The MIT/Marine Industry Collegium

ADVANCES IN UNDERWATER WELDING

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Sea Grant Program

ADMINISTRATIVE STATEMENT

In 1975 the MIT Sea Grant Program formed the MIT/Marine Industry Collegium, a working partnership between MIT Sea Grant and U.S. Industry to promote the commercial development and application of new marine technologies. In seeking to meet this objective, the Collegium acts as an information resource for industrial members, conducts meetings, workshops, and special programs, and publishes information on new ocean-related business opportunities.

The principal pulblications of the Collegium are Opportunity Briefs. These 15-25 page papers deal with specific business opportunities growing out of Sea Grant or other MIT sponsored marine research. Opportunity Briefs describe a new technology or process, outline economic and marketing implications, review technical requirements, and consider environmental, regulatory, and political factors. Briefs are a joint effort of subject experts, the MIT Sea Grant Marine Industry Advisory Service and Collegium members. The briefs remain anonymous to give greater freedom in the expression of opinions and in speculation about particular future opportunities.

The five Opportunity Briefs prepared during the Collegium's 1975-1976 year were:

Chitin and Chitin Derivatives

Offshore Mining of Sand and Gravel

Telemanipulators for Underwater Tasks

Advances in Underwater Welding

Untethered Robot Submersible Instrumentation Systems

Each of these Briefs was first issued to Collegium members in draft form. Following this, we held meetings to explore the topic in more depth and to discuss further directions with representatives of interested companies. The Brief in its edited form incorporates many of the comments and suggestions that we received from members through correspondence, phone conversations, and Collegium meetings.

If you would like to receive any of our other Opportunity Briefs, or wish to pursue further any of the topics covered, please contact the Marine Industry Advisory Service, MIT Sea Grant Program, Room 1-215, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.

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Director

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1.0 A BUSINESS PERSPECTIVE

Offshore platforms, undersea oilwell completion systems, and pipe lines associated with obtaining oil beneath the sea offer product and service opportunities for companies that can repair and fabricate structures in the marine environment. The cost of down-time while awaiting repairs is immense and hence the value of or price for underwater repair is very high. Underwater "wet" welding is a technology showing great potential if certain specifications can be met. It is the purpose of this Brief to outline the needs and the potential for underwater welding and to indicate some current, promising techniques.

Underwater welding techniques have been used since the early 1900s for repair of metal structures in the sea. However, these techniques have been extremely limited in their application because they are expensive to utilize and the welds have been of uncertain quality. The underwater welds are generally weaker and more brittle than comparable welds made in air. They require operating personnel who combine skills in both diving and welding. They involve working activities that must be carried out in a hazardous environment, with limited mobility and poor visibility. For these reasons, underwater welding applications have been largely restricted to temporary repairs and salvage operations.

Until recently, underwater welding was accomplished through trial and error, with little theoretical foundation. As a result, the state-of-the-art in underwater welding techniques remained virtually static. Over the past five years, however, the picture has begun to change rapidly.

Recent changes owe their genesis to the need for repairing the greatly expanding numbers and types of offshore structures--platforms, pipelines, etc. Down-time for many of these is very costly and so development of "code-quality" underwater welding techniques for permanent repairs is an attractive chance to save money. High quality, permanent underwater welds for ships could also in some cases end the need for costly time used in dry-docking.

This growing need has motivated a substantial amount of both academic and industrial research. A survey of the articles published within the last 40 years shows a recent sharp surge in international interest in underwater welding. Of the approximately 50 significant articles published between 1960 and 1974, twenty-six were published in the early 1970s. More than half were from the U.S., and many were from the USSR, Japan, and England.

Dr. Koichi Masubuchi of MIT's Department of Ocean Engineering recently completed a three-year study done to establish theoretical foundations for underwater welding and cutting. Sponsored by the National Sea Grant Program, the National Science Foundation, and the Welding Research Council, his study considered such basic aspects as heat flow, mechanisms of metal transfer, effects of water on metallurgical structures and properties of welds. From his research and that of others reported in literature, there appear to be new understanding, new technologies, and new methods emerging to meet needs for improved underwater welding systems.

Marine shipping, drilling, mining, fishing, or almost any other aspect of ocean utilization could expect to benefit significantly from advances in underwater welding because of more convenient and less costly repairs.

Advanced underwater welding technology could also have a profound and beneficial effect on the methods of constructing certain offshore structures.

For example, conventional methods of laying offshore pipelines become increasingly expensive as distance from shore becomes greater, as larger pipes are required, and as depths increase. Advanced underwater welding techniques could make feasible new construction methods, which could serve to hold down those costs.

Builders of offshore platforms might also benefit from new welding techniques. Presently, almost all platforms and associated structures used offshore are completely fabricated on land, towed to a site, and submerged into place. Towing and submergence operations pose high operational risks and place severe constraints on the possible size and geometric complexity of the structures. New underwater welding technology might mean that smaller sub-assemblies could be pre-fabricated on shore in conveniently handled sections and then welded at the site. Such a procedure would open a new range of design options and lessen the danger of damaging a structure in transit.

In summary, there is an existing need for technology that permits permanent, code-quality welding underwater. The need grows out of the increasing numbers of offshore structures that require repair from time to time. Further, if such technology were available, the construction industry could take advantage of certain new procedures in building offshore structures. Some new technology is already available. Additional advances appear near at hand. In this Opportunity Brief, we report on existing new methods of underwater welding and the directions of current research that show promising potential.

