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Heat input and metal transfer influences on the weld geometry and microstructure during underwater wet FCAW

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ABSTRACT

FCAW experiments were conducted under water and in the air. Influences of surrounding water on the weld geometry and weld metal microstructure were investigated through analyzing the heat input and metal transfer. The underwater welds have a lower proportion of acicular ferrite and pro-eutectoid ferrite. Two metal transfer modes in wet FCAW were observed, i.e. repelled globular transfer and surface tension based quasi-short-circuit transfer. The former one is the main cause of asymmetric and less uniform weld appearance.

1. Introduction

Characterized by low cost, good adaptability, simple equipment, the underwater wet welding has been widely applied. Particularly, the underwater wet flux-cored arc welding (FCAW) has been developed for automatic and semi-automatic welding processes in deep water. It has a great potential to be applied to repair or even to construct oceanographic structures.

Liu et al. (1993) mentioned that the harsh underwater environment has significant effect on the welding process, which dramatically alters the cooling rate during welding and further affects the nature of the weld-metal phase transformation. The behavior of the welding arc, metal transfer and weld pool is seriously influenced by the special environment which results in completely different metallurgical process with weld geometry and micro-structure changes. Consequently the weld joint quality and mechanical properties might be lowered.

Tsai and Masubuchi (1979) investigated the bubbles dynamics, arc heat distribution, and heat input mechanism. They concluded that a fast cooling of the weld zone during underwater welding was the result of surface heat losses in weld area behind the arc. Liu et al. (1993) found that the much lower cooling time $t_{8/5}$ (from 800 °C to 500 °C) during underwater wet shielded metal arc welding (SMAW) resulted in significant amount of heat affected zone (HAZ) martensite in nearly all low carbon steels. Wang and Yang (1997) studied the underwater welding arc plasma by means of spectral diagnostics. They concluded that the temperature of underwater arc plasma was lower than in air and the difference was bigger for deeper water. Shi and Zheng (2013) studied the influence of welding parameters on weld bead geometry in wet FCAW. They concluded that comparing with travel speed and arc voltage, welding current was less sensitive to the geometries of the bead. Jia et al. (2013) observed that the width of the underwater weld was about two-thirds in air, presuming that the arc plasma was compressed by the water environment even in shallow water.

Gao et al. (2015b) observed more pro-eutectoid ferrite in the weld metal during wet shielded metal arc welding. They assumed that this phenomenon is due to the loss of alloying elements under water deeper than 11 m. Perez et al. (2003) presented evidence of toughness improvements on wet welds by adding nickel to the coating of rutile type electrodes. Al-Abbas et al. (2011) revealed that the wet weld columnar grains were finer than those found in the dry welds at low welding current but with different columnar grain morphology, whereas were coarser at high welding current with similar columnar grain morphology. Guo et al. (2015b) concluded that the addition of Ni can be helpful for suppressing the formation of the coarse strip pro-eutectoid ferrite (PF) in the columnar grain zone of the weld metal. Di et al. (2015) simulated the local dry underwater welding process. They concluded that as the cooling rate increased, the volume fraction of proeutectoid ferrite

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and ferrite side plate decreased, acicular ferrite increased accompanied with refined grain. Their findings suggested that rapid cooling rate can improve the impact toughness and tensile strength of weld metal in local dry underwater welding. Gao et al. (2015a) obtained martensitic dominated coarse grain heat affected zone in wet shielded metal-arc welding. They improved the fatigue property by the combination of grinding and underwater ultrasonic impact treatment. Garašić et al. (2009) carried out research to determine optimum parameters that minimize the generation of cold cracks in wet SMAW and self-shielding FCAW at three levels of heat input. They concluded that FCAW provided better conditions for reducing the risk of cold cracks' occurrence.

Zhang et al. (2004) observed that direct wet underwater laser welding produced a kind of plasma with strong ultraviolet emission and obtained smaller penetration when the water depth is less than 3 millimeters. Cui et al. (2014) conducted friction taper plug welding experiments in wet conditions. They found a large volume of lath bainite, small amounts of acicular ferrite, polygonal ferrite, martensite in HAZ and the lower region of the weld metal. Meanwhile, they observed mainly lath martensite in the upper weld metal region.Yin et al. (2015) investigated the material flow influence on the weld formation and mechanical performance in underwater friction taper plug welds. They indicated that the microstructure of both weld zone and HAZ mainly consists of lath bainite which results in an overmatching condition (i.e. specimen breaks in the base material far away from the plug area and HAZ during tensile testing) through the weld.

