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A study of keyhole behavior and weldability in zero-gap laser welding of zinc-coated steel sheets at subatmospheric pressures

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Abstract

Experiments were conducted to investigate how the keyhole responds to a decrease in the ambient pressure using a coaxial observation method in the laser welding of zinc-coated steel sheets. To understand the effect of zinc coating on keyhole dynamics, both zinc-coated and uncoated DP 590 steel sheets were studied using a 2 kW multi-mode fiber laser in a zero-gap lap-weld configuration. Two energy density conditions (1830 W, 12.5 mm/s and 1230 W, 21.2 mm/s) and four ambient pressures (101.3, 10, 1 and 0.1 kPa) were considered systematically. For these conditions, time-averaged 3-D keyhole shapes were reconstructed by analyzing top and bottom surface video images. This study showed that zinc evaporation was much more intensified than the evaporation of steel at subatmospheric pressures, which made the keyhole highly fluctuating and elongated in the welding direction for the zinc-coated steel. Also, the bottom aperture opening time increased as the ambient pressure was decreased due to the enhanced effect of evaporation, which led to less energy absorption and smaller melt pools. The weld quality became poorer as the spacing of weld chevrons were wider and more erratic, and more fumes with less light emission were observed at reduced ambient pressures.

Keywords: laser welding; subatmospheric pressures; zinc-coated steel; zero gap; keyhole behavior;

I. INTRODUCTION

Laser welding at subatmospheric pressures possesses unique benefits, such as substantially improved penetration depth and no shield gas requirement. Unlike electron beam welding, ultra-high vacuum conditions are not required either. In recent years, therefore, a great deal of effort has been made by researchers in investigating the effect of decreased pressures on laser welding processes and weld quality.

Verwaerde et al. (1995) conducted an experimental study of CO_2 laser welding at subatmospheric pressures. They observed plasma suppression at low pressures by measuring the size of plasma, electron density, and electron temperature. Their result showed that under reduced pressures, deeper and thinner welded zones were obtained because the perturbing effects (the lensing effect and absorption by inverse bremsstrahlung) of plasma were suppressed, leading to a constant deposited energy per unit length inside the keyhole. Katayama et al. (2001) studied the effect of vacuum on weld penetration and porosity formation in high-power continuous CO_2 and YAG laser welding of aluminum alloys. They observed that evaporation in vacuum was strong, so that the vapors swelled the middle and bottom rear wall of the keyhole, which led to prevention of pore generation. Recently, Katayama et al. (2011) obtained sound welds with up to 70 mm penetration depth for Type 304 stainless steel at a pressure of 0.1 kPa using a 26 kW disk laser. Luo

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