

## Microstructures of brazing zone between titanium alloy and stainless steel using various filler metals

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**Abstract:** Titanium alloy (Ti–Al–V alloy) substrate was brazed with stainless steel (STS304) using filler metal. At an optimized brazing condition, various filler metals were used. Microstructures were observed at each condition. Filler metals were titanium based 40Ti–20Zr–20Cu–20Ni, silver based Ag–5Pd, and nickel based Ni–7Cr–3.1B–4.5Si–3Fe–0.06C (BNi<sub>2</sub>) and Ni–14Cr–10P–0.06C (BNi<sub>7</sub>). To select a good filler metal for brazing process, wetting test was performed at 880–1050 °C. It was not brazed using silver based filler metals, but at the conditions using titanium and nickel based filler metals had brazed zone between titanium alloy and stainless steel. However, titanium alloy was eroded during brazing using titanium based filler metals. Nickel based filler metal has a good brazed zone between titanium alloy and stainless steel among the filler metals.

**Key words:** brazing; filler metal; titanium alloy; stainless steel

### 1 Introduction

With ever increasing many special purpose alloys in the market place, joining processes, such as welding, brazing and diffusion welding, plays an important role in practical application of these alloys. Well-developed joining process can not only promote the application of these alloys, but also can provide designers versatile choices of materials. Brazing is one of the most popular methods in joining dissimilar alloys [1,2]. Both titanium alloy (Ti–6Al–4V) and stainless steels (STS304) are good engineering alloys and widely used in industry due to their excellent mechanical properties as well as corrosion resistance. However, there are two major problems in brazing dissimilar materials. First, residual thermal stresses are usually developed after brazing due to thermal expansion mismatch between the joined alloys. Second, brittle intermetallic compounds are formed, especially at the interface between braze alloy and substrate after brazing. Both the above problems will be encountered in brazing titanium alloy and stainless steel.

Ti–6Al–4V is a type of  $\alpha$ - $\beta$  titanium alloy. With aid

of  $\beta$  stabilizer addition in the alloy, the  $\beta$  phase can be stabilized at room temperature. Therefore, Ti–6Al–4V can be heat treated by solution and aging procedure in order to obtain proper mechanical properties [3–5]. The brazing of titanium alloys has been extensively studied [2,6,7]. DECECCO et al [8] suggested using silver and its alloys metal to braze many titanium alloys. The joint demonstrates certain degree of toughness due to the formation of Ti–Ag intermetallic during brazing. On the other hand, it is also observed that many Ag-base filler metal can effectively braze many titanium alloys [9–11]. The primary advantage in using the Ag-base filler metal to joint titanium alloy is that the melting point of most Ag-based filler metal is lower than  $\beta$  transus temperature of most titanium alloys [6]. Heating titanium alloys above (or close to) its  $\beta$  transus temperature will result in excessive growth of the  $\beta$  phase in titanium alloy, and the mechanical properties of titanium alloys will be greatly deteriorated. Therefore, it is required that brazing of Ti alloys should not exceed its  $\beta$  transus temperature in order to avoid deterioration of its mechanical properties. Titanium alloy can be brazed with copper and silver based brazed alloys for low-temperature application. In

contrast, gold, palladium, platinum, reactive metals and nickel based brazed alloys can be applied in brazing with titanium alloy for low-temperature service [6,7].

STS304 is a typical type of austenitic stainless steels. It is one of the most popular species among all stainless steels, and is characterized of both excellent corrosion resistance and mechanical property. By addition of austenite stabilizing element Ni into the alloy, the austenite phase is stable at room temperatures [4]. It is important to note that sensitization of STS304 in heat affected zone in brazing or welding should be avoided [4,12]. As the STS304 heated above 1000 °C, huge chromium carbide precipitates will be formed along austenite grain boundaries. The consumption chromium content in STS304 may result in loss of corrosion resistance along grain boundary of the steel [12,13]. The sensitized STS304 will be suffered from intergranular corrosion in service. Therefore, it is crucial for STS304 to avoid sensitization in brazing [12,14]. Compared with the Ni-base filler metal, the low liquidus temperature of silver or other base filler metal makes it more suitable in brazing STS304 from the viewpoint of brazing temperatures.

