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Underwater Welding-Recent Trends and Future Scope

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Abstract: Welding in offshore and marine application is an area of research and understanding where, many problems are still unsolved. In the present paper, a brief classification of underwater welding is made, the principals involved and the advantages and disadvantages of the various types of underwater welding are described. Further discussion is made over the present conventional and some advanced techniques used. Finally, the scope of further research has been recommended.

Keywords: Underwater welding, hyperbaric welding, SMAW, TIG and THOR-1.

I. INTRODUCTION

Welding processes have become increasingly important in almost all manufacturing industries and for structural application (Khanna, 2004). Although, a large number of techniques are available for welding in atmosphere, many of them cannot be applied in offshore and marine application where presence of water is of majorconcern. In this regard, it is relevant to note that, a great majority of offshore repairing and surfacing work iscarried out at a relatively shallow depth, in the region intermittently covered by the water known as the splashzone. This is predominantly because of the fact that the probability of failure is maximum at a shallow depth ofwater because of maximum collision probability between the ship and platform. Though, numerically most shiprepair and welding jobs are carried out at a shallow depth, most technologically challenging task lies in therepairing at a deeper water level, especially, in pipelines and occurrence/creation of sudden defects leading to acatastrophic accidental failure. The fact that electric arc could operate underwater was known for over a 100 years.The first ever underwater welding was carried out by British Admiralty – Dockyard for sealing leaking ship rivets below the water line. Underwater welding is an important tool for underwater fabrication works. In 1946, special waterproof electrodes were developed in Holland by 'Van der Willingen'. In recent years the number of offshore structures including oil drilling rigs, pipelines, platforms are being installed significantly. Some of these structures will experience failures of its elements during normal usage and during unpredicted occurrences like storms, collisions. Any repair method will require the use of underwater welding.

II. CLASSIFICATION

Underwater welding can be classified as
1) Wet Welding
2) Dry Welding
In wet welding the welding is performed underwater, directly exposed to the wet environment.

In dry welding, a dry chamber is created near the area to be welded and the welder does the job by staying inside the chamber.

III. WET WELDING

Wet Welding indicates that welding is performed underwater, directly exposed to the wet environment. A special electrode is used and welding is carried out manually just as one does in open air welding. The increased freedom of movement makes wet welding the most effective, efficient and economical method. Welding power supply is located on the surface with connection to the diver/welder via cables and hoses.

A. Principle of operation of Wet Welding

The process of underwater wet welding takes in the following manner:

The work to be welded is connected to one side of an electric circuit, and a metal electrode to the other side. These two parts of the circuit are brought together, and then separated slightly. The electric current jumps the gap and causes a sustained spark (arc), which melts the bare metal, forming a weld pool. At the same time, the tip of electrode melts, and metal droplets are projected into the weld pool. During this operation, the flux covering the electrode melts to provide a shielding gas, which is used to stabilize the arc column and shield the transfer metal.

The arc burns in a cavity formed inside the flux covering, which is designed to burn slower than the metal barrel of the electrode.

B. Advantages of Wet Welding

Wet underwater MMA welding has now been widely used for many years in the repair of offshore platforms. The benefits of wet welding are: -

1) The versatility and low cost of wet welding makes this method highly desirable.

2) Other benefits include the speed. With which the operation is carried out.

3) It is less costly compared to dry welding.

4) The welder can reach portions of offshore structures that could not be welded using other methods.

5) No enclosures are needed and no time is lost building. Readily available standard welding machine and equipment are used. The equipment needed for mobilization of a wet welded job is minimal.

C. Disadvantages of Wet Welding

Although wet welding is widely used for underwater fabrication works, it suffers from the following drawbacks:

1) There is rapid quenching of the weld metal by the surrounding water. Although quenching increases the tensile strength of the weld, it decreases the ductility and impact strength of the weldment and increases porosity and hardness.

