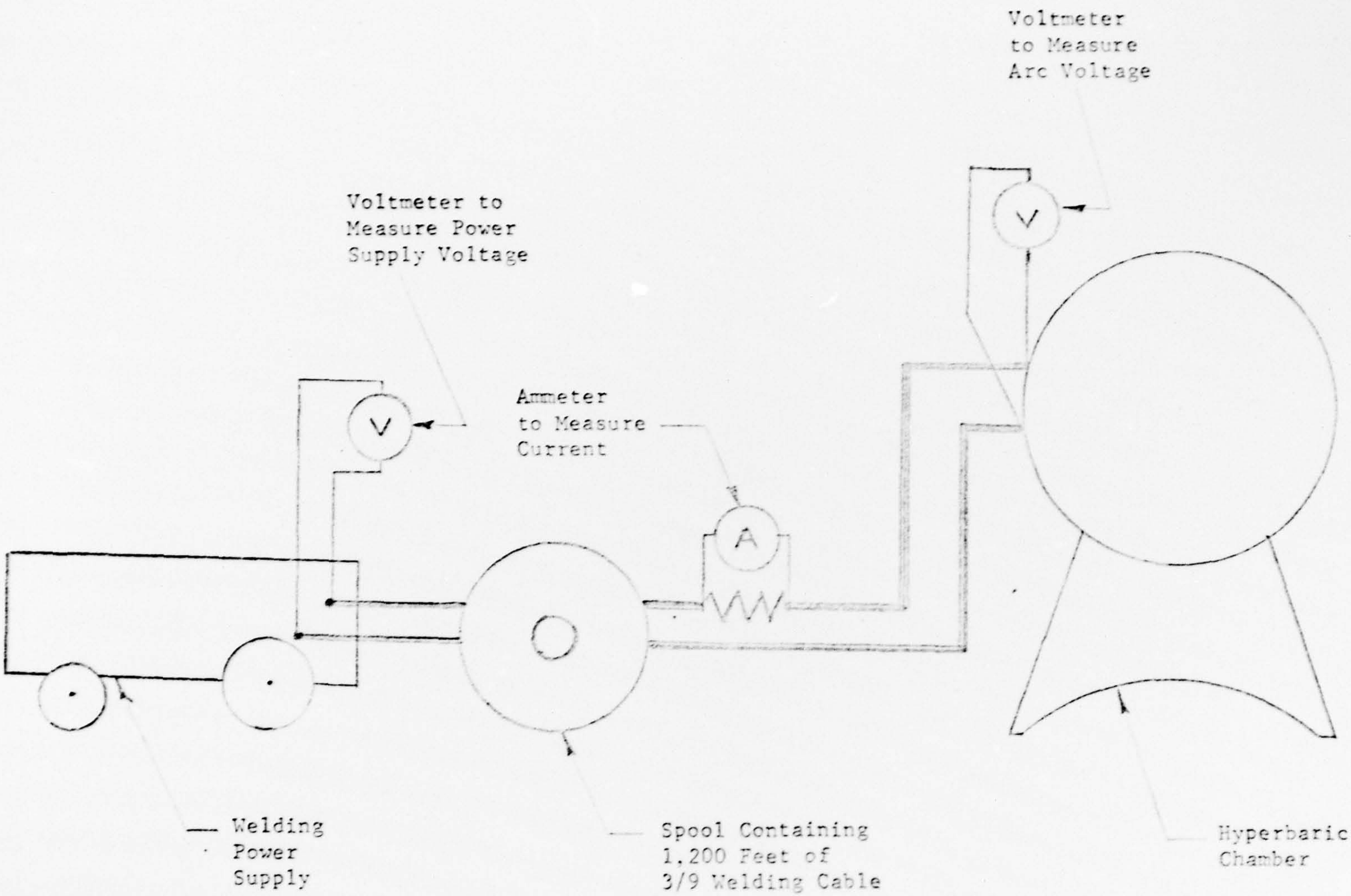


FIGURE 5. SCHEMATIC DRAWING OF EQUIPMENT CONNECTIONS FOR WELDING AND CUTTING.

would be only 30 psi. A 0-1200 psi pressure regulator was used to control the oxygen pressure. A relief valve, mounted on the chamber, prevented excessive buildup of pressure in the chamber during cutting.

