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Thick section laser beam welding of shipbuilding steels: fiber and optical parameters optimization and gap bridgeability

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Abstract

Laser beam welding (LBW) is expanding the process efficiency and material thickness range, therefore, making the process possible for industrial applications dealing with thick section welding: shipbuilding, offshore structures, bridge building and other industries. One of the main limitations of the LBW, however, is strict requirement for narrow air gap between the steel plates in butt-joint configuration.
Welding of AH36 14 mm thick shipbuilding steel plates was performed with continuous wave IPG fiber laser at 5 kW power level. Effect of the optical fiber diameter (200 – 600 µm) and focal length (200, 300 mm) on the efficiency and bridgeability of LBW was experimentally investigated. It was concluded, that use of 600 µm optical fiber and 300 focal length provide an acceptable quality weld with the air gap of up to 0.45 mm.

Keywords: laser beam welding; low-alloyed steel; butt joint; air gap; optical fiber

1. Introduction

The use of laser welding is ever grooving in number of applications. Currently the fraction of laser welding of materials processing laser market is 16%. (Belforte, 2016) Welding has successfully defended its fraction of market for very long time and actually the growth of sales for welding was very high (17%) from 2014 to 2015. (Belforte, 2016). Majority of the welding work in industries is still carried out using GMAW (Gas Metal Arc Welding), however switching to laser or laser-arc hybrid welding (HLAW) would typically bring significant economic benefits. The driving force in laser welding applications has traditionally been car manufacturing, but recently a grooving number of applications are found from probably the most profitable application area of laser welding, the manufacturing of components for different machines etc. These applications often utilize quite thick materials from thickness range from 6 to 100 mm. Traditional welding of such an applications often set tight requirements for the product itself being typically designed more by the rules of welding than the end customer needs. The utilization of laser welding in these applications has suffered from reasoning like: not high enough number of products produced, expensive machinery compared to manual arc welding, too sensitive for joint preparation flaws. With constant decrease in laser prices, introduction of new more reliable lasers with better beam quality these reasons are outdated in future. Laser is in various applications cheaper production even if only cost of manufacturing is considered and overwhelming if real customer value gained is considered. The customer value can be gained e.g. by the fact that the workpieces are subjected to smaller heat input, which reduces distortions and the need for post welding operations and design against distortion (Reutzel et al., 2008). There is various approaches to enlarge the area of laser welding applications to various new areas typically welding of joints or materials that are poor in weldability with autogenous laser welding or with any welding method. The recent studies are concentrating e.g. for improving the process by controlling the plasma plume and improving the quality and welding performance (Zou et al., 2016). Laser welding has been shown to produce acceptable weld quality even for ultra-high strength steels like 22MnB5 PH and S1100 QL steels with special extra cooling

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system. (Gerhards et al., 2016). In welding of ultra-high-strenght steel S960 MC the fatigue resistance of GMA, laser-GMA hybrid, and laser welded S960 MC butt joints are close to the recommendations of IIW and from those the autogenous laser welding reached slightly higher characteristic FAT value compared to GMA and laser-GMA hybrid welded butt joints. (Siltanen et al., 2016) On the other hand effect of changes in focal point diameter has shown to enable good mechanical properties e.g. for ultra-high-strength S960 MC steel in low temperature (Salminen et al., 2016). For thick section the multipass welding is very promising when compared with single pass very deep penetration welding. There is results reported in which the laser power of 7.5- 8 kW has been used successfully to weld 30 mm thick ferritic steel with excellent weld quality (Feng et al., 2016). This techniques shows also opportunities in changing between processes of single and multipass welding even with higher strength steels in mid-thickness range like S960 and S700 steels, 8 mm and 13 mm in thickness respectively (Guo et al., 2016).

The problems of joint manufacture is often a problem for thicker sections laser welding or HLAW could be suitable for large number of serial production applications where throughput volumes are high. In HLAW, the beam and the arc act simultaneously, support each other and in comparison to laser welding produce improved gap bridgeability and in comparison to arc welding higher processing speeds, increased quality, less distortion and thus less re-work and shorter production times (Kristensen et al., 2009).