However, only few of the studies mentioned above analyzed the physics of FCAW welding process in underwater environment, especially metal transfer and arc behaviors. This partly owing to the difficulty to acquire visual images as evidence. Guo et al. (2015a) acquired clear images of droplets' transfer via X-ray photographing. They (Guo et al., 2016) also analyzed the effect of boric acid concentration on the arc stability but the bubbles and welding arc could hardly be recognized from the images they provided. Actually, the generation and burst of bubbles are significant factors to determine the welding arc stability and metal transfer. Jia et al. (2014) obtained clear images of droplets and welding arc during underwater FCAW. They found a typical repelled globular droplet transfer mode and a wandering compressed welding arc behavior.

Thus, an imaging system was developed to acquire the images of bubbles, arc and droplets at the same time (Fig. 1). This paper is aimed at exploring the influence of surrounding water on the weld geometry and weld metal microstructure of wet FCAW through analyzing the heat input and metal transfer.

Table 1
Chemical composition of Q235 carbon steel mass%.

C	Mn	Si	P	S	Fe
0.17	0.35–0.65	0.28	0.038	0.038	Balance

Table 2
Experimental parameters.

Parameters	Air 1	Water 1	Air 2	Water 2
Arc voltage (V)	30	30	31	31
Wire feed speed (cm/s)	6.32	6.32	6.32	6.32
Travel speed (mm/min)	240	240	240	240
Surrounding	Air	Water	Air	Water

2. Experimental method

Experiments were conducted under water (fresh water, 0.4 m depth) and in the air with the same parameters. The welding voltage was set constant and the current varied according to the arc length. Four sets of bead-on-plate experiments were conducted in direct current electrode positive (DCEP) mode. The travel speed and the wire feed speed were maintained fixed. The base material is Q235 mild steel with the dimensions of 300 mm × 100 mm × 8 mm. Its composition is listed in Table 1.

The imaging system (Fig. 1) was developed based on a high speed camera (Optronis CamRecord 5000 × 2) with frequency 2000 fps and resolution 512 × 512. Visual and electrical signals were collected simultaneously. During welding, the torch was kept stationary, and the test piece was controlled to move uniformly and straightly. Through the transparent glasses a high speed camera could sense the welding process perpendicularly to the welding direction. The welding power source was LET 500. A rutile type flux-cored wire made by E. O. Paton Electric Welding Institute specially for underwater wet welding was used. Other experimental parameters were shown in Table 2. Air 1 and Water 1 were set as group A, while Air 2 and Water 2 as group B.

The cross-sections of weld beads were submitted to standard mechanical grinding, polishing and corrosion procedures. Bead

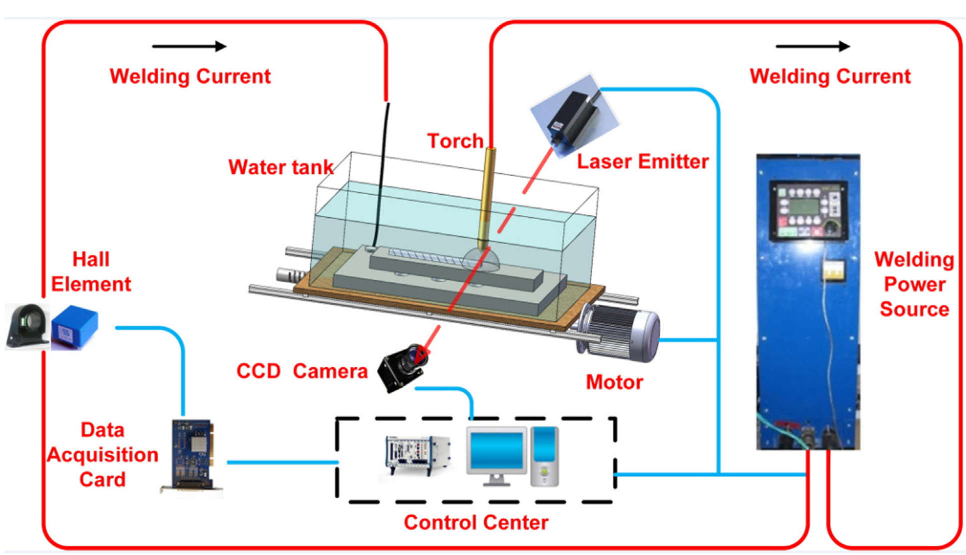

Fig. 1. Schematic of underwater wet flux-cored arc welding imaging system.