UNDERWATER SHIELDED METAL-ARC WELDING

The primary goal of the investigations conducted in this portion of the program was to determine the feasibility of striking and maintaining the welding arc. In addition, welding parameters were determined that could be usable at the extended depths, the weld quality was evaluated, the amount of hydrogen in the gas effluent was determined, and the voltage drop in the welding cables was measured.

Welding Procedures

The welding procedures that were used simulated conventional underwater welding techniques as closely as possible. Conventionally, the diver-welder does not attempt to hold a given arc length when welding underwater. Instead, the "self-consuming" technique is utilized wherein the diver holds the end of the electrode in contact with the workpiece at an angle of 15 to 45 degrees. He applies enough pressure to feed the electrode toward the workpiece as the electrode melts off. The electrode is not moved along the joint although the arc moves along the joint as the electrode is consumed because the electrode is held at an angle to the workpiece.

A similar technique was used in the chamber welds. The electrode was bent so that it formed an angle of about 30 degrees to the workpiece (see Figure 3). The workpiece was stationary during welding; it was not moved horizontally. To start the weld, the operator moved the electrode down vertically until contact was made between the end of the electrode and the workpiece. An arc was established when this contact was made. The operator proceeded to weld by maintaining a constant pressure on the electrode as it was consumed. The only movement involved was the vertical down motion of the electrode holder as the electrode was consumed. When the electrode melted to within six inches of the electrode holder, the power supply was turned off and the electrode holder was retracted.

All welds were bead-on-plate welds; no groove welds were made. The bead-on-plate welds are easier to produce and for a feasibility study provide satisfactory results.

Prior to welding, the chamber was pressurized with nitrogen to the desired equivalent depth. A new solution of simulated sea water was used for each test weld. The buildup of foreign material in the water was quite rapid during welding and the frequent water changes were necessary to keep the amount of foreign material to a reasonable level. This foreign material is a product of the breakdown of the electrode flux covering during welding.

Welding Studies

Initial welds were made underwater at atmospheric pressure. These welds were made to establish welding techniques, check out the operation of the equipment, and to determine base welding parameters. These welds also formed a basis of comparison for the welds made at high pressures.

The optimum welding conditions developed with these initial welds were:

Welding current, amps	225
Polarity	straight (electrode negative)
Arc voltage, volts	27
Voltage at power supply, volts	45
Open-circuit voltage, volts	90
Welding speed, ipm	8 - 10

The welding parameters were measured by the meters shown schematically in Figure 5.

The welds that were made had a good bead contour and were relatively smooth. Welds made at higher currents (up to 245 amperes) were undercut along the weld bead edges. Sections taken of these welds showed that the welds were sound with no porosity or slag inclusions.

A series of welds were made at pressures corresponding to depths of 295 feet (130 psig), 680 feet (300 psig), and 1200 feet (530 psig). Welding parameters were adjusted as necessary to produce a weld at these depths. No attempt was made to optimize the welding parameters although some changes were made to improve the weld bead contour. However, the parameters selected could be used for on-site welding although further refinement would be desirable.

The range of welding parameters that were used is shown in Table 1. Most of the experimental welds were made at 680 feet simulated depth. The welds at 295 and 1200 feet were made to observe what changes, if any, occurred as a function of pressure. Welds were made with both straight and reverse polarity. Straight polarity normally is used for underwater arc welding to prevent electrolytic attack on the metal components of the electrode holder.

TABLE 1. PARAMETERS USED FOR WELDING AT EXTENDED DEPTHS.

Simulated Depth, Feet	Electrode Polarity[1]	Welding Current, Amps Set[2]	Welding Current, Amps Measured	Arc Voltage, Volts	Voltage at Power Supply Terminals, Volts	Open Circuit Voltage, Volts
295	Straight	325	235	22		
	Reverse	325	230	22		
680	Straight	400	300-340	32-36	60	96
	Reverse	350-450	260-325	24-42	48-68	98
1,200	Straight	500	380-400	32-34	65	98
	Reverse	500	300-320	42-46	70	98

(1) Straight polarity: electrode negative; reverse polarity: electrode positive

(2) Power supply settings are included to illustrate the difference that can exist between the set and measured currents. This difference will vary from one power supply to another.

