The Research on Welding Sources and Ni Interlayer Synergy Regulation in Laser-Arc Hybrid Welding of Mg and Al Joints

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Abstract. Mg and Al alloys were joined by a laser-arc hybrid welding method with addition of Ni interlayer. The macrostructure and elements distributions of the joints were observed by the SEM and EPMA, and the plasma forms of the laser-arc hybrid welding sources were analyzed by the high speed camera. The results showed that the welding mode in Al fusion zone changed from conductive mode to keyhole mode, the intermetallic in the Al fusion zone increased obviously, which still influence the property of the joints evident. The effect of the laser induced arc was changed with the varying of laser and arc welding parameters, which made influence on the welding mode and reactions in the welding process. The regulation of the hybrid welding sources between the elements reactions was an important factor for the joining of dissimilar metals.

Keywords: Laser-arc hybrid welding · Intermetallic · Welding mode · Magnesium · Aluminum

1 Introduction

The joining technology of dissimilar metals were paid more attentions with the improvement of the materials property. If the two materials with different characteristics could be joined favorable, the advantages of the materials would give better expression. The intermetallic makes obviously influence on the property of the dissimilar welding joint. It has been reported that the formation of the intermetallic was mainly decided by the joining methods, welding parameters and interlayer [1, 2].

The joining technology of the Mg and Al alloys was the one of typical problems in dissimilar welding joining process. The Mg-Al intermetallic made harmful effect on the joint, which should be controlled carefully [3, 4]. A Ni interlayer was used by the W.S. Chang in Hybrid Laser-Friction process, and the property improvement of the joint was mainly based on the formation AlNi and $MgNi_2$ instead of brittle intermetallic compound [5]. Jian Zhang et al. used Ni interlayer in diffusion bonding Mg to Al process [6]. P. Penner et al. [7] reported the resistance spot welding of dissimilar Al/Mg combinations with Au-Ni interlayer, and the Mg_3Au intermetallic compound layer and gold–magnesium eutectic structure made obviously effect on the

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joint. Gao, M. et al. had used the Ti interlayer in laser welding Mg to Al process, and the IMC layer consisted of Al-Ti was stronger than Mg–Al IMCs [8]. It could be found that the addition of the interlayer eliminate the Mg-Al intermetallic, which made active effect on the dissimilar Mg/Al joint. Still, some new intermetallic formed during welding process, which influenced the property of the joint directly.

It was well known that the interlayer made obviously effect on the property of the joint, which changed the reaction process of the different elements [9]. However, the reactions between the dissimilar metals and the interlayer were not only decided by the interlayer, but also the thermal cycling and the solidification in the welding process, which was often decided by the welding source and the welding parameters. Therefore, there should be a synergy regulation between the welding source and the interlayer, which was helpful for the control of the reaction process.

In this study, the laser-arc hybrid welding technology was used to joining the Mg alloy to Al alloy. The hybrid welding source was used to regulate the temperature gradient in the fusion zone. The arc source was mainly used to weld the upset plate, and form the Mg fusion zone. The laser source was mainly used to weld the lower plate, and form the Al fusion zone, which was obviously smaller than that of Mg fusion zone. The interlayer was applied to control the intermetallic at the interface of the dissimilar Mg/Al joint. The objective of the current study was to explore the effects of the heat source on the bonding modes and the reactions in laser-arc hybrid welding process.

2 Experiments

A 1.5 mm thick AZ61 Mg alloy sheet and a 1.5 mm thick 6061Al alloy sheet were used in this study. The chemical compositions for the AZ61 Mg alloy and 6061 Al alloy are Mg-6 wt% Al-1 wt% Zn-0.2 wt% Mn-0.1 wt% Si and Al-1 wt% Mg-0.8 wt% Si-0.7 wt %Fe-0.3wt% Cu, respectively. A 0.1 mm thick Ni foil (99.5% purity), was elected as the interlayer. The schematic diagram for the laser–TIG hybrid welding technology is illustrated in Fig. 1.

