Optics & Laser Technology 44 (2012) 2186–2196

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Real-time monitoring of laser welding of galvanized high strength steel in lap joint configuration

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ARTICLE INFO

Article history:
Received 3 November 2011
Received in revised form
9 February 2012
Accepted 3 March 2012
Available online 28 March 2012

Keywords:
Laser welding
Galvanized steel
Plasma spectroscopy

ABSTRACT

Two different cases regarding the zinc coating at the lap joint faying surface are selected for studying the influence of zinc vapor on the keyhole dynamics of the weld pool and the final welding quality. One case has the zinc coating fully removed at the faying surface; while the other case retains the zinc coating on the faying surface. It is found that removal of the zinc coating at the faying surface produces a significantly better weld quality as exemplified by a lack of spatters whereas intense spatters are present when the zinc coating is present at the faying surface. Spectroscopy is used to detect the optical spectra emitted from a laser generated plasma plume during the laser welding of galvanized high strength DP980 steel in a lap-joint configuration. A correlation between the electron temperature and defects within the weld bead is identified by using the Boltzmann plot method. The laser weld pool keyhole dynamic behavior affected by a high-pressure zinc vapor generated at the faying surface of galvanized steel lap-joint is monitored in real-time by a high speed charge-coupled device (CCD) camera assisted with a green laser as an illumination source.

1. Introduction

Laser welding of galvanized steel in lap joint configuration is one of the most challenging issues in the welding community because the presence of highly pressurized zinc vapor can easily disturb the stability of liquid flow in the weld pool resulting in poor weld quality. Some experimental approaches have been undertaken to resolve the zinc vapor problem in the welding of galvanized steels in lap joint configuration, for example, removing the zinc at the faying surface [1], presetting aluminum [2] or copper foil [3] along the faying surface, adopting dual beam laser [4], introducing arc to preheat the galvanized steel coupon [5], etc. In order to guarantee the weld quality of galvanized steel joints, real-time detection of the weld defects could be indirectly achieved by monitoring a number of different signals during the welding process, such as emissivity of light, sound, image of the molten pool, etc.

The interaction between the laser beam and metal is often related with the ejection of material in the liquid and gaseous states from the molten pool in the high power laser beam welding process. The ejected metal usually consists of excited ions and atoms, which is referred to as a plume [6]. The material under the laser radiation will be rapidly heated to a temperature exceeding the boiling point accompanied by the formation of plasma. Considering that the plasma is generated only when vaporization occurs, its presence is related to a minimum temperature and specific event such that it may provide useful information about the welding conditions. Some light signals coming from the plasma may be utilized to achieve information regarding the possible presence of defects during the process. Fabbro et al. [7] studied both the keyhole dynamic and the trajectories of the escaping zinc vapor at the interface of two steel sheets across the keyhole both numerically and experimentally. However, neither qualitative nor quantitative detection of the zinc above the top sheet or under the bottom sheet was achieved in their experiments, which is a severe limitation for application to an industrially relevant condition. Park et al. [8] experimentally monitored the CO_2 laser welding by a photodiode-based acquisition of the ultraviolet (UV) emission from the plasma zone and the infrared radiation (IR) from the weld pool and spatter. By this means authors studied the relationship between welding conditions including laser power, welding speed and nozzle position and the spectral line intensities from the plasma emission together with IR emission from the weld pool. However, the limitation of this method is difficult to separate the IR emission related to the weld pool from the IR emission related to the plasma zone [6]. Park and Rhee [9] experimentally studied the welding mechanism as well as weld defects such as spattering during CO_2 laser welding of galvanized steel, in which a bead-on-plate configuration was chosen without

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0030-3992/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlastec.2012.03.003

any problem of zinc vapor worsening the weld quality. In addition, Bruncko et al. [10] experimentally monitored the influence of focal position of the laser beam on the featured emission line intensities detected from the laser induced plasma by using optical emission spectroscopy in the bead-on-plate welding by laser for an austenitic steel sheet. Rodil et al. [11] monitored the laser welding quality in a bead-on-plate weld by using spectroscopy and studied the correlations between the power spectrum and the weld defects. In addition, Mirapeix et al. [12], Ancona et al. [13], Sadek et al. [14], Kato et al. [15], Li et al. [16], and Allende et al. [17] separately applied spectroscopy to study the correlations between the emission line intensities of selected elements detected from arc plasma and penetration depth of the weld and welding defects like blowhole and pores retained in the weld. However, there were limited literature which can be found studying the correlations between the featured optical spectrum and zinc vapor induced spatters in the laser welding of galvanized steel for an overlap joint configuration. Considering the importance of welding of galvanized steel applied into the automobile industry, it will be very meaningful to real-time monitor the welding quality by detecting the featured change of emission line intensities in the welding of galvanized steel.

