

Study on underwater hyperbaric dry GMAW welding

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Abstract. Hyperbaric dry welding is an effective way of underwater repair in offshore engineering. Though various welding methods have been attempted at home and abroad for years, problems and limitations exist. This paper conducted a systematic study on character of GMAW method in hyperbaric dry environment. Experimental study on arc characteristics and the establishment of welding process stability are both developed by means of determination of test condition and the application of High-speed camera technology. Combining with analysis of microstructure and mechanical property of welded joints, a complete technology is formed. The research has opened a new road for the development of welding technology in underwater repair engineering.

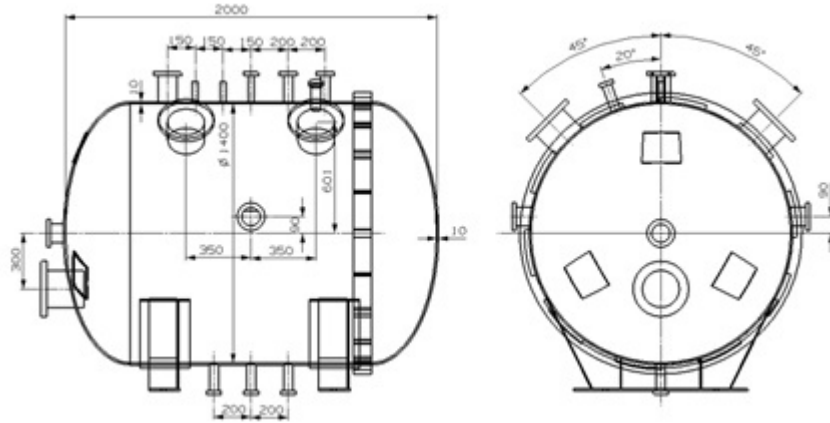
Introduction

Ocean development is an important direction of petroleum industry. A enormous increase occur in submerged pipelines along with the offshore oil and gas resources development and utilization. Underwater maintain is becoming more extrusive due to the long-term operation. Research and develop welding and repair technology with practical applicability and adaptive capacity for submarine pipeline is becoming a more and more urgent task. The welding in water environment is totally different from on land. Underwater wet welding is characterized by poor visibility, high hydrogen content, fast cooling rate and poor welding forming, joint quality cannot meet the requirement of pipeline welding. Hyperbaric dry underwater welding whose electric arc burns stability and droplet transfer is in high pressure gas environment show good quality guarantee, which the welding process is achieved by automated and intelligentized welding system and remote control. According to welding condition and quality requirements, arc characteristic, droplet transfer, welding forming and property of welded joint is carried out in this paper, which lays the foundation for the development of offshore oil and has a good application prospect.

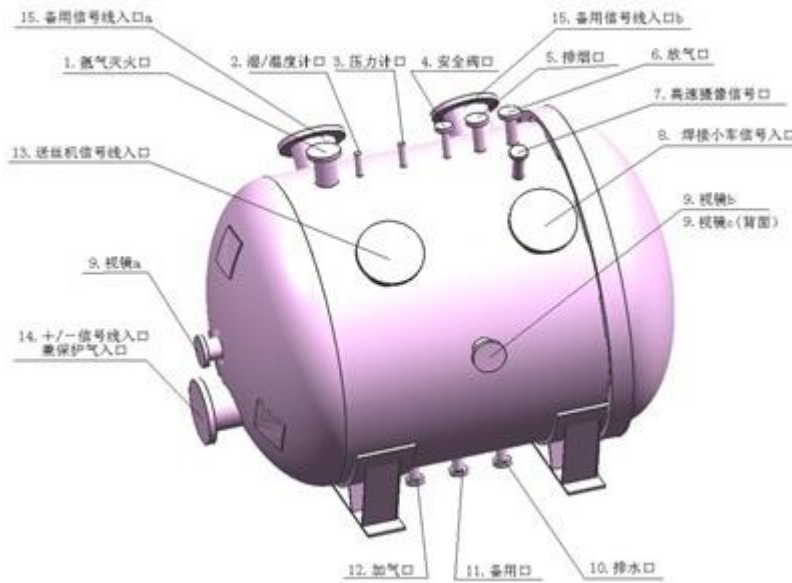
The establish of experimental condition and method

Design of test chamber

The test chamber, which can simulate underwater dry welding condition, consist of a shell satisfying the requirement of pressure, a hatch door open automatically, a hole for welding equipment and experimental apparatus, a observation port and smoke exhausting device which keep the pressure balance.



