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Dissimilar Joining of Magnesium Alloy and Steel by Resistance Spot Welding

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Abstract

Recently, there are strong demands for light-weight, fuel efficient cars. An effective joining technique to join light metals, such as Al and Mg alloys, with steel is required. Mg alloy and steel are especially difficult pair of metals to join. Due to not only Mg alloy's surface oxide, but also their complete phase separation nature, Mg alloy and steel do not form an intermetallic at the joint interface. We aimed to join Mg alloy and steel by using Mg-Zn eutectic reaction, Zn layer was inserted between Mg alloy and steel as plating on steel. A conventional resistance spot welding machine was used, and joint strength was evaluated by tensile strength tests. It was found that Mg alloy surface oxide are removed along with eutectic melt at low temperature, and at the same time, thin and uniform intermetallic layer of Fe-Al and Al-Mg were formed at the joint interface.

1. Introduction

Reduction of fuel consumption and curbing carbon dioxide (CO_2) emissions are key issues being tackled by the automotive industry to resolve energy problems and the problem of global warming. Vigorous efforts are being made to develop technologies for improving powertrain efficiency [1] and for lightening the vehicle body [2] as measures for addressing these issues. Material substitution of light metals such as aluminum alloys, magnesium alloys for steel is an effective way to reduce the vehicle body weight, and the establishment of effective techniques for joining aluminum alloys and steel has been strongly desired [3-5] Previously, we developed an effective method for dissimilar joining of aluminum alloys and steel sheet by resistance spot welding [6]. Further weight savings can be expected by applying magnesium alloys to the body at the view point of the strength-to-weight ratio. Proceeding from the dissimilar joining of aluminum alloy and steel, we then developed a dissimilar joining of magnesium alloy and steel.

2. Dissimilar materials joining concept for magnesium alloys and steel

Figure. 1 shows a binary phase diagrams of Mg and Fe. The Mg and Fe system has an almost complete phase separation nature. The fact that there is little reactivity between the two elements makes it difficult to join them directly. Furthermore, the presence of an oxide film on the surface of a magnesium alloy also makes it difficult to achieve dissimilar joining of a magnesium alloy and a steel sheet. These issues must be solved in order to join a magnesium alloy and a steel sheet.

Figure. 2 shows a binary phase diagram of Mg and Zn. The Mg and Zn system has an eutectic point at 341 degrees Celsius and undergo a eutectic reaction at the low

