Materials and Design 35 (2012) 701–706

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Short Communication

Laser welding of AZ31B magnesium alloy to Zn-coated steel

M. Wahba [a,b,*], S. Katayama [c]

[a] Central Metallurgical Research & Development Institute, Helwan 11421, Egypt
[b] Graduate School of Engineering, Osaka University, 1–1 Yamadaoka, Suita, Osaka 565-0871, Japan
[c] Joining and Welding Research Institute, Osaka University, 11–1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

ARTICLE INFO

Article history:
Received 22 August 2011
Accepted 18 October 2011
Available online 28 October 2011

ABSTRACT

The characteristics of laser lap welding of AZ31B magnesium alloy to Zn-coated steel were investigated. Welding was difficult when the laser beam was irradiated onto the AZ31B alloy and the processing parameters were set to obtain a keyhole welding mode. The difference in the physical properties between the two materials resulted in unstable welding process particularly when the laser beam penetrated into the steel specimen and a keyhole was formed therein. By switching to a conduction mode, the process stability was improved and successful welding could be achieved because the liquid metal film remained unbroken and the laser beam did not penetrate into the material. A 25 mm wide joint failed in tensile shear testing at loads exceeding 6000 N. This high joint strength was attributed to the formation of a 450 nm thick layer of Fe_3Al intermetallic compound on the steel surface as a result of the interaction between Al from the AZ31B alloy and Fe. The presence of Zn-coating layer was essential to eliminate the negative effects of oxides on the joining process.

1. Introduction

Recently, there has been an increasing demand for light weight and high specific strength materials in the automotive industry because of resources and environmental concerns. Magnesium alloys have received a considerable interest in this regard since magnesium is approximately 75% lighter than steel and 34% lighter than aluminum [1]. A wider application of magnesium alloys in vehicles construction entails the production of high quality joints between magnesium alloys and other materials. Zn-coated steel is one of the major materials used in the automotive industry. However, very few studies have been reported on welding magnesium alloys to Zn-coated steel using friction stir welding [2] and resistance spot welding [3]. The inherent drawbacks of these processes including the need to access both sides of the workpiece, the tool damage and the consequent contamination of the fusion zone, and the need to apply large forces [4,5] make it necessary to investigate other welding processes.

Laser welding has been recognized as one of the major welding processes in the automotive industry since the invention of the welded tailor blanks [6]. In addition to other unique characteristics such as fiber optic delivery and high processing speeds, it can overcome the above-mentioned shortcomings since it is a non-contact and one-side access process [7]. Some recent studies were conducted on laser welding of Mg alloys to uncoated steel. Liu and Zhao [8] have applied hybrid laser-TIG process to lap weld Mg to stainless steel claiming that it is almost impossible to join Mg alloys to steels by conventional fusion welding processes. However, adequate joint strength could not be realized. Given that Mg does not dissolve in Fe below 1000 °C and the maximum solid solubility of Fe in Mg is 0.00041 at.% Fe [9], the metallurgical bonding and consequently the joint strength could be improved by the application of interlayers that can interact with both Mg and Fe such as Ni, Cu and Sn [10,11]. As for butt welding, a maximum tensile strength of 185 MPa could be obtained by laser penetration brazing where the laser beam was offset and irradiated on Mg side [12]. Nevertheless, no work has been reported on laser welding of magnesium alloys to Zn-coated steel.

In the current study, high power disk laser was employed to lap weld AZ31B magnesium alloy to Zn-coated steel under different processing parameters. The joint strength was evaluated and the joining mechanism was analyzed. The influence of the Zn-coating layer on the joining process was elucidated by comparative welding experiments on uncoated steel.

2. Experimental procedures

AZ31B extruded magnesium alloy (3.28 wt.% Al, 0.81 wt.% Zn, 0.29 wt.% Mn and balance Mg) plates of 3 mm thickness and 1.2 mm thick plates of SP781 Zn-coated steel and SP121 uncoated steel (0.002 wt.% C, 0.014 wt.% Si, 0.159 wt.% Mn, 0.0107 wt.% P, 0.0048 wt.% S and balance Fe; thickness of Zn layer ~9 μm) were used as the base materials. The laser source employed was 16 kW continuous-wave disk laser (Trumpf-TruDisk 16002) producing a

---

* Corresponding author. Address: Joining and Welding Research Institute, 11–1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan. Tel.: +81 80 3843 0055.
E-mail address: wahba@jwri.osaka-u.ac.jp (M. Wahba).

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.10.031

beam with 1.03 μm wavelength and 8 mm mrad beam parameter product (BPP). A laser beam was transmitted through an optical fiber of 200 μm diameter and focused on the workpiece surface by a lens of 280 mm focal length. The focusing head was set at a forward angle of 80° relative to the workpiece. During welding, the top surface of the specimens was shielded by Ar gas flowing at 30 L/min through a 16 mm diameter nozzle directed in the welding direction at an angle of 50° with the specimen.