Autogenous welding is always the simplest way to use laser welding. It still suffers from the fact being very sensitive for joint manufacture. The air gap in joint is ruining the process. This study is concentrating on enlarging the area of laser welding applications by studying the effect of beam dimensions on the weldability of various air gaps.

2. Experimental procedure

The test material used in the welding experiments with a continuous wave fiber laser (IPG YLS 10000, wavelength: 1070 nm) was commercially available shipbuilding steel AH36 steel. Chemical composition and mechanical properties of the steel are given in Table 1. Plates of 14 mm thickness were cut into test pieces size 150 mm x 250 mm. The resulting approximate weld length was 200 mm. Argon shielding gas was delivered in the welding zone via copper tube at the rate of 20 l/min.

Table 1. Nominal alloying composition and mechanical properties of AH36.

Chemical composition, wt%				
C max	Si max	Mn max	P max	S max
0.18	0.1-0.5	0.9-1.6	0.035	0.035
Mechanical Properties				
Min Yield Strength, MPa		Min Tensile Strength, MPa		Min. Elongation, %
355		490		21

It is expected that wider beam formed by the thicker optical fiber will result in lower penetration depth. This may occur because the radiation will be spread on the larger area of the surface. However, the wide laser beam can be used when straightness or positioning errors cause air gaps between the welded parts. To verify the increase in bridgeability, two variants of the setup for laser welding were used: a butt joint and a butt joint with a pre-set air gap. The air gap in the latter case was created with use of carbon steel 1.1274 foil strips. Welding was performed at constant welding parameters.

The optical fiber core diameter and focusing lenses focal distances were varied: optical fiber with core diameter of 200 and 600 μm and welding head focusing lens focal distance of 200 and 300 mm were be used. Measured beam parameters are given in Table 2.

Table 2. Beam parameters.

Fiber diameter, μm	**Collimation length, mm**	**Focal length, mm**	**Beam radius, mm**	**M^2**	**BPP**
200	150	200	0.185	26.3	8.86
200	150	300	0.245	22.7	7.70
600	150	200	0.459	68.1	22.99
600	150	300	0.550	57.5	19.41

The quality of the welded samples was evaluated according to ISO 13919-1 standard: D – moderate; C – intermediate; B – stringent.

3. Results and discussion

Laser power (P_L), welding speed (V_W) and focal point position (fpp) were constant for all experiments based on previously obtained optimal parameter (Salminen et al., 2016) and are specified in the captions of the figures. Macrograph photos for each air-gap level are included in the separate appendix, each with a millimeter scale enclosed. The results for the first set of experiments for both the butt joint setup and the butt joint with a pre set air gap set up are shown in Fig. 1 and Fig. 2.