2) **Hydrogen Embrittlement–** Large amount of hydrogen is present in the weld region, resulting from the dissociation of the water vapour in the arc region. The H_2 dissolves in the Heat Affected Zone (HAZ) and the weld metal, which causes Embrittlement, cracks and microscopic fissures. Cracks can grow and may result in catastrophic failure of the structure.

3) Another disadvantage is poor visibility. The welder some times is not able to weld properly.

IV. DRY WELDING

Dry welding in underwater may be achieved by several ways [Oates, 1996]:

1.Dry habitat welding:

Welding at ambient water pressure in a large chamber from which water has been displaced, in an atmospheresuch that the welder/diver does not work in diving gear. This technique may be addressed as dry habitat welding.

2. Dry chamber welding:

Welding at ambient water pressure in a simple open-bottom dry chamber that accommodates the head andshoulders of the welder/diver in full diving gear.

3. Dry spot welding:

Welding at ambient water pressure in a small transparent, gas filled enclosure with the welder/diver in the waterand no more than the welder/diver's arm in the enclosure.

4. Dry welding at one atmosphere:

Welding at a pressure vessel in which the pressure is maintained at approximately one atmosphere regardless of outside ambient water pressure.

5. Cofferdam welding:

Welding inside of a closed bottom, open top enclosure at one atmosphere.

6. Hyperbaric Welding :

Hyperbaric welding is carried out in chamber sealed around the structure to be welded. The chamber is filled with a gas (commonly helium containing 0.5 bar of oxygen) at the prevailing pressure. The habitat is sealed onto the pipeline and filled with a breathable mixture of helium and oxygen, at or slightly above the ambient pressure at which the welding is to take place. This method produces high-quality weld joints that meet X-ray and code requirements. The gas tungsten arc welding process is employed for this process. The area under the floor of the Habitat is open to water. Thus the welding is done in the dry but at the hydrostatic pressure of the sea water surrounding the Habitat.

A. Principle of operation of Dry Welding

Underwater welding in a dry environment is made possible by encompassing the area to be welded with aphysical barrier (weld chamber) that excludes water. The weld chamber is designed and custom built toaccommodate braces and other structural members whose centerlines may intersect at or near the area that is tobe welded. The chamber is usually built of steel, but plywood, rubberized canvas, or any other suitable materialcan be used. Size and configuration of the chamber are determined by dimensions and geometry of the area thatmust be encompassed and the number of welders that will be working in the chamber at the same time. Water isdisplaced from within the chamber by air or a suitable gas mixture, depending upon water depth and pressure atthe work site. Buoyancy of the chamber is offset by ballast, by mechanical connections and chamber to thestructure, or by a combination of both.

B. Advantages of Dry Welding

1) **Welder/Diver Safety** – Welding is performed in a chamber, immune to ocean currents and marine animals. The warm, dry habitat is well illuminated and has its own environmental control system (ECS).

2) **Good Quality Welds –** This method has ability to produce welds of quality comparable to open air welds because water is no longer present to quench the weld and H_2 level is much lower than wet welds.

3) **Surface Monitoring –** Joint preparation, pipe alignment, NDT inspection, etc. are monitored visually.

4) **Non-Destructive Testing (NDT) –** NDT is also facilitated by the dry habitat environment.

C. Disadvantages of Dry Welding

1) The habitat welding requires large quantities of complex equipment and much support equipment on the surface. The chamber is extremely complex.

2) Cost of habitat welding is extremely high and increases with depth. Work depth has an effect on habitat welding. At greater depths, the arc constricts and corresponding higher voltages are required. The process is costly – a $ 80000 charge for a single weld job. One cannot use the same chamber for another job, if it is a different one.

V. RISKS INVOLVED

There is a risk to the welder/diver of electric shock. Precautions include achieving adequate electrical insulation of the welding equipment, shutting off the electricity supply immediately the arc is extinguished, and limiting the open-circuit voltage of MMA (SMA) welding sets. Secondly, hydrogen and oxygen are produced by the arc in wet welding.

