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Effect of shielding conditions of local dry cavity on weld quality in underwater Nd:YAG laser welding

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Abstract

During underwater laser beam welding (LBW), the welding quality is severely influenced by the shielding condition of the local dry cavity. In this paper, the stability of the local dry cavity and the effect of shielding condition on the weld quality during laser welding of Type 304 stainless steel were investigated.

Firstly, welding experiments under various water depths without any way to exclude water from the welding zone were performed. It was found that one kind of laser-induced plasma having strong shielding effect to the incident laser beam forms when the laser irradiates the water directly if the water depth is larger than 3 mm. This shielding effect will lead to the impossibility of deep penetration welding in water. So in the welding, a water curtain nozzle was used to form a local dry cavity. The effect of the shielding conditions, e.g. water flow rate, gas flow rate and water flow angle, on the stability of the local dry cavity was studied. The welding results under various shielding conditions show the relationship between the shielding condition and the quality of the weld bead.

Keywords: Nd:YAG laser; Underwater welding; Local dry cavity; Water curtain; Weld quality

1. Introduction

Underwater welding is one important repairing and maintenance technology for the structures and facilities used in offshore and sub-sea, and it is also widely used for repair of components and structures damage caused by fatigue and mishandling in nuclear power plants [1–3]. In recent years, underwater laser beam welding (LBW) technology is being investigated to meet the repair of defect or damage induced by irradiation for reactor internals [4–6]. Comparing with the other underwater welding methods, underwater Nd:YAG laser welding has remarkably low heat input and high cooling rate, and a small heat affected zone (HAZ) and lower residual stress are of importance to the structures used in nuclear plant [6]. In addition, Nd:YAG laser beam can be easily transmitted to the position to be welded by using optical fiber, which is very easy for control and flexible to precision repair welding.

In general, two problems should be considered for the assurance of welding quality in underwater LBW, one being the effect of water on the metallurgical behavior of weld metal which is dependent on the materials to be welded [7], the other being the absorption of water to laser beam. It was ideal if the laser beam could be transmitted through water with little attenuation; in that case underwater LBW became easy and low cost. It was measured that the absorptivity of water to 1.06 μm wavelength light is $0.014\,\mathrm{mm}^{-1}$ [8], on which the calculated transmission efficiency as a function of water depth is shown in Fig. 1 based on the following formula:

$$T(z) = 1 - \mathrm{e}^{-\alpha z}$$

where $T(z)$ is the transmission efficiency at water depth z (%), α the absorptivity of water to laser beam and z is the water depth (mm).

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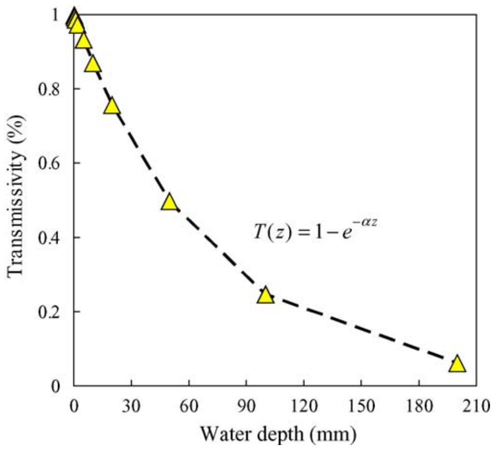


Fig. 1. Transmissivity of water to Nd:YAG laser beam as a function of water depth.

Considering the common distance between welding nozzle to workpiece is usually several millimeters and some kind of gas would be used to protect weld pool in laser welding, it seems that direct underwater welding is possible because even the water depth is 30 mm, about 75% of the incident laser intensity could be transmitted. In fact, however, the interaction of water and laser beam is rather complex and the water may be vaporized or even ionized by high power intensity laser beam, so it is necessary to study the effect of water on the laser beam and the welding quality. In the following contents, experiments of direct underwater deep penetration welding are performed firstly. The effect of water depth on the weld bead shape is studied.

In the case that the water around the welding zone must be excluded, local dry cavity is considered as one of the methods. For traditional underwater arc welding, in spite of using a chamber named as underwater dry welding method, underwater wet welding with a local dry cavity formed by water curtain or wire brush has been developed. Water curtain method is believed to be easy for control and adjustment, flexible for various joint comparing with the wire–brush method [9,11]. As shown in Fig. 2, when the water flows out from the nozzle in a certain angle and flow speed, a water curtain could be formed. At the same time the coaxial gas exclude the water out from the cavity shielded by water curtain. Under appropriate shielding conditions, the shielding gas only escapes from the bottom of the water curtain in small bubbles and a stable dry zone surrounding the weld pool can be kept. Only using shielding gas to exclude the water out from the welding zone is also possible, and the experiment of underwater Nd:YAG LBW with a normal welding nozzle, namely a local dry cavity is formed by the coaxial gas has been tried [10].

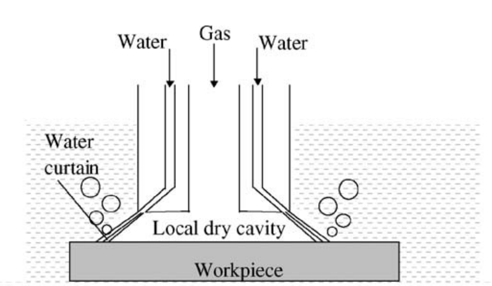


Fig. 2. Diagram of local dry cavity formed by water curtain.

However, gas-shielding nozzle is not so stable as water curtain nozzle because the gas bubbles may grow to bigger size before escape from the nozzle, and in this case the size and inner pressure of the local dry cavity will oscillate more severe. In this paper, water curtain shielding method was chosen because the local dry cavity formed by water curtain is more stable than that of gas nozzle. The relationship between shielding conditions of local dry cavity and the weld quality was discussed.

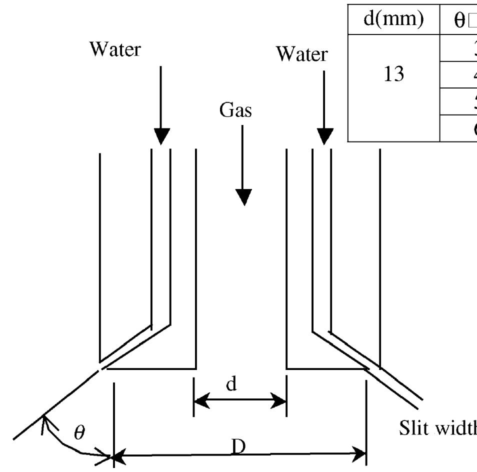
2. Experimental procedures

2.1. Laser welding system

A HL4006D laser was used to perform welding experiments. The output power (the actual laser power arrival to the workpiece surface) can be continuously adjusted from 40 to 4000 W, and the beam parameter product is 30 mm mrad. The core diameter of fiber is 0.6 mm. The lens is 100 mm in focal length and 40 mm in diameter. The diameter of the focal spot is 0.3 mm. The welding process was realized by using an Almega 6-axial robot.

A water tank was set up for underwater welding. To form a local dry cavity around the welding zone, a water curtain nozzle whose structure and sizes are shown in Fig. 3 was developed. Considering the effects of water flow angle and curtain thickness, four kinds of water flow angles were designed (30°, 40°, 50° and 60°). The thickness of the water curtain was varied by adjusting the slit width of the exit.

For observation of shielding status of the localized dry cavity, a digital CCD camera was used to observe the condi-



d(mm)	θ	D(mm)
13	30	32
	40	35
	50	40
	60	45

Fig. 3. Structure and size of water curtain nozzle used in underwater laser welding.