STUDY ON THE MICROSTRUCTURES AND BRAZING CONDITIONS OF TITANIUM ALLOYS

TAESHIN CHUNG

Agency for Defense Development, Daejeon 305-600, Korea
Email: giantchung@nate.com

Abstract - Titanium alloys have good mechanical and chemical properties for aerospace and biomedical materials. For using titanium alloys, the manufacturing processes like machining, surface treatment and welding have to be developed. Especially, brazing is one of the most important processes for making parts. Titanium alloys are mostly brazed with same or similar titanium alloys in previous researches. But, for making special parts, dissimilar brazing process has to be needed for titanium alloys and other materials. In this study, titanium alloy substrate was brazed with Fe-Ni-Co alloy using various filler metals. For an optimized brazing condition, various filler metals are used. Microstructures are observed for each condition. Filler metals are Ti-based 40Ti-20Zr-20Cu-20Ni, Ag-based Ag-5Pd, and Ni- based Ni-7Cr-3.1B-4.5Si-3Fe-0.06C (BNi_2) and Ni-14Cr-10P-0.06C (BNi_7). 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 the conditions using Ti- and Ni-based filler metals have brazed zone between titanium alloy and Fe-Ni-Co alloy. However, titanium alloy was eroded during brazing using Ti-based filler metals. Ni-based filler metal has a good brazed zone between titanium alloy and Fe-Ni-Co alloy among the filler metals

Keywords - Brazing Conditions, Titanium Alloy

I. INTRODUCTION

Titanium alloy accounts for an important role in the various modern industrial areas for its characteristics of low density, high strength, fatigue and corrosion resistance and high performance of specific strength [1-3]. Application for diversified fields including architecture, civil, automobile component, medical component and accessories as well as existing applied fields like aircraft component and petrochemical system is being attempted [4,5].

As a jointing method of titanium alloy, welding, brazing and diffusion welding have been developed and among these, brazing technology is one of the jointing technologies being widely used even today [6,7]. By this method, jointing both similar metal and dissimilar metal is allowed and material cost reduction and development of new component are convenient and component design of diversified forms is allowed as jointing metals of different size and thickness is easy [8-10]. In addition, as jointed part is metallurgical joint, diversified features including ductility, shock resistance, vibration-proof, air tightness, thermal conductivity and corrosion resistance are provided and therefore, brazing technology is most widely used [11].

Titanium alloy is classified into α, β, α + β type depending on component of compound under normal temperature and over critical temperature of β-transus, α → β phase transformation is taken place and crystal structure and mechanical property are changed. Therefore, in order to maintain mechanical property of microstructure and mechanical property of brazing structure base metal, it is desirable to perform brazing below the critical temperature (-880° C). In addition, as most of Ti-based intermetallic phase (e.g., Ti_xNi_y, Ti_xCu_y) is easy to be broken and a new phase created by reaction of base metal and filler metal is important, selection of filler metal is important [12].

Filler metal used for brazing of titanium alloy is mainly divided into three kinds including Ag-base, Al-base and Ti+Zr-base and it is manufactured by adding alloy component including Cu, Ni, Mn, Be, Pb, V and Nb. Brazing jointed part of titanium alloy requires special attention in its using environment and in particular, in case of aerospace industry that requires resistance against high cycled fatigue, its importance is further emphasized. At the time of brazing of titanium alloy, proper jointing strength should be obtained and reactivity and reactant for two base metals should not be vulnerable [4,5].

In this study, as a study of brazing of dissimilar materials between titanium alloy (Ti-6Al-4V) and Fe-29Ni-17Co alloy, wetting test between filler metal and titanium alloy was performed and through cross-section analysis, compliance for each filler metal reaction was determined. Afterwards, brazing between titanium alloy and Fe-Ni-Co alloy 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.

II. EXPERIMENTAL

2.1. Materials

As titanium alloy used for this study, alloy having a chemical component of Ti-Al-V was used and alloy having a chemical component of Fe-Ni-Co alloy was used. Chemical component ratio per each alloy is as shown on Table 1. As filler metal, total four kinds of filler metal was used and Ti+Zr-based 40Ti-20Zr-20Cu-20Ni, Ag-based Ag-5Pd and Ni-based BNi_2 and BNi_7 were used, respectively. Contents of

component and meting point per each filler metal are shown on Table 1 in detail.

Name		Chemical Component	Melting Point
Alloy	Ti	Ti-6Al-4V-0.25Fe-0.2O	1604-1660 °C
	Fe-Ni-Co alloy	Fe-29Ni-17Co-0.3Mn-0.2Si-0.02C	1450 °C
Filler Metal	40Ti	Ti-20Zr-20Cu-20Ni	830 °C
	Ag-5Pd	Ag-5Pd	985 °C
	BNi_2	Ni-7.0Cr-3.1B-4.5Si-3.0Fe-0.06C	1000 °C
	BNi_7	Ni-14Cr-10P-0.06C	890 °C

Table 1 Chemical Component and Brazing Temperature of Each Filler Metal.

