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Influence of interfacial reaction layer morphologies on crack initiation and propagation in Ti/Al joint by laser welding–brazing

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ABSTRACT

Influence of interfacial reaction on crack initiation and propagation in Ti/Al joint by laser welding–brazing (LWB) was investigated to obtain strong joints. According to in situ observation of crack initiation and propagation and analysis of fracture surface, the effects of different reaction layer including interfacial layer with insufficient interfacial reaction, lamella-shaped morphology, cellular/serration-shaped morphology, club-shaped morphology, and thick continuous morphology on crack initiation and propagation was discussed. It was found that the joint with lamella-shaped, cellular or serration-shaped, club-shaped interfacial layer has the highest mechanical property in current study.

1. Introduction

Dissimilar alloy joints are widely used in modern industry due to its low cost, lightweight and demand combining with hybrid mechanical property [1,2]. The joining of dissimilar alloy, such as Al alloy and Ti alloy [3], is confronted with many problems because of the differences in crystal microstructure, melting point, thermal conductivity, coefficient of linear thermal expansion, etc. Preventing the formation of brittle intermetallic compounds is a major challenge in welding dissimilar materials. Therefore, diffusion-bonding, brazing, welding–brazing and explosive welding have been used to join dissimilar alloy so that the growth of intermetallic compounds layer can be controlled. In order to obtain high strength joint, investigations on joining of dissimilar alloy prefer to control thickness of reaction layer [4–6]. Results of aluminum to steel joining by Qiu et al. [7] showed that the crack propagated in the reaction layer and aluminium, and that crack propagation was arrested by the interface between the reaction layer and steel. However, the knowledge about the influence of interfacial reaction layer morphology on mechanical property of the joint is inadequate in the literature.

Recently, various methods of joining dissimilar alloy have been developed, which diversifies the morphology of interfacial reaction layer. For example, related plate layer can be formed by diffusion-bonding [8,9] and brazing [10], and cellular/serration-shaped layer can be obtained by laser welding–brazing [11–13] during joining Al to Ti. It is found that the morphology of reaction layer play an important role on the mechanical property of dissimilar joints. Therefore, understand this effect is vital to optimize the interfacial reaction.

To evaluate the effect of the interfacial reaction on mechanical properties, this study focus on in situ observation of crack initiation and propagation and analysis of fracture surface of Ti/Al joints with different interfacial reaction layer morphologies by laser welding–brazing. Further more, better interfacial reaction layer morphologies were found in order to enhance mechanical property of Ti/Al joint.

2. Materials and experiments

In this study, Ti–6Al–4V alloy and 5A06 Al alloy plates with thickness of 3 mm were selected as the laser joining materials. The flux-cored wire filler AlSi12 with diameter of 2 mm was used. Compositions and tensile strength of the 5A06 Al alloy, Ti–6Al–4V and filler metal are listed in Table 1.

The filler wire and Al base metal were melted by CO_2 laser beam, and joining of the molten metal and solid Ti alloy was achieved in a butt joint configuration. The circular laser spot with Gaussian energy distribution was modulated to a rectangular ($2 \times 4\ mm^2$) with uniform energy distribution by an integral mirror to stabilize welding process. The laser beam irradiated the workpiece vertically, and the angle between filler wire and workpiece was 30°. The filler wire was fed in front of the laser beam. In order to compare the influence of reaction layer morphologies on initiation and propagation of the crack, more reaction layer morphologies were obtained at same joint. According to experimental results, more interface layer morphologies can be obtained when the offset of the laser beam from the center toward the aluminum alloys is 0.8 mm. Double shielding gas argon was used at

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Table 1
Compositions of 5A06 Al, Ti–6Al–4V alloy and filler metal used in this study.

Alloys	Elements (wt.%)									Tensile strength (MPa)
	Al	Ti	Mg	Si	Cu	Mn	Fe	Zn	V	
5A06 Al	Bal.	0.02	5.8–6.8	0.4	0.1	0.5–0.8	0.4	0.2	–	350–360
Ti–6Al–4V	5.5–6.8	Bal.	–	–	–	–	0.3	–	3.5–4.5	960–970
Filler wire	Bal.	0.15	0.1	12.0	0.3	0.15	0.8	0.2	–	190–200

both sides of matrix to avoid oxidation of the liquid filler, as well as to improve the wetting behavior between liquid metal and solid Ti alloy. Schematic figure of process is shown in Fig. 1a. To enhance the spreadability, a groove with a 55° angle was fabricated on Al alloy, as shown in Fig. 1b.

After laser welding–brazing, in situ tensile test specimens with thickness of 1.0 mm were cut from a weldment by a linear cutting machine alone cross-section. Dimension and figure of in situ tensile test specimen is shown in Fig. 1c. Excess weld metal of both sides in specimens was ground to flat. Standard grinding and polishing sample preparation procedures were used and solutions of 1%-HF, 1.5%-HCl, 2.5%-HNO_3 and 95%-H_2O were utilized to etch the samples. Interfacial zone at cross-section of the joint was observed during in situ tensile testing by scanning electron microscope (SEM FEI Quanta200). The strain rate of the in situ tensile test was 3.33 μm/s. After specimens were broken, fracture surface were observed by SEM S-4700. The tensile strength of the specimens at room temperature was evaluated by a testing machine (INSTRON 1186) at a cross head speed of 0.5 mm/min.