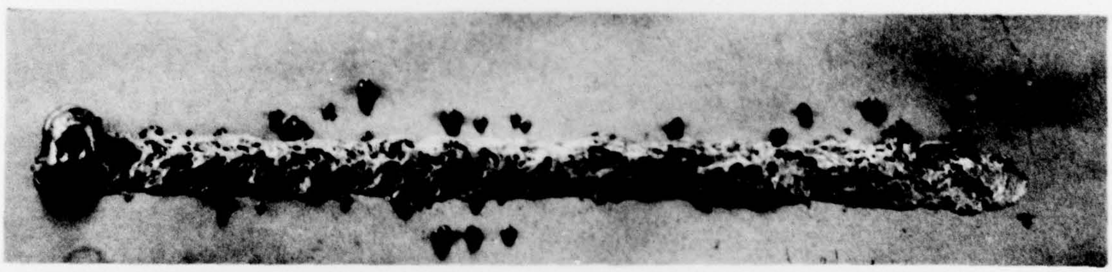
Reverse polarity was investigated also to see if the different heat balance present with reverse polarity would have any effect on the welds.

Welds made at a simulated depth of 680 feet are shown in Figure 6. Photomacrographs of sections of these welds are in Figure 7.

The welds are extremely porous. Similar degrees of porosity were also present in the welds made at 295 and 1200 feet. As mentioned earlier in the report, the welds made underwater but at atmospheric pressure were sound with no evidence of porosity. Therefore, the porosity can be attributed to some effect caused by the increase of pressure.

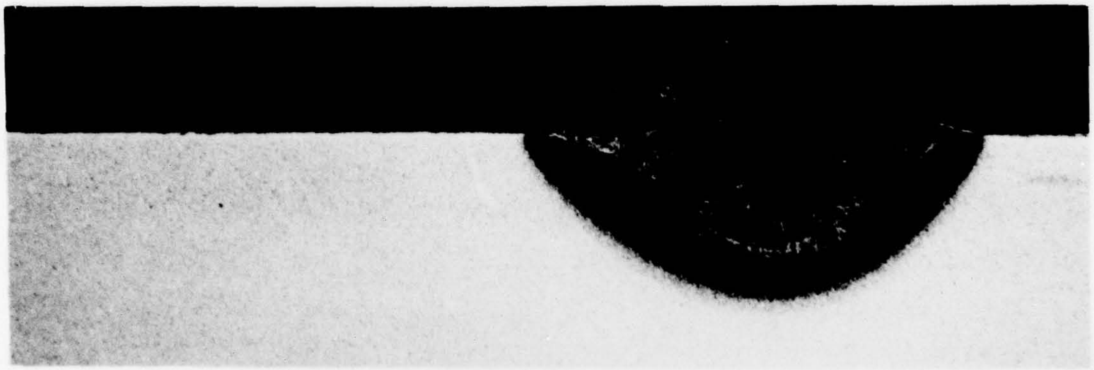
At high pressures, the size of the gas bubble generated from the electrode covering will be reduced significantly. The volume of a given weight of gas is directly related to the pressure of the gas. At a depth of 680 feet, the pressure on the gas is approximately 20 times the pressure at sea level. Therefore, the volume of a given weight of gas at 680 feet would be 1/20 the volume of the same weight of gas at sea level. If the volume of the gas bubble is reduced 1/20th, the surrounding water will contact the weld metal much closer to the arc than at sea level. This will further increase an already fast cooling and freezing rate of the molten weld metal. The fast freezing rate can have two effects. First, gas bubbles in the molten weld metal will be trapped before the bubbles can reach the surface and dissipate. Second, there will be much less time for deoxidizing agents in the electrode covering to react with gases that may be dissolved in the metal being welded. The gases were originally dissolved in the base metal when it was made in the steel mill. To produce a sound weld in such steels, the electrode covering contains deoxidizers that react with the dissolved gases

A. Straight Polarity

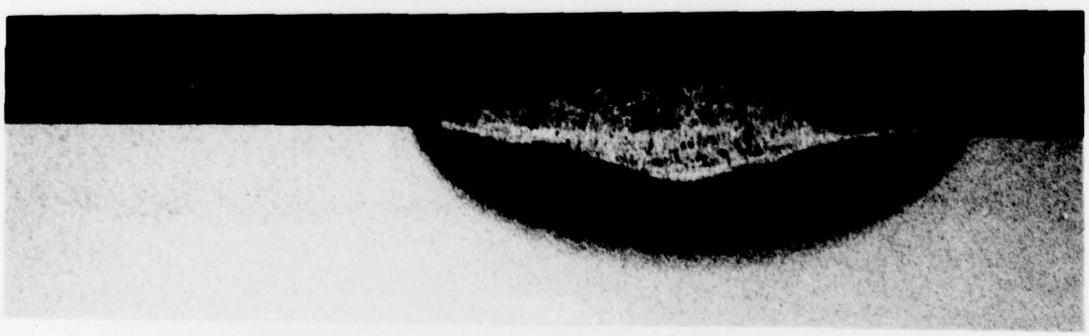


B. Reverse Polarity

FIGURE 6. UNDERWATER ARC WELDS MADE AT A SIMULATED DEPTH OF 680 FEET.