In this work, as a study of brazing of dissimilar materials between titanium alloy (Ti-6Al-4V) and stainless steel (STS304), wetting test between filler metal and titanium alloy, stainless steel was performed and through cross-section microstructure, compliance for each filler metal reaction was determined. Afterwards, brazing between titanium alloy and stainless steel was performed by using diversified filler metals and through observation of microstructure of cross-section, a study on selection of optimized filler metal was progressed.

## 2 Experimental

### 2.1 Materials

As titanium alloy used for this work, alloy having a chemical composition of Ti-Al-V was used and stainless steel (STS304) was used. Chemical component of each alloy is shown in Table 1. As filler metal, total four kinds of filler metal were used and Ti+Zr-based 40Ti-20Zr-20Cu-20Ni and Ag-based Ag-5Pd and Ni-based BNi<sub>2</sub> and BNi<sub>7</sub> were used, respectively. A content of component and melting point of each filler metal is shown in Table 1.

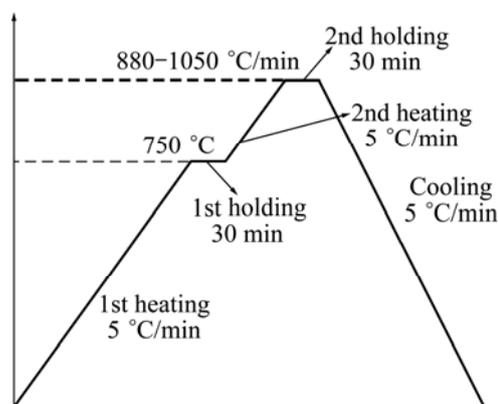
### 2.2 Brazing temperature condition

Brazing test was performed based on following heating rate, brazing temperature per each filler metals, duration and data of cooling rate under vacuum ambience. Heating was maintained for 200 min

**Table 1** Chemical component and melting temperature of material

Material	Chemical component/%	Melting point/°C
Ti	Ti-6Al-4V-0.25Fe-0.20	1604-1660
STS304	Fe-0.044C-18.3Cr-8.2Ni-0.045Si-0.9Mn	1400-1455
40Ti	Ti-20Zr-20Cu-20Ni	830
Ag-5Pd	Ag-5Pd	985
BNi <sub>2</sub>	Ni-7.0Cr-3.1B-4.5Si-3.0Fe-0.06C	1000
BNi <sub>7</sub>	Ni-14Cr-10P-0.06C	890

regardless of kind of filler metal and heating was raised to brazing temperature again after maintaining heating temperature at 50 °C for 30 min in order to maintain unstable temperature distribution to a stable condition. Brazing temperature was performed based on 50 °C, melting point of each filler metal. Duration was set at 30 min as a whole so that filler metal could be sufficiently wetted down into jointed metal inside. Generally, titanium is divided into  $\alpha$ ,  $\beta$ ,  $\alpha+\beta$  phase but as mechanical property is significantly changed at the time of phase transformation, proper fraction control of two phases is required. For this, fraction was controlled by cooling with speed of 5 °C/min (Fig. 1).



**Fig. 1** Standard thermal cycle used for wetting and brazing tests

### 2.3 Analysis

#### 2.3.1 Wetting test

If wetting condition of filler metal and base metal is bad, jointing doesn't work and furthermore, if jointing space is large, incomplete jointing is resulted as filler metal is not fully filled between both base metals. Generally, in case that base metal is left to atmosphere for a long time or becomes inactivated due to generation of oxide by combining with oxygen at the time of heating, liquid metal is hard to get wet. In order to

improve wetting property, flux is used or generation of oxide is restricted by heating under reduction or vacuum ambience. Wetting property represents affinity level between filler metal and base metal and becomes a scale of determining the proper function of flux or ambience. In case of dropping a drop of liquid phase on flat plain of solid phase, when expressing surface tension of base metal as  $\gamma_{SL}$ , surface tension of filler metal as  $\gamma_{SV}$  and surface tension of base metal of filler metal as  $\gamma_{LV}$ , it could be expressed as following formula.

