Materials and Design 31 (2010) 605–609

Contents lists available at ScienceDirect

Materials and Design

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

Short Communication

Interfacial structure of the joints between magnesium alloy and mild steel with nickel as interlayer by hybrid laser-TIG welding

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A R T I C L E I N F O

Article history:
Received 12 May 2009
Accepted 29 June 2009
Available online 1 July 2009

A B S T R A C T

The joint interface of Mg alloy to steel with Ni interlayer was investigated. Comparing with that without any interlayer, the joint shear strength was improved significantly. The characterization of interfaces in the joint with Ni interlayer was analyzed and discussed. The results show that the formation of intermetallic compound Mg_2Ni and solid solution of Ni in Fe at the interface altered the bonding mode of joints which contributed to the increase of the tensile shear strength in contrast to the direct joining of Mg alloy to steel. Owing to the addition of Ni interlayer, the conclusion is that the bonding mode of Mg alloy to steel from mechanical bonding to semi-metallurgical joining.

1. Introduction

Mg alloy is the lightest structural material in industry, and its application will go rapidly in the near future because of many unique properties such as low density, high specific strength along with good damping capacity [1]. Currently, it is no doubt that steel is a widely used material almost everywhere in industry. However, it is a trend for industry to join dissimilar materials together such as Mg alloy and steel to achieve versatile properties of one part [2–4].

Since differences between the two materials in properties are great, like melting point, thermal conductivity etc., so far the report on welding of the two materials has been rare. Liu and Zhao [5] investigated joint formation of Mg alloy to steel without any interlayer, showing that there was complex metallic oxide which could deteriorate the joint strength at the interface of Mg and steel. As is well known, it is almost no inter solubility and reaction between Mg and Fe element, thus it is a big challenge to be joined them together through welding directly. That searching for another material which can interact with both Mg alloy and steel may be an available method.

Hybrid Laser-TIG welding is an advanced technique for Mg alloy and that with dissimilar materials [6]. The incorporation of TIG that is tungsten inert gas welding could help materials improve not only the absorption of laser power [7] but also the penetration of molten pool. Generally, the action of laser and TIG welding is different applying to work-piece consisted of dissimilar materials. The TIG torch that can provide much heat input is employed to melt materials with high thermal conductivity, whereas laser is used to create a deep penetration on other materials. Such technology is especially suitable for welding of dissimilar materials like Mg alloy and mild steel.

In accordance with the binary diagrams, nickel was picked as an intermediate element in the present experiment. The aim of the study is to investigate the interfacial microstructure of the joints between Mg alloy and steel with Ni as an interlayer by hybrid Laser-TIG welding. The characterization of interfaces at joints was analyzed and discussed.

2. Experimental procedure

The base materials used in this study were a 1.7 mm thick AZ31B Mg alloy sheet with nominal composition of Mg–3Al–1Zn–0.2Mn–0.1Si (wt.%), and a 1.2 mm thick Q235 steel with that of Fe–0.2C–0.3Si–0.7Mn (wt.%), whose dimensions are both 60 × 100 mm. The pure Ni interlayer with a dimension of 0.1 × 68 × 10 mm was employed. The two sheets were degreased and ground before welding. Mg alloy was put on the steel sheet in a lap joint configuration with hybrid laser-TIG welding setup above, the relative position of which is shown in Fig. 1a. The optimum parameters that joined the two different metals with Ni layer successfully in the experiment were 100 A of TIG current, 420 W of laser power, 850 mm/min of welding speed, and gas flow of 10 L/min. Thereafter the weldment was machined into rectangular shape (the dashed in Fig. 1a) and undergone tensile shear test in an electronic tension machine (Css-2205 in Fig. 1c) with a travel speed of 2 mm/min at room temperature. Tensile shear strength of joints is the average value of 3–4 specimens. Supporting plates were added at each end to maintain the lap joint parallel to the load direction shown in Fig. 1b.

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doi:10.1016/j.matdes.2009.06.043

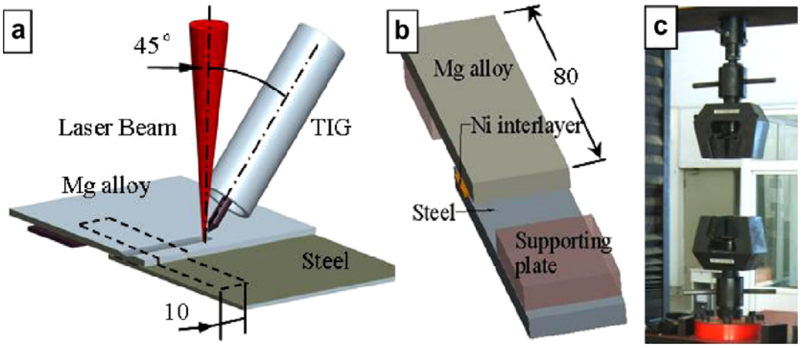

Fig. 1. Sketch of (a) setup, (b) the specimen for tensile test and (c) tensile test machine (mm).