A. Straight Polarity



B. Reverse Polarity

FIGURE 7. CROSS SECTIONS OF UNDERWATER ARC WELDS MADE AT A SIMULATED DEPTH OF 680 FEET.

to form compounds that float to the surface of the molten weld metal. If the reaction time is too short, the compounds will not form and the dissolved gases will form bubbles or porosity in the weld metal.

The heat of the underwater welding arc forms steam in the gaseous atmosphere immediately surrounding the arc. Some breakdown of the steam into hydrogen and oxygen will occur in the arc. The closer proximity of the water to the arc at the higher pressures probably results in the formation of greater amounts of oxygen and hydrogen in the arc atmosphere. Large quantities of oxygen in the arc atmosphere will cause porosity.

It is quite possible that the porosity in these experimental welds is a result of all of these factors in combination. A suggested solution to this problem is the development of an electrode that will produce larger quantities of gas to provide a larger gas bubble. Supplementary devices for keeping the water farther from the arc also might help to alleviate the porosity problem.

The welds made with reverse polarity generally were wider and shallower and the weld surface was smoother than welds made with straight polarity. This was true for the welds made at all three depth levels. This behavior can be noted in the illustrations of the 680-foot welds in Figures 6 and 7. In conventional metal-arc welds (made in air at atmospheric pressure), reverse polarity normally produces deeper welds than does straight polarity. Therefore, the increased pressures appear to cause a reversal of this behavior. Since the welding arc could not be observed closely in these studies, no explanation for this behavior can be provided.

The size, shape, and quantity of porosity varies depending on the polarity. Porosity in the wide, shallow reverse-polarity welds is finer and the individual pores are more circular than in the deeper straight-polarity welds. The gas bubbles have less distance to travel to reach the surface of the reverse polarity welds. Thus, more of the gas bubbles can dissipate before freezing with reverse polarity. Also, more base metal is melted with straight polarity. If the porosity source is the gas dissolved in the base metal, there is a larger source of gas with straight polarity than with reverse polarity.

The strengths and ductilities of underwater welds are lower than welds made in air even when the welds are sound. The very porous welds made at the extended depths would have even poorer mechanical properties. Therefore, although arc welds could be made in 295, 680, and 1,200 feet of water, the strengths of these welds would be expected to be very low. It is doubtful that these welds would be leak free, since the pores in the welds could provide leakage paths.

No effort was made to optimize welding parameters. However, some changes in weld bead shape were noted with changes in the welding parameter. At 680 feet, the smoothest bead surface was obtained at around 320 amperes and 30-32 arc volts. At lower currents and voltages, the welds were narrower and more humped. At higher currents and voltages, the weld widths were about the same but the surface became rougher. All straight polarity welds were severly humped and changes in the current and arc voltage did not seem to have any effect. The angle of the electrode with the plate surface was not varied although changes in this angle would be expected to have some effect on the weld shape.

Voltage Drop in the Welding Power Cables

The voltage drop in the welding power cables was measured while welding underwater at atmospheric pressure and at simulated depths of 680 and 1,200 feet. The voltage during welding was measured at the terminals of the welding power supply and at the cable attachments in the pressure vessel walls as shown in Figure 5. The difference in these readings is the voltage drop in the 1,200 feet of welding power cable (600 feet of electrode cable and 600 feet of ground cable). These measurements were not exact because:

(1) During welding the voltages are not constant but fluctuate rapidly. Thus, an exact value cannot be read from the meter and only an approximate value can be recorded.

(2) Since the cables were coiled due to lack of space, there would be a voltage drop in the cables from the inductive field in the coiled cable. This is in addition to the voltage drop from electrical resistance. The measured voltage drop is the sum of the inductive and resistance losses.