$$\cos\theta = ((\gamma_{SV} - \gamma_{SL}) / \Gamma_{lv})$$

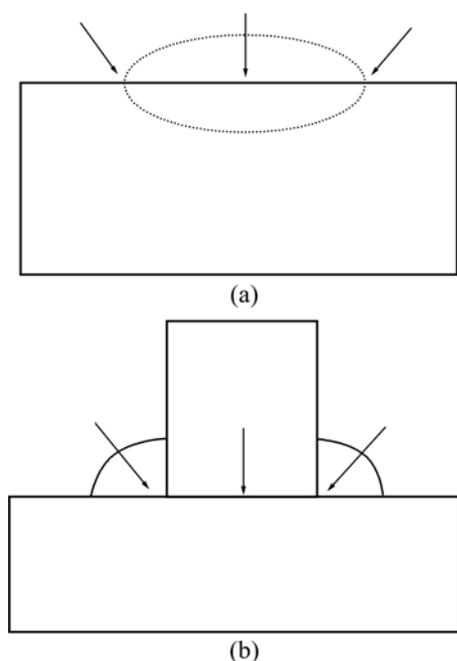
where  $\theta$  is the contact angle.

Boundary of occurrence or non-occurrence of wetting property could be determined by  $90^\circ$  ( $\theta$  angle). In other words, if contact angle is below  $90^\circ$ , wetting property exists and over  $90^\circ$ , wetting property does not exist. In general, at the time of most of brazing,  $\theta$  angle is between  $10^\circ$  and  $40^\circ$  and most of wetting property is determined by jointing space of brazing base metal [15–17].

In this work, wetting test was performed by confirming contact angle between filler metal and base metal by observing cut section of specimen that brazed filler metal—titanium alloy with scanning electron microscope (Quanta, FEG model, 20 kV). As shown in Fig. 2(a), wetting part of filler metal was divided by titanium alloy into 3 parts, an analysis was performed.

### 2.3.2 Microstructure and lining/mapping scanning

In order to select optimized filler metal through



**Fig. 2** Lay-out of microstructural analysis: (a) Brazing sample of titanium alloy and filler metals; (b) Brazing sample of titanium alloy and stainless steel using filler metals

dissimilar materials brazing between titanium-metal, microstructure of cut section after brazing was divided into 3 places as shown in Fig. 2(b) and observed through SEM (Quanta, FEG model, 20 kV) and a study on diffusion of metal particle and phase transformation after brazing was carried out.