2.0 CURRENT UNDERWATER WELDING PROCESSES

In general, underwater welding processes can be categorized as "wet" or "dry." In wet welding processes, the material that is being welded, the welding equipment, and the diver/welder are enveloped in water. In dry underwater welding, also known as hyperbaric welding, large pressurized air chambers are used to exclude water from the work area, permitting the welders to work in a dry environment. The trade-offs between the two methods are readily apparent. Wet welding is relatively cheaper in terms of support equipment, and requires only that a diver/welder and his equipment be able to get to the worksite.

Wet welding generally produces inferior joints because hydrogen bubbles (from disassociated water) get into the metal: the weld is cooled too quickly and becomes brittle. The hyperbaric approach assures "air" quality welds because the welding is carried out, if not in air, at least in a dry gaseous environment. The welders need not be qualified divers. The major problem is that hyperbaric chambers can be built only for limited, simple geometries and the logistic support required to get the hyperbaric chamber to the worksite is frequently very time consuming and expensive.

Hybrid systems in which the welder is in water and the work piece is in air share both the advantages and limitations of wet and dry systems.

2.1 Wet underwater welding processes.

2.11 Shielded metal arc:

The shielded metal arc (SMA) method is the oldest metal arc process used underwater (Collateral readings are given in Section 4.0). As shown in Figure 1 (page 6), the arc burns in a cavity formed inside a waterproof shield that is designed to burn more slowly than the metal barrel of the electrode. The diver exerts a downward pressure on the electrode to keep the shield chipping and burning away to provide a relatively constant arc barrel length, even in conditions of very poor visibility. Diverse compositions of the shield are used. The choice of composition is more art than science and may have an important influence on underwater weld quality.

With SMA methods the welding may be done on a single pass or on multiple passes. Chicago Bridge and Iron Company (CBI) has in the past several years had a high degree of success using multipass techniques. Using welders trained as divers (rather than the more usual approach of divers who take a short welding course) CBI has produced multipass welds with a quality that is claimed to often be better than the Navy's rule of thumb estimates of 80% tensile strength and 50% ductility in contrast to comparable air welds.

2.12 Shrouded metal arc:

The shrouded metal arc is a variation of the shielded metal arc designed to keep water away from the local work area as shown in Figure 2 (page 6). The shroud is a small device used to displace the water from the immediate vicinity of the weld pool. The gas evolved from the arc is used to displace the water so that no external shielding gas is required. This helps keep equipment to a minimum and still provides some advantage from the small air pocket covering the welding puddle. The gas atmosphere contains a large amount of hydrogen and does not reduce the problems of hydrogen embrittlement. A shroud does help slow down the cooling rates and so enables welds with more