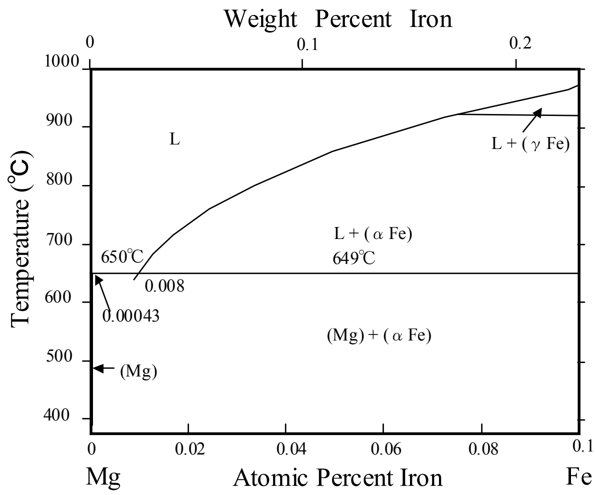

Fig. 1 Mg-Fe binary phase diagram

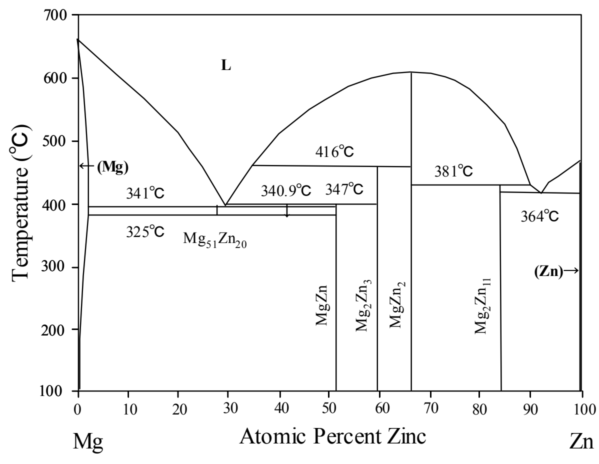

Fig. 2 Mg-Zn binary phase diagram

temperature. We focused on this point and tried to use the low-temperature eutectic reaction of Mg and Zn to remove the oxide film on the magnesium alloy surface. And both Fe-Al and Al-Mg are combinations that generate intermetallic compound (IMC) layers. By using Al, IMC layers of Fe-Al and Al-Mg can be obtained at the joint interface. In this way, we devised our concept for dissimilar joining of a magnesium alloy and steel sheet metallurgically by means of aluminum. Our joining concept is to achieve such like a joint structure within the short cycle time of resistance spot welding.

3. Experimental procedure

The materials used were a zinc coated steel (GI steel) sheet and a magnesium alloy plate (AZ31). Cross-sectional observations were performed by an auger electron spectroscopy (AES) and a scanning electron microscope (SEM) to verify whether the oxide film on the magnesium alloy surface was removed and whether the IMC layer was formed. In addition, transmission electron microscope (TEM) observation and selected area electron diffraction (SAED) analysis were performed in order to analyze and identify in detail the reaction products produced at the joint interface.

Joint strength was evaluated using a tensile test complying with Japanese Industrial Standards Z3136. Fatigue property was evaluated under a tensile shear mode using test procedure and test pieces complying with Japanese Industrial Standard Z3138 that specifies a fatigue test procedure for spot-welded joints. The test was discontinued at a maximum number of cycles of ten to the seventh power. And we found the maximum load that indicated the fatigue limit.

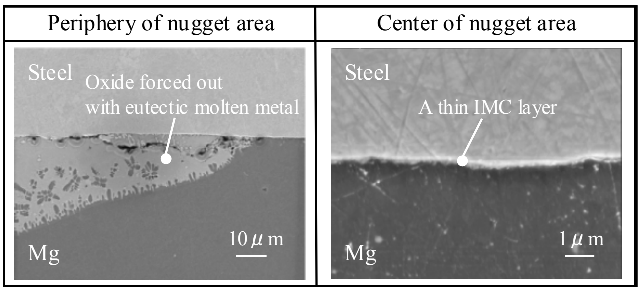

Fig. 3 Cross section of joint interface

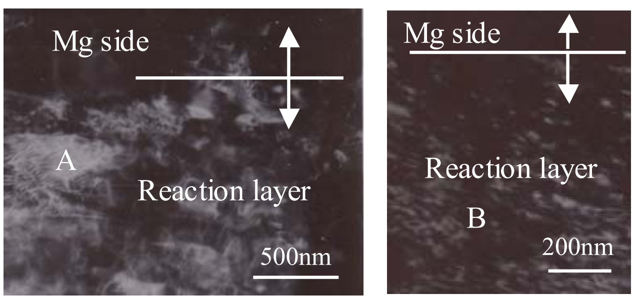

Fig. 4 TEM microphotographs of joint

4. Results and discussion

4.1 Results of joint interface observations

Figure. 3 shows SEM images and the AES analysis of the interface of the joint formed with the proposed joining technique, for a combination of the galvanized steel sheet and magnesium alloy plate. These observation results confirmed that an IMC layer can be formed with this process as a result of removing the oxide layer on the magnesium alloy surface in the eutectic melt and effectively evacuating it toward the periphery of the joint area.