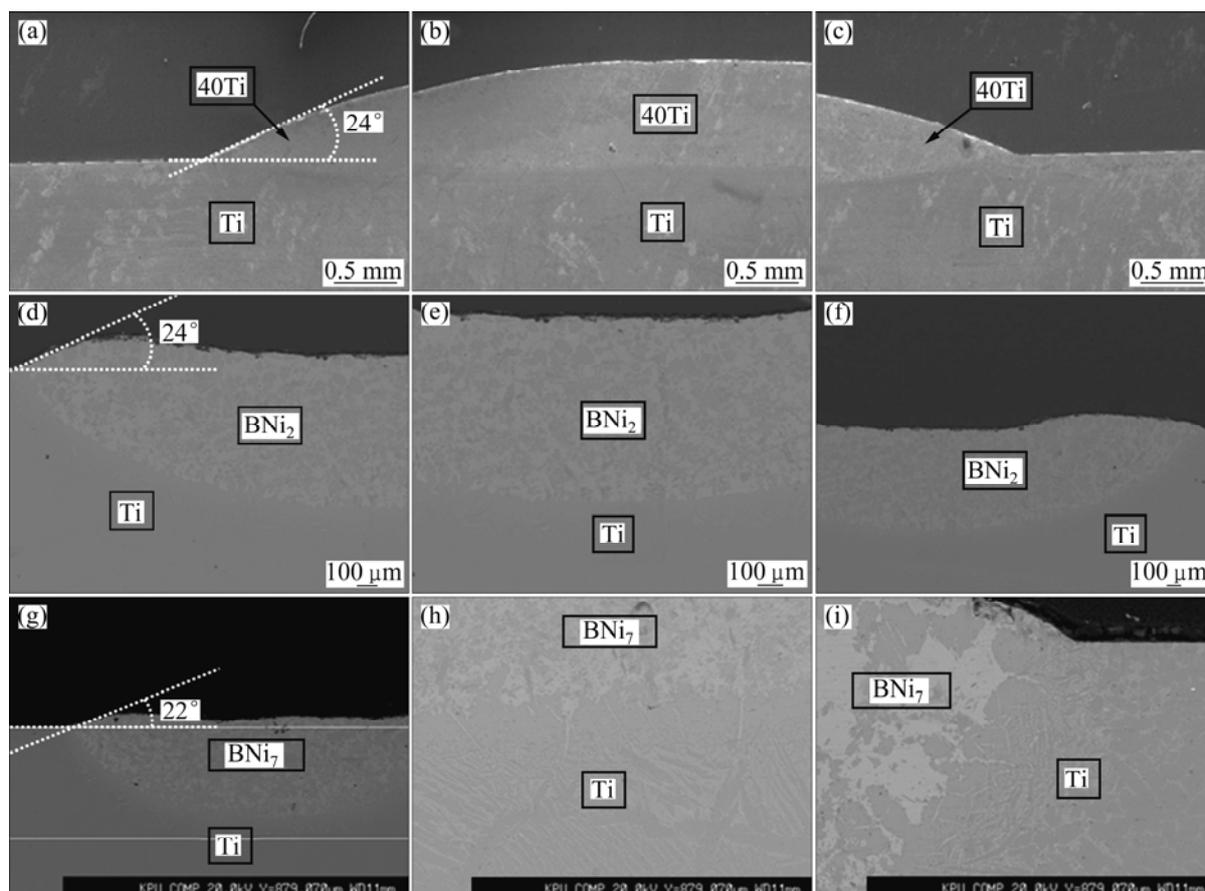
## 3 Results and discussion

### 3.1 Wetting test of Ti-alloy brazed various filler metal

Figure 3 shows a result of wetting test between base metal and filler metal subsequent to observation of microstructure of cross-section of sample brazed titanium alloy and each filler metals. Figures 3(a)–(c) show the test result of wetting property of sample brazing Ti+Zr-based filler metal with titanium alloy, Figures 3(d)–(f) show that of sample brazing Ni-based  $\text{BNi}_2$  filler metal with titanium alloy and Figures 3(g)–(i) show that of sample brazing Ni-based  $\text{BNi}_7$  filler metal with titanium alloy. Microstructure of sample of brazing Ag-based Ag-5d filler metal with titanium alloy was failed to be observed due to occurrence of titanium erosion after brazing. In wetting test between filler metals excluding Ag-5d filler metal and titanium alloy, it could be confirmed that contact angle of about  $23^\circ$  was represented. In particular, Ni-based filler metal was observed to be diffused into titanium inside through microstructure. This diffusion is derived from the fact that nickel added to titanium in small amount has stabilized liquid phase and  $\beta$  solid phase. In other words, it could be realized that Ni-based filler metal plays a role of  $\beta$  stabilizing element by dropping melting point of titanium significantly and lowering critical temperature of  $\beta$  transus [2,6,7,18]. Therefore, as a result of confirming contact angle and diffusion status of base metal, wetting property with titanium alloy could be confirmed in the order of  $\text{BNi}_7 \geq \text{BNi}_2 > 40\text{Ti} \gg \text{Ag-5Pd}$ .

