Interfacial Structure of the Joints between Magnesium Alloy andmild Steel with Nickel as Interlayer

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Abstract—The joining of magnesium alloy AZ31B and mild steel Q235 is realized by the addition of a Ni interlayer using resistance spot welding technique. The bonding mechanisms of the dissimilar joining have been investigated using mechanical testing and metallurgical examination. The results show that the formation of intermetallic compound (Mg2Ni) and solid solution of Ni in Fe at the interface plays an important role in the bonding of Mg alloy and steel at the centre of the nugget zone, which contributes to the increase of the tensile shear strength of joints. Besides, Mg alloy and Ni interlayer are joined by Mg2Ni intermetallic compound layer at the edge of the nugget zone, but steel and Ni interlayer only form a mechanical bonding.

Keywords- Mg; Steel; Interlayer; Welding; Introduction

I. INTRODUCTION

As is well known, steel is one of the dominant materials in industry and Mg is the lightest structural materials, therefore dissimilar welding of Mg alloys and steel is of great significance for the increased fuel economy and improved vehicle performance [1-4].Several studies are available in literature regarding the processes used to join Mg to Fe, such as friction stir welding [5, 6], laser-tungsten-inert gas (TIG) hybrid welding [7, 8] and laser penetration brazing [9]. The problems encountered during dissimilar welding of Mg alloys and steel stem from the widely differing thermophysical properties (melting points, tensile strength), few solid solubility of Mg in Fe and the no tendency for intermetallic layer formation during the welding process. It is apparent from the binary Mg/Fe equilibrium phase diagram that the solid solubility of Mg in Fe is 0.00043 at.%, furthermore, there are not any types of intermetallic compounds between them. Therefore, resistance welding remains the principal joining process in the vehicle industry, but dissimilar joining between Mg alloy and steel using resistance spot welding (RSW) is problematic [10].

Liu et al. studied the joining of Mg alloy AZ31B and zinc-coated DP600 steel sheets using RSW. The result showed that Zn coating played an important role in facilitating the joining of Mg alloy to steel [10]. However, limited publications focused on the RSW of Mg to bare-steel. In the previous studies, the addition of Ni interlayer was proved to be an effective method to enhance the shear strength of weld joint of Mg alloy to steel [8, 11]. Ni can react with Mg and Fe in terms of their binary diagrams, thus metallurgical bonding between Mg alloy and Q235 mild steel may be realized, which may contribute to the improvement of strength of weld joints. Therefore, the RSW of Mg alloy and bare-steel may be potential by the addition of Ni interlayer.

In the present paper, the feasibility of joining of Mg alloy AZ31B and bare steel sheets with the addition of Ni interlayer using RSW is investigated. In addition, interfacial characterization of the joints between Mg alloy and steel with Ni as an interlayer is discussed.

II. EXPERIMENTAL PROCEDURES

A. Materials and welding parameters

The plate (80×12×1.7 mm) of AZ31 Mg alloy and the plate (80×12×1.2 mm) of Q235 steel were used for RSW with the compositions of Mg-3Al-1Zn-0.2Mn-0.1Si(wt%) and Fe-0.2C-0.3Si-0.7Mn (wt%), respectively. The two plates were overlapped with the Mg alloy plate on top. The Ni interlayer with 99.9 wt% in purity and 0.1 mm in thickness was set between the two plates. Before welding, they were degreased and ground by acetone and

abrasive papers. The specimens were welded using a median-frequency DC RSW machine. RSW process was carried out in an air atmosphere. The Flat-ended, round, Cu-1.0%Cr electrodes of 8 mm diameter were used. In addition, the welding force and weld time were 1100N and 0.4s, respectively.

B. Analyzes of weld joint

The samples used for microstructure analyses were abraded by 80#, 400#, 800# and 1000# grit emery papers and then polished by 1.0 μm diamond paste. Afterwards, the samples were etched with nital or picric acid based etchant solution. Transverse cross-sections were analyzed by scanning electron microscope (SEM) with energy dispersive X-ray spectros-copy (EDS). The average value of strengths for at least 3 specimens was taken as the shear strength of the lap joint.

The weld joints were machined into the specimens for the shear testing. The tensile shear strength was calculated as follows:

$$\sigma_{\text{b-shear}} = \frac{F}{S}$$

where, F and σb_shea are the load and the ultimate shear strength, respectively. S is a rectangular bonding area of the joint before the shear testing, which could be evaluated according to the size of the fracture surface. The average value of strengths for at least 3 specimens was taken as the shear strength of the lap joint.

III. RESULTS AND DISCUSSIONS

Macrostructure characterization of weld joint

Fig. 1 shows the surface view of Ni-added Mg-steel weld joints. It is found that the Mg alloy and steel could be joined by RSW. Fig. 2 shows the cross-section macrograph of Mg-steel joints. It can be seen that there are some pores in the nugget zone. In the RSW, the symmetric tip contours are used to weld Mg to steel, and then the heat generation and peak temperature at the steel side are much higher than those on the magnesium side (bulk resistance and thermal conductivity of magnesium are less than those of steel and Ni), which could induce the melting of steel, evaporation of magnesium, and formation of pores in the nugget zone.

