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A practical approach for increasing penetration in hybrid laser-arc welding of steel

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Abstract

Hybrid laser-arc welding of thick-section steel requires high power lasers, appropriate process parameters, and alternative techniques for obtaining deeper penetration. Conventional techniques for increasing penetration/efficiency include groove beveling, preheating, and the use of pre-set gap, but they are costly and inconvenient. Therefore, investigating alternative approaches for increasing process efficiency is of great importance. Recent studies on laser welding of steel reveal that the edge surface roughness, geometry, and preparation method of the joint can influence the penetration in a butt joint configuration. In this study, a number of experiments were carried out on 25 mm steel plates using current industrial procedures. Common industrial preparation methods such as standard quality machining and pre-set gap were compared with alternative methods providing different edge surface roughness values and roughness patterns. The results showed that the preparation of edge surface quality should be considered as an alternative approach for increasing process efficiency.

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Keywords: Hybrid laser welding; edge surface morphology; weld penetration.

1. Introduction

The development of high power solid-state lasers has led to increased interest in hybrid laser-arc welding (HLAW). When it comes to applications involving the manufacture of heavy sections, the unique advantages of new solid-state laser systems make them far more attractive than the previous generation of high power CO_2 lasers (Gumenyuk and Rethmeier (2013)). Examples of these applications include the use of HLAW in shipbuilding, wind turbine structures, offshore constructions, and the fabrication of large diameter oil and gas pipelines.

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The HLAW of thick-section steels requires high brightness, high power lasers, appropriate process parameters, and alternative techniques for obtaining deeper penetration. However, as the power level of current commercial lasers is technologically limited, welding greater thicknesses can be challenging. A great deal of experimental research has been conducted on the HLAW of thick section steel. Vollersten et al. (2010) and Rethmeier et al. (2009) suggest using either a beveled groove or preheating to increase penetration. Another conventional technique for increasing penetration is the use of a pre-set gap. Depending on the plate thickness, Webster et al. (2008) suggested a certain gap to increase penetration, thus boosting process efficiency. However, these techniques have drawbacks of their own. Beveling is the most commonly used technique, but it is costly. Preheating is not only costly but also inconvenient, especially for the manufacture of large structures. Moreover, the processing of thick materials involves the positioning of large workpieces, making it difficult (if not impossible) to keep a constant gap throughout the joint (Seffer et al. (2014)). Consequently, a varying gap, including zero gap, must be considered for the welding (Webster et al. (2008)).

These issues mean that the investigation of alternative solutions for increasing process efficiency is of great importance. For instance, the geometrical and physical characteristics of the weld groove surface must be considered in order to improve the energy coupling into the workpiece. On the basis of the results of absorptance measurements in Bergstrom et al. (2007) that were preformed for solid-state lasers at wavelengths of 1.053 and 0.527 μm, it is evident that surface roughness, surface oxides, surface contamination, and the presence of alloying elements in the steels can increase absorptance. Moreover, according to Kaplan (2012), an analytical investigation of the absorptivity of 1 μm laser rays across a wavy molten steel surface has shown that even a rather low level of roughness (of the order of 5-7 μm) strongly modulates the local absorptivity across the surface. Recent experimental studies on the solid-state laser welding of steel reveal that the edge surface roughness, geometry and preparation method of the joint have a significant influence on penetration in a butt joint configuration. In Farrokhi et al. (2015), a study of the HLAW of 25 mm steel with different edge surface roughness showed that the welding of samples with sand-blasted laser cut surfaces required less laser energy than the welding of samples that had been prepared by water jet cutting or milling. In Sokolov et al. (2015), a study of reduced pressure laser welding of 40 mm thick steel revealed that the combination of increased edge surface roughness and a pre-set gap increases the weld penetration. Moreover, an earlier study investigated the influence of edge surface roughness on laser absorption at power levels of above 10 kW (Sokolov et al. (2012)). From the latter, it is evident that the influence of cut quality and surface roughness must be taken into consideration when laser welding heavy section steel, as the processing of higher thicknesses requires laser power levels higher than 10 kW.

So far, only standard milling has been used for groove preparation prior welding in the vast majority of HLAW research. Very few studies have been published on the effect of edge surface quality on laser absorption and on the efficiency of the subsequent welding process. Despite the importance of adequate topography in surface quality evaluation, the effect of different roughness patterns has not been taken into account. Moreover, in Bergstrom et al. (2007), the absorptance measurements were performed at room temperature within a range of 0.05 to 5.6 μm average roughness, and there is not enough knowledge about the absorption characteristics in weld grooves at elevated temperatures with roughness values extending far above this limited range. In Sokolov et al. (2012), the research was limited to a range of 1.6 to 8 μm average roughness because at levels higher than 8 μm, the quality of autogenous laser welding was unacceptable. With hybrid laser welding, however, this range is more flexible due to the better bridgeability of the process.

To address these issues, this study aims to investigate the effect of different edge surface qualities, including both roughness value and its pattern, on the subsequent HLAW of steel. For this reason, different edge surface roughness levels have been chosen for the study, ranging from the common industrial milling quality to roughness levels above 8 μm. In addition, the influence of differences in pre-set gap has been taken into account to allow comparison with the influence of edge surface preparation as an alternative approach for increasing process efficiency.