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Spectroscopic analysis of the arc plasma of underwater wet flux-cored arc welding

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ABSTRACT

Experiments in air and under water (0.4 m depth) were conducted and the spectrum signals collected. The width of the weld under water was about two-thirds of the width in air, suggesting that the arc plasma was compressed by the water environment. The two sets of spectrum signals were largely similar except for the ultraviolet spectrum, from where the environmental effects were inferred. The analysis identified a unique peak at 656.2793 nm in the underwater spectrum, consistent with H atomic transitions, suggesting that H atoms become involved, although without affecting the overall spectral similarity of the two environments. In either environment the arc plasma was mainly composed of self-shielding gas and evaporated metals, with only minor effects stemming from the interaction with water.

1. Introduction

The underwater welding technology has been widely applied in many industries like marine construction, nuclear power plants, marine salvage, undersea oil–gas exploration, etc. It can be put into three categories: dry, local dry and wet underwater welding. It was acknowledged by Paton (1997), Shi et al. (2007) and Yushchenko et al. (1997) that the wet underwater welding especially the wet self-shielded flux-cored arc welding (FCAW) is promising in the future. The wet underwater welding costs much lower than the other two methods because extra engineering vessels, complicated chamber and shielding gas are unnecessary. Richardson et al. (2002) thought that the underwater FCAW has much higher production efficiency than the underwater manual metal arc welding and can be applied in the automatic welding process for deep water.

Because of the special operating environment, the atmosphere of underwater arc is much different from the traditional FCAW. This significantly influences the arc behavior, metal transfer, welding metallurgy and mechanical properties. Fig. 1 shows the arc and bubbles in the underwater wet FCAW. The welding arc is burning in the continuously changing bubbles. Because the bubbles are always irregular globular with rippled walls, the shape of the arc is blurred and rarely observed. Research by Liu et al. (2000) proved that many weld fumes, light absorption, refraction and reflection seriously influenced the image acquisition of welding arc, metal transfer and weld pool. Traditional research approach like high speed camera is difficult to apply to the arc physics investigation. Therefore, the electrical signals have been usually used to investigate the welding arc behavior and metal transfer, and some important information was obtained by Pokhodnja et al. (1990). However, the information obtained from the electrical signals are not adequate for investigating the essence of the arc plasma. The arc physics of the underwater FCAW is still not clear. Limited reports about the arc plasma composition and characteristics during underwater wet FCAW have been published.

The spectroscopic analysis is effective for analyzing the composition, temperature and many other features. The arc plasma spectrum has been employed in many arc welding technologies in air, such as studying the metal vapors in gas tungsten arcs by Dunn et al. (1986), measurement of oscillations in partially penetrated weld pools by Sorensen and Eagar (1990), analyzing the temperature field of TIG, MIG and MAG by Jiang et al. (2001), improving image quality of weld pool visual sensing by Yan et al. (2005), measuring and control of the composition and intensity of gases by Song (1990), measuring and control of TIG arc by Li and Zhang (2001), control of metal transfer in MIG by Yang et al. (2003) and MIG welding quality diagnose by Li et al. (2009a). Some important spectroscopic research results of underwater arc welding have been obtained. Wang and Yang (1997) studied the temperature of underwater welding arc with spectroscopic method. Pan et al. (1997)

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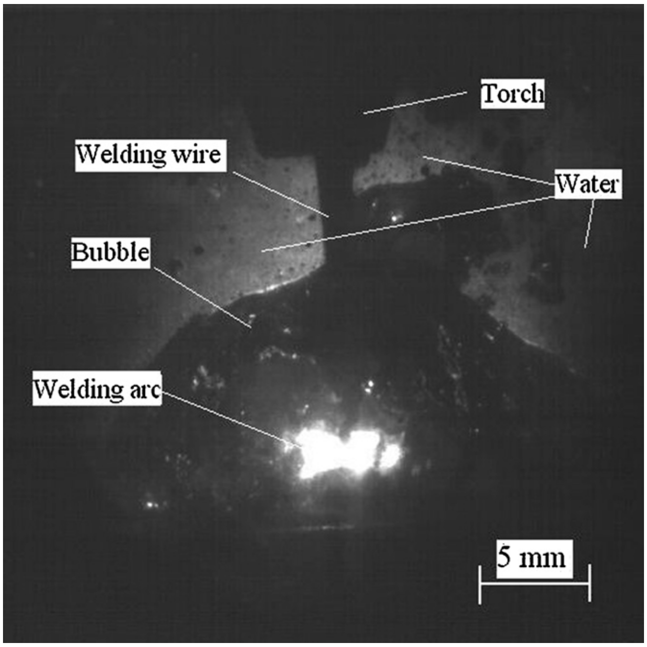

Fig. 1. Arc and bubbles during underwater wet FCAW.

proved that underwater plasma arc is in local thermodynamic equilibrium (LTE) under certain conditions and the spectroscopic studies are reliable. Li et al. (2009b) calculated the underwater arc components at different water pressures and temperatures under the local thermodynamics equilibrium state based on the potapov model.