Figure 1. The surface view of Ni-added Mg-steel weld joints

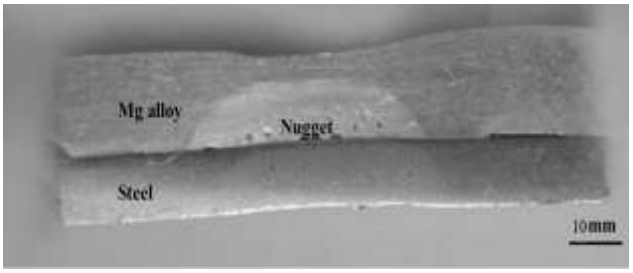

Figure 2. The cross-section macrograph of Mg-steel joints.

Microstructure characterization of nugget zone

Fig. 3 shows the microstructure characteristic of right side of a cross-sectioned joint. Two regions are defined according to the reaction content of Ni interlayer and substrate.

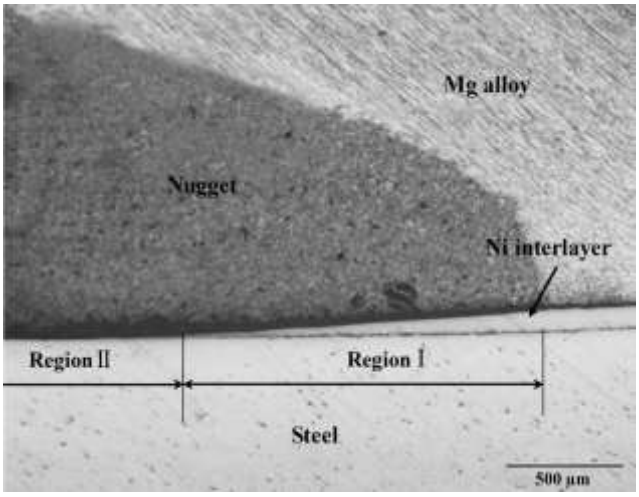

Figure 3. The microstructure characteristic of right side of a cross-. sectioned joint

Fig. 4 and 5 show the microstructure of Mg-steel interface in Region Ⅰand Ⅱ, respectively. In the Region Ⅰ, it is found that the melting of Ni is not sufficient because of the low temperature at the edge of nugget zone. Between Mg alloy and Ni interlayer, a new ribbon-shaped phase layer is generated indicting that Mg and Ni interlayer form a good metallurgical combination. However, Ni and steel almost could not form a connection in this zone. With increasing the temporary, the Ni interlayer almost disappears and begins to dissolve into the Mg substrate in the Region Ⅱ.

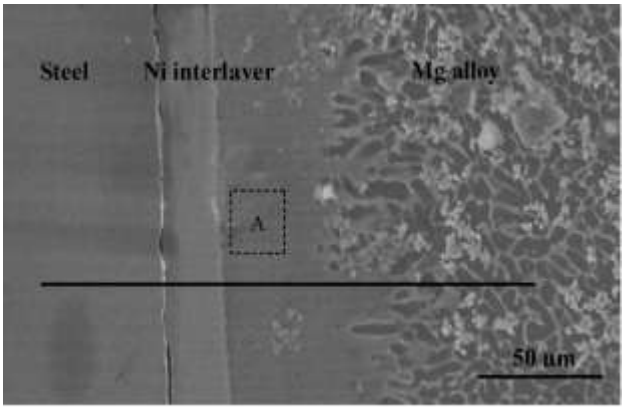

Figure 4. The microstructure of Mg-steel interface (Region Ⅰ)

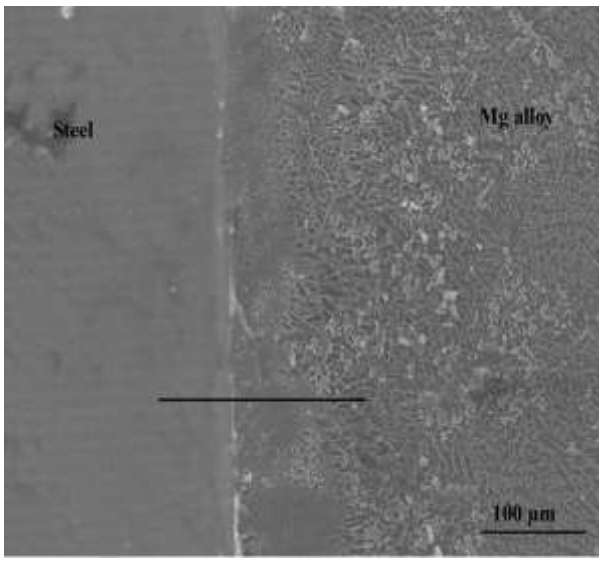

Figure 5. The microstructure of Mg-steel interface (Region Ⅱ)

The new phase formed by the Mg and Ni interlayer improves the wettability of the Mg substrate on the steel surface and enhances the bonding strength of Mg alloy and steel. EDS results show that point A of Fig. 4 contains (wt) 40.1% Mg and 59.9% Ni implying that the IMC layer is composed of Mg_2Ni. However, for Ni-steel interface, little interdiffusion between Ni and steel is detected, which indicates that there are no reactions between them. According to the results of EDS and Fe-Ni binary phase diagram, the transitional layer is solid solution of Ni in Fe [12].