The cross-sectioned specimen was prepared in accordance with the metallographic method, and was etched by Keller's reagent for Mg alloy and Nital's (4 vol.% HNO_3 + ethanol) for steel. Transverse cross-sections and fracture surface were analyzed by scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDS), element distribution in the joints was carried out by electron probe micro-analyzer (EPMA), and phases at the interface of Mg alloy/Ni interlayer and that in the fracture were analyzed by X-ray diffraction (XRD).

3. Results

Due to the addition of Ni interlayer, the fracture of joints exhibited some new characteristics comparing with that in Ref. [5]. Ni interlayer was attached to AZ31B magnesium alloy tightly, and specimens were failed between Ni interlayer and steel as shown in Fig. 2b and c after tensile shear test. Fractured surfaces at both sides can be seen as rectangular shape, and almost parallel to the load direction as there is not much deformation occurred at the lap joint shown in Fig. 2c, thus the shear strength of the joint could be defined in the present experimental process as $\sigma_{b\_shear} = F/S_{||}$, where F and σ_{b_shear} are the load and the maximum shear strength, respectively; $S_{||}$ is a rectangular sectional area paralleled to the load before tensile shear test, whose width is shown in Fig. 3 and located at the start and end of the gap between Ni and steel.

The macro-morphology of the weld seam is also shown in Fig. 2a. As the energy of hybrid laser-TIG is highly concentrated, some splash of molten Mg alloy was generated causing the bead a little rough. Nevertheless, there are not any porosities or cracks at the bead.

Fig. 3 shows characteristics of a cross-sectioned joint. Some big particles distributed unevenly in the joints exhibited by arrows, which may ascribe to the stirring effect resulted from strong convection in the welding pool under the action of high power laser. From the interface of Mg alloy and Ni interlayer, we can see that a new ribbon-shaped phase layer was generated at both upper ends of the molten pool along the surface of Ni interlayer shown in Fig. 4a and b, with a distinct dendrite on top and compact lamellar structure at the bottom shown in Fig. 4c.

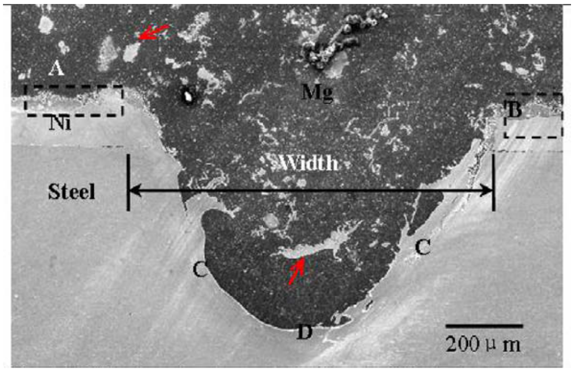

Fig. 3. SEM microstructure of a joint with Ni interlayer.

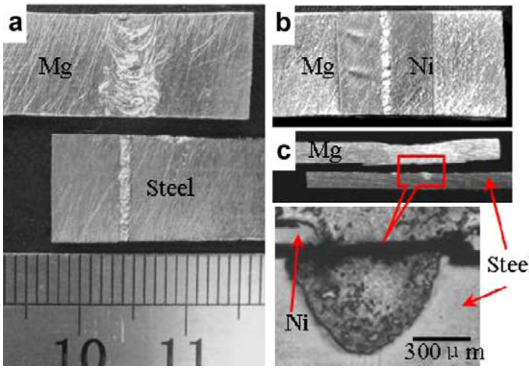

Fig. 2. Fracture location of joints: (a) front location; (b) interfacial fracture location and (c) side fracture location.

Fig. 4d and e present the interface between Mg alloy and steel in the molten pool. it is observed that a transitional layer between the dashed and the distinct white boundary existed, map analysis shows that these layers did not contain Mg element shown in Fig. 5b, indicating that Mg did not react with Ni or diffused into the layer. However this layer is not net Ni interlayer any more, as is shown in Fig. 5c. In light of Fe element distribution in Fig. 5d and the Fe–Ni binary phase diagram, the transitional layer is solid solution of Ni in Fe [8,9]. As the flow in the present experiment was intense and the compelling convection moved clockwise [10,11] on the right of the centerline shown in Fig. 4f, thus the vortex was produced in molten pool. Due to the action of the flow, the solid solution accumulated at the bottom of the pool, formed the final morphology shown in Fig. 4e.

Fig. 6 shows the XRD spectra obtained from the fracture of Mg alloy/steel and from the interface of Mg alloy/Ni interlayer. As Ni interlayer attached to Mg alloy tightly and the appearance of fracture is too tiny, it is inevitable for Ni interlayer at the margins of fracture to be detected. Some low intensity peaks of α-Mg shown in Fig. 6a indicating that the fracture is consisted of a majority of remelted Mg alloy. The analysis shown in Fig. 6b shows that the solid solution of Ni in Fe and remelted Mg alloy were filled in the welding pool. Combining with Fig. 4d, e and EDS analysis, the solid solution in welding pool was the area that is between the distinct boundary and the dashed. However, intermetallic compound (IMC) Mg_2Ni is not found at the fracture from Fig. 6a and b, suggesting that the phase may not be in the pool. Whereas the XRD pattern in Fig. 6c exhibits some new but weak peaks suggesting that Mg_2Ni