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A study of narrow gap laser welding for thick plates using the multi-layer and multi-pass method

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ABSTRACT

This paper details a new method that combines laser autogenous welding, laser wire filling welding and hybrid laser-GMAW welding to weld 30 mm thick plate using a multi-layer, multi-pass process. A "Y" shaped groove was used to create the joint. Research was also performed to optimize the groove size and the processing parameters. Laser autogenous welding is first used to create the backing weld. The lower, narrowest part of the groove is then welded using laser wire filling welding. Finally, the upper part of the groove is welded using laser-GMAW hybrid welding. Additionally, the wire feeding and droplet transfer behaviors are observed by high speed photography. The two main conclusions from this work are: the wire is often biased towards the side walls, resulting in a lack of fusion at the joint and the creation of other defects for larger groove sizes. Additionally, this results in the droplet transfer behavior becoming unstable, leading to a poor weld appearance for smaller groove sizes.

1. Introduction

Thick plate welding technology is very important to the shipbuilding, pipeline, nuclear, and submarine manufacturing fields. The equipment for these processes is quite large, and for plate thicknesses of 20 mm, workpieces only can be jointed piece by piece using traditional methods. However, many problems arise as a result of the large groove area that is necessary to join two pieces, such as the residual stress and residual deformation that results from the large restraints required and poor weld joint mechanical properties because of a lack of plasticity [1]. Presently, laser welding refers mainly to single-run autogenous operations in which the weld joint is formed by solidifying the base metal without the addition of any other material. This method has many disadvantages, including the precise fit-up requirements prior to welding and the limited weld range for a certain laser output power even if high efficiency lasers are used and small welding deformations are observed. After 40 years, the most popular two lasers, YAG and CO_2, are still the two primary lasers that are used to join most sheet, (< 5 mm), medium and heavy plate (5∼20 mm) thicknesses. Even for the most advanced fiber laser, the single-run penetration depth that can be achieved is less than 25 mm [2]. Katayama et al. [3] achieved deep-penetration weld beads to depths of 70 mm in Type 304 stainless steel using 10 kW and 16 kW high power disk lasers, a welding speed of 0.3 m/min and at pressures of 0.1 kPa. Unfortunately, the cost to control the atmosphere around the workpiece is unrealistic for industrial production of large and thick plates. Overall, the best method for thick plate (> 20 mm) welding is likely through the use of multi-pass non-autogenous welding.

Presently, few studies have been conducted on the use of laser non-autogenous welding technologies. Hybrid YAG-MIG welding processes have been used to successfully weld 8 mm thick aluminum alloy plate in two passes at the Huazhong University of Science and Technology [4]. The Beijing University of Technology [5] successfully laser welded a 20 mm thick aluminum alloy plate with a narrow gap using filler wire in six passes with a 3.5 kW CO_2 laser. The results from this project have not yet been reported. Wang Baiping [6] et al. reported welding 16 mm thick stainless steel plates using laser wire filling welding in three passes. Meanwhile, a number of foreign researchers have made contributions to this field. Osaka University welded 24.5 mm thick plate successfully using a 10 kW fiber laser, at a welding speed of 0.3 m/min [7]. Karhu Miikka [8] et al. reported welding thick AISI 316 L austenitic stainless steel using a 3 kW hybrid YAG laser-GMAW by employing multiple-layers and multiple passes. Hot cracking was observed in this weld. Hayashi, Tomotaka et al. [9] successfully welded a 22 mm thick steel plate with a square groove and a 4 mm gap using a high power CO2 laser-MIG hybrid welding technique [9]. Choi and Hae Woon [10] welded 15 mm thick A572 Gr50 steel with a 3.2 mm gap using a hybrid welding process in six passes. MHI has made a great deal of progress in this field with the help of a self-produced super-power (13.5 kW) YAG laser and a specially

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designed external ray, which permitted a 41 mm thick plate to be laser-GMAW hybrid welded in six passes [11].

In recent years, the Corus in England, the FORCE in Denmark, and the Fraunhofer ILT in Germany have performed research on thick plate hybrid laser arc welding to achieve penetration depths down to 30 mm. This work has been funded by the European Coal and Steel Research Foundation [12]. Although western researchers, especially Europeans, have already made many significant contributions to this field, thick plate laser non-autogenous welding has not been widely adopted for practical applications. The existing studies suffer from difficulties related to process control stability, technological adaptability, joint appearance and internal defects (lack of fusion and porosity). Therefore, the advantages of these three methods, laser autogenous welding, laser wire filling welding and laser-arc hybrid welding, are a good place to start to weld thick plate for practical applications and for different thicknesses and materials.

