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RESEARCH ON CHARACTERISTICS OF WELDING FOR Al/Ti DISSIMILAR ALLOYS WITH TRAILING ULTRASONIC

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Abstract. In this dissertation, Tungsten Inert Gas Welding (TIG) between Ti-6Al-4V and AlMg6 was conducted by using 380 filler metal by the condition of different parameters, welding technology, and the ambiance was full of Ar gas. Formation of intermetallic was controlled effectively with changing welding parameters of metal flush, and using of ultrasonic oscillating obtained favorable weld line. Hybrid characteristic of welding and brazing joint were obtained. The difficulty of burning question during Al to Ti was solved. The parameter rules of influence on weld appear, interfacial reaction and mechanical properties were clarified. It provided a foundation for controlling joint quality. Microstructure characteristics of Al/Ti joints had been analyzed by optical microscopy, SEM, ED. Joint strength was measured via tensile test. The results showed that an intermetallic compound layer had formed at the brazing interface between mixed seam metal and titanium. The intermetallic compound layer at interfacial top includes an acicular Ti-Al-Si intermetallic layer and a continuous Ti-Al intermetallic layer nearby titanium alloy. The microstrcture can be improved by using of ultrasonic oscillating, and it made the mechanical properties better than before. According to the research on the characteristics relation of interfacial reaction layer growth, the interfacial reaction layer growth and preventing formation of intermetallic layer growth was controlled by using of ultrasonic oscillating. The problems of the joining of Al to Ti was restrained, and the optimized mechanical welding parameters was obtained. The results provides a academic basis for Al/Ti dissimilar alloying.

1. INTRODUCTION

Hybrid structures of titanium and aluminum have great potential in aerospace and automobile industry. However, strength of welded joint decreased dramatically because of the great differences between their thermophysical and thermochemical performances. Continuous distribution of the intermetallic compound layer (IMC) is formed easily while the oxidation film is difficult to clear [1,2].

Intersolubility and intermetallic compounds are most influential on the process of Al/Ti dissimilar alloy welding. Two main conditions contribute to the obtaining of good dissimilar joint, absolute mutual solubility between the dissimilar alloy and ability of forming interstitial continuous solid solution. When conditions mentioned above are not satisfied and big differences in physic and chemic exists between them, brittle intermetallic compound and eutectic which lead to the difficulty of welding extensively will be fabricated. But if intermetallic compound scatterely distribute in alloy grains in the form of fine intermatellic compound, it will have no harm to the joint completely [3]. However, possible danger of brittle rupture of metal material can happen when intermetallic compound distribute in grain boundary in the state of zonate or needle structure or transition layer exists in the joint. So how to solve the problem of dissimilar welding of Al/Ti depends

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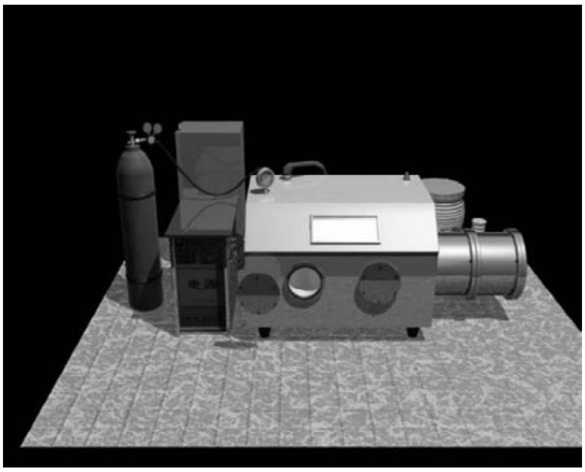

Fig. 1. Full of Ar gas ambiance equipments.

on the controlling of the formation of intermetallic compound.

Ultrasonic can affect the procedure of alloy solidification, crushing and refining grain, for which it was widely used. Ultrasonic cavitation and acoustic streaming effect contribute to the refining of solidification structure, shorten solidification time and decrease start time of solidification, which leads to obtain of fine and uniform equiaxed grain. Besides ultrasonic cavitation effect can efficiently suppress the fabrication of intermetallic compound. So we come up the idea of TIG arc welding-brazing to implement welding, in which process ultrasonic will be introduced in the welding pool to change the state and distribution of intermetallic compound by means of ultrasonic cavitation and acoustic streaming effect.

2. EQUIPMENTS AND MATERIALS

2.1. Method and equipments

As shown in Fig. 1, this self-made device is a air-locked welding chamber providing pure argon atmosphere. Put weldments in the hermetic container first until the welding chamber is full of pure argon and then welding job can be started with this device.