The voltage drops in the cables also were calculated using the plot of voltage drop versus current contained in the U.S. Navy Underwater Cutting and Welding Manual. The measured and calculated voltage drops are listed in Table 2. The measured voltage drop was about 3 or 3-1/2 volts higher than the calculated voltage drop. This difference is the added voltage drop due to the inductive field in the coiled cable.

The voltage drop at 1,200 feet was the same as the 600-foot voltage drop since the same length of cable was used for both sets of experimental welds. The voltage drop at 680 feet was higher than at sea level since higher

TABLE 2. VOLTAGE DROP IN WELDING POWER CABLE

Simulated Depth, Feet	Voltage Drop in 1,200 Feet of Cable, Volts	
	Measured	Calculated
Sea Level	18(1)	14-1/2
680	27(2)	24
1,200	27(3)	24

(1) Average of two measurements

(2) Average of eleven measurements

(3) Average of two measurements

welding currents were being used at 680 feet. The higher current heats the cable and increases the cable resistance. As a result, the resistance voltage drop in the cable is greater. In actual underwater welding, the cable would be in the water. The cooling effect of the water might lessen the rise of cable temperature and the accompanying increase in cable voltage drop.

Gas Analysis

The gas bubbles evolved during welding were analyzed for oxygen and hydrogen to ascertain if a buildup of these gas bubbles could constitute an explosive safety hazard. An underwater weld was made in the nitrogen-filled chamber at atmospheric pressure. The chamber was purged with nitrogen for 15 minutes prior to welding. A sample of gas taken from the chamber after the weld was completed was analyzed by mass spectroscopy. The results were:

Sample	Composition, Percent by Volume				
Number	N_2	CO_2	O_2	H_2	Unidentified
1	98.6	0.10	0.95	0.27	0.02
2	99.5	0.08	0.10	0.26	0.06
3	98.3	0.10	0.34	1.23	0.03

Since the chamber was filled with nitrogen prior to welding, the samples had a high nitrogen content. The oxygen, hydrogen, and carbon dioxide in the sample were evolved during welding. Some additional atmospheric oxygen probably remained in the chamber in spite of the 15-minute nitrogen purge.

In this analysis, the relative amounts of oxygen and hydrogen are the primary interest. If it is assumed that all of the oxygen was evolved during welding, then the oxygen and hydrogen contents of the sample would be the contents of the welding gas bubble. The relative amounts of oxygen and hydrogen in the gas bubble were:

Sample Number	Composition of Gas Bubble, Percent by Volume		
	O_2	H_2	CO_2
1	72	20.4	7.6
2	22.8	59	18.2
3	20.4	73.5	6.1

Since the explosive limits for hydrogen in oxygen are from 4 to 94 percent, a gas bubble having these amounts of hydrogen and oxygen would be an explosive mixture. A build-up of gas bubbles being evolved from underwater arc welding therefore would constitute an explosive hazard.

UNDERWATER OXYGEN-ARC CUTTING

The underwater oxygen-arc cutting studies were made to determine if the oxygen-arc cutting process would be usable at extended depths. As with the welding studies, cutting parameters were measured and gas analyses were made.

Cutting Procedures

In general, cutting procedures were similar to the welding procedures. Some changes in technique were required, however, because of differences in the two processes.

The cutting electrode was positioned vertical to the workpiece instead of being angled as in welding. To make the cut, two simultaneous movements were required: vertical movement of the torch to compensate for the burn-off of the electrode and horizontal movement of the workpiece under the electrode. The self-consuming technique is not used in oxygen-arc cutting. Instead, the electrode is moved along the piece being cut. Thus, it was necessary to move the workpiece horizontally. Also, it is necessary to hold an arc rather than allowing the end of the electrode to rest on the workpiece.

The cutting operation was initiated by striking an arc by moving the electrode down until the end contacted the workpiece surface. After the arc was established, the cutting oxygen was turned on. As soon as the plate was pierced, horizontal movement of the plate was begun. The operator simultaneously moved the electrode vertically down to maintain the cutting arc.

Cuts were made in mild steel plate 1/4-inch and 1/2-inch thick. Cuts were made underwater at atmospheric pressure and at 300 psi (simulated depth of 680 feet). Prior to cutting, the chamber was purged with nitrogen for 15 minutes and then pressurized. The test plates were immersed in sea water as in the welding studies.

