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High power laser welding of thick steel plates in a horizontal butt joint configuration

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ABSTRACT

In this investigation, two laser-based welding techniques, autogenous laser welding (ALW) and laser welding assisted with a cold wire (LWACW), were applied to join thick plates of a structural steel (A36) in a horizontal narrow gap butt joint configuration. The main practical parameters including welding method and laser power were varied to get the sound weld with a requirement to achieve a full penetration with the reinforcement at the back side of weld in just one pass. The weld-bead shape, cross-section and mechanical properties were evaluated by profilometer, micro-hardness test and optical microscope. In order to investigate the stability of laser-induced plasma plume, the emitted optical spectra was detected and analyzed by the spectroscopy analysis. It was found that at the laser power of 7 kW a fully penetrated weld with a convex back side of weld could be obtained by the LWACW. The microstructural examinations showed that for the ALW the acicular ferrite and for the LWACW the pearlite were formed in the heat affected zone (HAZ). The prediction of microstructure based on continuous cooling transformation (CCT) diagram and cooling curves obtained by thermocouple measurement were in good agreement with each other. According to the plasma ionization values obtained from the spectroscopy analysis the plume for both processes was recognized as dominated weakly ionized plasma including the main vaporized elemental composition. At the optimum welding condition (LWACW at the laser power of 7 kW) the fluctuation of the electron temperature was reduced. The spectroscopy analysis demonstrated that at the higher laser power more of the elemental compositions such as Mn and Fe were evaporated.

1. Introduction

The joining of thick plates of steel requires an advanced joining technology like laser welding. There is a typical way to join the thick plates of steel by multi-pass gas metal arc welding (GMAW) or submerged arc welding techniques (SAW). However, the conventional arc welding methods could not result in a high-quality weld in just one pass. Low efficiency and weak mechanical properties have been accounted as main disadvantages of these joining processes [1,2]. In comparison to the conventional fusion welding methods, laser beam welding offers many benefits which include deep penetration, narrower fusion zone (FZ), lower residual stresses, smaller heat-affected zone (HAZ), and higher degree of productivity. It was shown that application of a high power disk laser could be useful to get a deep-penetration weld [3]. Laser welding could be carried out in both form of autogenous (without filler metal) and utilizing a wire metal. The autogenous laser welding (ALW) has limited tolerance to joint fit-up compared with other conventional arc welding methods [4]. Thus, application of a wire could be useful to facilitate the strict joint fit-up demand for the laser welding. Moreover, modification of the composition of the fusion zone is feasible through addition of filler metal and it helps improvement of the weld properties [5,6].

Tailoring different kind of grooves is a common approach in welding of thick plates. It has been made clear that machining of appropriate groove prior to the welding is the cost effective method to gain a well-connected parts [7]. However, increasing the groove area significantly increases the solidification time and consumption of wire and in turns reduces the welding efficiency. Moreover, poor weld mechanical properties due to high amount of residual stresses and deformation resulted from large restraints are considered as other disadvantages of a large groove area [8]. On the other hand, it was shown that the moderately smaller groove favored on the condition that the laser beam assisted with the cold wire (LWACW) could fill the groove in a few passes [9]. A comparison was presented for the LWACW in narrow gap configuration and hybrid laser-arc welding (HLAW) to weld 20 mm thick

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Table 1
Chemical compositions (wt%) of the steel (A36) and filler wire.

Materials	Elemental composition				
	C	Mn	P	S	Si
A36	0.25–0.29	1.03	0.04	0.05	0.28
ER70S-6	0.06–0.15	1.4–1.85	0.025	0.035	0.8–1.15

stainless steel [10]. It was shown that both processes were feasible for welding thicker plates with good quality and minimal distortion. Sound weld without defects was achieved in welding 17 mm thick low-carbon steel plates by the ALW and laser welding with filler wire techniques [9]. It was shown that the application of specific shielding gas nozzle could avoid concave surface at the bottom of weld. The thick plates of steel (30 mm) with narrow gap were successfully joined by multi-pass laser welding including autogenous, wire feeding and HLAW methods [11]. Although the weld appearance was sound, the pores were formed, caused by the incompletely cleaned scale that was left by previous welding passes. The welding of 20 mm thick butt joint of stainless steel with a gap up to 1.5 mm by application of 1 kW single-mode fiber laser was also investigated showing the feasibility of the welding method [12]. It was demonstrated that significant improvement in weld quality could be achieved through the use of statistical modeling.