The welding chamber can provide air-locked welding atmosphere. Its working mechanism goes like this: first, vacuum pump air-removal system is used to pump the inside air out, then let inert gas in (e.g. argon gas). A pre-put room for weldments is installed in the backside of the chamber. It links outside with inside of the chamber with two blocking caps in the back and front separately to segregate gas from penetration into each other. Air is pushed out from pre-put room by argon pumped in. When argon is full in the chamber, weldments can be sent in from pre-put room to apply welding job. They can also be fetch out form pre-put room after job is done. In this way, a pure argon atmosphere is maintained.

The study of the distribution of ultrasonic vibration in the welding pool and analysis of ultrasonic cavitation, acoustic streaming, and impact effect was performed. The specific method is shown in Fig. 2. By this means, the state, distribution and growth of brittle compound can be controlled to improve the properties of Ti-Al dissimilar joint [4].

2.2. Materials

Tables 1 and 2 show the composition of base metal (TC4) and filler metal (380) in detail. Sheet of TC4 (Ti-6Al-4V) and aluminum is used for butt welding experiment and welding wire NO .380 with a diameter of 2.8 is adopted [3].

3. DISCUSSIONS

3.1. Morphology of welding seam

It is still a gap at home and foreign studies on the problem of ultrasonic effect to control compound growth and improve its state and distribution in order finally to improve the properties of Ti-Al dissimilar

Table 1. The composition of TC4 base metal, (wt.%).

element	Al	V	Fe	Si	Mn	Cu
content	5.5~6.8	3.5~4.5	≤0.3	≤0.15	-	-

Table 2. The composition of 380 filler metal, (wt.%).

element	Mg	Mn	Fe	Si	Ti	V
content	5.8~6.8	0.5~0.8	≤0.4	≤1	0.02~0.10	≤0.08

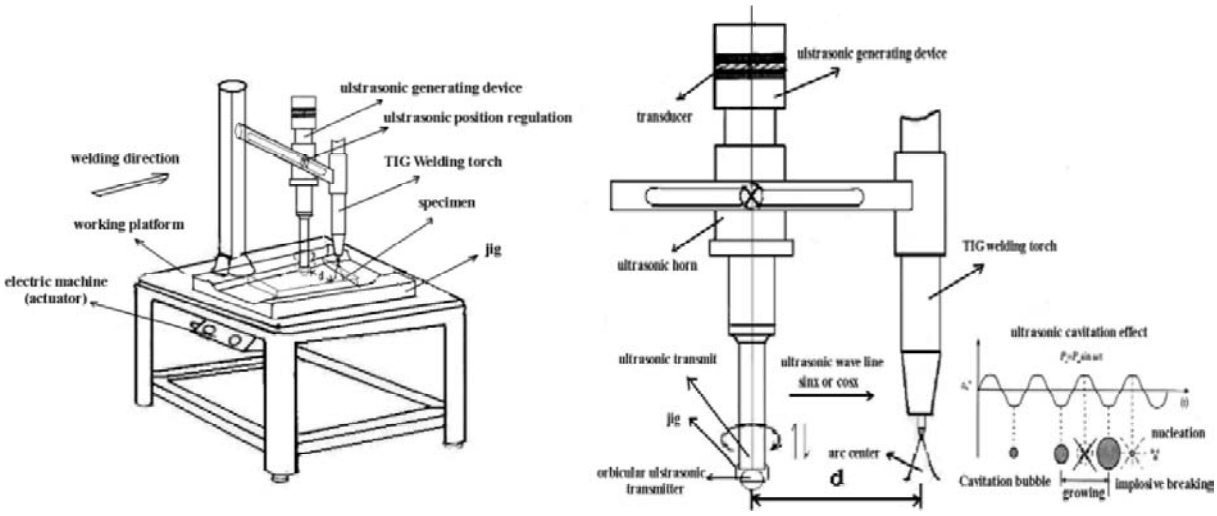

Fig. 2. Principle diagram of trailing ultrasonic.

joint. There is neither a mature theory nor techniques of guidance. So we propose the method of TIG arc welding-brazing, in which ultrasonic is introduced into the welding pool to influence the state and distribution of intermetallic compound with ultrasonic cavitation and acoustic streaming effect. Besides, the effect of Si element is investigated to control growth of compound synthesized during metallurgical reaction so as to obtain good welding joint, which can solve the difficulty in Ti-Al dissimilar welding [5-7].