In the welding process, the steel and Ni interlayer at the interface could be melted at the same time and dissolved into each other, whereas the mixture of them could still be maintained without decomposition due to swift solidifying in the welding process. However, when the mixture of Ni and Fe is in liquid state, its temperature must be as high as 1400 ℃ at which Mg element must be in gaseous state. Therefore, there is no chance for Mg and Ni to be reacted at the same time, and thus no IMC layer is found in the TZ adjacent to the steel side. In the TZ adjacent to the Mg alloy side, there is obvious element diffusion of Mg and Ni. In the welding process, the reaction of molten Ni and Mg is sufficient, consequently, a layer of intermetallic compound is generated in this zone. At the same time, some Ni elements dissolve into the nugget zone of Mg alloy side. The content of Ni element is much lower than that of Mg in the nugget zone, so the Mg2Ni phases are formed and present discontinuous reticular shape in the nugget zone as shown in Fig. 6.

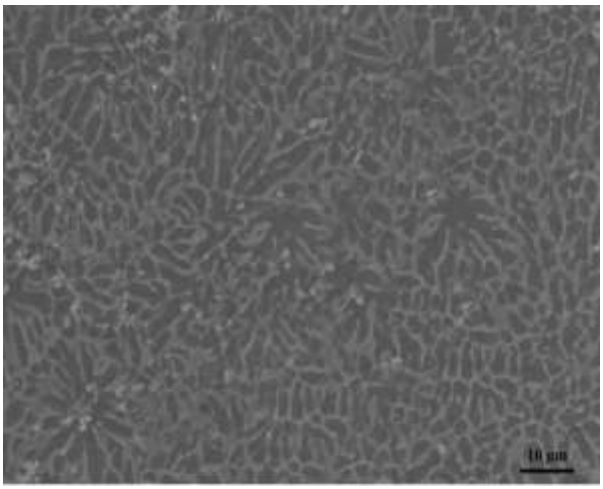

Figure 6. The microstructure of nugget zone on Mg alloy side

A. *Testing of tensile shear strength*

Fig. 7 shows the fracture location of Mg-steel joint. It can be seen that fracture usually occurs at such locations between interlayers and steel. The tensile shear test shows that the average shear strength of the joint is 75MPa, which indicates that Mg and steel forms a good joining with the addition of Ni interlayer using RSW.

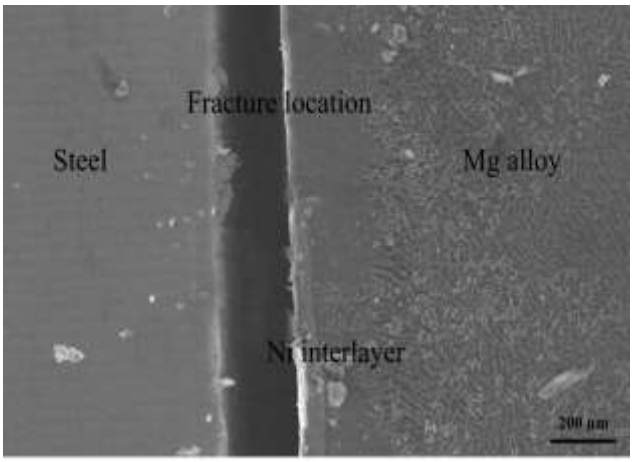

Figure 7. Fracture location of Mg-steel joint

IV. CONCLUSIONS

AZ31B Mg alloy and Q235 steel are successfully joined using RSW technique. The shear strength of joint could

reach 75 MPa. The addition of Ni interlayer plays an important role in enhancing the strength of Mg-steel joints. The IMC layer Mg2Ni is generated at the Mg-Ni interface (Region Ⅰ and Ⅱ), and the solid solution of Ni in Fe is detected at the centre of the nugget (Region Ⅰ), but there is no metallurgical bonding between them at the edge of the nugget zone (Region Ⅰ).

ACKNOWLEDGMENT

The authors gratefully acknowledge the sponsorship from University Students' innovative training program (2012099), Liaoning Province Doctor Startup Fund Program Funded by Liaoning Province Education Administration (20131087) and Doctor Starting Foundation for Shenyang Aerospace University (12YB09).

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