Effect of Beam Oscillating Parameters on Laser Welding of Mg/Ti Joints

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Abstract. Laser oscillating welding of AZ91 and Ti-6Al-4V was carried out and the influence of oscillating parameters on morphology and mechanical property was investigated. The joint strength obtained with beam oscillating was enhanced compared that without oscillating. With oscillating frequency increased, welding width of Mg improved while the melting amount of Ti decreased. The tensile strength improved initially and then decreased when oscillating frequency increased.

1. Introduction
With the development of lightweight industry, the reliable connection between Mg/Ti alloys by welding has important research significance and application prospect [1-2]. However, the metallurgical combination of Mg/Ti needs to overcome the huge differences in physical and chemical properties. Al element plays an important role in welding Mg/Ti alloys because Al element can achieve large proportion of mutual solubility with Mg and it also forms diffusion reaction layers with titanium alloys [3]. Tan et al. presented laser welding of Mg alloy with high Al content and Ti alloys to obtain joints with certain performance. It could be found that the distribution of Al element has a great influence on the interface morphology and properties of the joints [4-5]. Therefore, it is necessary to employ beam oscillating technology to regulate the distribution of Al element and explore the effect of oscillating parameters on performance of the joints.

2. Materials and Welding Process
The schematic diagram of experiments was shown in figure 1. The base material adopted 3 mm-thick AZ91 and 1 mm-thick Ti-6Al-4V with the size of 50×100 mm². Before welding, the oxidation on the surface of Ti-6Al-4V should be removed by 5% hydrofluoric acid, 15% hydrochloric acid and 80% distilled water and magnesium base metal used mechanical grinding. The welding parameters adopted in this study were shown in Table 1. In this study, beam oscillation technology was employed on the basis of laser welding to increase the agitation of the magnesium alloy molten pool. The agitation of the molten pool promoted the uniform distribution of alloying elements, which facilitated the analysis of regulating effect of Al elements on the Mg/Ti interface.
3. Results and Discussion

3.1. Weld Appearances

Figure 2 showed the appearances of laser oscillating welding of Mg/Ti joints. Joints with sound morphologies were obtained and no obvious defects were observed using adopted parameters. Comparing figure 2(a)-(e), as the oscillating frequency increased, the fish-scale texture of the fusion zone formed on the front surface of the welds was more obvious and thinner with the oscillating diameter of 2 mm. It indicated that increasing of the scanning frequency improved the flow of the molten pool on the magnesium alloy side during welding process. Then, the effects of oscillating diameter was analyzed from figure 2(a), (c) and (f). When the oscillating diameter increased, the weld width of the front surface increased significantly indicating that the wider magnesium base metal was melted due to the increasing oscillating diameter. However, it reduced the laser penetrating performance slightly, the weld width of the back surface did not change obviously with the change in oscillating diameter.

![Figure 1. Schematic diagram of laser oscillating welding of AZ91/Ti-6Al-4V.](image1)

![Figure 2. Full weld profile of laser oscillating welding of Mg/Ti joints at various parameters.](image2)
The representative cross sections of the laser oscillating welding Mg/Ti joints was shown in figure 3. At the Mg side, the size of fusion zone did not change significantly with the increasing of the oscillating frequency, while it increased obviously with the oscillating diameter of 4 mm, especially at the upper surface of the joints. This results was in good agreement with the weld appearances. The interior of the fusion zone was observed, it was found that the content of precipitates or inclusions increased first and then decreased, reaching a minimum at the oscillating frequency of 160Hz. It demonstrated that the agitation of the molten pool was strengthened with oscillating, however, the excessive oscillating frequency would broke and refine the precipitates or inclusions again. At the Ti side, with the increase of the oscillating frequency, the melting degree of the titanium alloy decreased continuously which resulted from the reduction of the total time that laser stayed at the Mg/Ti interface. In addition, comparing figure 3(c) and (f), it could be found that the increase in oscillating diameter did not change the morphology of Ti side.

Figure 3. Cross sections morphology of laser oscillating welding of Mg/Ti joints.