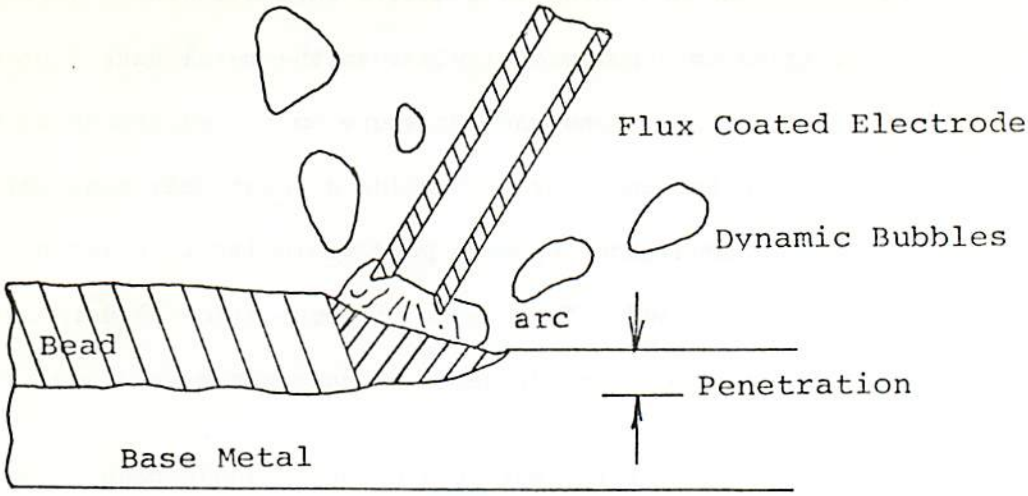


Figure 1: Shielded Metal Arc

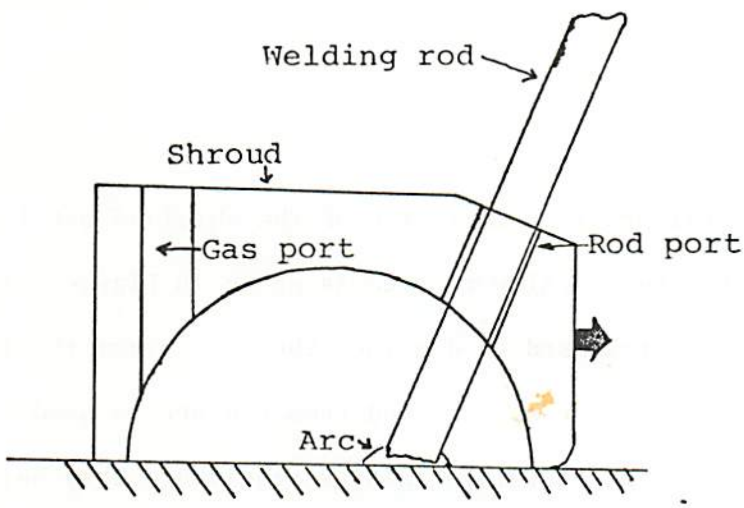


Figure 2: Shrouded Metal Arc

ductility to be produced. The mechanical properties of such welded joints are found to be intermediate between air welding and unshrouded underwater welding quality. In the actual operation, the size of the vent must be compatible with the amount of gas formation at the arc. Too much gas will tend to bounce the shroud off the workpiece. Too little gas will be ineffective in displacing the water under the shroud. The most practical design for a shroud would include a controllable venting system to allow an equilibrium between the gas formed at the arc and the gas flow under the shroud, which will vary with depth.

2.13 The gas metal arc (GMA):

The gas metal arc (GMA) process is illustrated in Figure 3 (page 8). A gas shield provides a known atmosphere around the weld area and can provide a more consistent quality weld than the shrouded metal arc. This process has been used both in the ambient water environment and in conjunction with either portable, hand-held air chambers or with large hyperbaric enclosures.

The wet GMA welding process is more complex than the shielded metal arc process because a consumable electrode is fed continuously from a spool through the welding gun by means of a wire feed mechanism that automatically maintains a stable welding arc length. This arc length regulation accomplishes the same task as the eroding shield of shielded metal arc welding. Complexity is increased by the need to provide controlled shielding gas flow independent of depth.

Underwater semiautomatic GMA equipment was first developed in the USSR in the late 1950s. The equipment has been successfully used with and without