In this study, we are expecting that spectrographic monitoring of the laser weld pool and associated plasma zone has the potential to be utilized as a feedback for process control to enable defect-free welds. The Boltzmann-plot method is introduced to calculate the electron temperature of laser induced plasma by selected zinc and iron elements in the overlapped galvanized steel weld. A series of experiments is also performed to study the influence of welding parameters on the weld quality in the laser welding of galvanized high-strength steel in a lap joint configuration, in which a high speed CCD camera with a green laser as an illumination source and a spectroscopic monitoring system are used to study weld defects by monitoring weld pool dynamics and emission lines from the laser induced plasma zone, respectively.

2. Experimental setup and procedure

Experiments are carried out using a 4 kW fiber laser (see Fig. 1). The welding head has a 150 mm focal distance, which generates a 0.6 mm focal spot. Pure argon is used as a shielding gas at a typical flow rate of 35 standard cubic feet per hour (SCFH). The coupons of galvanized steel are 1.2 mm and 1.5 mm in thickness, with a 10 μm thick zinc coating on the top and bottom surfaces. A zero gap in the lap joint configuration is assured by using a controlled clamping force. The surface quality of the weld seam is verified by an optical microscope. Finally, in order to visualize the dynamics of the molten pool, a CCD camera, with a frame rate of 4000 frames per second is used. The spectrometer is set above the coupons at a distance of 200 mm from the weld pool and fixed to the robotic arc together with the laser head (see Fig. 1). An Ocean Optics spectrometer (SD2000) was used to detect the elemental composition in the laser induced plasma. The integration time is 3 ms, the wavelength resolution is 0.364 nm, and the slit width is 50 μm. First, the chemical composition referenced in literature [18,19] was input into the analysis software of spectrometer as known condition. Then the featured emission lines are linked to the chemical elements by using the corresponding software of the spectrometer. Among all of the chemical elements, only zinc and iron are selected as major elements of interest in the laser welding of DP980 steel. A flowchart representing the experimental procedure is presented in Fig. 2. The coupons are cut by an abrasive water jet machine at the required size of 300 mm in length and 50 mm in width. Then, the coupons are clamped into the fixture. The robot is programmed to follow the designated motion trajectory at a given welding speed. The CCD camera and spectrometer are also attached to the robotic arm to simultaneously capture the optical image of the weld pool and spectrum irradiated from the plasma zone and weld

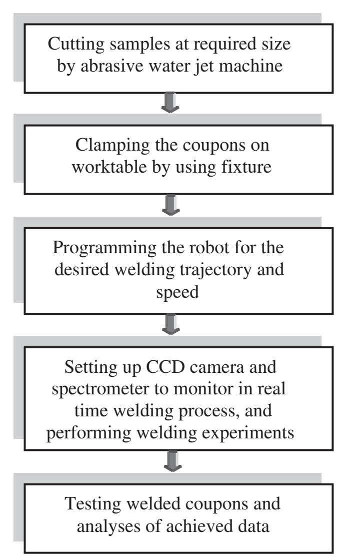

Fig. 2. Flowchart of experimental procedure of laser welding of lap jointed galvanized steel with real-time monitoring.

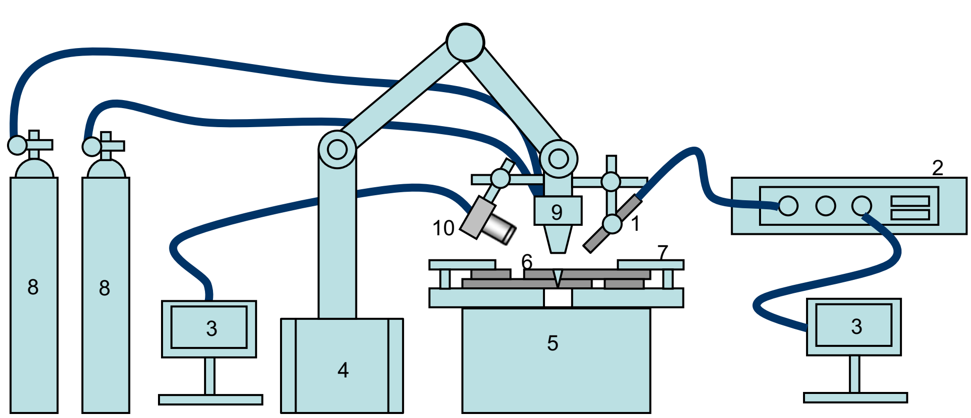

Fig. 1. Schematic of robot-controlled laser welding equipment with a spectrometer and a CCD camera monitoring system (1-colimator lens, 2-spectrometer, 3-computer, 4-robot control system, 5-worktable, 6-specimen, 7-clamp, 8-shielding gas cylinders, 9-laser welding head, and 10-CCD camera).