Precautions must be taken to avoid the build-up of pockets of gas, which are potentially explosive. The other main area of risk is to the life or health of the welder/diver from nitrogen introduced into the blood steam during exposure to air at increased pressure. Precautions include the provision of an emergency air or gas supply, stand-by divers, and decompression chambers to avoid nitrogen narcosis following rapid surfacing after saturation diving.

For the structures being welded by wet underwater welding, inspection following welding may be more difficult than for welds deposited in air. Assuring the integrity of such underwater welds may be more difficult, and there is a risk that defects may remain undetected.

VI. CHARACTERISTICS OF A GOOD UNDER WATER WELDING

(a) Requirement of inexpensive welding equipment, low welding cost easy to operate, flexibility of operation in all positions.
(b) Minimum electrical hazards, a minimum of 20 cm/min welding speed at least.
(c) Permit good visibility.
(d) Produce good quality and reliable welds.
(e) Operator should be capable in supporting himself.
(f) Easily automated.

VII. APPLICATION OF UNDERWATER WELDING

The important applications of underwater welding are:
(a) Offshore construction for tapping sea resources,
(b) Temporary repair work caused by ship's collisions or unexpected accidents.
(c) Salvaging vessels sunk in the sea
(d) Repair and maintenance of ships
(e) Construction of large ships beyond the capacity of existing docks.

VIII. CONVENTIONAL UNDERWATER WELDING TECHNIQUES

A. Shielded Metal Arc Welding

Shielded Metal Arc Welding (SMAW) is among the most widely used welding processes. During the process,the flux covering the electrode melts during welding. This forms the gas and slag to shield the arc and moltenweld pool. The slag must be chipped off the weld bead after welding.

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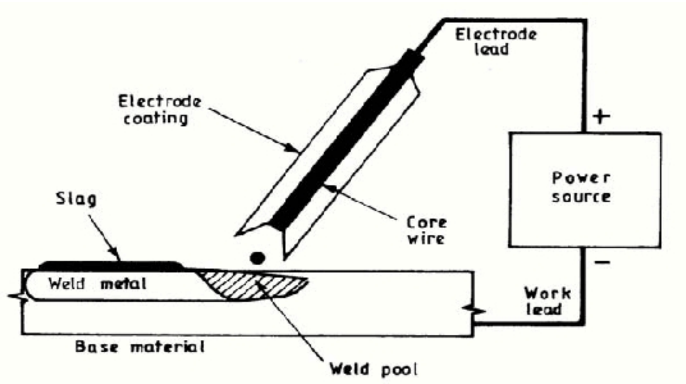

Fig. 1. Schematic of shielded metal arc welding process

The flux also provides a method of adding scavengers, deoxidizers, and alloyingelements to the weld metal.For underwater wet welding with shielded metal arc welding (SMAW) technique, direct current is used andusually polarity is straight. Electrodes are usually water proofed. Furthermore, it is flux coatedwhich causesgeneration of bubble during welding and displaces water from the welding arc and weld pool area.Hence, the flux composition and depth of flux coating should be optimized to ensure adequate protection.Electrodes for shielded metal arc welding are classified by AWS as E6013 and E7014 (Khanna, 2004).Versatility, simple experiment set-up, economy in operation and finished product quality are notable advantagesof the technique. However, during welding, all electrical leads, lighting gear, electrode holder, gloves, etc., mustbe fully insulated and in good condition. Ferrite electrodes with a coating based on iron oxide should be used asthey resist hydrogen cracking. Flux cored arc welding is another technique which could not yet competed witSMAW because of reported excessive porosities and problems with underwater wire feeding system (Oates,1996).

