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A study of keyhole geometry in laser welding of zinc-coated and uncoated steels using a coaxial observation method

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ABSTRACT

Experiments were conducted over a large process parameter space using a 2 kW multi-mode fiber laser, and the effect of zinc-coating on the keyhole geometry was investigated using a high-speed coaxial video camera. From the top and bottom coaxial surface images of erratic keyhole motions that were obtained from separately conducted experiments, time-averaged keyhole structures were calculated using a physics-based semi-statistical frame analysis. For uncoated steel, the keyhole bottom aperture is located mostly within the laser beam area. In this case, because there is no zinc evaporation, the bottom aperture tends to be closed to absorb enough laser energy for sustaining a keyhole. For zinc-coated steel, the keyhole is mostly open at the bottom, and the front keyhole wall is tilted so that the laser beam is located on the front keyhole wall. The keyhole tilting angle is more important for zinc-coated steel and the beam interaction area is more relevant to uncoated steel.

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1. Introduction

In laser keyhole welding, the keyhole is the place where the interaction between a laser beam and a substrate takes place, and due to unstable and erratic keyhole motions the interaction is also highly unstable even for a stable welding process. Therefore, the prediction of the keyhole geometry is critical in the understanding of a laser keyhole welding process.

Many researchers have investigated keyholes during laser welding by using various observation methods. The keyhole behavior during the deep penetration laser welding of steel was observed by using the high speed imaging method and the X-ray transmission method. Matsunawa et al. (1998) observed the inside of a keyhole by employing the X-ray transmission method and their study showed the porosity formation mechanism and the dynamics of plasma plume and keyhole. Fabbro et al. (2005) conducted a high speed imaging of the specimen top surface during full penetration laser welding. They constructed the keyhole geometry by using the top surface coaxial images and the bottom keyhole shape was estimated from the top surface images. Several research groups observed the longitudinal keyhole wall by using a special specimen that contains a transparent material which serves as a window for imaging. For example, Zhang et al. (2013) observed the longitudinal keyhole wall during laser welding by using a sandwich specimen that consists of one sheet of stainless steel and a piece of GG17 glass. Because GG17 glass does not absorb the laser beam and is melted by the molten stainless steel, however, the actual keyhole behavior can be affected by the molten GG17 glass. The keyhole behavior during laser welding of zinc-coated steels has been also investigated. Pan and Richardson (2011) observed the keyhole behavior during laser welding of zinc-coated and uncoated steels by using the high speed coaxial visualization of specimen top surfaces. They reported that the uncoated steel produces stable keyholes for the whole process parameters, but the keyhole is relatively stable only at low welding speeds when the steel is zinc-coated. Fabbro et al. (2006) conducted the twin-spot laser welding of zinc-coated steels using a CW Nd:YAG laser. During the experiment, they observed the top surface coaxially and the bottom surface was observed laterally. Their results showed that the top-hat intensity profile is more useful for obtaining good quality weld seams than the Gaussian profile.

All these previous studies have significantly contributed to the understanding of keyhole geometry. However, most of them have focused on the specimen top surface or lateral side imaging of keyholes, and the observation of the specimen bottom surface has been relatively ignored. In this study, specimen top and bottom surfaces were observed both coaxially during laser welding of zinc-coated and uncoated steels, and keyholes were reconstructed by connecting the top and bottom keyhole shapes. As far as the reconstruction of a keyhole is concerned, coaxial observation is believed to be more accurate than other observation methods. To calculate statistically

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Table 1
Chemical compositions (%) of DP 590 and GA DP 590 steels.

Steel type	C	Si	Mn	P	S	Fe
DP 590	0.078	0.0345	1.796	0.0128	0.0014	Balance
GP DP 590	0.09	0.26	1.79	0.03	0.003	Balance

meaningful results, the experiments were conducted twice, and for each experiment 70 frames were analyzed to obtain an averaged keyhole shape. This study investigated the overall differences in the keyhole geometry between the zinc-coated and uncoated steels over a large process parameter space.

2. Experimenal setup

Experiments were conducted using a 2 kW multi-mode fiber laser (IPG YLS 2000) with a wavelength of 1070 nm. The beam was focused at the specimen top surface by a focusing lens with a focal length of 160 mm, and the focused beam has a top-hat intensity profile with a beam diameter of 200 μm. In this study, 1 mm thick DP 590 dual phase steel sheets, both zinc-coated (GA DP 590) and uncoated (DP 590), were used in order to investigate the effect of zinc coating. The chemical compositions of both steels are given in Table 1. Specimens were 137 mm × 30 mm in size, and two sheets

Table 2
Experimental parameters.