(a) 2d detail map



(b) 3d drawing

Fig.1 high pressure welding test module

Equipment and apparatus

Special welding test-bed, air compressor, welding equipment, observation and detecting instrument are used in the experiment. Welding test-bed, wire feed and welding torch are installed in the pressure chamber, welding power source (CMT4000) and control system are placed outside the chamber. All the equipment and apparatus are shown in figure 2 and figure 3.



Fig. 2 Layout of equipment in the cabin



Fig. 3 Welding power

Arc stability test

Welding blast test in air pressure environment

In order to remove seawater and obtain dry environment, high pressure gas is charged into the dry cabin in the underwater dry environment. The gas can be air, inert gas or gas mixture including inert gas. Obviously air is the most economically beneficial, however, blasting may occur when arc-time. Blasting test is safe when conducted in shallow water for GTAM. Due to GMAW is different from TIG and need more measuring and observing instruments, blasting tests were conducted first in high-pressure air environment. The results are shown in table 1.

Table 1 shielding gas blasting test in air pressure environment

Air pressure (MPa)	Shielding gas flow (L/min)	Welding current (A)	Arcing and record of observations
0.2	20	140	Arc stable
	20	180	Arc stable
0.4	30	140	Arc stable
	30	180	Arc stable
0.6	50	140	Arc unstable, Splash obvious
	50	180	Arc unstable, Splash obvious

It is known by table 1 that in the condition of 0.1MPa – 0.6MPa air pressure, shielding gas (Ar 82% + CO₂ 18%) and welding current 140A – 180A, there is no phenomena of flame burning or blasting, which not qualified to ignite testing apparatus around, so it is capable of ensure the security of the test.

Arc characteristic of high pressure

The influence of environmental pressures

In order to verify the stability of welding arc in high pressure, two welding mode was employed: one is CMT method; the other is convention GMAW with cooperative control.

The base metal is X65 steel pipe with the dimension $\Phi 168 \times 8$, welding wire is JM-56 with diameter $\Phi 1.0$ mm, wire extension 10mm, shielding gas Ar+CO₂, gas flow 20L/min. Test results are as follows:

(1) CMT mode

Arc voltage both present rising trend with the environment pressure increasing and current

increasing in different current, which is shown in figure 4 (a) . The welding arc is stable curing welding process.