B. Flux Cored Arc Welding

Flux Cored Arc Welding (FCAW) is a commonly used high deposition rate welding process that adds the benefits of flux to the welding simplicity of MIG welding (Khanna, 2004). As in MIG welding wire iscontinuously fed from a spool. *Fig*. 2 shows the schematic of flux cored arc welding process. Flux cored weldingis therefore referred to as a semiautomatic welding process. Self shielding flux cored arc welding wires areavailable or gas shielded welding wires may be used. Less pre-cleaning may be necessary than MIG welding.

However, the condition of the base metal can affect weld quality. Excessive contamination must be eliminated.Flux cored welding produces a flux that must be removed. Flux cored welding has good weld appearance (smooth, uniform welds having good contour). Flexibility in operation, higher deposition rate, low operator skilland good quality of the weld deposits are the notable advantages of flux cored arc welding. However, presenceof porosities and burnback are the problems associated with the process. Recent development of nickel basedflux cored filler materials have provided improved wet weldability and halogen free flux formulation specificallydesigned for wet welding application (Oates, 1996). Similarly, improved underwater wet welding capabilitiesand halogen-free flux formulations have been developed with stainless steel flux-cored wires.

C. Tungsten Inert Gas Welding

TIG-welding (Tungsten Inert Gas) or GTAW-welding (Gas Tungsten Arc Welding) uses a permanent nonmeltingelectrode made of tungsten (Khanna, 2004). Filler metal is added separately, which makes the processvery flexible. It is also possible to weld without filler material. TIG welding has got the advantage that it gives astable arc and less porous weld. *Fig*. 3 shows the schematic of tungsten inert gas welding technique.The most used power source for TIG-welding generates alternating current (AC). Direct current can be used. ACTIG-welding usually uses argon as a shielding gas. The process is a multi purpose process, which offers the usergreat flexibility. By changing the diameter of the tungsten electrode, welding may be performed with a widerange of heat input at different thicknesses. AC TIG-welding is possible with thicknesses down to about 0,5 mm.For larger thicknesses, > 5 mm, AC TIG-welding is less economical compared to MIG-welding due to lowerwelding speed. DC TIG-welding with electrode negative is used for welding thicknesses above 4 mm. Thenegative electrode gives a poor oxide cleaning compared to AC-TIG and MIG, and special cleaning of jointsurfaces is necessary. The process usually uses helium shielding gas. This gives a better penetration in thickersections.

In deep see construction, free burning arc is used for fusion welding. The arc is then operated in a localized dryregion created around the weldment at elevated pressures. Similar ambient conditions can be found in highpressure discharge lamps and in some plasma heaters and torches. The tungsten inert gas welding process atatmospheric pressures has been investigated extensively from the experimental and theoretical side (Lancester,1987; Haddad & Farmer, 1985). The properties of the free-burning arc column are studied for ambient pressures of 0.1 MPa (i.e., atmospheric) to 10 MPa for applications in underwater welding (Schmidt, 1996).

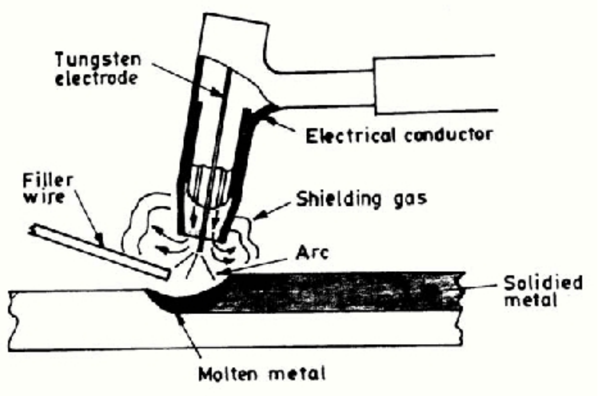

Fig. 2. Schematic of a Gas Tungsten Arc Welding Technique.