### 3.2 Microstructure of Ti-alloy brazed stainless steel with various filler metal

In brazing dissimilar materials between titanium alloy and stainless steel, a result of observation of microstructure as per filler metals is shown in Fig. 4. Figures 4(a)–(c) show a result of observation of cross-section of sample brazed by using Ti+Zr-based filler metal, Figures 4(d)–(f) show that of sample brazed by using Ni-based  $\text{BNi}_2$ , Figures 4(g)–(i) show that of sample brazed by using Ni-based  $\text{BNi}_7$  and Figures 4(j)–(l) show that of sample brazed by using Ag-based filler metal, respectively. A result identical with the previous result of wetting test between titanium alloy and filler metal could be deduced from dissimilar



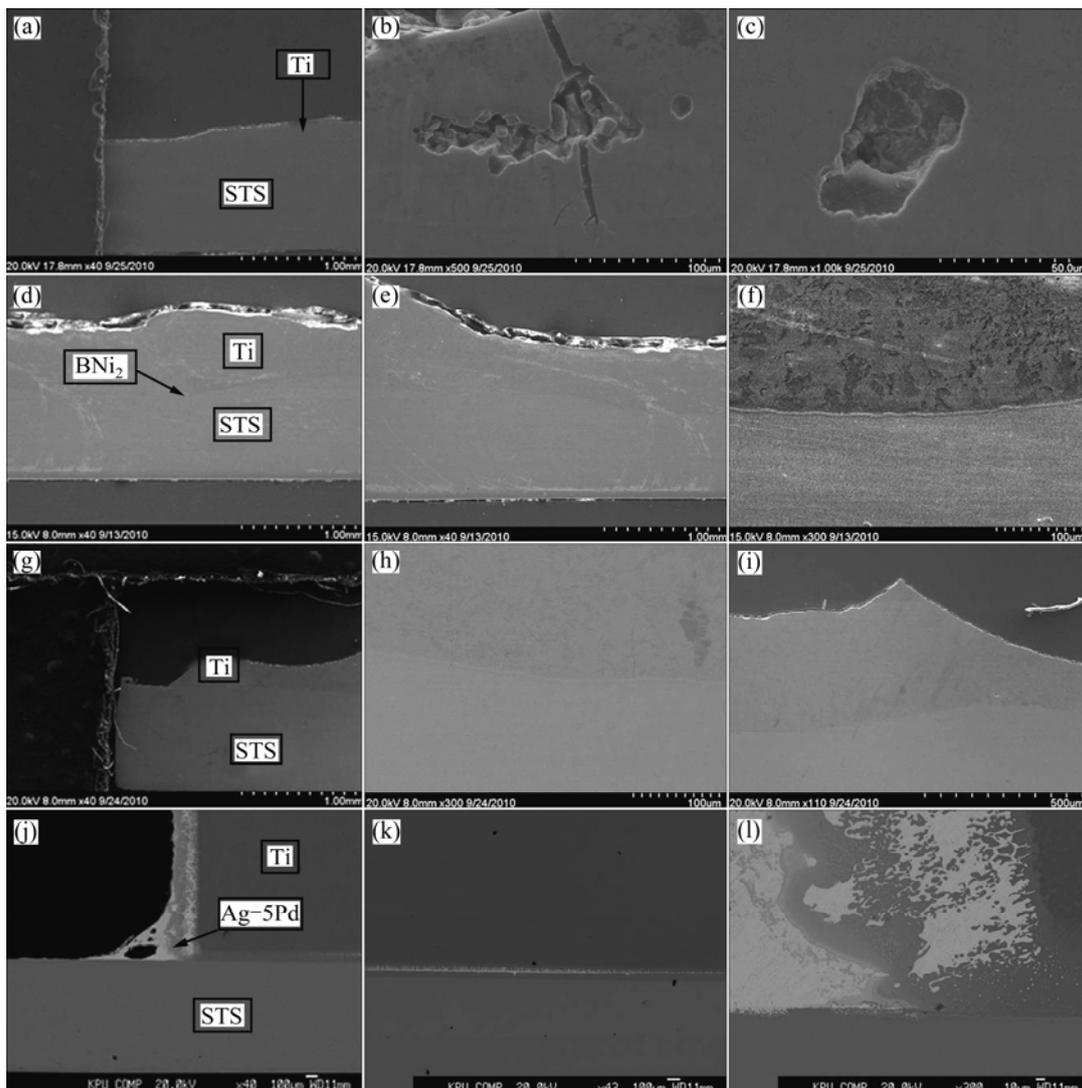
**Fig. 3** Cross-section microstructures of titanium alloy brazed with Ti+Zr filler metal (a)–(c), BNi<sub>2</sub> filler metal (d)–(f) and BNi<sub>7</sub> filler metal (g)–(i)