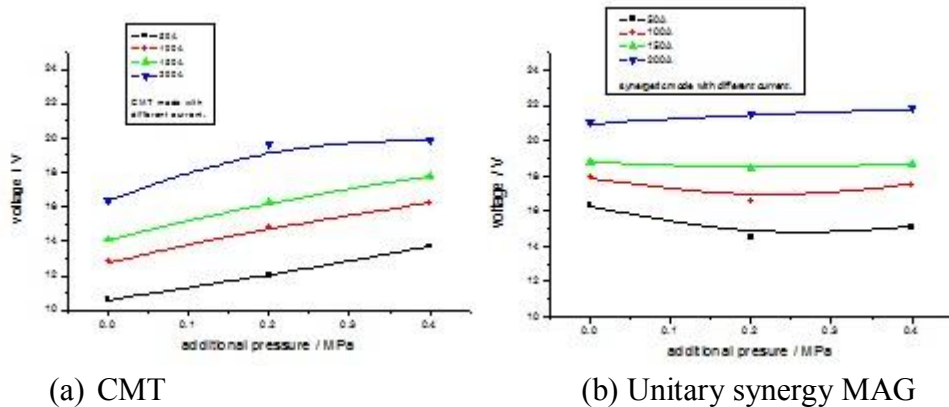


Fig. 4 The relation between environment pressure and arc voltage

(2) Unitary synergy MAG

It is known from figure 4 that arc voltage increase with the increasing of current. Arc voltage increase with the increase of environment pressure as well, but the law is not obvious. It is possible concerned with great fluctuation of arc voltage. The welding arc is basically stable curing welding process. There is more weld spatter in cooperative control compared to CMT mode.

Arc voltage increases with the increase of environment pressure. To obtain stable welding process, output voltage should be enhanced with the increase of current, or welding source with dropping characteristic can be employed.

The influence of weld current

Arc voltage both present increasing trend with the current increasing in either CMT or MAG mode, which is shown in figure 5. That is arc have the rising characteristic. The welding arc is stable curing welding process.

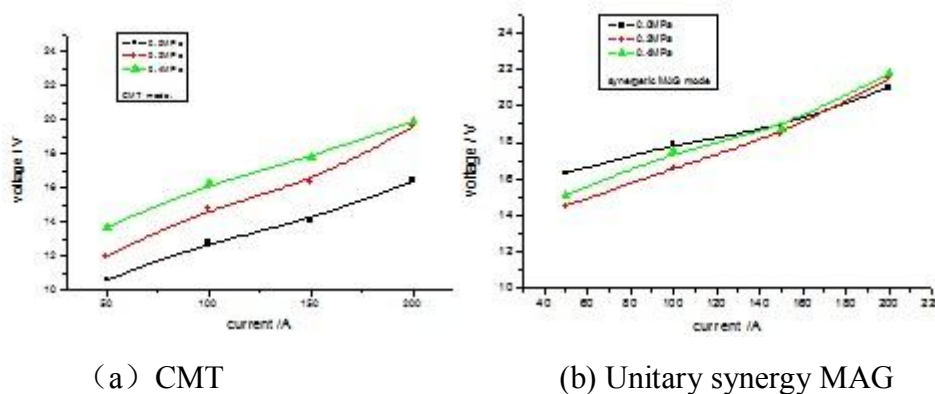


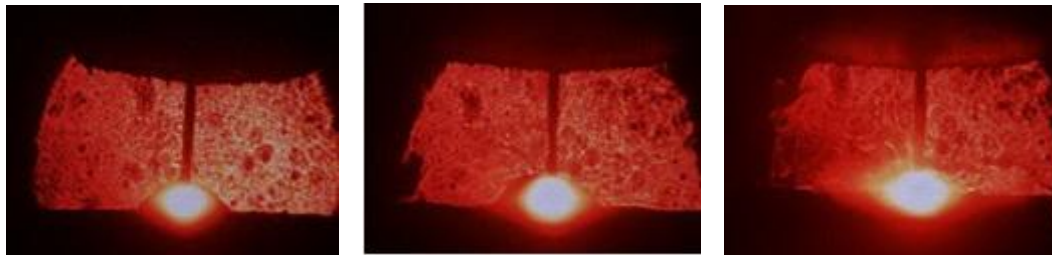
Fig. 5 The relation between weld current and arc voltage when environmental pressure change

Arc feature of high environment

The welding process was record high speed camera system whose speed is 1000f/s. Arc feature corresponding to different welding mode, different shielding gas, different environment pressure and different current. Maximum diameter and height of arc was compared to find some laws by image processing.

Arc morphology photos are shown in figure 6 in different environment pressure. Arc height increases appreciably along with the increase of environment pressure. Generally, arc increases with

the increase of environment pressure. Because when environment pressure has been increased, arc voltage increases correspondingly in the case of the same current (see research on arc static characteristic ahead). Then the arc energy increases, arc bright area is greater.