IX. ADVANCED UNDERWATER WELDINGTECHNIQUE

A. Friction welding (FRW)

Friction welding is a solid state welding process which produces coalescence of materials by the heat obtainedfrom mechanically-induced sliding motion between rubbing surfaces (Khanna, 2004; Blakemore, 2000). Thework parts are held together under pressure. This process usually involves rotating of one part against another togenerate frictional heat at the junction. When a suitable high temperature has been reached, rotational motionceases and additional pressure is applied and coalescence occurs. *Fig*. 4 shows the schematic of friction weldingprocess. The start of the new millennium will see the introduction of friction welding for underwater repair ofcracks to marine structures and pipelines.

There are two variations of the friction welding process. In the original process one part is held stationary andthe other part is rotated by a motor which maintains an essentially constant rotational speed. The two parts arebrought in contact under pressure for a specified period of time with a specific pressure. Rotating power isdisengaged from the rotating piece and the pressure is increased. When the rotating piece stops the weld iscompleted. This process can be accurately controlled when speed, pressure, and time are closely regulated.The other variation is called inertia welding. Here a flywheel is revolved by a motor until a preset speed isreached. It, in turn, rotates one of the pieces to be welded. The motor is disengaged from the flywheel and theother part to be welded is brought in contact under pressure with the rotating piece. During the predeterminedtime during which the rotational speed of the part is reduced the flywheel is brought to an immediate stop andadditional pressure is provided to complete the weld. Both methods utilize frictional heat and produce welds ofsimilar quality. Slightly better control is claimed with the original process.

Friction welding requires relatively expensive apparatus similar to a machine tool. There are three importantfactors involved in making a friction weld:

1. The rotational speed which is related to the material to be welded and the diameter of the weld at theinterface.
2. The pressure between the two parts to be welded. Pressure changes during the weld sequence. At thestart it is very low, but it is increased to create the frictional heat. When the rotation is stopped pressureis rapidly increased so that forging takes place immediately before or after rotation is stopped.
3. The welding time. Time is related to the shape and the type of metal and the surface area. It is normallya matter of a few seconds. The actual operation of the machine is automatic and is controlled by asequence controller which can be set accordingto the weld schedule established for the parts to be joined.

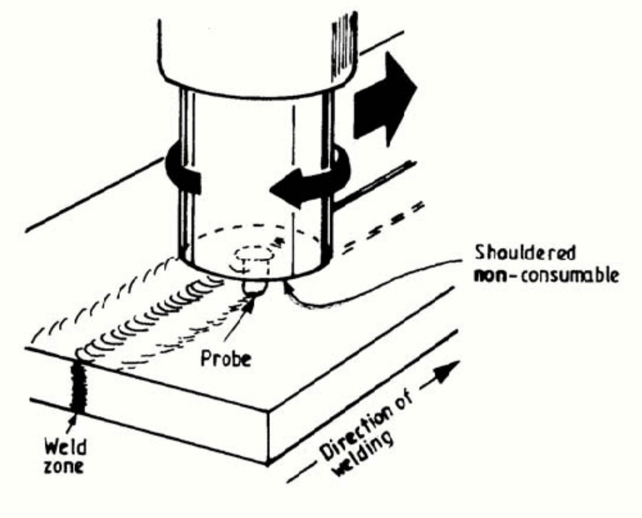

Fig. 3. Schematic of friction welding.

Normally friction welding one of the parts to be welded is round in cross section; however, this is not anabsolute necessity. Visual inspection of weld quality can be based on the flash, which occurs around the outsideperimeter of the weld. Normally this flash will extend beyond the outside diameter of the parts and will curlaround back toward the part but will have the joint extending beyond the outside diameter of the part. If the flashsticks out relatively straight from the joint it is an indication that the time was too short, the pressure was toolow, or the speed was too high. These joints may crack. If the flash curls too far back on the outside diameter itis an indication that the time was too long and the pressure was too high. Between these extremes is the correctflash shape. The flash is normally removed after welding.

