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Single-pass hybrid laser welding of 25 mm thick steel

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Abstract

The manufacturing of large steel structures involves welding thick-section steels. Using hybrid laser welding, it is possible to reduce production costs significantly. However, avoiding solidification cracks in the weld is difficult when welding thick-section steels. In this study, a number of experiments were performed on the hybrid laser welding of 25 mm steel. Different techniques of full penetration and partial penetration welding were discussed. Crack-free welds were obtained using single-pass or two-pass welding techniques. The results of the experiments showed that the joint preparation method and the penetration mode are very important factors in obtaining crack-free welds in welding thick section steels. With the same process parameters applied to hybrid laser welding, partial penetration welds were more susceptible to cracking than full penetration welds. This was partly attributed to a change in the melt flow and, consequently, a different solidification mode that occurred during the full penetration mode welding.

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Keywords: Hybrid laser welding; solidification mode; solidification cracking; joint preparation; thick-section steel.

1. Introduction

With ongoing technical development and the increasing power levels of high power solid-state lasers, heavy industries such as shipbuilding, offshore windmills, power plants, and pipelines industries are looking for new opportunities to substitute their conventional welding methods with hybrid laser welding (Nielsen 2015). Hybrid laser-GMA welding is a promising welding process and is capable of processing thick-section steels as it can compensate for the limitations in laser welding and Gas Metal Arc (GMA) welding by utilizing the features of both.

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Despite the advantages of this process, the control of solidification cracks is still a key challenge when it comes to welding thick-section steels. In general, solidification cracking appears on the weld centerline and occurs in the fusion zone in the final stage of solidification, when a liquid film may appear along the solidification boundaries. It is, in fact, the inability of this liquid film to deal with shrinkage-induced strain and extrinsic mechanical strain during solidification and subsequent cooling of the weld that results in the formation of a solidification crack (Lippold 2015). The cause of hot cracking can ultimately be attributed to the complex interaction between the main influences of welding parameters, the chemical composition of the alloy, and restraint intensity (Cross 2005). One of the crucial ways to control restraint intensity, which is one of the main interests of this paper, is the design of joint geometry and welding sequences. With the optimum design, it is possible to control not only mechanically induced strains but also thermally induced strains by controlling cooling rate and heat dissipation through the component.

The manufacture of large structures often involves welding steel plates with thicknesses of 20 mm or more. However, when experimental research investigated the design of joint geometry and welding sequences and the chance of cracking on the hybrid solid-state laser welding of structural steels, only a few investigations used wall thicknesses exceeding 20 mm. For example, Vollersten et al. (2010) and Rethmeier et al. (2009) conducted studies on welding X65 pipe steel up to 20 and 32 mm thick, respectively, and suggested using either a beveled groove (Y-groove) or preheating to obtain sound joints. They performed a one-sided multi-pass welding procedure in which hybrid laser welding was used only for the root pass. Gook et al. (2014) suggested a double-sided welding procedure for 23 mm X80 pipe steel, but they used hybrid laser welding only for the root pass of Y-grooves where the root welding was performed from the flat side. Wahba et al. (2016) developed a new single-pass hybrid laser welding technique on 25 mm SM490A low-alloyed steel. They used a 2.5 mm gap in butt joint configuration, filled up with cut wires and supported by backing. All these experiments that yielded crack-free welds used hybrid laser welding only for one pass where full penetration of the sample thickness was achieved and where there was no solid material below the bottom of the laser weld. However, when hybrid laser welding was used for double-sided partial penetration welding of 20 and 25 mm thick steel in Akselsen et al. (2013) and Farrokhi et al (2015, 2016), solidification cracks could not be avoided in the welds. This leads to the assumption that a correlation exists between the chance of solidification cracking and the *penetration mode* (full/partial) of hybrid laser welding.

Two mechanisms related to the difference between full and partial penetration laser welding could explain this phenomenon: (i) melt flow dynamics (Schaefer et al. 2015), and (ii) thermal and mechanical induced stresses (Gebhardt 2013). Schaefer et al. (2015) analyzed the influence of laser beam quality and parameters on the formation of solidification cracks in tempered steels. They observed that crack formation could be avoided when full penetration of the sample thickness was achieved, while partial penetration experiments required cautious optimization of beam parameters to avoid solidification cracks. In a recent study, Schaefer et al. (2017) also related the formation of cracks to melt flow dynamics, which, according to their previous study, differ in full and partial penetration laser welding (Schaefer et al. 2015). Moreover, Gebhardt et al. (2012) conducted an experimental study on the full and partial penetration hybrid laser welding of a number of different carbon steels with wall thicknesses up to about 15mm. They reported that crack-free welds were obtained only when full penetration welding was carried out and shrinkage restraint was limited. This was later confirmed by a numerical analysis carried out on S460NH low-alloyed high strength steel (Gebhardt 2013). The results showed that higher magnitude of stresses occurred in the partial penetration mode and in the regions that solidification cracks were found in the experiments.

The above review shows that despite the importance of the subject, only a limited number of studies have related the effect of penetration mode and the design of weld sequences to the chance of cracking. Moreover, preparation methods other than milling, such as laser cutting, have not been taken into account. Accordingly, this paper aims to provide more experimental data on the qualitative and microstructural differences between full and partial penetration in hybrid laser welding. In addition, two welding procedures with novel preparation methods were introduced for the single-pass and two-pass welding of 25 mm thick steel. Both procedures used full penetration and single-pass hybrid laser welding technique to reduce the chance of cracking.