(a) 0.1MPa, 200A

(b) 0.3MPa, 200A

(c) 0.5MPa, 200A

Fig. 6 Arc photos of different pressure (CMT, shielding gas Ar+CO₂)

Structure and property of welded joints

CMT mode was employed in the welding. The pipe rotated driven by the workbench, and welding gun was foxed on particular position which including downward welding, vertical down welding, over-head position welding. The specimen is X65 pipeline with dimension of Φ168mm×12mm, welding Materials JM—68, GB\ER55—G, shielding gas Ar80%+CO₂20%, environment pressure 0 MPa (ordinary pressure) and 0.4MPa respectively. Test parameters are shown in table 2.

Table 2 Welding test parameters

Welding position	Environment pressure	Layers	Curre nt	Voltag e	Swing speed	Amplitude	Shielding gas flow (L/min)
downward welding	0.4Mpa	Root	130	17.0	170	60	30
		Filling、 Cap	150	17.5	180~250	105~210	30
	0.0Mpa	Root	130	16.0	185	60	20
		Filling、 Cap	150	16.5	200~250	100~200	20
vertical down welding	0.4Mpa	Root	150	17.5	200	70	30
		Filling、 Cap	165	17.5	200~250	130~230	30
	0.0Mpa	Root	150	16.5	210	70	20
		Filling、 Cap	140	16.5	200~250	80~220	20
over-head position welding	0.4Mpa	Root	170	18.0	170	71	30
		Filling、 Cap	170	18.0	175~250	115~230	30
	0.0Mpa	Root	160	16.5	160	40	20
		Filling、 Cap	145	16.3	195~250	83~210	20

Metallographic analysis of welded joints

(1) Ordinary pressure

Typical metallographic structure of welded joint at ordinary pressure is shown from figure 7 to figure 10.

