Influence of water environment on wet underwater manual self-propagating high-temperature synthesis welding

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Abstract. Manual SHS welding is a kind of quick welding technique for emergency maintenance. In this paper, influence of water environment on the welding quality and performance has been studied. Results showed that water had significant influence on the welding. The visibility for welding was significantly reduced, which increased the difficulty of welding operation. The brightness of weld pool in wet welding were darker than that in land welding and the shape of combusting arc was compressed significantly. The highest temperature of weld pool in underwater welding was obviously lower than that in land welding, and the cooling rate of HAZ was faster. The welding quality was worsen remarkably by water. The weld seam was irregular and discontinuous, and a lot of gas pores and inclusions existed in the weld metal. And the amount of deposited metal was obviously reduced. Microstructure analysis showed that the matrix of weld metal was α-Cu solid solution, with Fe-rich second phase distributing orderly on it, which was same as that of land welding. But water caused many apparent inclusions and pores in the weld metal. The tensile strength of weld joints for underwater welding was obviously lower than that of weld joints for land welding.

1. Introduction

Underwater welding is a key technology for building and installing of offshore structures, and it is also an important method for emergency maintenance of warships in battlefield and other civil ships on sailing[1]. According to the welding environment, underwater welding can be divided into three types, which are dry welding, local dry welding and wet welding[2]. In wet underwater welding, the weldments were welded directly in the water without any protection. Wet underwater welding has the advantages of simple equipment, low cost, flexible operation, and so on. It has been widely used in ocean facilities maintenance and submarine pipeline repair, and has a good development prospect. At present, manual arc welding and flux cored wire arc welding are usually used in wet welding[3]. But both of the two welding methods need high-power power supply and heavy equipment, and their operation processes are strict, which restricted the mobility of the welding. Therefore, underwater manual arc welding and flux cored wire arc welding can not meet the needs of battlefield emergency repair and advanced wet welding technology should be developed.

Manual SHS welding is a kind of new method of quick welding[4]. It is based on self-propagating high-temperature synthesis theory (ab.SHIS) and manual arc welding technique[5-6]. By this method, the damaged metal components can be welded quickly and reliably on the condition of no electricity, no
gas and no equipments. The manual SHS welding technique is an ideal method for emergency maintenance in battlefield and outside field. In this paper, wet underwater manual SHS welding experiments would be carried out, and the effects of water environment on the welding quality and performance would be studied.

2. Experiment

Manual SHS welding experiments were conducted on land and in water with the same combustion rod. The combustion rods were prepared as followed. The welding flux powders, including high heat thermit, alloying additives, slagging agent and other additives, were mixed homogeneously in the three dimensional mixer and baked at 200°C for 2 hours. Then the mixture was pressure molded into a Ф15 mm×160 mm paper shell with waterproof coating. At last, the plug for ignition should be fixed on the end of the rod.

Q235 steel plates without groove were welded in the manual SHS welding experiments, which chemical composition was shown in table 1. The two pieces of test plate were docked no space, and the rust and oil stain on the plates were not cleaned up. The size of the tested plates was 70 mm × 35 mm × 5 mm. The plates welded in water were compared with that welded on land.

| Chemical composition of welded plate (wt.%) |
|-------------------------------------------|
| C  | Si | Mn  | P  | S  | Cr | Ni |
| 0.12-0.2 | <0.3 | 0.3-0.8 | <0.045 | <0.05 | 0.3 | 0.3 |

The tested plates were welded with manual SHS welding process on land and in water, the combustion of the rod and welding qualities would be compared. In underwater welding, the immersion depth was kept in 300mm. The process parameters for manual SHS welding were as followed: the welding velocity was 5mm/s, the length of combustion arc was 10mm and the welding slope was 85°.

The course of the combustion and welding, the fluidity of liquid slag, the separation of slag from the metal pool have been observed. The temperatures of combustion arc and the weld pool were measured by handle held infrared thermometer of Raytek 3i1ML3 style. The temperature change of heat affected zone was tested with K-style thermocouple and Multi-channel data acquisition system. The microstructure of the welded joints was observed by metallurgical microscope and Hitachi S-4800 scanning electron microscope. The mechanical properties were tested by DNS100 tensile testing machine and HV-1000DT micro hardness tester.

3. Results and discussion

3.1. Influence of water on combustion and welding course

Welding experiments showed that SHS reaction could self maintain in water and the combustion rod could combust and release heat in water, as shown in Fig.1(a). Thus the combustion rod could provide heat for welding and wet underwater manual SHS welding was feasible. But severe effects were caused on the combustion and welding. The combusting status of combustion rod in water and on land were shown in Fig.1 (a) and (b) respectively. The influence of water on the combustion and welding were mainly reflected in the following two aspects.
Firstly, the visibility for welding was significantly reduced by the water, and it was almost blind welding during wet manual SHS welding. The rod combusted directly in water and the water surrounding the combusting arc was vaporized and many gas bubbles were generated around the weld pool and arc. Furthermore, the powders of the combustion rod and the soot produced in the reaction dispersed in the water, which lowered the welding visibility further. The weld pool and weld bead could not be observed clearly during welding, which significantly increased the difficulty of welding operation.