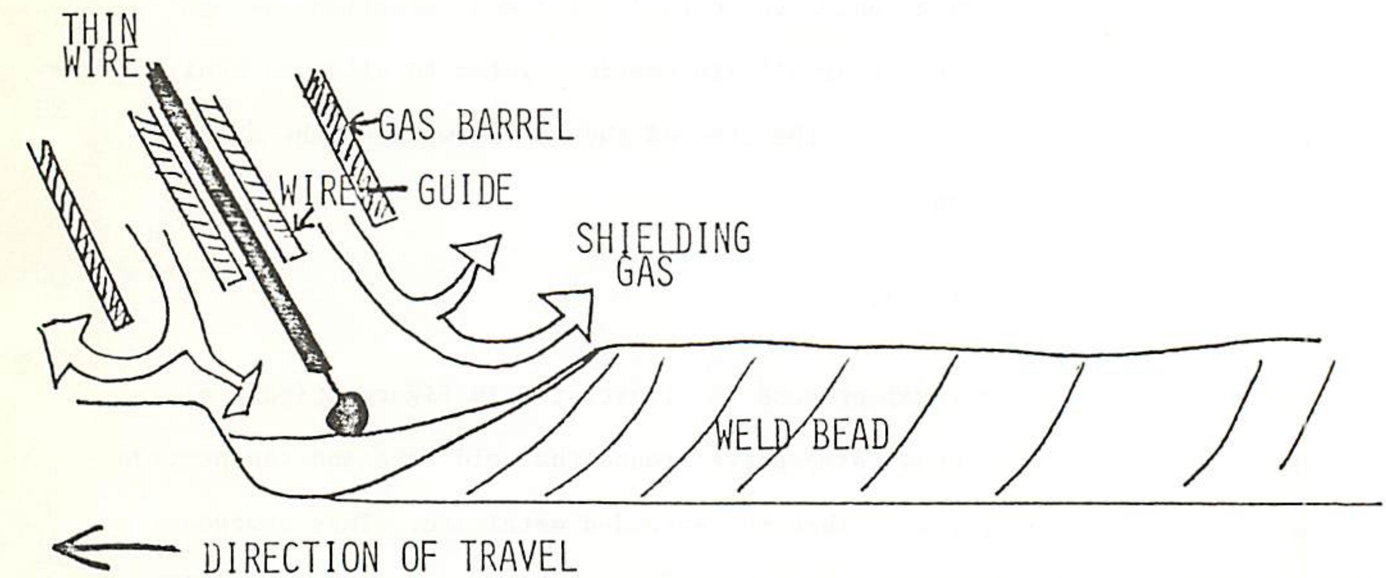


FIGURE 3

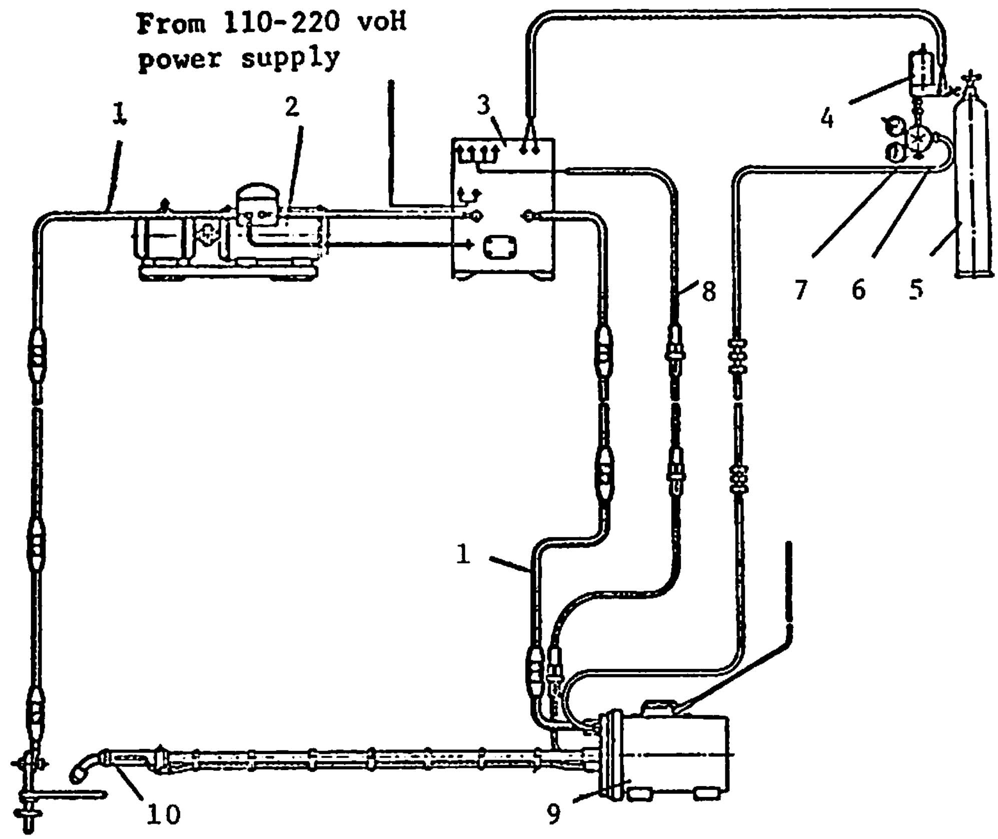
GAS METAL ARC PROCESS

CO_2 shielding to depths of 200 ft.

Beginning in 1968, Ocean Systems Incorporated and Linde Division of Union Carbide developed a prototype gas metal arc wet welding apparatus consisting of a pressurized submersible wire feeder, a torch, and related controls. As indicated by Figure 4 (page 10), the support equipment required to feed the metal continuously and to provide the shielding gas flow is quite complex.

2.2 Dry underwater welding processes. In dry welding processes a sealed air chamber is used to enclose a portion of the underwater structure to be welded and to provide work space for welders. Water is displaced by pressurized gases that are nonexplosive and capable of sustaining life for short periods of time in the event of a malfunction of the welder's life support systems. A helium-oxygen mixture with an oxygen partial pressure of 6-8 psi is typical below 200 feet.

Figure 5 (page 11) illustrates typical dry chambers for underwater welding. Because of the welding heat, the chamber is often at an elevated temperature of $90\text{-}100^{o}$ F and combined with the high humidity, working conditions remain far from ideal inside these chambers. However, problems with visibility and positional stability are solved using these chambers. Because the chamber atmosphere contains gases that cause weld defects, a separate shielding gas is often used for the welding arc. The most practical applications of this process have been for pipeline welding where the chamber shape is simple and also reusable. In spite of the process's high specialization to enclosable weld joints, it remains an extremely expensive technique. But, in applications where code-quality welds are necessary, this



1. Welding cable
2. Power supply
3. Control unit
4. Heater and flow gage
5. Gas cylinder
6. Gas hose
7. Reducing valve
8. Welding cable
9. Gas reservoir and wire feed unit
10. Welding head.