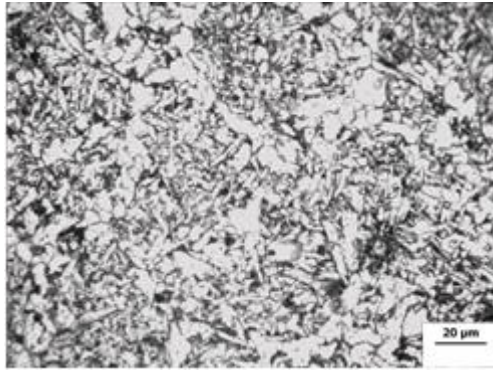


Fig. 7 HAZ

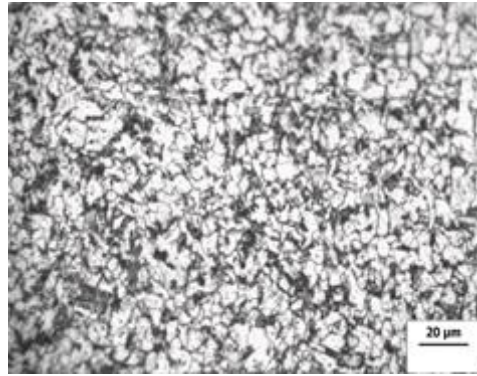


Fig. 8 Root of weld

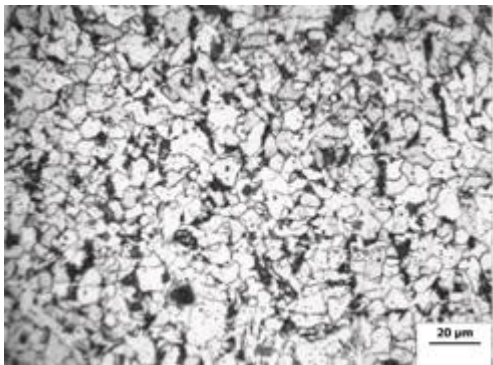


Fig. 9 Centre weld



Fig. 10 Cap weld

It can be seen from figure 7 to figure 10 that there is a great number of upper bainite in centre weld and cap weld at 0.4MPa, which present featheriness. The forming of upper bainite has to process C redistribution and Fe crystal lattice reorganize. C diffuses and redistributes in austenite with a certain speed. While Fe and alloy atoms almost don't spread. During the transformation of $\gamma \rightarrow \alpha$, meanwhile C comes off ferrite, which across phase boundaries of ferrite and spread to austenite, then forming upper bainite. Because of welding was at 0.4MPa, diffusion velocity of C atoms was affected, thus mass upper bainite appear in centre weld and cap weld. The exist of upper bainite is bound to low the toughness of welded joints. In addition, carbide is more dispersed, this is also the result of the change of diffusion velocity of C atoms at high pressure.

mechanics performance analysis of welded joints

According to AWS D3.6, the specimen was machined after NDT, then mechanics performance was carried out. The results are shown in table 3, table 4 and figure 11.

Table 3 Transverse tension test data

Sample Numbers		Tensile strength (MPa)	Percentage elongation (%)	Rupture position
0 MPa	T1	565	14	Weld
	T2	560	12	Weld
0.4 MPa	T1	535	11	Weld
	T2	570	14	Weld

Table 4 Charpy impact test data at low temperature

Sample name	Location of notch	Impact energy (J)	Minimum impact energy (J)	Average impact energy (J)	Temperature (°C)
0.0 MPa	Weld	144, 133、137	133	138	-20
	HAZ	107、127、84	84	106	
0.4MPa	Weld	47、57、78	47	61	
	HAZ	71、155、67	67	98	

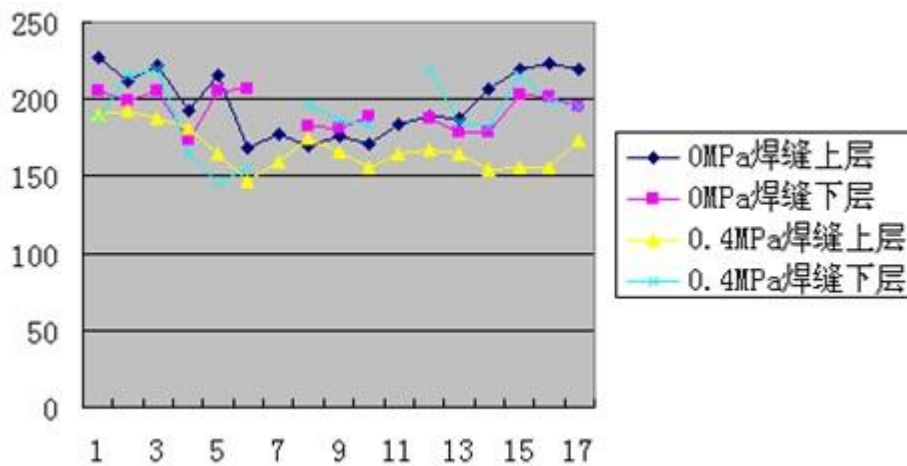


Fig. 11 HV10 hardness test data of welded joints

Imperfections were not found in macro metallographic examination by magnifier macroscopic; guided bend test was qualified as well. The test results demonstrate that all the index sign meet the requirements of the standard. Qualified welding joints are able to obtained according to this specification in underwater high pressure dry GMAW welding.

Conclusions

- (1) Blasting test at air pressure demonstrate that there is no phenomena of flame burning or exploding in the pressure chamber by remodeling of hyperbaric chamber and effective protection to special parts.
- (2) In order to obtain stable welding process, the increase of output voltage of power source is necessary. With respect to wire extension, lower limit at ordinary pressure is advisable, shielding gas flow should be more than 15L/min. Compared to unitary mode, CMT is the first choice for high pressure welding method at different environment pressure, which welding process is relatively stable.
- (3) According to AWS D3.6, welding processes and techniques were carried out, and the results meet the requirements of standard through mechanics test.
- (4) The research result of this paper opens up a new way to underwater welding in pipeline repairing. With the development of offshore oil engineering and related technology, the technology

is sure to have a good application prospect.

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