Issues like lack of penetration, and undercut on the weld bead surface and melt sagging at the bottom of the weld have been observed in a single-pass laser welding of thick metallic plates especially in the flat welding position [13]. In order to deliver a defect-free joint, there have been some remedies like application of backing plate and excitation tools to generate the upward electromagnetic force to back the weight of the molten pool [14]. Based on the requirement determined by the size of product, welding could be performed in different positions but generally for manufacture of the large and heavy structures, it seems that the horizontal position is one of the hardest positions over other configurations [15,16]. In the case of ALW in the horizontal position there is limited information in terms of penetration depth as a function of the welding parameters, especially for the thick

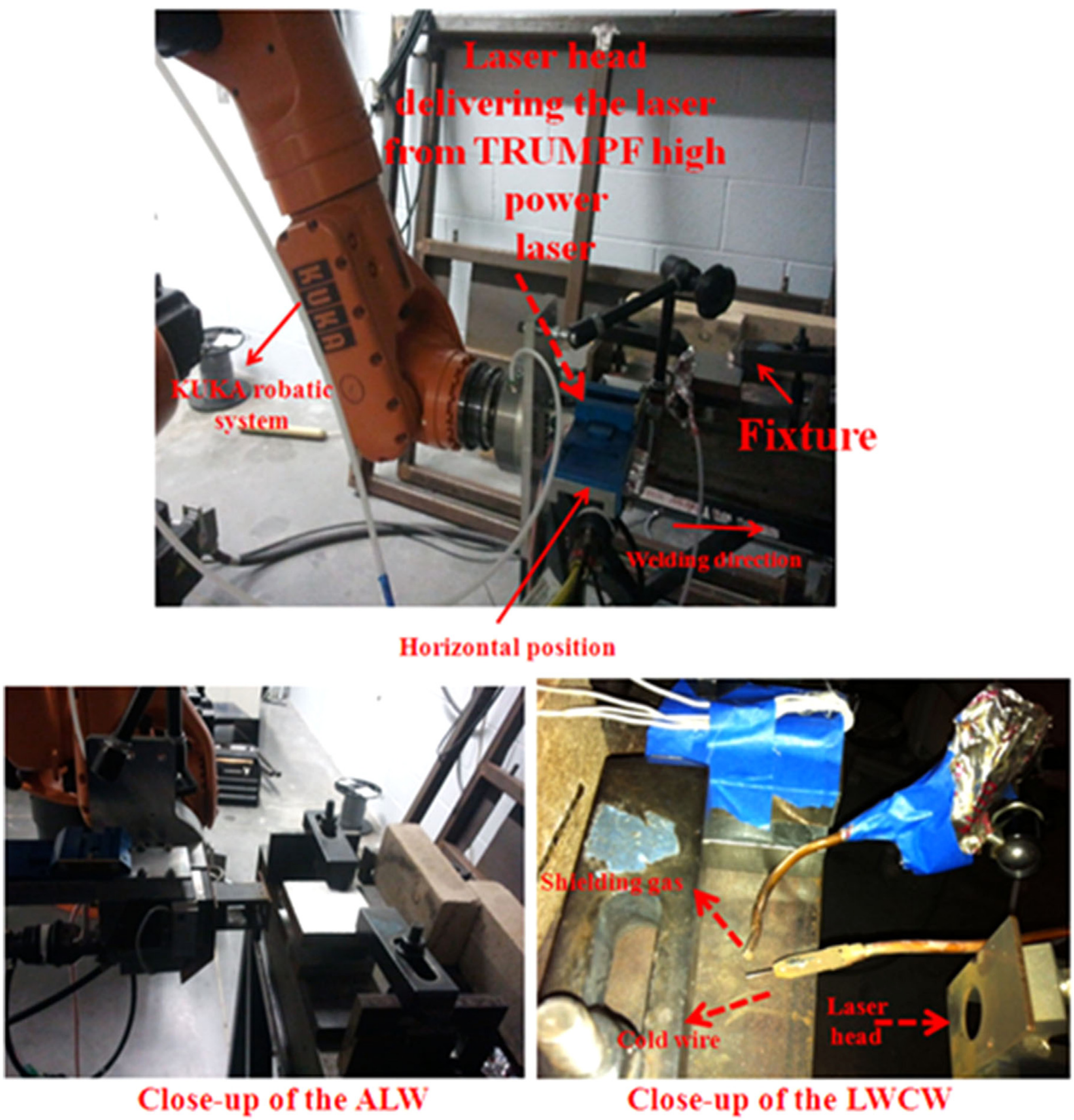

Fig. 1. (a) The experimental set-up of robot used in a horizontal but joint configuration and close-up view of the (b) ALW and (c) LWACW process.