Secondly, the brightness of weld pool and combusting arc in wet welding were darker than that in land welding, which could be shown by comparing Fig.1 (a) with (b). This appearance indicated that combustion temperature of wet welding was much lower than that of welding on land. It was also shown that the shape of combusting arc changed a lot. It was compressed significantly in water.

3.2. Influence of water on welding temperature

The highest temperatures of weld pool in wet underwater welding and land welding were shown in Fig.2. It was shown that the highest temperature of weld pool in wet underwater welding was obviously lower than that in welding on land.

It was thought that the high thermal conductivity of water was the main reason for the lowering of the temperature of the combustion arc and the molten pool. The thermal conductivity of water was more than 20 times that of air. The heat generated by the SHS reaction scattered and lost rapidly during wet underwater welding, so the heat rest for welding reduced significantly and the highest temperature the combustion arc and weld pool could reach became lower.

3.3. Influence of water on cooling rate of heat affected zone

![Fig.2 The highest temperatures of weld pool in different environments](image)
The cooling rates of HAZ in different environments were calculated, as shown in table 2. It could be seen that the cooling rate of HAZ in wet welding was much faster than that in land welding, especially during high-temperature range. The average cooling rate was higher than 65°C/s when the temperature was above 500°C. The fast cooling was also caused by the high thermal conductivity of the water. At the same temperature, the thermal conductivity of the water was much higher than that of the gas, so heat lost fast into water and the temperature of HAZ and weld pool dropped soon. At high temperatures, the bigger temperature difference between the weld pool and the environment caused the faster cooling rate.

| Temperature range (°C) | 1100~800 | 800~500 | 500~200 |
|------------------------|----------|---------|---------|
| Land welding           | 75.3     | 65.7    | 41.2    |
| Underwater welding     | 59.6     | 48.1    | 23.6    |

3.4. Influence of water on the welding quality

Photographs of tested plates welded in different environments were shown in Fig.3. From Fig.3(a) it can be shown that the appearance of weld joint in land welding was well, the weld seam was smooth and well-distributed and there were no obvious weld defect in it. The tested plate was one side welded with back formation. From Fig.3(b) it was shown that the appearance of weld joint in wet underwater welding was undesirable, the weld seam was irregular and discontinuous, and there were many gas pores and inclusions in the weld metal. In addition, the amount of deposited metal by underwater welding was obviously less than that by land welding. It could be seen that the quality of underwater welding was obviously more undesirable than that of land welding.

![3.4. Influence of water on the welding quality](image)

First, the poor visibility was an important reason causing the poor quality for underwater wet welding. Welders could not observe the weld pool clearly. Welding was operated only by the feel of the operator. Secondly, the less heat for welding and fast cooling rate caused by the high thermal conductivity was another important reason. The highest temperature the weld pool could reach was low and the cooling rate was high, so the weld pool would cool and solidify fast. The nonmetallic phase and gas generated from the reaction could not precipitate from the molten metal, slag inclusion and gas pore produced.

3.5. Influence of water on the microstructure and performance of the weld joint

3.5.1. The microstructure

The micro morphologies of the weld metal in different environments was shown in Fig.4. For the weld joints welded by land welding, the matrix of weld metal was α-Cu solid solution with Fe-rich second phase distributing orderly on it. The second phase crystallized along the cooling direction of the pool. There were no apparent inclusions and pores in the weld metal. From Fig.4(b) it could be seen that there was no obvious change for the microstructure of the weld metal welded underwater, which matrix was α-Cu solid solution still, with Fe-rich second phase distributing orderly on it. But there were apparent inclusions and pores in the weld metal, which was due to the low temperature and fast cooling rate of weld pool in water. The weld defects would reduce the working area of weld metal and cause stress concentration, and would lower the mechanical properties of welded joints.
3.5.2. The tensile-strength

Tensile strength has been tested for samples welded in different environments. The tested samples were all fractured at the fusion zone, which indicated the fusion zone was the weakest zone of the weld joint. The tensile strength of welded samples in different environments was shown in Fig.5. Because of the defects in the weld metal, the tensile strength of weld joints for underwater welding was obviously lower than that of weld joints for land welding.

3.5.3. The micro hardness

Micro hardness has been tested for samples welded in different environments, as shown in Fig.6. It was shown that water resulted in the raise of the micro hardness of weld seam and fusion zone. It was thought that quenched structures generated during the fast cooling course of weld pool in wet welding, which hardened the weld metal. The highest hardness occurred in fusion zone for, indicating that the composition and microstructure were complicated in fusion zone, and it was the weakest zone of the weld joint.

4. Conclusions

(1) The combustion rod could combust in water and wet underwater manual SHS welding was feasible. The visibility for welding was significantly reduced, and the brightness of weld pool in wet welding were darker than that in land welding.

(2) The highest temperature of weld pool in wet underwater welding was obviously lower than that in land welding, and the cooling rate of HAZ was faster.

(3) The welding quality was worsen remarkably by water. The weld seam was irregular and discontinuous, and many gas pores and inclusions existed in the weld metal.
(4) The matrix of weld metal for underwater welding was α-Cu solid solution, with Fe-rich second phase distributing orderly on it, which was same as that of land welding. But the amount of inclusions and pores in the weld metal increased.

(5) The tensile strength of weld joints for underwater welding was obviously lower than that of weld joints for land welding.

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