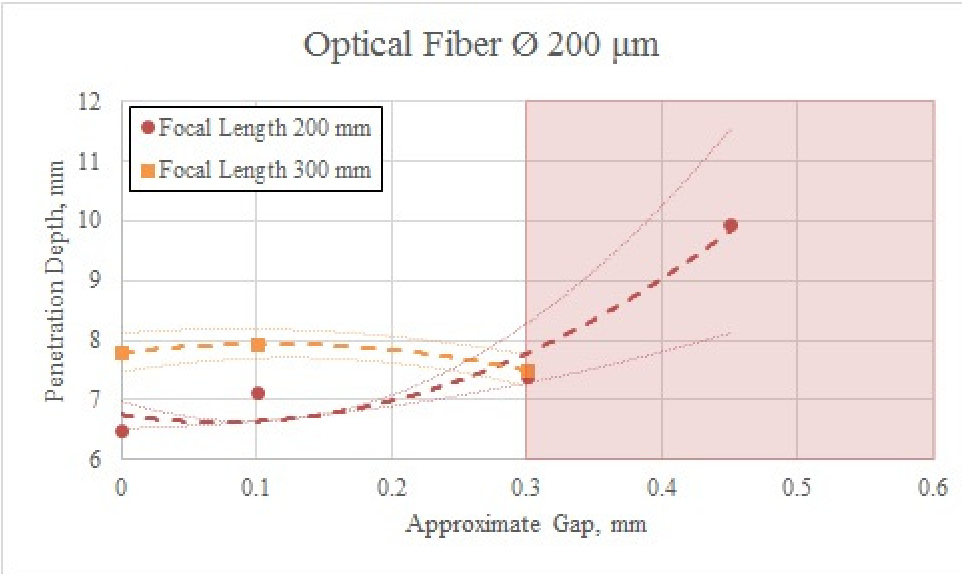

Fig. 1. Penetration depth of AH36 laser welds with optical fiber diameter 200 µm and welding heads of focal length of 200 and 300 mm with confidence intervals (0.95), zone of unacceptable quality is marked with red, t = 14 mm, P_L = 5 kW, V_W = 1 m/min, fpp = -4 mm.

As seen in Fig. 1, the use of 300 mm focusing lens focal distance provides a deeper penetration, however, with the use of both welding optics, the quality of the weld drops down with the air gap of more than 0.3 mm.

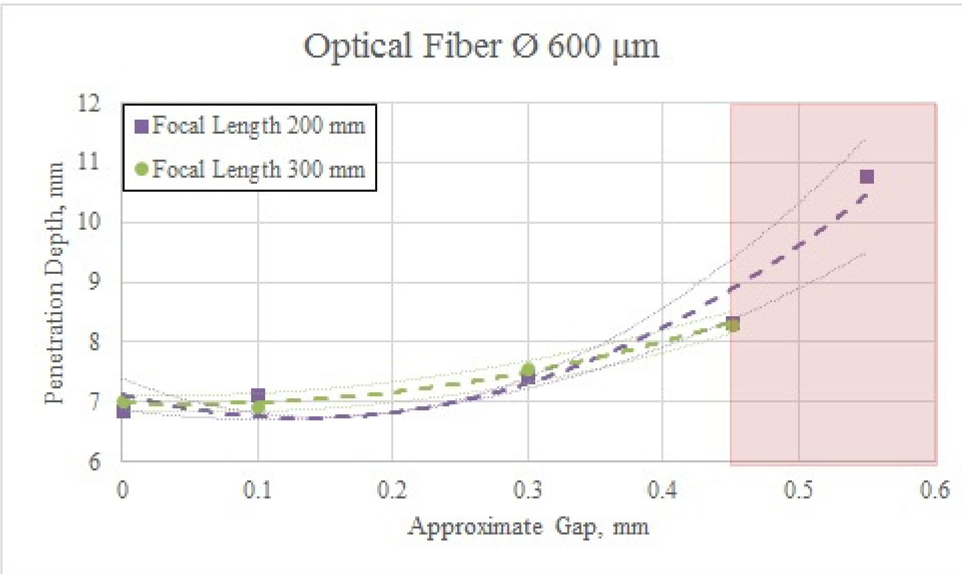

Fig. 2. Penetration depth of AH36 laser welds with optical fiber diameter 600 µm and welding heads of focal length of 200 and 300 mm with confidence intervals (0.95), zone of unacceptable quality is marked with red, t = 14 mm, P_L = 5 kW, V_W = 1 m/min, fpp = -4 mm.

With the use of 600 µm diameter optical fiber the penetration depth remains at the same level, although the quality acceptance window is shifted for 0.1 mm forward, allowing to achieve an acceptable quality weld with air gap up to 0.45 mm.

4. Conclusions

The present study was designed to evaluate the autogenous laser beam welding on the example of AH36 shipbuilding steel. The aim of the study was to test the efficiency and bridgeability of laser beam welding at wider air gaps with the variation of optical fiber diameter (200 – 600 µm) and focal length (200, 300 mm).

