Journal of Materials Processing Technology 216 (2015) 114–122

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Two-pass laser welding of AZ31B magnesium alloy

Masoud Harooni [a], Junjie Ma [a], Blair Carlson [b], Radovan Kovacevic [a,*]

[a] Research Center for Advanced Manufacturing, Mechanical Engineering Department, Lyle School of Engineering, Southern Methodist University, 3101 Dyer Street, Dallas, TX 75205, USA

[b] GM: Research Center, Warren, MI 48090-9055, USA

ARTICLE INFO

Article history:
Received 29 March 2014
Received in revised form 27 August 2014
Accepted 28 August 2014
Available online 6 September 2014

Keywords:
Laser welding
Magnesium alloy
Two pass
Oxide layer
Porosity
Electron temperature

ABSTRACT

A two-pass laser welding process was applied to AZ31B magnesium sheet in a zero-gap, lap-shear configuration. The first pass decomposed the magnesium hydroxide into magnesium oxide and molecular water while the second pass, which was designed for keyhole welding of the magnesium, provided a path for the vaporized water to escape and thereby producing a pore free weld. Two groups of samples including one pass laser welding (OPLW) and two pass laser welding (TPLW) were studied. In the two pass laser welding procedure, the first pass was performed by a defocused laser beam on the top of the two overlapped sheets in order to preheat the faying surface prior to laser welding, while the second pass was applied to melt and eventually weld the samples. The need for preheating using a defocused laser beam was related to the decomposition of magnesium hydroxide that was the cause of pore formation in one pass laser welding process. The chemical compositions of the welds and metal sheet surfaces were evaluated using an energy dispersive spectroscopy (EDS). The presence of the oxide layer on the faying surface of two overlapped sheets resulted in an unstable process. Tensile and microhardness tests were used to measure the mechanical properties of the laser welded samples. A spectrometer was used in real-time to correlate pore formation with calculated electron temperature using the Boltzmann plot method. The experimental results revealed that a two pass laser welding process could effectively mitigate gas pore formation at the faying interface of two overlapped sheets.

1. Introduction

Among a variety of issues in welding of magnesium alloys, porosity has a major effect upon the weld joint mechanical properties. There are several reasons for pore formation in the welding of magnesium alloys. Hydrogen is the only gas that dissolves in molten magnesium. Mikucki and Shearouse (1993) investigated the relationship of hydrogen inclusion in molten magnesium and porosity level in the solidified magnesium. They concluded that the hydrogen level should be kept as low as possible in order to have fewer pores in the solidified magnesium. Zhao and Debroy (2001) reported that pre-existing pores can cause pore formation in the weld bead. They stated that during the welding process small pre-existing pores coalesced to form larger pores. They mitigated the formation of such pores by employing higher welding speeds. Surface coatings could generate pores during the laser welding process. Harooni et al. (2014a–c) revealed that the oxide layer existing on the surface of magnesium alloy leads to porosity in laser welded samples. They found that the mechanism of pore generation was related to the decomposition of magnesium hydroxide during the laser welding process. Matsunawa et al. (1998) studied the dynamic behavior of the molten pool and keyhole during the pulsed and continuous-wave laser welding process. They revealed that by selecting optimal parameters for pulsed laser it could effectively stablize the keyhole which finally resulted in less pore formation.

Laser welding process parameters such as laser power, welding speed, and focal distance affects the quality of welded samples. A number of researchers have reported applying optimized process values such as welding speed, laser power, and beam intensity to achieve a superior weld joint quality. Marya and Edwards (2000) found that higher welding speed as well as increasing the beam density mitigated pore formation. They revealed that higher welding speed did not allow pores to nucleate. Padmanaban and Balasubramanian (2010) studied the effect of laser power, welding speed and focal position on the final strength of the weld. They developed a relationship with an accuracy of 95% and stated that welding speed had a higher influence on the final weld strength. Splitting a laser beam into two separate beams improves the weld bead quality by mitigating pore formation. Xie (2002) used a dual-beam laser heat source and reported that the welding process was

* Corresponding author. Tel.: +1 214 768 4865; fax: +1 214 768 0812.
E-mail address: kovacevi@lyle.smu.edu (R. Kovacevic).

http://dx.doi.org/10.1016/j.jmatprotec.2014.08.028
0924-0136/

Table 1
The nominal chemical composition of the AZ31B magnesium alloy.

Element	Al	Zn	Mn	Si	Fe	Cu	Ni	Mg
Wt.%	2.46	1.70	0.58	< 0.1	< 0.005	< 0.05	< 0.005	Bal.

more stable and as a result, an improved weld quality was achieved. Haboudou et al. (2003) found that using a dual-beam configuration could improve the surface quality as well as the weld bead quality by reducing humping and pores. Harooni et al. (2014b) found that an in-line configuration of dual-beam laser heat source was advantageous based on achieving an improved weld quality. Liu et al. (2005) used a hybrid laser-arc heat source and reported that by applying optimum parameters of shielding gas, pore formation in the weld bead was suppressed. Li and Liu (2013) compared four different methods including laser welding, arc welding, hybrid laser-arc welding and hybrid laser-arc welding with cold wire to weld thin sheets of magnesium in a T-joint configuration. They achieved the best weld quality using the hybrid laser-arc welding with cold wire process. Preheating the samples prior to laser welding was also reported as a method to mitigate pore formation (Harooni et al., 2014a–c). Loredo et al. (2002) performed two-spot laser welding on galvanized steel to achieve a high quality laser weld. They found that the first spot vaporized the zinc and the second spot welded the samples. Ma et al. (2013) used a two-pass laser welding process and reported that it could effectively mitigate pore formation in laser welding of zinc coated steel. They found that the preheating procedure performed by a defocused laser beam prior to laser welding had a prominent influence on the quality of the welds. This was correlated to vaporization of zinc prior to laser welding.