(i) Advantages of Friction Welding

1)It has the ability to produce high quality welds in a short cycle time.

2) No filler metal is required and flux is not used.

3) The process is capable of welding most of the common metals.

4) It can also be used to join many combinations of dissimilar metals.

5) It also produces a fine-grained forged weld without any weld dilution, or weld inclusions.

6) Since there is never a liquid weld pool, hydrogen enrichment and hydrogenembrittlement are eliminated. Similarly nitrogen enrichment cannot occur.

7)No shielding gasses or fluxes are required and it is possible to join dissimilar and exotic materials impossible to weld by any other means – including aluminium to ceramic.

B. Laser Welding

Laser as a source of coherent and monochromatic radiation, has a wide scope of application in materials processing (Steen, 1991; DuttaMajumdar& Manna, 2003). Laser assisted welding, because of the sheervolume/proportion of work and advancement over the years, constitutes the most important operations amongthe laser joining processes (Dawas, 1992; Duley, 1999).

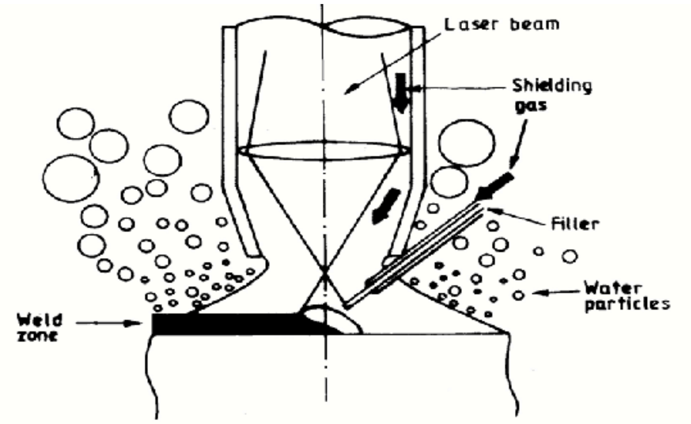

Fig. 4. Schematic of laser welding with a filler rod.

Argon shroud removes heat and prevents undueoxidation and displaces water. The relative position of the laser focus determines the quality and configuration of the weld. [Kruusing, 2004].

The focused laser beam is made to irradiate thework piece or joint at the given level and speed. A shroud gas protects the weld pool from undue oxidation andprovides with the required oxygen flow. Laser heating fuses the work piece or plate edges and joins once thebeam is withdrawn. In case of welding with filler, melting is primarily confined to the feeding wire tip while apart of the substrate being irradiated melts to insure a smooth joint. In either case, the work piece rather than thebeam travels at a rate conducive for welding and maintaining a minimum heat affected zone (HAZ).

There are two fundamental modes of laser welding depending on the beam power/configuration and its focuswith respect to the work piece: (a) conduction welding and (b) keyhole or penetration welding (*Fig*s. 5a, b) (Dutta and Majumdar, 2003).

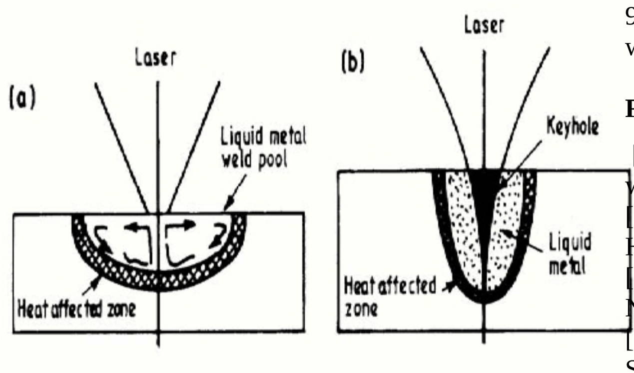

Fig. 5. Schematic of (a) conduction welding and (b) keyhole or penetration welding.