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 minutes regardless of kind of filler metal and heating was raised to brazing temperature again after maintaining heating temperature at 50° C for 30 minutes 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 minutes as a whole so that filler metal could be sufficiently wetted down into jointed metal inside. Generally, titanium alloy is divided into α, β, α + β 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 per minute (Figure 1).

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 γSL, surface tension of filler metal as γSV and surface tension of base metal of filler metal as γLV, it could be expressed as following formula. Where, θ is

contact angle. $\cos\theta = \frac{(\gamma SV - \gamma SL)}{\gamma LV}$

Boundary of occurrence or non-occurrence of wetting property could be determined by 90 ° (θ angle). In other words, if contact angle is below 90 °, wetting property exists and over 90 °, wetting property does not exist. In general, at the time of most of brazing, θ angle is between 10 ° and 40 ° and most of wetting property is determined by jointing space of brazing base metal [13-15].

In this study, 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, 20kV). As shown on Figure 2 (a), by dividing wetting part of filler metal wet by titanium alloy into 3 parts, an analysis was performed.

2.3. 2. Microstructure and Mapping scanning

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

III. RESULTS AND DISCUSSION

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

Figure 3 is 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. Figure 3 (a)-(c) is a test result of wetting property of sample brazing Ti+Zr-based filler metal with titanium alloy, Figure 3 (d)-(f) is that of sample brazing Ni-based BNi_2 filler metal with titanium alloy and Figure 3 (g)-(i) is that of sample brazing Ni-based 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 app. 23 ° 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 β solid phase. In other words, it could be realized that Ni-based

filler metal plays a role of β stabilizing element by dropping melting point of titanium significantly and lowering critical temperature of β transus [16-20]. 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 $BNi_7 \geq BNi_2 > 40Ti >> Ag\text{-}5Pd$.

3.2. Microstructure of Ti-alloy brazed Fe-Ni-Co alloy with various filler metal

In brazing dissimilar materials between titanium alloy and Fe-Ni-Co alloy, a result of observation of microstructure as per filler metals is as shown on Figure 4 (a)-(c) is a result of observation of cross-section of sample brazed by using Ti+Zr-based filler metal, Figure 4 (d)-(f) is that of sample brazed by using Ni-based BNi_2, Figure 4 (g)-(i) is that of sample brazed by using Ni-based BNi_7 and Figure 4 (j)-(l) is 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 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 Figure 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 Fe-Ni-Co alloy at all. On the contrary, in case of BNi_2 and BNi_7, 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 Fe-Ni-Co alloy. 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 $BNi_2 \geq BNi_7 > 40Ti >> Ag\text{-}5Pd$.

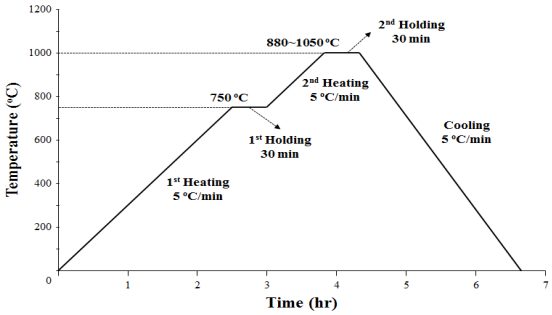

Figure 1 Standard thermal cycle used for wetting and brazing tests.

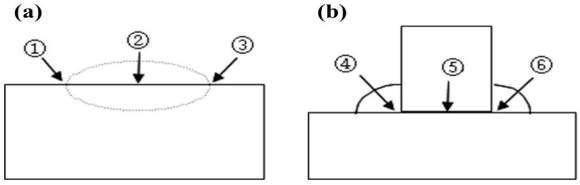

Figure 2 Lay-out of microstructural analysis (a) brazing sample of titanium alloy and filler metals, (b) brazing sample of titanium alloy and Fe-Ni-Co alloy used by filler metals.

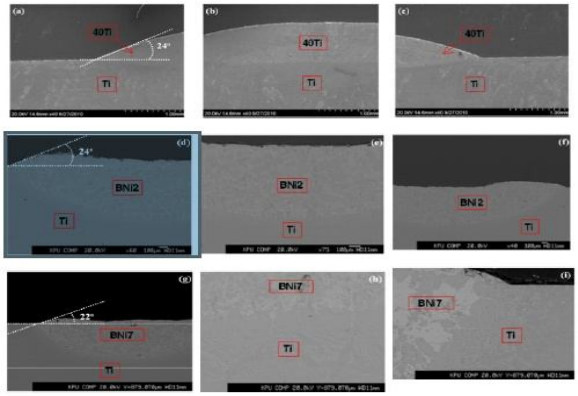

Figure 3 Microstructure of titanium alloy brazed with various filler metal. SEM images of cross-section of titanium alloy brazed (a)-(c) Ti+Zr filler metal, (d)-(f) BNi_2 filler metal and (g)-(i) BNi_7 filler metal.

