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Dissimilar material laser welding between magnesium alloy AZ31B and aluminum alloy A5052-O

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Abstract

Joining technology of lightweight dissimilar metals between magnesium and aluminum alloys is essential for realizing hybrid structure cars and other engineering applications. In the present study, the normal center-line welding of lap joint was carried out by laser welding. It was found that the intermetallic layer formed near interface between two metals significantly degraded the joining strength. FEM heat transfer analysis was carried out to find out an available method to control penetration depth and width of molten metal, which contributes to control thickness of intermetallic compound layer. Based on the results of FEM analysis, the edge-line welding of lap joint was carried out, which could easily control the thickness of intermetallic layer and successfully obtained high joining strength.

Keywords: Dissimilar metal joint; Laser welding; Lap joint; Light weight metal; Magnesium alloy; Aluminum alloy

1. Introduction

Magnesium and aluminum alloys are attractive in vehicle structure application for improving energy efficiency, which also contributes to reduction of the emission of green house affecting gases. In order to apply these alloys to vehicle structures, dissimilar joint between magnesium and aluminum alloys is required. The intermetallic compounds are found in phase diagram between Mg and Al; Al_3Mg_2, $Al_{12}Mg_{17}$ and $Al_{30}Mg_{23}$ [1]. Due to brittleness of intermetallic compound, the intermetallic compound formation has to be controlled as less as possible during joining process. According to Rathod and Kutsuna [2] and Miyashita et al. [3], in case of dissimilar joints such as steel/aluminum alloys and titanium/aluminum alloys, it is easy to realize solid/liquid state reaction only at joining interface between two metals, where only the metal with lower melting temperature is melted. However, it is difficult to apply this method to magnesium/aluminum alloys joint due to the small difference of melting point between the two metals. Therefore, another approach to control intermetallic compound formation has to be developed for joining magnesium and aluminum alloys. The controlling penetration depth of molten metal in lap joint configuration as shown in Fig. 1 might be a possible approach for reducing intermetallic compound formation. In the present study, laser welding between magnesium alloy AZ31B and aluminum A5052-O was carried out. Since the penetration depth of molten metal in lap joint will be one of important factor for controlling the thickness of intermetallic compound layer, FEM analysis for estimating shape of molten metal was also carried out. Based on the results of laser welding experiments and FEM analysis, suitable lap joint configuration as well as laser welding conditions were investigated.

2. Experimental procedure

Magnesium alloy AZ31B and aluminum alloy A5052-O of 1 mm thickness sheet were used in this study. The chemical composition specified by ASTM and mechanical properties obtained by a tensile test of these metals is shown in Tables 1 and 2, respectively. Nb–YAG laser with continuous wave was used for welding. Oxide film on

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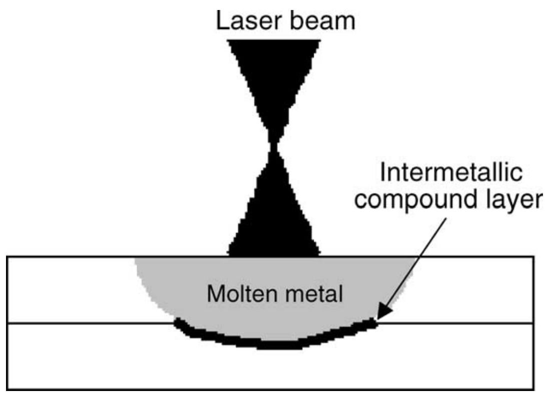

Fig. 1. Laser welding of lap joint.

the specimen surface was removed by 1500 grids emery paper before welding. Argon gas with flow rate of 40 l/min was used as a shield gas. After welding, tensile–shear tests and cross-sectional observations of welding region were carried out. Tensile–shear specimens were machined from welded lap joints, geometry of which is shown in Fig. 2.

3. Results and discussion

3.1. Center-line welding lap joint

Laser was applied on the center-line of lap part of the upper plate, as shown in Fig. 3. The laser power and focal distance used were 3 kW and +5 mm, respectively. Power density at the condition is about 370 W/mm^2. From the experimental results, it was found that welding was possible only for the case of AZ31B upper plate. Oxidation layer was found on the faying surface of AZ31B in case of A5052-O upper plate, as shown in Fig. 4. The free energy of reaction between Al surface layer and Mg molten metals, which is given in Eq. (1), has been calculated to be negative in the temperature range between 923 and 1380 K [4,5].

$$Al_2O_{3(s)} + Mg_{(l)} \rightarrow MgO_{(s)} + Al_{(l)} \quad (1)$$

Therefore, magnesium molten metal can reduce Al_2O_3 but the aluminum molten metal cannot reduce MgO. MgO oxide layer may be remained and influence on weldability of AZ31B/A5052-O in case of A5052-O upper plate.

From the cross sectional observations, molten metal of upper plate partially penetrated in the lower plate in all welded specimens. From EDS analysis, the intermetallic compound layer between weld pool and lower plate metal was found for all welded samples. The layer was composed of Al_3Mg_2 and $Al_{12}Mg_{17}$. After tensile–shear tests, it was found that failure occurred inside intermetallic compound layer, which degraded strength of the joint. The maximum failure load and strength obtained for the center-line welding lap joint were 520 N and 20 MPa, respectively, under a welding speed of 2 m/min. This failure load is about 37% of yield load of A5052-O alloy, which is calculated from to multiply the area of cross section at the gage section of the tensile specimen (14 mm^2) by yield strength of A5052-O.

3.2. FEM analysis for development a suitable welding method

Shallow penetration depth of molten metal in the lower plate may suppress the formation of intermetallic compound. Larger welding width will contribute to higher failure load of the joint. In order to realize these conditions and to develop an effective welding method for joining of AZ31B/A5052-O, a finite element method (FEM) analysis was carried out. ABAQUS (Version 6.3) was used for the present FEM analysis. Physical properties of the materials used in the analysis are shown in Table 3 [6,7]. The laser absorption rate and the heat transfer coefficient used were experimentally obtained. K-type thermocouples were attached on the specimen for measuring temperature during laser welding. Heating and cooling history of the FEM model was calculated by varying the values of laser absorption rate and heat transfer coefficient until it becomes coincident to the experimental results. The laser absorption rate for AZ31B plate and A5052-O plate were obtained as 0.19 and 0.165, respectively. The heat transfer coefficient of AZ31B plate and A5052-O plate were 120 and 130 W/m^2/K, respectively. Two-dimensional conduction heat transfer analysis was carried out for two kinds of models. One is the center-line welding lap joint model, as shown in Fig. 5(a), and the other is the edge-line welding lap joint model, as shown in Fig. 5 (b). Fig. 6 shows examples of the results of FEM analysis. In the analysis, molten metal zone was assumed as the region where the temperature reached to the melting temperature of the material. It is found from the figure that the shape of molten zone for center-line welding lap joint is deep, while that for edge-line welding lap joint is shallow. The welding width for edge-line

Table 1
Chemical compositions of AZ31B and A5052-O specified by ASTM

Materials	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ni	Ca	Others
AZ31B	2.5–3.5	<0.10	<0.03	<0.10	>0.2	Bal.		0.5–1.5	<0.005	<0.04	<0.30
A5052-O	Bal.	<0.25	<0.40	<0.10	0.15–0.35	2.2–2.8	<0.1				<0.15