The welding process was performed using the laser–TIG hybrid welding technique. Argon gas (15 L/min flow rate) was employed to protect the welding zone. The optimum parameters were as follows: 450 W pulse laser power (pulse peak value 7500 W); pulse width 2 ms; frequency 30 Hz; 60 A, 80 A and 100 A TIG currents; and 800 mm/min welding speed. The microstructure was examined using a scanning electron microscope equipped with an energy dispersive spectroscopy (EDS) system. The elemental distribution in the joint was determined via Electronic probe micro-analyzer (EPMA). Phase identification was performed via X-ray diffraction (XRD) from 20° to 100° at 0.02° step. Tensile test perpendicular with size of 100 mmm × 20 mm was cut to the weld direction after welding which was shown in Fig. 1, too. Tensile shear tests of samples are performed at room temperature using an Instron-type testing machine with 2 mm• minute-1 cross-head speed.

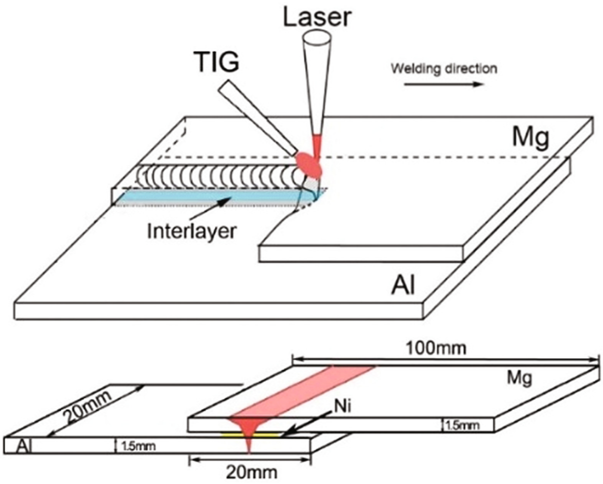
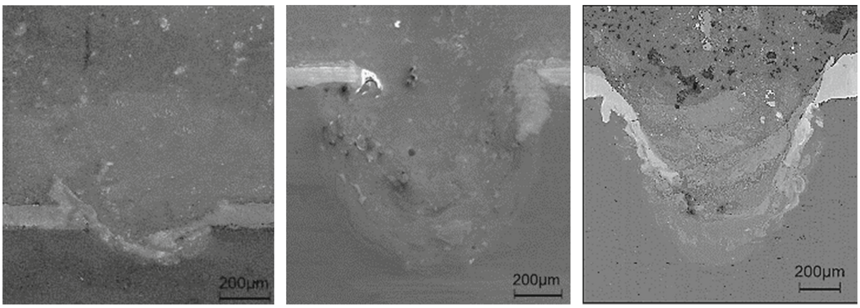


Fig. 1. Schematic diagram for laser-arc hybrid welding Mg to Al joint with Ni interlayer

3 Results and Discussion

3.1 The Welding Shape and Property of Hybrid Welding Joint

Figure 2 shows the macrostructure of the laser-arc hybrid welding Mg to Al joints with different arc welding currents. It was found that the welding penetrations were as increasing as the arc currents. When the welding currents was 60 A, the Ni interlayer was partly melted, and the tensile shear load of the joint was only 1.2 kN. As the welding currents was 80 A, the Ni interlayer was completely melted in laser area, and the tensile shear load of the joint was 2.2 kN. When the welding current was 100 A, the area of the melted Ni interlayer and the penetration were enlarged, and the tensile shear load of the joint was 1.6 kN.

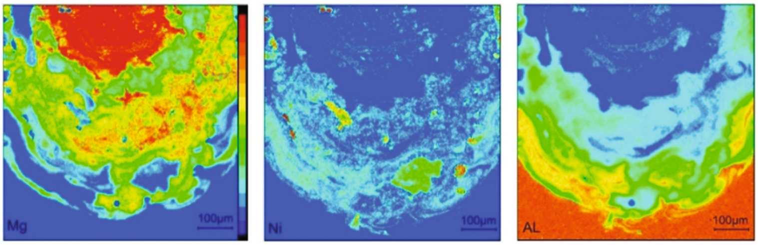


(a) I_{arc} = 60A (b) I_{arc} = 80A (c) I_{arc} = 100A

Fig. 2. Macrostructure of the hybrid welding Mg to Al joints with different arc welding currents