Fig. 3 presents the morphology of Al-Ti joint by TIG with trailing ultrasonic. The side of base metal Al has property seen in TIG welding with filler wire. The domain from left to right are as follows: A area is TC4, B region is heat effected zone of Ti, C is brazing interface, D is mixing zone of Al and Ti, E is fusion zone of welding of Al, F represents HZT of Al base metal and domain F is base metal of Al.

3.2. Morphology of welding seam

Figs. 4a and 5a show that the interface topographies of arc welding-brazing in the situation of same current and same welding wire feeding. However, Figs. 4a and 5c obviously displays the interface behavior affected by ultrasonic added. It is cleared that the thickness of interface with ultrasonic is not so much thick as that of interface without ultrasonic. So is the amount of intermetallic compound because of the depress effect of ultrasonic on the growth of compound. Besides, original cylindrically and thickly growing compound in regular is turned into dispersing growth by ultrasonic effect, which changes compound to reinforcement phase, improving the mechanic property of weld joint [8].

Meanwhile, as shown in Fig. 5b, by the means of trailing ultrasonic, a new light gray phase can be found in the interface of the weld seam whose color is between the color of intermetallic compounds and Al matrix. The new phase at the crystal boundary of the weld seam contains little Si element, but higher Al element than common Al-Si system intermetallic compounds.

It can be seen from Fig. 5b that asymmetric distributing of Si element in the intermetallic compound layer happens because of selective crystallization. The layer containing asymmetric distributing Si element is composed of two compounds of different forms. One is non-Si intermetallic compounds and the other is Si intermetallic compounds. Si element is discovered in the upward bonding interface of welding seam. The phenomenon of Si element aggregation also emerges in the intermetallic compound in the bonding interface of welding seam. Si element

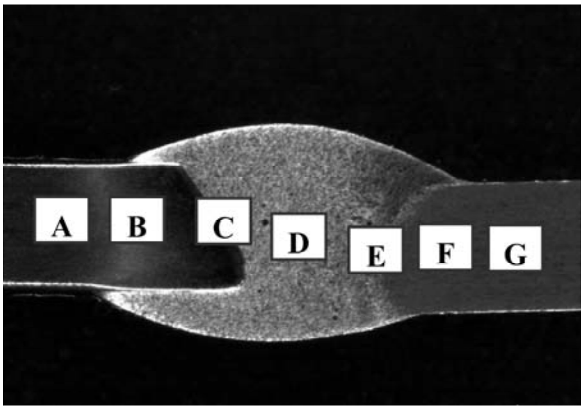

Fig. 3. Cross section morphology of Ti-Al dissimilar joint by trailing ultrasonic method.

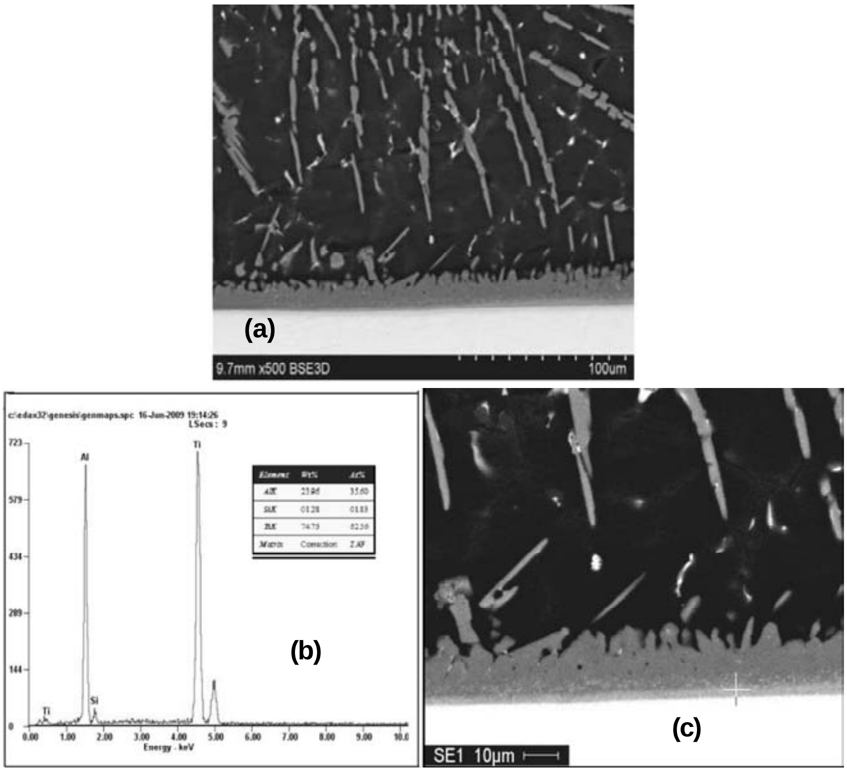

Fig. 4. Morphology of welding joint without trailing ultrasonic (current I = 50 A) a) macro morphology, b) energy spectrum, c) micro morphology.