2. Experimental details.

2.1. Experimental materials and device.

The material used in this study was Q235 plate steel with dimensions of 150 mm x 75 mm x X mm (where X = 16, 18 and 30). A 1.2 mm diameter solid filler wire was used (H08Mn2SiA).

The values X = 16, 18, and 30 represent the groove total height for the laser wire filling welding, hybrid laser-GMAW welding and the new welding processes.

The chemical composition of the base metal and the filler wire are given in Tables 1 and 2.

The laser equipment consisted of an IPG Photonics 4 kW solid-state Yb-fiber laser system (YLR-4000) mounted to an ABB IRB4400 special welding robot. The optics consisted of a 250 mm focal length and a focal diameter of 300 μm. A Fronius MAG arc welding machine was used that consisted of a Fronius TPS4000 inverter power supply, a special push and pull wire feeder and a Fronius VR2000 MIG/MAG welding torch. A CMOS high speed camera (Photofocus, Switzerland) was used to observe the welding process at acquisition rates of up to 10000 frames per second. To suppress the light bloom associated with the welding process, several optical lenses were employed that matched the wavelength (808 nm) of the laser source. As shown in Figs. 1 and 2, the high speed camera optical lens combinations included band attenuators to lower the intensity of the light to protect the sensor, a narrow-band filter determined by the backlight conditions and an outer layer glass applied to prevent the inner optical lens from being damaged.

2.2. Experimental methods.

Prior to welding, the grooved surface was polished and cleaned with acetone. Every welding seam was initially rubbed with different types of sandpaper or ground with a grinding wheel, and cleaned by acetone. Laser autogenous welding was used first to form the backing weld. Pure Ar shielding gas was flowed into the groove bottom to protect the backing weld. A special shielding gas supply nozzle, capable of entering the narrow gap groove was designed for this purpose, as shown in Fig. 3

The parameters for the laser autogenous backing welding were: a laser power = 4 kW, a welding speed = 1.0 m/min, and a defocusing length = 0 mm.

Laser wire filling welding was used to fill the lower portion of the groove. The wire led at a distance of 0.35 mm ~ 0.65 mm and at an angle of 30° with respect to the surface. The defocusing length was kept at 0 mm and the same shielding gas nozzle was used.

Table 1
Elemental breakdown of Q235 steel.

element	C	Mn	Si	S	P	Cr	Ni	Cu
content/%	0.16	0.61	0.20	0.023	0.019	< 0.30	< 0.30	< 0.30

Table 2
Elemental breakdown of H08Mn2SiA.

element	C	Mn	Si	S	P
content/%	0.06 ~ 0.09	1.80 ~ 1.95	0.70 ~ 0.85	≤ 0.020	≤ 0.015

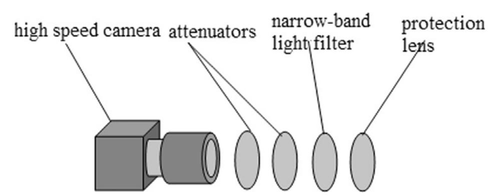

Fig. 1. High speed camera optical system diagram.

Fig. 2. Image of the high speed camera.

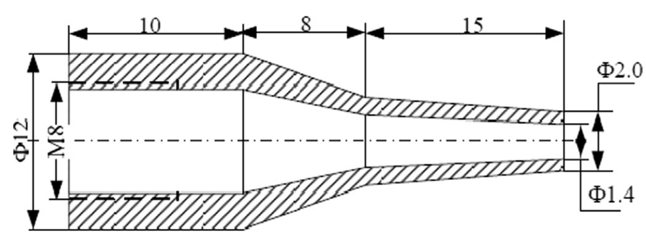

Fig. 3. Narrow gap air supply device.

Fig. 4 shows the "Y" shaped groove used. Two different angles (α = 10°/6°) were used to study how the groove size affects the wire feeding process and the weld shape during laser wire filling welding in a narrow gap.

According to previous experimental results, the most appropriate parameters for the welding process are a speed of 0.5 m/min and a wire diameter of 1.2 mm to fill the groove gap. The melt wire was employed to fill the groove gap entirely. The wire feeding speed is shown in eq. (1) and is determined based on the law of the conservation of mass:

$$V_F = \frac{V_W \times A_G}{A_F}, \quad (1)$$