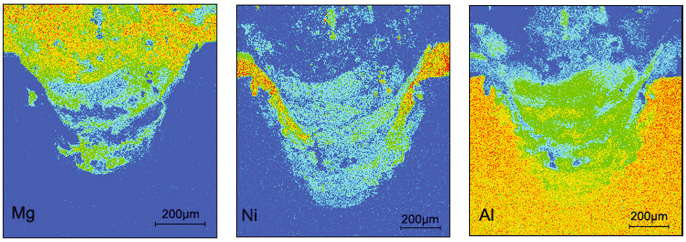
3.2 The Reaction in Welding Joint

The element Ni could react with both elements Mg and Al, which formed the Mg-Ni and Al-Ni intermetallic. In order to understand the reaction process, the elements distributions of the joints are observed by the EPMA, as shown in the Figs. 3 and 4. The joint with the 60 A current was not analysis, because the Ni interlayer was only partly melted and the property of the joint was relatively lower.



(a) Element Mg (b) Element Ni (c) Element Al

Fig. 3. Elements distributions in the hybrid welding Mg to Al joints with arc current 80 A



(a) Element Mg (b) Element Ni (c) Element Al

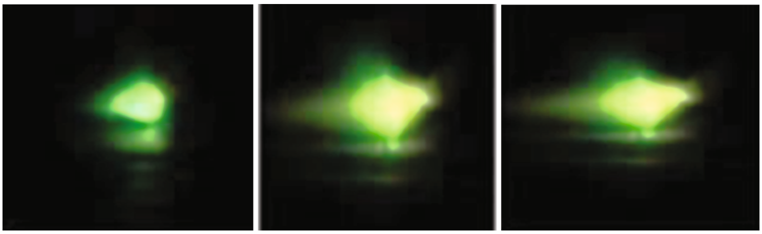
Fig. 4. Elements distributions in the hybrid welding Mg to Al joints with arc current 100 A

Seen from the Fig. 3 the concentration of element Ni approaching to the Al fusion zone is higher than that of the area approaching to the Mg fusion zone. The composition of the joint was tested and analyzed by the EDS, the results showed that it consisted of 75.86 at. % of Mg, 11.85 at. % of Ni and 12.29 at. % of Al, and the microstructure of the joint were mainly the Mg-Mg_2Ni and Mg-$Mg_{17}Al_{12}$ hypoeutectic microstructure. The element Ni and Al in these areas were distributed in high concentration, and nearly no element Mg. This kind of layer structure was firstly found in the laser-arc hybrid welding joint. In laser induced arc hybrid welding process, the welding mode for Al fusion zone was in a conducive mode. Therefore, the joint showed a layer structure. It meant that in this situation the lower laser power made little impacting and mixing effect on the fusion zone. Thus, the melted Ni interlayer was reacted with Mg and Al alloys slowly.

Figure 4 presents the elements distributions in the laser-arc hybrid welding Mg to Al joint with Ni interlayer, as the arc current is 100A. With increasing of the arc current, the welding mode in the Al fusion zone changed to the keyhole mode. Therefore, the temperature in the fusion zone would be increased, and the reactions among the elements Mg, Al, Ni were changed. In this condition, the Ni interlayer was melted drastic, and the element Ni distributed in the whole Al fusion zone dispersed, replacing the layer structure in Fig. 3. From the EDS analyses of the transition zone, it consisted of 13.15 at. % of Mg, 14.40 at. % of Ni and 72.45 at. % of Al, which were mainly composed of the Al-Ni and Mg17Al12 phase. More Al-Ni and Mg17Al12 intermetallic formed in the Al fusion zone that made harmful influence on the property of the joint obviously, and the results was nearly same with that of Chang [5]. Except the reaction in the fusion zone, the welding mode in the laser-arc hybrid process was decided by the heat source.