3.2. Interfacial Microstructure
Figure 4 showed the interfacial morphology of laser oscillating welding of Mg/Ti joints produced with different parameters. It was difficult to observe the formation of the interfacial reaction layer without oscillating and titanium alloy interface presented an irregular shape due to the wide range of melting. With the increasing of the oscillating frequency, interface contour of Ti alloy gradually became flat, which was caused by the slight melting based on the original surface of the base material. When comparing figure 4(c) and (f), obvious interface layer could be observed and its became thicker as the diameter increased, which indicated that increased oscillating diameter would promote growth of interfacial reaction layer.

In order to explore the element diffusion behavior and interface layer growth, line scanning analysis was carried out across the interface of Mg/Ti and the results were shown in figure 5. When beam oscillating was not employed, the enrichment of Al element at the interface was not obvious and it was considered that a reliable Ti-Al reaction layer cannot be formed. When oscillating frequency increased to 40Hz, the content of Al element at the interface slightly increased while clearly enrichment of Al element indicated the formation of interfacial reaction layer when oscillating frequency increased to 80Hz. With the further increase of oscillating frequency, Al element enrichment could also be observed at the interface. However, no clear change happened in terms of the highest atomic fraction of Al element or the enrichment distance of Al element. Comparing figure 4 (c) and (f), the enrichment distance of Al element at the interface increased indicated that interfacial reaction layer was thicker with the increasing of oscillating diameter. In the Mg-Ti-Al ternary system, Al element could diffuse uphill to the Mg / Ti interface and formed Ti-Al reaction layer and the diffusion degree was related to the welding process. When beam oscillating was employed, Al element in AZ91 was easier to diffuse and enrich to the Mg/Ti interface. With the increasing of oscillating diameter, the
large-scale melting of Mg alloys led to an increase in the solidification time of the fusion zone due to the decrease in temperature gradient during the welding cooling process. The enrichment width of Al element increased resulted from the increase of the diffusion time.

Figure 4. Microstructure of laser oscillating welding of Mg/Ti joints at different welding parameters.

3.3. Mechanical Property

The tensile tests of laser oscillating welding of Mg/Ti joints were performed to analyze the influence of beam oscillating on mechanical property and the results was shown in figure 6. The fracture loads of the joints with beam oscillating were obviously higher than that without beam oscillating. At the same oscillating diameter, the fracture load increased initially and decreased subsequently when oscillating frequency continued to increase. The highest mechanical strength attained 322 MPa in the case of 2mm/80Hz. Keep the optimal oscillating frequency at 80 Hz, the tensile strength of the joint decreased to 294 MPa when the oscillating diameter increased to 4 mm. In addition, the addition of beam oscillation improved the displacement of the joints which indicated better plasticity during testing process. It could be found that the displacement of the joints at the oscillating frequency of 80 Hz was much larger than joints at other parameters.

Figure 5 showed the fracture path of the joints with maximum tensile strength (2mm/80Hz), minimum tensile strength (2mm/160Hz) and maximum oscillating diameter (4mm/80Hz). It should be noted that all the joints failed at fusion zone, however, macro-morphology of fracture surface were
different with various parameters. The fracture surface existed obvious feature of tearing at the oscillating frequency of 80Hz while it characterized by smooth and flat when oscillating frequency added to 160Hz.

The results above suggested that with the addition of beam oscillating technology, the performance of Mg/Ti dissimilar joints has been significantly improved. The suitable oscillating parameters regulated distribution of Al element and promoted interfacial reaction. Appropriate distribution and morphology of interfacial compounds improved mechanical property of the joints. The addition of the beam oscillating technology made it possible to achieve a reliable connection between magnesium and titanium alloys.

![Figure 6. Tensile force of laser oscillating welding of Mg/Ti joints at different parameters.](image)

![Figure 7. Fracture path of laser oscillating welding of Mg/Ti joints.](image)

4. Conclusions
In this study, laser oscillating welding of Mg/Ti with different parameters was performed. The results showed that with the increasing of oscillating diameter, the welding width of Mg base metal improved while the melting amount of Ti decreased when oscillating frequency increased. The addition of beam oscillating promoted the interfacial reaction by regulating distribution of Al elements. The mechanical property reached highest in the case of 2mm/80Hz. Excessive oscillating frequency and diameter would damage the performance of Mg/Ti joints.

5. References
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