FIGURE 4

GAS METAL-ARC WELDING EQUIPMENT ARRANGEMENT
FOR UNDERWATER WELDING

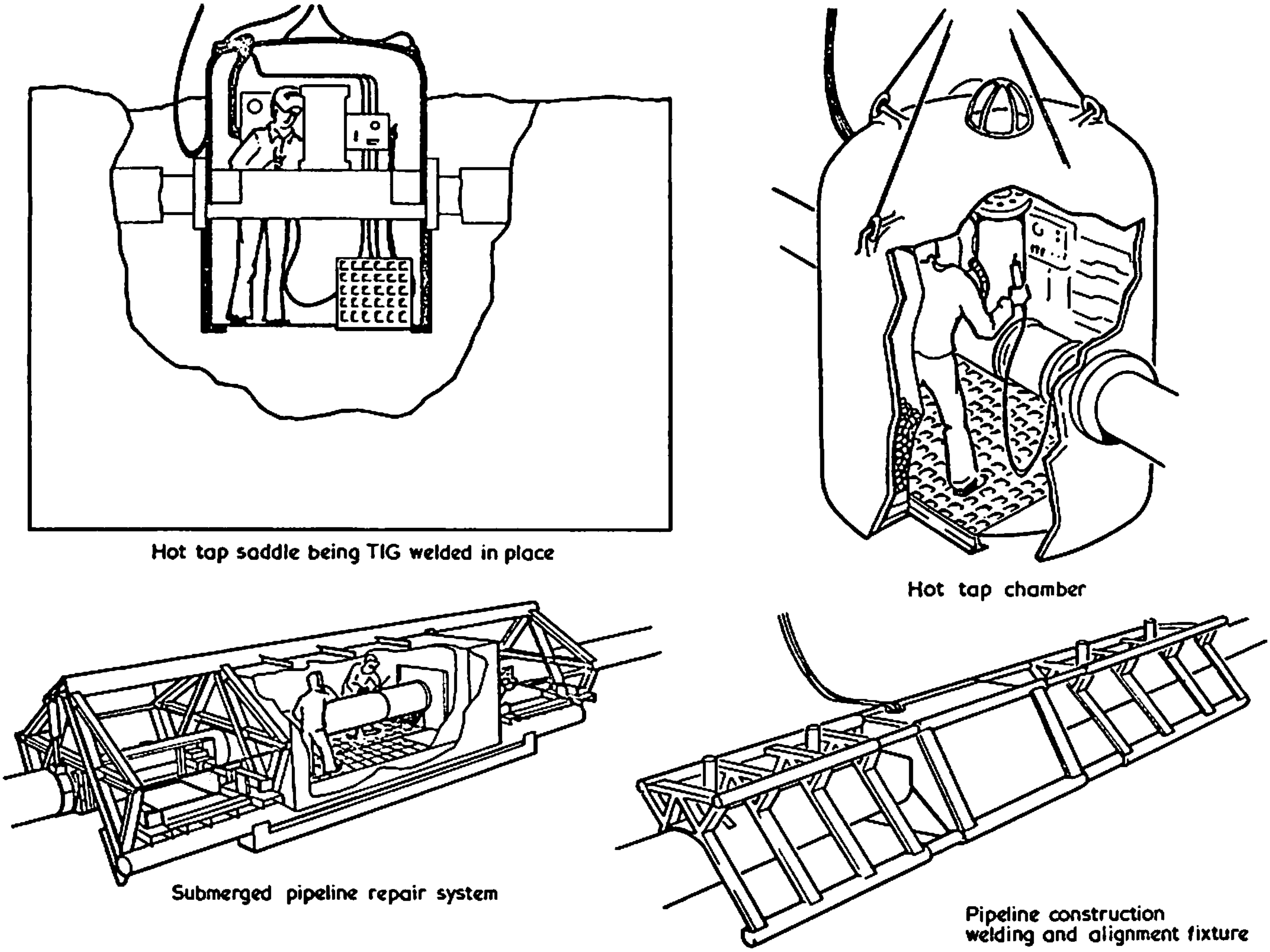


FIGURE 5

MOVABLE CHAMBER - "DRY SPOT" TECHNIQUE

type of underwater welding is well worth the cost. It will continue to be an extremely useful underwater fabrication tool, especially as underwater construction materials become more standardized.

A moveable chamber combines some of the features of dry chamber welding and wet processes. Figure 6 (page 13) illustrates the significant features of the technique. The chamber is made of clear plastic to enable the diver to see his work.

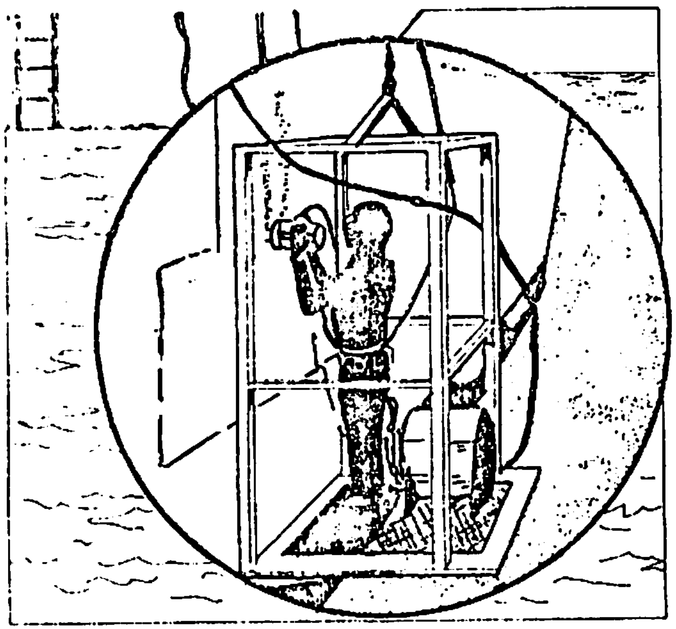
The movable chamber process allows underwater welds to be completed without direct contact with the surrounding water until the weld metal is cooled enough to prevent significant hardening. The mechanical properties are therefore excellent. Using GMA as the basic process, the technique achieves air quality welds. The disadvantages of the process lie primarily in its practical limitations of maneuverability and flexibility.

2.3 <u>Special considerations in underwater welding.</u> A number of factors combine to make either wet or dry underwater welding processes significantly different from welding in air. These factors include the physics involved in the process, economic constraints, and special limitations imposed by working in the ocean environment. These limiting considerations, which highlight the problems that research and development in underwater welding must address, are summarized below.