Harooni et al. (2014a–c) investigated the oxide layer influence on the weld quality of AZ31B magnesium alloy in zero-gap lap joint configuration. They reported a significant improvement in laser weld quality using a plasma-arc preheating source prior to laser welding. This improvement was correlated to the decomposition of the magnesium hydroxide prior to laser welding. By perceiving the advantages of preheating, a laser beam and a plasma arc preheating source were replaced with a focused and defocused laser source. The defocused laser beam acted as a preheating source and the focused laser beam welded the two overlapped metal sheets. To the best of the author's knowledge, no research has been done on using a two-pass laser welding process to mitigate porosity caused by oxides on the surface of magnesium alloy. The surface cleaning and preparation is a time-consuming and costly procedure for industrial applications and using a two-pass laser welding process, without any mechanical cleaning, to achieve a high quality weld offers a significant improvement. Pore formation was mitigated using a two-pass laser welding process with an optimum focal distance and laser power. Weld quality was analyzed using an optical microscope applied on polished weld cross-sections. The mechanical properties investigated by tensile and hardness tests. A spectroscopy sensor was used in real-time in an effort to correlate pore formation with the calculated electron temperature using Boltzmann plot method.

2. Experimental procedure

2.1. Material

The used material was 1.5 mm thick AZ31B magnesium alloy sheets with a size of 500 × 250 mm and a chemical composition presented in Table 1. The color of the sheets was dark gray as a result of the oxide layer that formed during the preceding manufacturing process. In order to prepare the samples for welding, coupons of 100 × 100 mm in size were cut by using an abrasive waterjet cutting machine. Before welding, all of the coupons were cleaned with acetone in order to make sure that the surface was free from contaminants. Experimental samples were fixed tightly into a fixture to ensure a zero gap.

2.2. Two-pass laser welding procedure

A fiber laser with a maximum laser power of 4 kW and a focused beam spot size of 0.6 mm was used to preheat and weld magnesium samples. The two-pass configuration details are shown schematically in Fig. 1. As shown in this figure, the first pass was performed using a defocused laser beam in order to preheat samples prior to laser welding. The welding process was done by a focused beam on top of the two overlapped magnesium sheets (Fig. 1(b)). All of the experiments were performed using a KUKA robot (Fig. 2). The first pass, i.e. preheating, was run and the laser head returned to the starting point to perform the second pass, i.e. welding. The lapse time between the first and second pass was 10 s. The preheating and welding parameters are shown in Table 2. The preheating speed was set at 100 mm/s. Two levels of laser preheating power and two levels of defocused off-set distance were selected for the

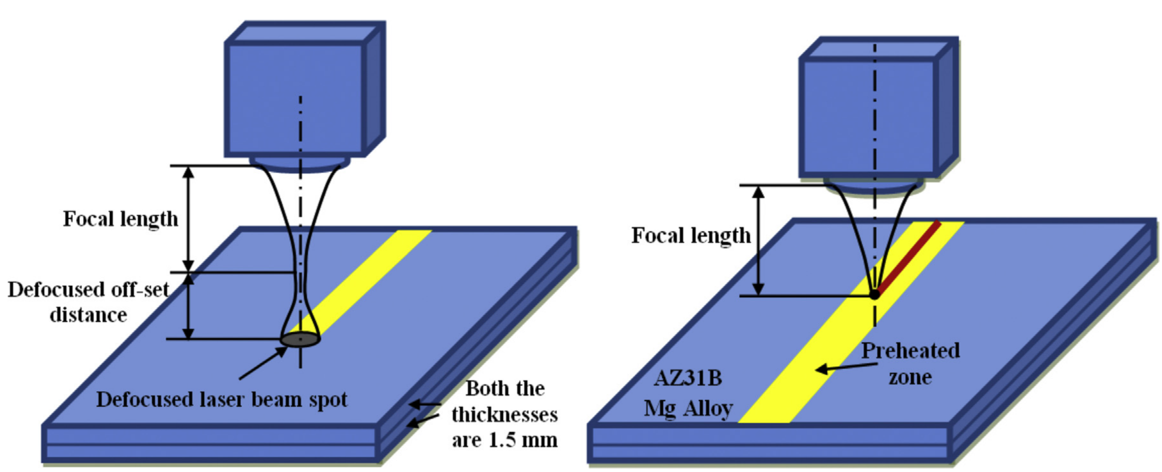

Fig. 1. Schematic view of two-pass laser welding process (a) preheating by a defocused beam (b) welding by a focused beam.