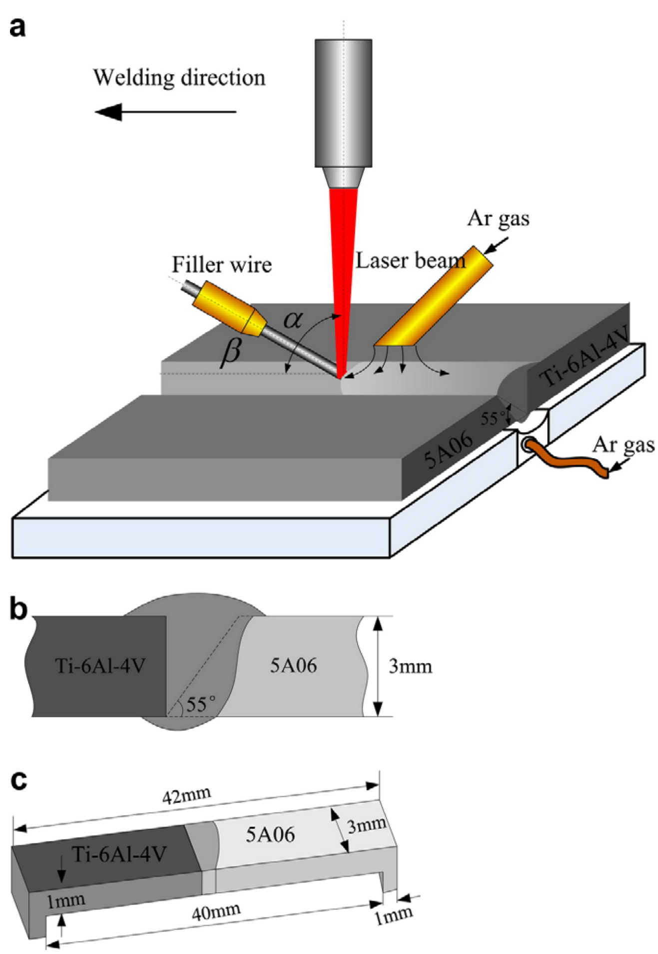

Fig. 1. Schematic figure of the process, joint cross-section and in situ tensile test specimen of LWB: (a) schematic figure of the process, (b) dimension and figure of joint and (c) in situ tensile test specimen.

3. Results

Fig. 2a shows a cross-section of Ti/Al joint by laser welding–brazing for in situ strength testing. During welding, laser power, welding speed and filler wire speed are 2400 W, 0.35 m/min and 1.4 m/min, respectively. Fig. 2b–f exhibits interfacial microstructure micrograph of regions A–E indicated by rectangle in Fig. 2a, respectively. Thermal cycle suffered at interface from the top to the bottom is different because LWB process has high temperature gradient of through-thickness, which induced uneven distribution of reaction layer morphology. At the top zone A, interfacial reaction layer have thick continuous morphology. At the zones B, C and D, the layers exhibit club-shaped, cellular/serration-shaped and lamella-shaped morphology, respectively. At the bottom zone E, no obvious reaction layer was observed. The non-homogeneous morphology distribution is convenient to evaluate the influence of different shape layer on crack initiation while the specimens are observed by SEM during load. The identification of phase components at Ti/Al joint interface had been described in detail elsewhere [11].

During tensile testing, crack initiation at the interface at the bottom of joint was observed firstly when load of the specimen reached 642 N, as shown in Fig. 3a. In this zone, no obvious reaction layer was observed, which is attributed to the insufficient interfacial reaction. With further increasing to 671 N, the crack initiated sequentially at just above bottom of joint, as shown in Fig. 3b. In this zone, lamella-shaped morphology reaction layer was observed. However, crack initiation appears in the seam near the front of reaction layer. The specimen was broken rapidly along the adjacent interfacial reaction layer when load reached 724 N. Crack initiation at the joining zone with club-shaped reaction layer was never found during the in situ tensile testing.

Only partial information of crack initiation and propagation can be found through the in situ tensile strength by SEM. Trace of crack propagation can also be estimated by observing the fracture location of the specimen. The interface of joint bottom is high-incidence area of crack initiation during load. Fig. 4 shows fracture surface in this zone. Obviously, zone Z1 is relatively smooth due to lack of interfacial reaction, and zone Z2 is relatively rough as it is performed by interfacial reaction. The interfacial reaction non-appeared at partial zone and performed at other zone is called "insufficient interfacial reaction" in this paper. Therefore, at the bottom interface of joint with insufficient interfacial reaction zone, the bond is weak, and crack tends to initiate and propagate along the interface.

Fig. 5 exhibits microstructure and fracture surface of the zone with lamella-shaped reaction layer. Crack tends to propagate along the seam close to the layer/seam interface, as shown in Fig. 5a. Fig. 5b shows fracture surface of Ti side at the zone with lamella-shaped reaction layer. It is clear that many micro tear ridges appear at the fracture surface, which is induced by metal Al adhering to reaction layer. It indicates that the cohesion between reaction layer and seam is stronger than fracture strength of metal Al. Therefore,