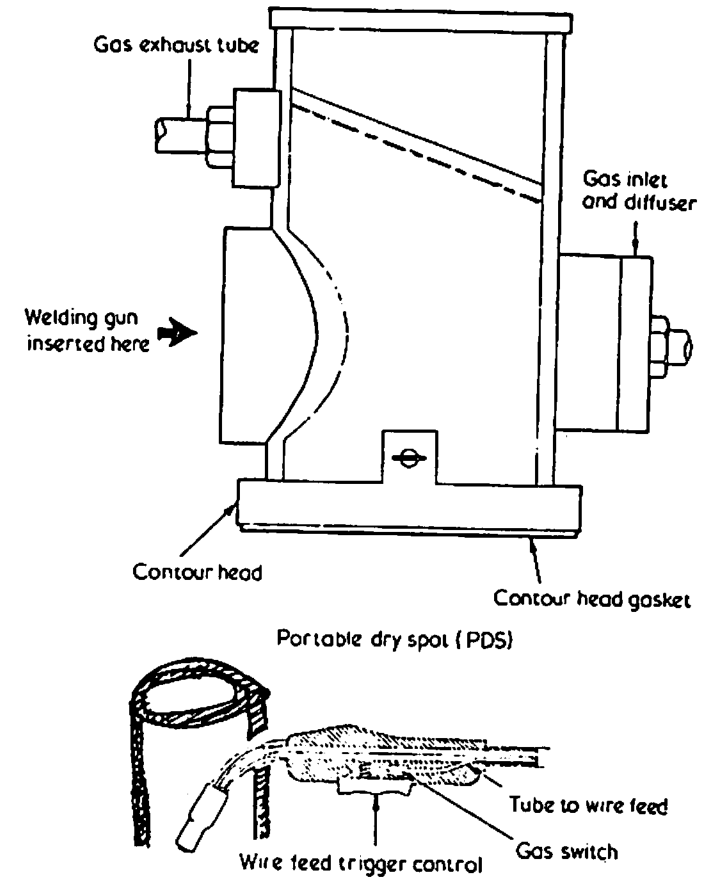
2.31 Physical and metallurgical problems:

Arc welding underwater is affected by the following undesirable phenomena.

1) Hydrogen-induced cracking may occur, owing to the ionization of



OPERATIONAL VIEW



"DRY SPOT" DESIGN

FIGURE 6

DRY CHAMBER UNDERWATER WELDING PROCESS

water and the formation of bubbles with a high proportion of hydrogen.

2) Bubbles formed by the intense heat of the welding arc may make the weld material porous and weak.

3) The rapid cooling effect of the surrounding water may result in a hard and brittle weld.

2.32 Human factors:

Welding in any environment requires good visibility of the work area and a considerable amount of time. Underwater visibility is rarely very good and time is a very precious commodity. To accomplish good underwater welds, a person must be a competent diver and welder, both of which are difficult skills to master. The hazards of the environment require the diver to concentrate primarily on his safety and only secondarily on the welding task, making all processes of welding underwater very much slower compared with air welding.

2.33 Electrical hazards:

All arc welding uses electric power, thereby creating problems of diver safety, since salt water is an excellent conductor of electricity. Special equipment has been designed to minimize the hazards, but the problem remains of greater concern for underwater welding than for welding in air.

2.34 Power supply:

Economics and logistic factors in underwater welding require that power supplies be on the surface, requiring long electric cables of large cross-section to minimize voltage drops between the surface and the work site. The welding processes also use greater power underwater. These two effects combine to require substantially larger power supplies. Table 1 (page 16) summarizes the processes, applications and limitations of the current underwater welding techniques discussed above.

TABLE 1

SUMMARY OF UNDERWATER WELDING PROCESSES

PROCESS	APPLICATIONS	LIMITATIONS
1. WET WELDING TECHNIQUES		
A. Shielded Metal-Arc	Complex lap, tee or butt welds. Very maneuverable. Single or multipass.	Simplest to use, but discontinuities occur because of need to change electrodes. Multipass techniques help in improving quality.
B. Shrouded Metal-Arc	Fairly uniform joints. Single-pass. Fair maneuverability	Same as above, but better weld quality. Some problems in controlling gas flow generation to assure a "dry" atmosphere.
C. Gas Metal-Arc (Continuous Wire electrode)	Butt, tee, lap joints. Moderate maneuverability. Multipass. Superior quality to metal arc.	Requirement for shielding gas and wire feed raises complexity of equipment.
D. Plasma Arc	Butt, lap, tee joints. Very good weld bead shape and penetration. (experimental state only.)	Significantly better welds, but extreme complexity of equipment keeps this process in the laboratory.
2. DRY WELDING TECHNIQUES		
E. Movable Chamber	Uniform joint design. Butt and filet joints, pipelines joining possible. Multipass. Very high quality.	Provided chamber can be fitted properly, excellent welds can be achieved. Chamber & support equipment are complex.
F. Fixed Chamber (complete enclosure) Gas Tungsten-Arc Process	Pipelines, simple enclosable structures. Very high quality.	Expense of equipment, operational costs very high. Elaborate support crews & equipment.

3.0 DIRECTIONS OF CURRENT RESEARCH AND DEVELOPMENT IN UNDERWATER WELDING

While underwater welding in air chambers is the best method presently available for obtaining permanent welds, the previously noted disadvantages of this approach have motivated a significant amount of new research and development related to the wet processes. These efforts hold the potential of providing special equipment and processes that can overcome the deleterious effects of welding directly in water.

Research at MIT over the last three years has been aimed at understanding the basic physics and metallurgy of underwater welding processes. This research is intended to provide a theoretical foundation from which directed, parallel developmental activities can proceed.