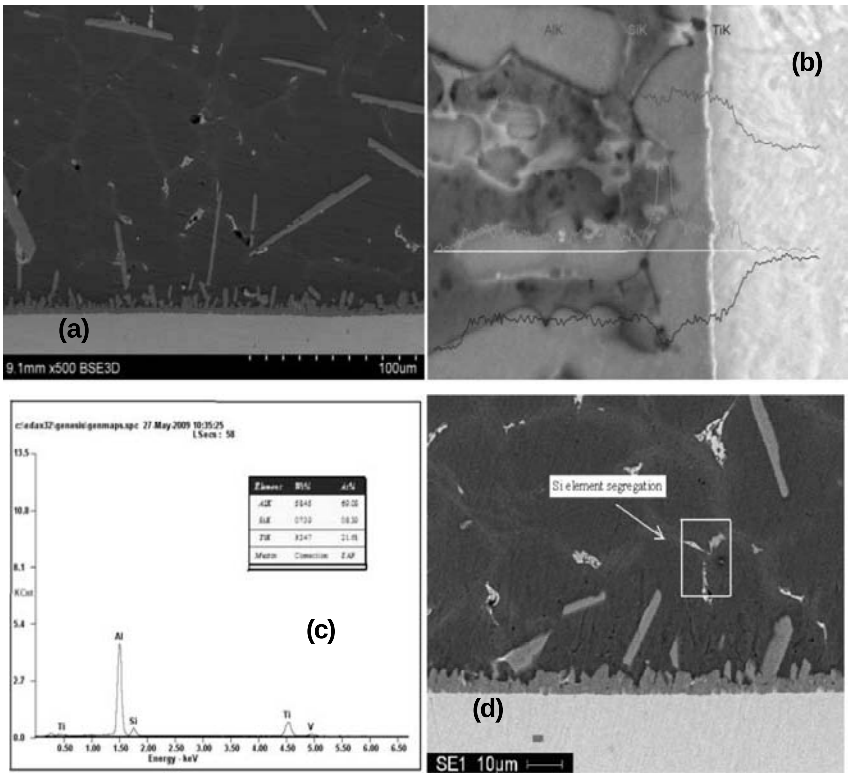

Fig. 5. Morphology of welding joint with trailing ultrasonic(current I = 50 A) macro morphology, b) EDX line scanning, c) energy spectrum, d) micro morphology of Si element segregation.

aggregation happens because the new phase smashed by ultrasonic along the interface of welding seam leads to selective crystallization. Thus, a large number of Si element segregates in the growth direction of grain boundary. It is found that the distributional pattern of Si element segregation is deter-