Cutting Studies

The initial underwater cuts were made at atmospheric pressure. The parameters used for these cuts were for a comparison with those developed at 680 feet. The parameters are listed in Table 3. The only change required in going from sea level to 680 feet was an increase in oxygen pressure from 40 psi to 330 psi. This increase was necessary to compensate for the pressure at 680 feet (300 psi). Satisfactory operation was obtained at both sea level

TABLE 3. PARAMETERS USED FOR UNDERWATER OXYGEN-ARC CUTTING

Simulated Depth, Feet	Plate Thickness, Inch	Electrode Polarity	Cutting Current, Amps	Arc Voltage, Volts	Voltage At Power Supply, Volts	Open Circuit Voltage, Volts	Travel Speed, ipm	Cutting Oxygen Pressure, psi
Sea Level	1/4	Straight	260	40	65	95	12-15	40
680	1/4	Straight	260	40	65	95	12-15	330
680	1/2	Straight	280	40	65	95	8	330
680	1/2	Reverse	280	40	65	95	8	330

and 680 feet. A typical cut made in the 1/4-inch plate is shown in Figure 8. Cut quality and appearance were the same at both depths.

Cuts also were made in 1/2-inch-thick steel at 680 feet. An increase in cutting current of 20 amperes and a decrease in cutting speed to 8 ipm was necessary. Otherwise, the cutting parameters were the same. The 1/2-inch-thick plate was more difficult to cut than the 1/4-inch-thick plate. This was due chiefly to problems related to manipulating the electrode and plate. The operator could not observe the cutting operation closely so it was difficult to tell whether the plate was being moved at the correct speed. Maintaining the proper arc length also was difficult. Some improvement was gained by using reverse polarity. More heat is generated in the plate with reverse polarity than with straight polarity so it is easier to maintain the cutting action. In spite of these difficulties, however, the feasibility of arc cutting both 1/4 and 1/2-inch-thick steel at 680 feet was demonstrated.

The widths of the cuts in both 1/4 and 1/2-inch-thick plate were 3/8 to 1/2 inch. The rate of electrode consumption was about 6-1/2 inches of electrode per foot of cut for 1/4-inch-thick plate and 18 inches of electrode per foot of cut for 1/2-inch-thick plate.

Gas Analysis

Samples of the chamber gas were analyzed for oxygen and hydrogen in the same manner as during the welding studies. The relative percentages of oxygen and hydrogen for four samples were:

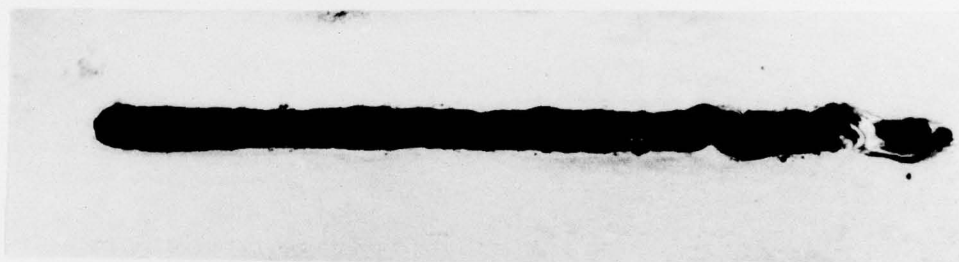


FIGURE 8. OXYGEN-ARC CUT IN 1/4-INCH-THICK STEEL MADE AT A SIMULATED DEPTH OF 680 FEET.

Sample Number	Composition, Percent by Volume	
	O_2	H_2
1	98.8	1.2
2	99.5	0.5
3	98.6	1.4
4	98.8	1.2

Other gases, e.g., nitrogen and carbon dioxide, also were present. These percentages refer only to the relative amounts of oxygen and hydrogen.

The hydrogen content of the gas is below the lower explosive limit for hydrogen in oxygen (4 percent). A buildup of this gas mixture in a confined space does not appear to constitute an explosive hazard. However, the relative oxygen content will depend on the oxygen pressure used and the efficiency of the cutting action. Variations in hydrogen content would be expected also. The relative amounts of oxygen and hydrogen could be expected to vary by a few percent and the hydrogen content could easily increase above the lower limit of 4 percent. Therefore, underwater arc cutting should never be conducted in a confined area where the cutting gases could be trapped.

Experimental data are recorded in Battelle Laboratory Record Book No. 26954, pp 1-46.