The research efforts described in sections 3.1-3.3 below are of important interest as welding processes, but they are complex systems. To be potentially useful, processes should protect the local high temperature weld area from sea water without recourse to gas or water shields, since the penalties associated with supplying and regulating gas and water are high. Two such methods appear very promising and are noted briefly in sections 3.4 and 3.5.

3.1 Underwater stud welding. An underwater stud welding system has been developed and tested by students of Professor Koichi Masubuchi of MIT. Weld strength of the new technique compares favorably with air stud welding. Stud welding could provide a means of accomplishing certain tasks without the disadvantages of presently used "velocity powered" stud drivers that sometimes damage the structure to which the stud is being attached. However, the stud-welding system requires both gas and electric power and its cost and complexity must be compared to its advantages in each potential application.

3.2 <u>Water shielded gas metal arc.</u> A second interesting approach under development by Mitsubishi Heavy Industries is the water shielded gas metal arc (WSGMA) process. This process is illustrated in Figure 7 (page 19). The technique has the potential advantage of providing a suspension system capable of "riding" over surface irregularities; removing sea water from the weld zone; creating a more stable gas zone; reducing gas composition; and creating a more nearly uniform heat distribution across the arc. Research is being done at MIT to determine the effectiveness and stability of the process, which appears promising from the welding viewpoint. However, the complexity of providing electric power, gas and water at carefully controlled rates suggests that the process may not be practical in the undersea environment.

3.3 <u>Underwater plasma arc welding.</u> Workers in Japan are experimenting with an underwater plasma arc welding process. The plasma arc is a constricted flow of partially ionized gas through an electric arc. The constricted arc nozzle produces greater arc stability and a high concentration of power. These are both found to be advantageous in underwater welding resulting in a very reliable arc producing an exceptionally even weld bead. Figure 8 (page 20) shows the plasma welding nozzle and equipment arrangement. The disadvantages of such a process are its slow speed compared to stick electrode welding and its complexity.

3.4 <u>Flux-cored wire electrodes.</u> The E. U. Paton Electric Welding Institute in Russia has recently developed a new wet underwater welding technique which employs a flux-cored wire electrode. The flux core provides a slag covering

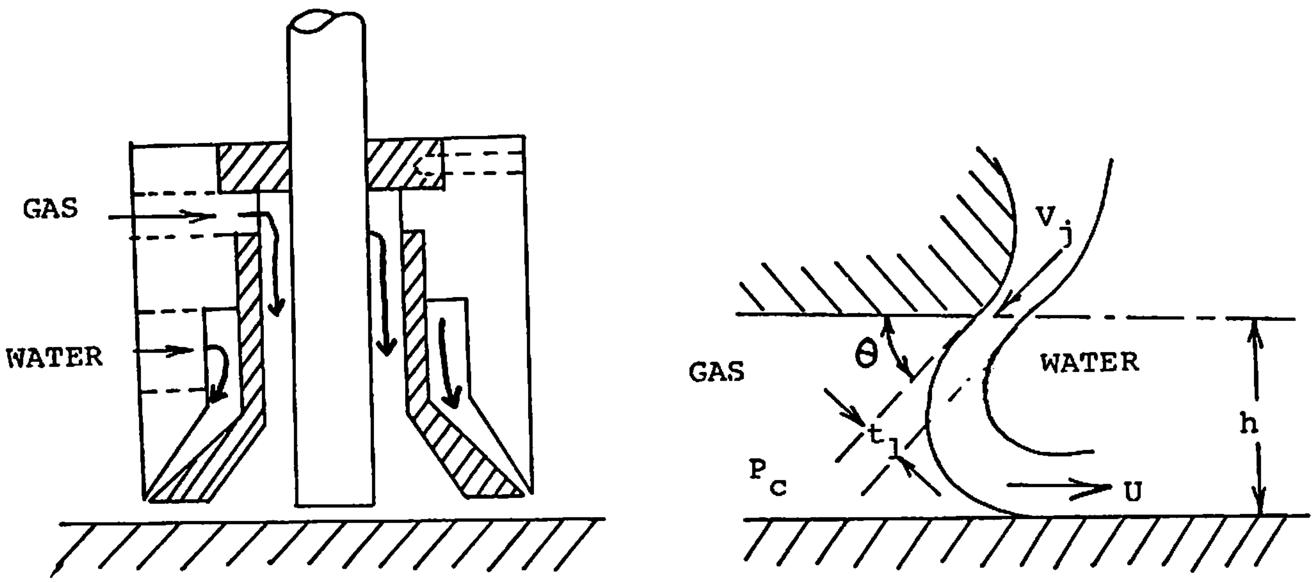
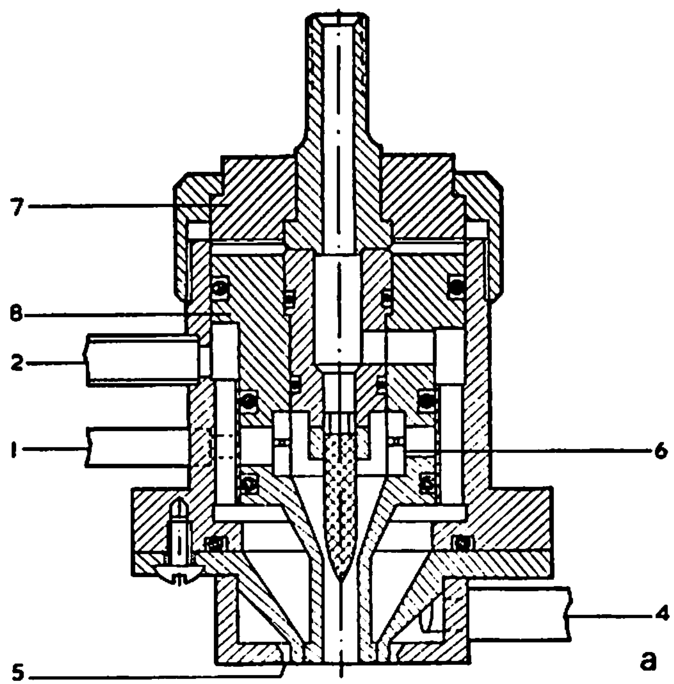