material brazing as well. In brazing using Ag–5Pd filler metal, titanium erosion was occurred after brazing and as a result of observation of microstructure, filler metal not only failed to flow into both base metal completely but also even pore or crack was observed. In general, in case of silver, it was learned that it has more strong strength by being combined with other elements but it was confirmed that brazing did not work as a result of failure of diffusion or combination due to very low reactivity between silver and titanium. This could be explained by mapping analysis of Fig. 5. Silver component did not exist at all in the part where titanium component existed and combination between these two components was unable to be confirmed. The part indicated in white color is a result of indicating the location where each component exists. It could be confirmed also that titanium alloy component was not diffused into stainless steel at all. On the contrary, in case of BNi<sub>2</sub> and BNi<sub>7</sub>, Ni-based filler metal, diffusion between these two base metals was progressed and filler metal was also properly diffused and its jointing characteristic was very excellent. Afterwards, it is considered that specific assessment on

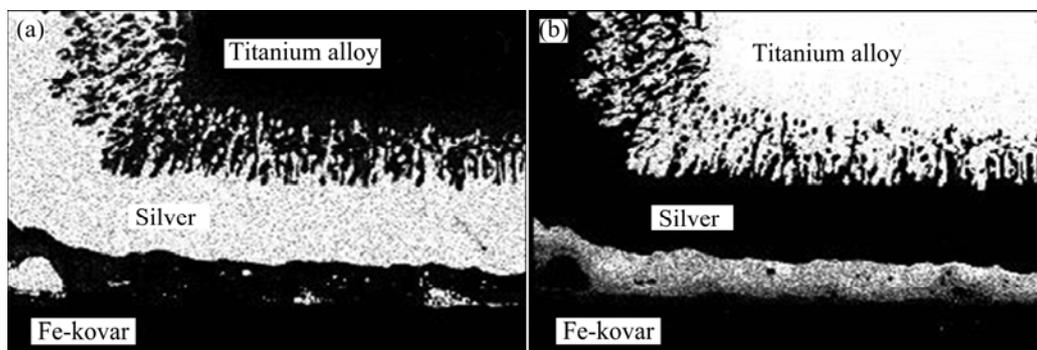
the welded part would be required through mechanical strength or chemical experiment. In case of Ti+Zr-based filler metal, jointing was taken place but it could be confirmed that a lot of internal crack was evident due to very weak diffusion of titanium alloy or stainless steel. As these cracks become an element of reducing mechanical strength, they should be removed without fail. As a result of observation of microstructure, it was identical with that of wetting test and jointing characteristic of Ni-based filler metal was excellent and its jointing degree could be confirmed in the order of BNi<sub>2</sub> ≥ BNi<sub>7</sub> > 40Ti ≫ Ag–5Pd.

#### 4 Conclusions

In order to confirm behavior of microstructure transformation as per filler metals at the time of dissimilar material brazing between titanium alloy and stainless steel, brazing was performed by selecting 3 kinds of filler metal. First, through wetting test between titanium alloy and filler metal, reactivity with base metal and diffusion status of metal component were analyzed



**Fig. 4** Cross-section microstructures of titanium alloy and stainless steel brazed by Ti+Zr filler metal (a)–(c), BNi<sub>2</sub> filler metal (d)–(f), BNi<sub>7</sub> filler metal (g)–(i), and Ag-5Pd filler metal (j)–(l)



**Fig. 5** Mapping scanning of titanium alloy brazed using Ag-5Pd filler metal: (a) Silver; (b) Titanium

through observation of microstructure and afterwards, regarding brazing of dissimilar materials, structural transformation as per filler metal was also analyzed through microstructure observation. As a result of analysis, it was confirmed that filler metals containing

nickel component had dropped high melting point of titanium significantly and induced diffusion into base metal and by lowering critical temperature of  $\beta$  transus, induced jointing between base metal and dissimilar materials.

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