The most efficient combination allowed to achieve 8 mm penetration depth with the use of 5 kW laser power at 1 m/min welding speed: 200 µm optical fiber diameter and 300 mm focusing lens focal distance. The use of 600 µm optical fiber diameter does not provide additional increase in penetration depth, but provides an additional bridgeability, resulting in the acceptable level partial penetration welds with the air gap between the plates up to 0.45 mm.

The results of current research enlarge the area of laser welding applications, showing the weldability of various air gaps.

References

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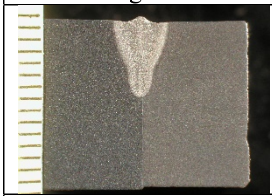
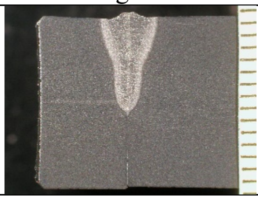
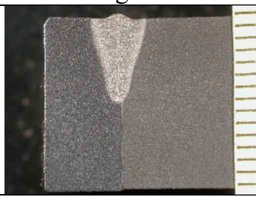
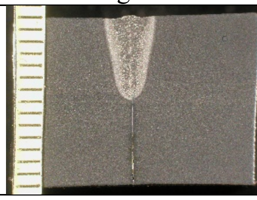
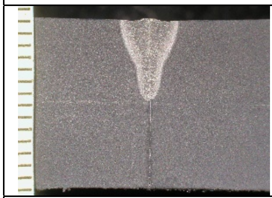
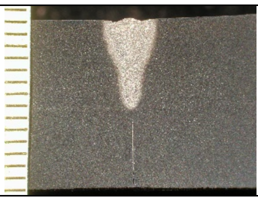
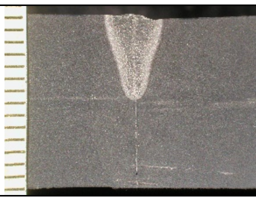
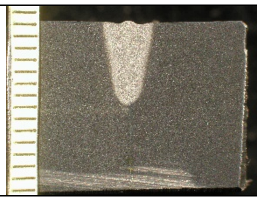
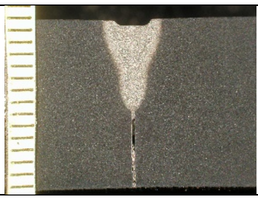
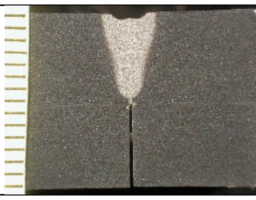
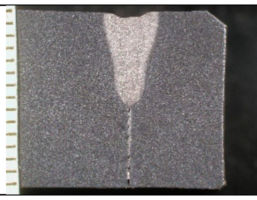
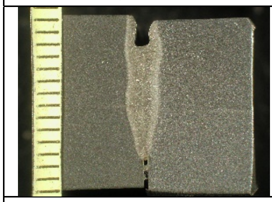
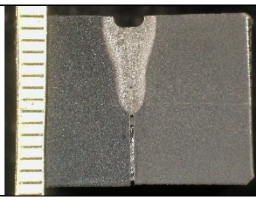
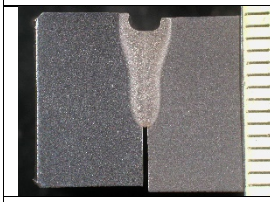
Appendix I. Macrosection Results

Optical fiber diameter 200 µm		Optical fiber diameter 600 µm		Air gap
Focal length 200 mm	Focal length 300 mm	Focal length 200 mm	Focal length 300 mm	
				>0.1 mm
6.8 mm	8.5 mm	7.5 mm	7.1 mm	
				0.10 mm
7.0 mm	7.7 mm	7.3 mm	7.1 mm	
				0.30 mm
6.6 mm	7.2 mm	6.8 mm	7.4 mm	
				0.45 mm
9.5 mm		7.3 mm	7.1 mm	
				0.55 mm
		8.0 mm		