AZ31B specimen was lapped on the top of SP781 specimen by a holding fixture. The specimens were positioned so that the top surface of the AZ31B specimen is 7 mm above the focal point of the laser beam. Laser power was set at 2 kW and the welding speed was varied from 2 to 4 m/min. Metallographic samples were cut across the weld line, mounted, polished and two-step etched with an aqueous solution of 30 mL acetic acid, 15 mL water, 6 g picric acid and 100 mL ethanol for AZ31B sample and then with 5% nital (95 mL ethanol + 5 mL nitric acid) for SP781 specimen. Macrostructures of the weld fusion zones were examined with optical microscope. The microstructures and the chemical compositions were investigated using a scanning electron microscope (SEM) coupled with energy dispersive X-ray spectroscopy (EDS) on as-polished specimens. Thin foils for transmission electron microscopy (TEM) were prepared by focused ion beam (FIB) technique. Specimens for tensile shear testing were cut perpendicular to the weld bead with 25 mm width. Testing was conducted at a constant cross head speed of 1 mm/min.

3. Results and discussion

Fig. 1a–c shows typical fusion zone macrostructure of AZ31B/SP781 joints. A high aspect ratio of fusion zones were formed in AZ31B indicating the formation of a keyhole. Owing to the large difference in the melting points and thermal conductivities between Mg and Fe, much narrower fusion zones were formed in SP781 specimens. The depths of penetration into SP781 specimens (hereafter referred to as Fe-penetration) were found to decrease with increasing the welding speed from 2 m/min (Fig. 1a) to 3 m/min (Fig. 1b). At 4 m/min welding speed (Fig. 1c) the energy input was inadequate to fully penetrate the AZ31B sheet and lap joining could not be achieved. Whenever the energy input was enough to penetrate into SP781 specimens (Fig. 1a and b), Fe particles were found to exist in the fusion zone of AZ31B specimens indicating a strong stirring action inside the AZ31B molten pool due to a keyhole induced with the laser beam. The welding speed not only affected the depth of penetration but the process stability as well. It was observed at a low welding speed that the molten metal was recurrently ejected from the weld pool in the form of an excessively large number of spatters. This resulted in underfilled joints, as seen in Fig. 1a. The process stability was observed to be improved with increasing the welding speed. Spatters were hardly formed when the laser beam did not penetrate into SP781 specimen.

These observation results suggest that decreasing the welding speed (increasing the energy input) resulted in the formation of a keyhole in SP781 specimens and the consequent evolution of Fe plume. At high energy inputs the Fe plume was strong enough to disturb the stability of the above molten pool and to eject the liquid metal in the form of spatters. A wide and deep Fe-penetration zone, which can be obtained at high energy input, is necessary in terms of the joint strength. However, the massive spatters that were formed at 2 m/min welding speed required a frequent replacement of the protective glass of the laser head. This, in addition to the concurrent large degree of underfilling, reduces the practicability of the welding process. On the other hand, the relatively more stable process at 3 m/min welding speed produced a

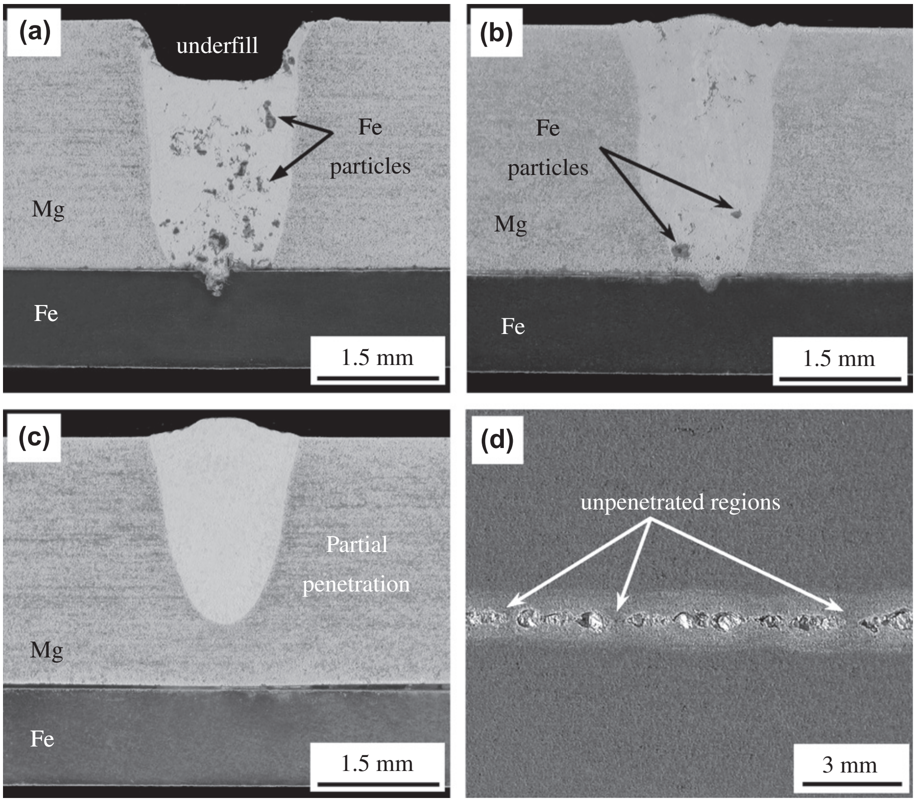

Fig. 1. Cross-sectional macrostructures (as-polished steel specimen) of AZ31B/SP781 joints produced at 2 kW laser power and welding speed of (a) 2 m/min, (b) 3 m/min and (c) 4 m/min and (d) fracture morphology on the steel side of joint in (b).