Steel type	Beam diameter (μm)	Laser power (W)	Scanning speed (mm/s)
DP590, GA DP590	200	1230, 1403, 1603, 1830	12.5, 14.3, 16.3, 18.6, 21.2

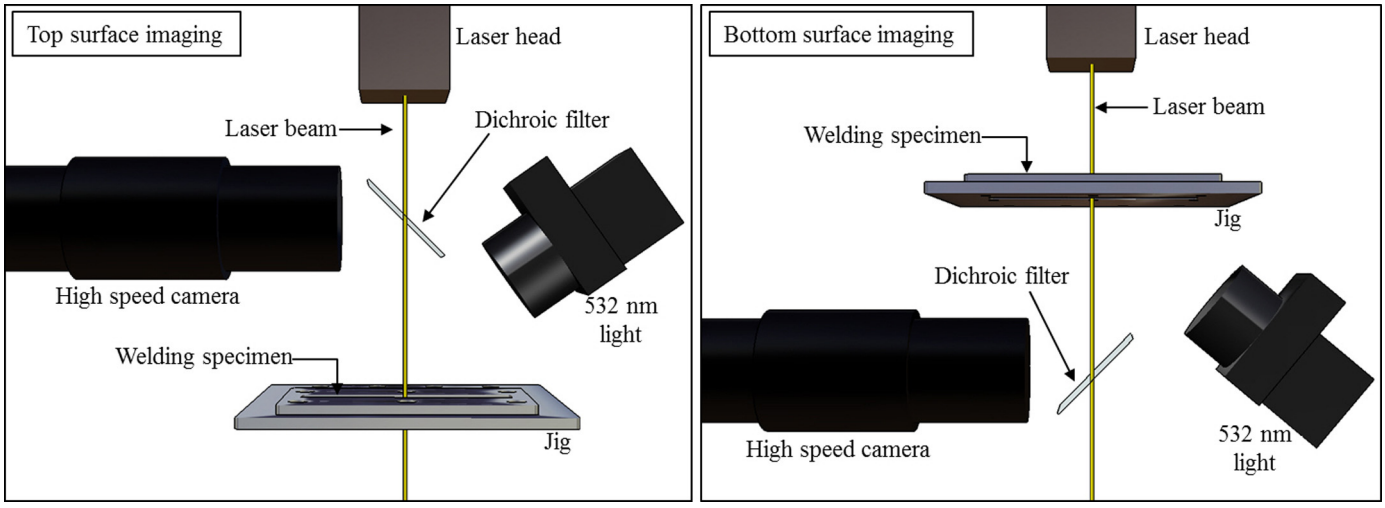

Fig. 1. High speed coaxial imaging experimental setup. Top and bottom surfaces were observed separately as shown in the figures.

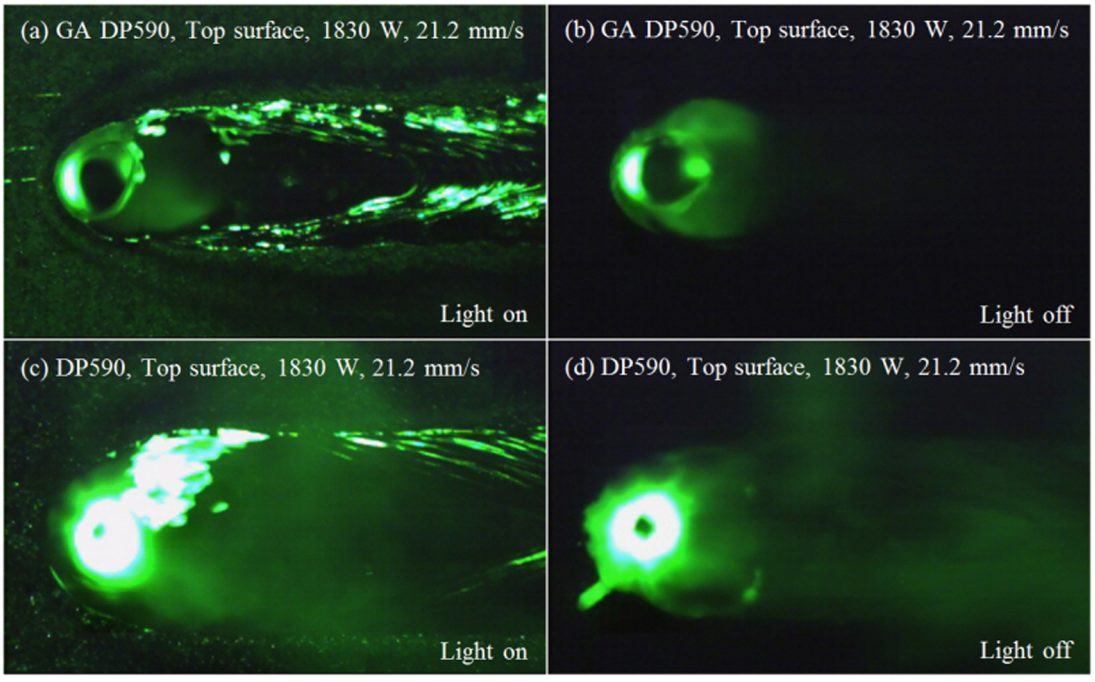

Fig. 2. Coaxially recorded images of top surfaces with and without using the external LED lighting. Top figures: zinc-coated steel, bottom figures: uncoated steel.

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