3.3 The Hybrid Welding Source in Welding Process

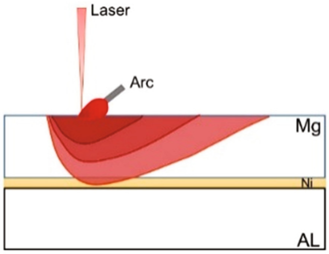
In different welding arc currents, the hybrid sources of the laser and arc were different. The pulse laser was used in the experiment. Although the average power of the laser beam was less than 500 W, the pulse peak value was about 7500 W, thus the effect of the pulse laser on the welding source varied with the arc currents obviously. In order to understand the influence of the welding arc on the hybrid mechanism, the plasma behavior of laser-arc welding is observed by the high-speed camera, as shown in the Fig. 5. When the arc current was 60 A, the plasma form was relatively small. In this situation, the welding fusion zone in the Mg alloy was comparatively small, and the enhanced effect of the low power pulse laser on the arc was exist but not obvious, thus the welding penetration was low. When the arc current was 80 A, the plasma form of the hybrid source was enlarged, because of the increasing of the arc current. When the arc current was 100 A, the plasma form was even larger. The temperature of the fusion zone was increased, more Mg alloy melted with the increase of arc current. There should be more Mg plasma forming the welding process, which made influence on the hybrid effect between the laser and arc [10].



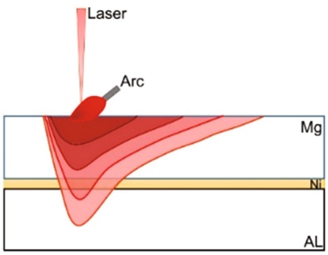
(a) $I_{arc} = 60A$ (b) $I_{arc} = 80A$ (b) $I_{arc} = 100A$

Fig. 5. The plasma behavior of the laser-arc hybrid welding Mg to Al processes

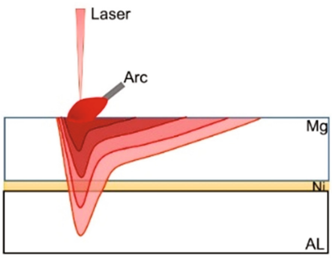
Different heat source models had different energy distributions, and different energy stated that influences the reaction and solidification process of the molten pool, eventually affecting the formation and distribution of intermetallic compounds in the fusion zone of the welded joints. Under the condition of thermal conductivity welding, the laser energy and arc power were relatively low, and the compression on arc and mixing effect of the laser beam on the fusion zone were not obvious. The main function of the laser was stabilizing the arc with the high welding speed. The arc heat source model was shown in Fig. 6(a). Under the condition of keyhole mode welding conditions, the compression of the laser to the arc would be significant due to the increase of the laser beam power. The keyhole welding mode formed and the heat source model is showed in Fig. 6(c). At this time, the distribution of arc energy was vertical downward projection. The effect of the pulse laser was enhanced by the welding arc. Therefore, the reaction in the fusion zone would be more sharply, and formed a number of intermetallic. Still, the laser induced arc could regulate the heat source power distribution. When the arc



(a) I_{arc}=60A



(b) I_{arc}=80A



(c) I_{arc}=100A

Fig. 6. Laser-arc hybrid heat source model with different arc currents

current was 80 A, the hybrid welding source had a certain penetrating power, but not forming the keyhole, which formed conductive mode welding, as shown in the Fig. 6(b).

4 Conclusions

The Mg and Al alloys were joined successfully by the laser-arc hybrid welding technology. The best tensile shear load joint was 2.2 kN (110 MPa), which was obtained with laser beam power 400 W and arc current 80 A. The welding mode in the Al fusion zone changed from the conductive mode to the keyhole mode with the increasing of the arc currents, and the reactions in the fusion zone altered. More intermetallic was found in the keyhole mode joint. In conductive mode welding joint, the elements distribution in the fusion zone showed the layer structure, and dispersed distribution in the keyhole mode joint. The welding mode in the Al fusion zone was influenced by the hybrid effect of the laser and arc. The welding mode in the fusion zone could be controlled through the regulating of laser induced arc mechanism.

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