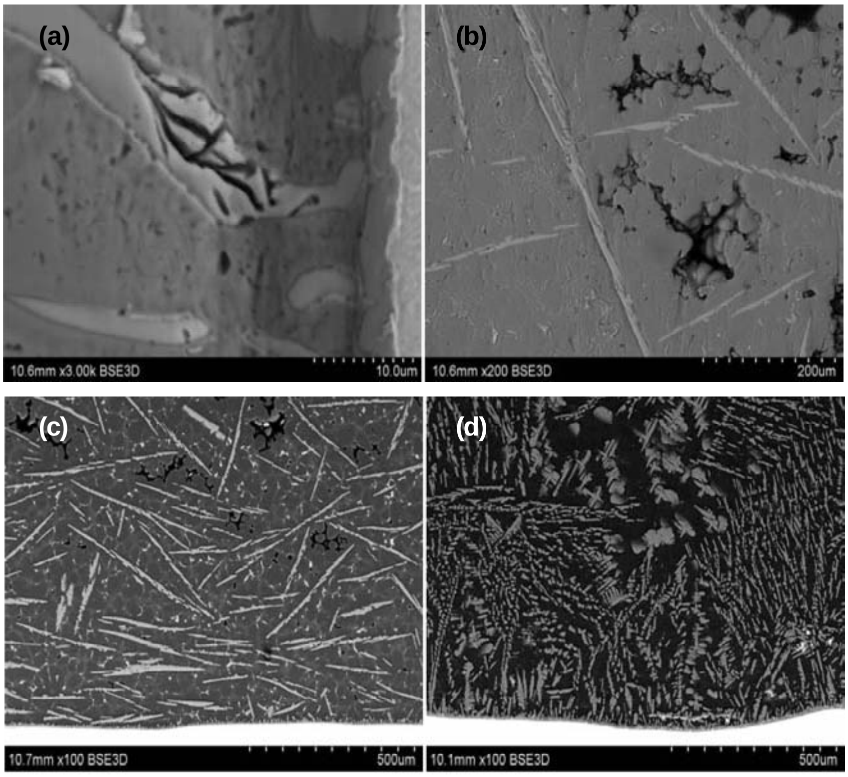

Fig. 6. Function of trailing ultrasonic to solve problem of shrinkage cavity a) internal stress of Al solid solution, b)shrinkage cavity of Al solid solution, c) shrinkage cavity of welding seam without trailing ultrasonic (current *I* = 80 A), d) morphology of welding seam with trailing ultrasonic (current *I* = 80 A).

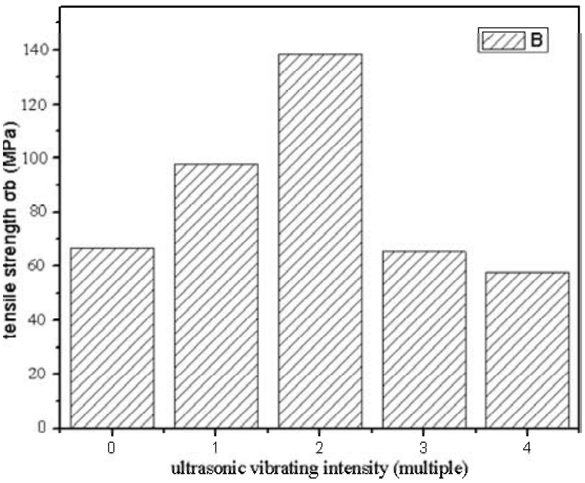

Fig. 7. Tensile strength of joint under ultrasonic vibration effect.

gation is determined by the diffusion behavior of Al-Ti solid solution.

What's more, when welding current is high, welding crack is induced easily, as shown in Fig. 6a. The reason is that brittle compound generated during welding will crack under steep cooling by thermal-stress. In addition, shrinkage cavity is found in Al based solid solution during solidifying as shown in Fig. 6b. The amount of shrinkage cavity increases with current rising. This is because higher current means quicker cooling speed, which causes swift solidification before liquid metallic phase flowing sufficiently to every corner it is needed, resulting shrinkage cavity in the end. However ultrasonic and scraping force added during welding can effectively depress shrinkage cavity as shown in Figs. 6c and 6d because intense stirring force is introduced into welding pool, driving liquid metallic phase to flow sufficiently and decreasing the amount of shrink cavity.

3.3. Mechanical properties of welding seam with ultrasonic

The comparison between samples in joint strength is shown in Fig. 7. As presented in Fig. 7, trailing ultrasonic can depress growth of intermatellic compound. With ultrasonic added in, joint strength improves obviously which is mainly because depression effect of ultrasonic on shrinkage cavity and its promotion on fabrication of disperse phase, leading to great change in joint strength. But, it is not increase infinitely with enhancement of ultrasonic's vibration rate. When joint strength raises to some point, however, it will decrease with vibration rate still raising. This is on a larger part because ultrasonic's vibration covers the whole process of welding. It definitely enhance the spreading of welding pool on Ti master material, but will do harm as well during solidification as excessive vibration causes brazing filler lose from interface, leading to incompletely fusion in local area , and induces fabrication of intermetallic compound in interface. Beside, excessive vibration is equivalent to fatigue load, making unfavorable effect on joint strength. So choosing proper vibration rate and intensity makes sense to obtain good welding joint with excellent mechanical property.

4. CONCLUSIONS

1. Cavitation effect of trailing ultrasonic can depress growth of intermetallic compound and its cylindrical growth style, promoting regularly disperse development and making reinforcement phase. However, ultrasonic's destroy effect on columnar grain can lead to segregation phenomenon of Si element.
2. Trailing ultrasonic can improve driving force of fluid flow, and hence effectively depress shrinkage during TIG arc welding-brazing process.
3. Joint strength can improves with trailing ultrasonic. With increase in vibration rate of ultrasonic, joint strength satisfy a first rising and then falling trend.

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