FIGURE 7

WATER SHIELDED GAS METAL ARC (WSGMA)

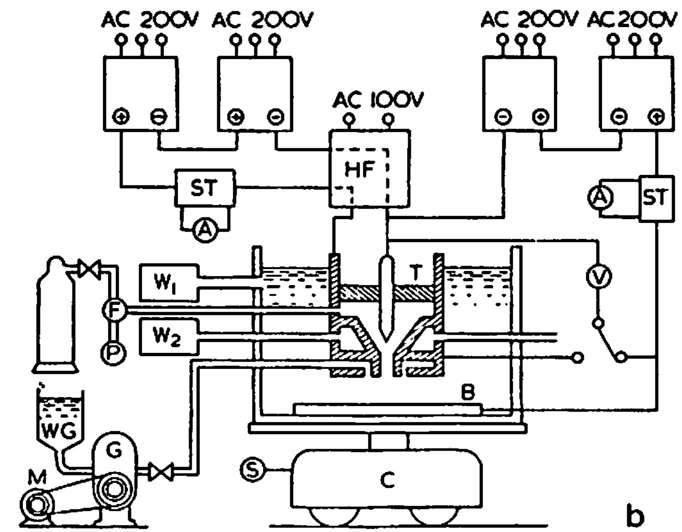
FIGURE 8

THE PLASMA ARC PROCESS



a Plasma Torch

1: Inlet of plasma gas
2: Inlet of cooling water
3: Outlet of cooling water
4: Inlet of shielding liquid
5: Gap for shielding liquid
6: Ring with four tangential passage for plasma gas
7,8: Insulator



b Arrangement of equipment

B: Base metal
T: Plasma torch
W_1,W_2: Water supply
C: Carriage
S: Speed regulator
HF: High frequency stater
ST: Shunt
A: Ammeter
V: Voltmeter
F: Flow meter for plasma gas
P: Pressure gauge
WG: Water glass
G: Gear pump
M: Variable speed motor

over the weld area and apparently prevents hydrogen absorption by the weld metal. The detailed mechanism of the process is not clear or well understood, but the results claimed are very impressive. An evaluation program to verify the results claimed is indicated since the technique has the merit of great simplicity.

3.5 Underwater submerged arc welding. MIT has recently done preliminary work on a radically different technique to obtain a submerged arc process by providing a continuous slag over the weld area. Water is kept away from the arc by a watertight enclosure that is pressed against the object to be welded. The electrode that produces the arc for the welding is inserted into the enclosure. A viscous polymer inside the enclosure keeps water out, while gas produced in the enclosure during the welding is expelled through valves. The enclosure also contains a layout of powder such as limestone powder, which acts as electrical insulation and absorbs water moisture that may seep through the viscous polymer. The flux shield provides some thermal insulation that serves to lower hydrogen embrittlement and to inhibit rapid quenching action.

Based on some preliminary experiments, weld quality appears excellent. Equally important, no shielding gas is needed, so the equipment is simple, qualifying the process for potential use in deep sea applications. Systematic development of such processes will be a major effort in MIT's future program.

3.6 Subsequent research in submerged arc processes. After the original draft of this Opportunity Brief was published in May, 1976, the MIT/Marine Industry Collegium held a workshop sponsored by the MIT Sea Grant Program. The workshop was attended by a number of representatives from industry who expressed a strong desire to have additional data on the submerged arc techniques. They also urged the establishment of standard procedures for obtaining objective data on the quality of underwater welds. Professor Masubuchi is currently carrying out efforts that are directed, in part at least, toward satisfying the expressed needs of industrial representatives attending the workshop.

During the summer of 1976 Professor Masubuchi conducted field tests of the submerged arc process. A German diver working in the Baltic Sea at depths of up to 50 feet used the method and was photographed by an MIT graduate student. Monitoring of the diver's movements by means of the underwater camera should provide important data on feasibility of the method from the standpoint of the human user. In addition, the tests are expected to produce valuable new data on the costs of such a process, the quality of the weld, and the safety of the welder/diver.

Another goal of the field test is to provide comparative data for evaluating the results obtained in controlled laboratory environments with the results of actual operations.

At the time of publication of this Brief, the data obtained in the field tests had not been analyzed and were not ready for public release.

4.0 ADDITIONAL READINGS

The readings listed below are taken from Professor Masubuchi's most recent Sea Grant proposals and reflect work done primarily at MIT.

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13. Savitch, I. M. "Underwater Welding of Metals." Paper 20, presented at the New Castle Conference on Welding in Offshore Construction, February 26-28, 1975.