X. UNDER WATER WELDING – FUTURE SCOPE OF RESEARCH

Considerable research effort has been made to improve process performance and control strategies for thevarious underwater welding processes over the last half century. However, there are still many problems toovercome. The major efforts on research and development should be focused on the following topics:

1. Automation of the underwater joining and inspection of the welded structures.
2. Mechanized underwater welding for actual usage of a very large floating structures.
3. Investigation of the potential of using a robot manipulator for underwater ultrasonic testing of welds injoints of complex geometry.
4. Application of advanced welding technique, like friction, laser welding and understand the behavior ofmaterials after the welding and process optimization.
5. Invention of new welding techniques and explore the possibility of its application in underwater welding.
6. Generation of research data book on weld ability of materials during underwater welding.
7. Wet MMA is still being used for underwater repairs, but the quality of wet welds is poor and are prone to hydrogen cracking. Dry Hyperbaric welds are better in quality than wet welds. Present trend is towards automation. THOR – 1 (TIG Hyperbaric Orbital Robot) is developed where diver performs pipefitting, installs the trac and orbital head on the pipe and the rest process is automated.
8. Developments of diverless Hyperbaric welding system is an even greater challenge calling for annexes developments like pipe preparation and aligning, automatic electrode and wire reel changing functions, using a robot arm installed. This is in testing stage in deep waters.
9. Explosive and friction welding are also to be tested in deep waters.

REFERENCES

[1]. Annon, Recent advances in dry underwater pipeline welding, Welding Engineer, 1974.
[2]. Blakemore, G. R. (2000): Underwater Intervention 2000 – Houston, Jan 24-26.
[3]. Dawas, C. (ed.) (1992): *Laser Welding*, Mc. Graw-Hill, New York.
[4]. Duley W. W. (ed.) (1999): *Laser Welding*, John Wiley & Sons, Inc., N. York, pp. 1.
[5]. Dutta Majumdar, J., IIT, KGP (2006) *Journal of Naval Architecture and Marine Engineering*.
[6]. Dutta Majumdar, J. And Manna, I. (2003): *Sadhana*, Vol. 28, pp. 495.
[7]. Haddad, G.N., Farmer, A.J. (1985): *Weld. J.*, Vol. **64**, No. 12, p. 339-342
[8]. Joshi, A. M.,IIT Bombay, Underwater Welding
[9]. Khanna, O.P. (2004): *A Textbook of Welding Technology*, Dhanpat Rai Publications (P) Ltd., N. Delhi, India.
[10]. Kruusing, A. (2004): Optics and Lasers in Engineering, Vol. **41**, pp. 329–352.
[11]. Lancester, J. F. (1987): The Physics of Fusion Welding – Part I: The Electric Arc in Welding, IEE Proc.
Lythall, Gibson, Dry Hyperbaric underwater welding, Welding Institute.
[12]. Oates W.A. (ed.) (1996): Welding Handbook, Vol. **3**, American Welding Society, Miami, USA.
[13]. Ogawa Y. (1998): Proceedings of Eighth International Off shore and Polar Engineering Conference, vol. **4**.
[14]. Schmidt, H.-P. (1996): IEEE Transactions on Plasma Science, Vol. **24**, pp. 1229 – 1238
[15]. Shida, T., Hirokawa, M. and Sato, S. (1997): Welding Research Abroad, Vol. **43, No.** 5, pp. 36.
[16]. Silva, Hazlett, Underwater welding with iron – powder electrodes, *Welding Journal*, 1971.
[17]. Steen, W. M. (1991): *Laser Material Processing*, Springer Verlag, N. York. (ed.),
[18]. Stepath M. D, Underwater welding and cutting yields slowly to research, Welding Engineer, April 1973.
[19]. Xiao, R. S., Ambrosy, G., Zuo, T. C. and Hugel, H. (2001): *J. Maters. Sci. Lett*., Vol. **20**,pp. 2163 – 2165.