Figure. 4 shows TEM images of a joint interface. We conducted SAED analysis on the regions labeled A and B in **Fig. 4**. The results showed that region A was the Fe_2Al_5 phase and that region B was the $Al_{12}Mg_{17}$ phase. The boundaries of regions A and B were not clear, and we presume that the reaction layer was a mixture of these two phases.

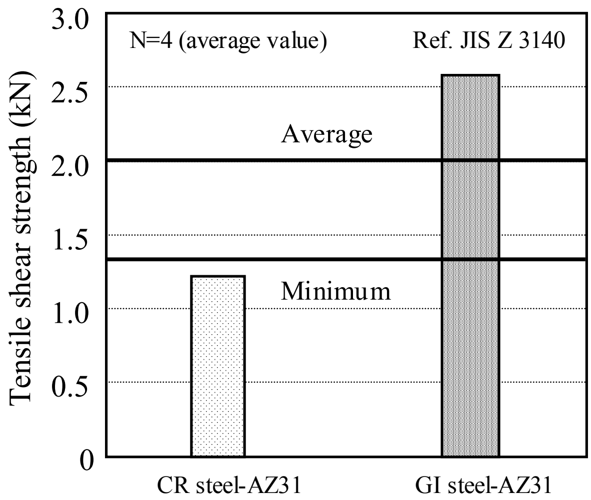

Fig. 5 Tensile test results

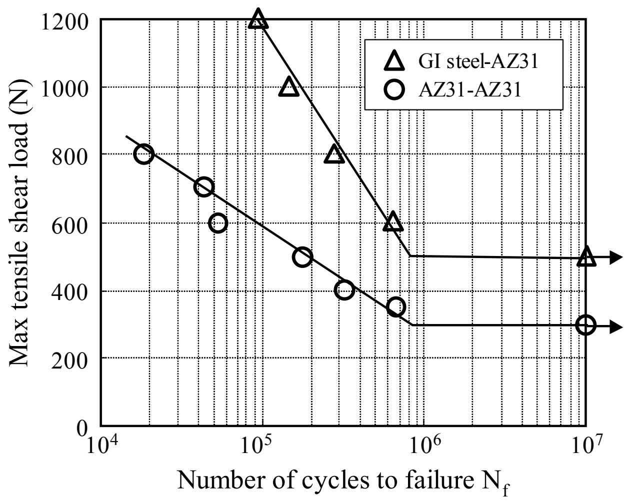

Fig. 6 Fatigue characteristics

4.2 Tensile test results

Figure. 5 shows the tensile shear strength results. Tensile shear strength was evaluated according to Japanese Industrial Standard Z 3140, which specifies a test method for spot-welded joints. The tensile shear strength of the joint formed with our method between the galvanized steel sheet and the magnesium alloy plate satisfied the average value of Class A of the standard, thus indicating a good joint property. In contrast, the joint between the cold-rolled steel (CR steel; without zinc coating) sheet and the magnesium alloy plate, which was used for comparison, showed a low level of strength and did not satisfy the joint quality specified by this standard. We presume that the oxide film on the magnesium alloy surface hindered joint formation, making it impossible to produce a reaction layer over a wide area of the joint surface. As a result, a metallurgical joint was not formed, which would result in the low level of strength.

4.3 Fatigue test results

Figure. 6 shows the fatigue properties under tensile shear loading.

The horizontal axis indicates the number of cycles to failure, and the vertical axis shows the maximum applied load. Under both loading modes, the joints formed with our proposed method showed excellent fatigue properties superior to the characteristics seen for the spot-welded joints made of the same magnesium alloy.

5. Conclusions

Developed a unique method for dissimilar joining of a magnesium alloy and a steel sheet.

Eutectic reaction between Zn and Mg is used effectively to remove oxide film on magnesium alloy surface at low temperature. Fe-Al and Al-Mg diffusion reactions are used to form IMC layers of Fe-Al and Al-Mg, enabling the dissimilar materials to be joined metallurgically.

Joints formed with proposed joining concept showed good fatigue properties at the same level as the joints of magnesium alloy.

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