The arc of wet FCAW is considered as a low-temperature plasma, which emits strong radiation containing much spectrum information. Li et al. (2004) introduced the basic theory and method of welding arc spectrum investigation. Researchers studied the composition, temperature, pressure, etc. of the traditional FCAW in air, and the temperature of the underwater arc was analyzed and measured through the spectrum from the arc plasma. The mechanism of the influences of the water environment on the arc plasma is still unknown. As far as in underwater wet FCAW research field, only a few reports about spectrum radiation have been published.

In this present study, the arc plasma of FCAW in air and under water were measured and analyzed using the spectrum radiation. The distribution, amplitude and other characteristics of the two sets of spectrum curves were compared to investigate their similarities and differences. Results of peak-seeking and identification of the spectrum curves showed the differences of the composition of arc plasma in air and under water, and important characteristics of the arc plasma of underwater FCAW were revealed.

2. Experimental

2.1. Arc plasma radiation theory

According to the book by Xin (2011), the welding arc is a high-temperature ionized gas, in which the charged particles collide frequently due to the thermal motion. The complex interactions between the particles such as ionization, recombination, etc. are followed by the strong spectrum radiation. Besides, the radiation can be detected from the high temperature molten metal including the droplet and weld pool.

According to different mechanism, the radiation is classified as exciting transition, recombination transition, breaking transition, blackbody radiation, etc. And according to different shapes, the spectrum radiation is classified as continuous spectrum and line spectrum. The spectrum curves from the arc welding are superposition of many kinds of spectrum radiation.

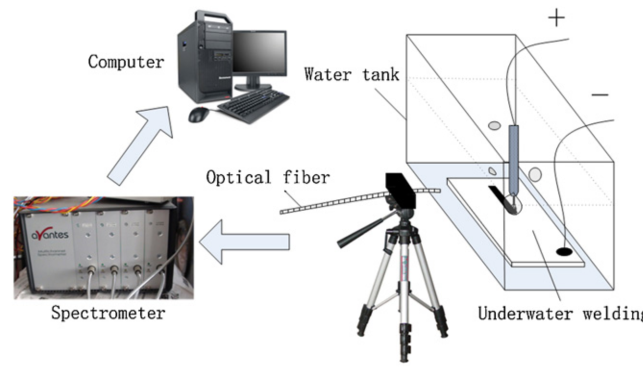

Fig. 2. Schematic of spectrum signals acquisition of underwater wet FCAW. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

The exciting radiation is a line spectrum, which is produced by the transition of the excited atoms and ions from higher energy levels to lower levels. There are various elements in different energy levels in the welding arc, so many different characteristic spectra may be detected. It can be used for studying and calculating the composition and temperature of the arc plasma. The braking radiation is a continuous spectrum. It is generated by the accelerating and braking of collision electrons and ions in the coulomb field, and the electrons are free before collision and after collision. The recombination radiation is generated by the collision and recombination of electrons and ions. The electrons get into a bound state from the free state followed by continuous spectrum after the collision. The blackbody radiation is mainly from the quasi black body including droplets, weld pool and high temperature solid metal. It is a continuous spectrum and its distribution obeys the Planck's law of radiation.

The various types of spectrum radiation from the welding arc contains different information. The line spectrum radiation is high correlative to the composition of the welding arc plasma. According to the spectrography and plasma physics, characteristic spectrum lines with certain wavelength and intensity will be generated by the transition of some particles (atoms, molecules or ions) from high energy levels to low energy levels if the welding arc is in local thermodynamic equilibrium (LTE) and optically thin (self-absorption ignored).

Based on the theory mentioned above, the composition of the arc plasma can be analyzed qualitatively through the spectrum signals analysis including relative intensity, peak-seeking, identification, etc.

2.2. Spectrum measuring

A four channel fiber digital spectrometer made by Avantes in Netherlands was employed to measure the spectrum signals. The spectrum ranges and resolution of the four channels were as follows: channel 1 (200–370 nm, 0.12–0.15 nm), channel 2 (369–515 nm, 0.1–0.13 nm), channel 3 (514–638 nm, 0.09–0.11 nm), channel 4 (636–840 nm, 0.15–0.2 nm). As shown in Fig. 2, a water tank in 0.5 m depth was designed with colorless transparent glasses to reduce the dissipation and attenuation of the weld arc radiation. During welding experiments the welding torch was kept stationary, and the water tank and the workpiece moved along the direction vertical to fiber. Therefore, the distance between the fiber optic probe and the welding arc was kept constant. A computer was used to control the spectrometer to collect and save the spectrum data.