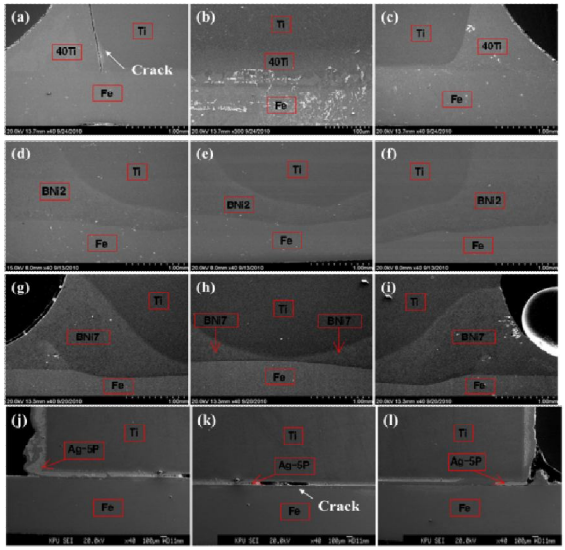

Figure 4 Microstructure of titanium alloy brazed Fe-kovar with various filler metal. SEM images of cross-section of titanium alloy brazed with Fe-Ni-Co alloy used by (a)-(c) Ti+Zr filler metal, (d)-(f) BNi_2 filler metal, (g)-(i) BNi_7 filler metal, (j)-(l) Ag-5pd filler metal.

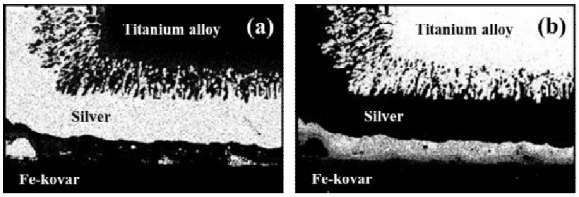

Figure 5 Mapping scanning of titanium alloy brazing used Ag-5Pd filler metal.

CONCLUSIONS

In order to confirm behavior of microstructure transformation as per filler metals at the time of dissimilar material brazing between titanium alloy and Fe-Ni-Co alloy, 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 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 β transus, induced jointing between base metal and dissimilar materials.

REFERENCES

[1] R. Roger, E. W. Collings, and G. Welsch, Materials Properties Handbook: Titanium Alloys, ASM International, Materials Park, Ohio ,1993

[2] J. R. Davis, Metals Hanbook, Vol. 2, Properties and Selection: Nonferrous Alloys and Special Purpose Materials, ASM International, Materials Park, Ohio,1990

[3] D. L. Olson, I. A. Siewart, S. Liu, and G. R. Edwards, ASM Handbook, Vol. 6, Wielding, Brazing and Soldering, ASM International, Materials Park, Ohio,1993

[4] J. R. Myers, H. B. Bomberger, and F. H. Froes, J. Mater., 36, 50, 1984

[5] J. F. Kahles, M. Field, D. Eyln, F. H. Froes, J. Met. 37, 27 ,1985

[6] D. Eylon, Internally Reinforced Hollow Titanium Alloy Components., U. S. Patent 5,429,82777, Jul 4, 1985

[7] C. H. Hamilton, S. Pedro, Mathods for Making Metallic Sandwich Structures, U. S. Patent 3,927,817, Dec 23 (1975)

[8] C. C. Chen, J. Mater. 34, 30,1982

[9] D. Eylon, F. H. Froes and R. W. Gardiner, J. Mater. 35, 35 ,1983

[10] F. H. Fores and I. R. Pickens, J. Mater. 36 14, 1984

[11] H. Hong, A. T. Riga, J. M. Cahoon and C. G. Scott, Wear 162, 34,1993

[12] A. Shapiro and A. Rabinkin, Welding J., 36,2003

[13] R. Standing and M .Nicholas, J. Mater. 36, 14,1978

[14] J. G. Li, J. Mater. Sci. Lett. 11, 1551 ,1992

[15] N. Grigorenko, V. Poluyanskaya, N. Eustathopoulos, Y. Naidich, Interfacial Science of Ceramics Joining, Boston ,1998 pp. 69 – 78

[16] M. M. Schwartz, Brazing, ASM International, Metals Park, Ohio ,1987, p. 77

[17] D. L. Olson, T. A. Siewert, S. Liu, G. R. Edwards, ASM Handbook, Vol. 6, Welding, Brazing and Soldering, ASM International, Materials Park, Ohio,1993

[18] M. Schwarts, Brazing: For the Engineering Technologist, ASM International, Materials Park, Ohio,1995

[19] G. HUmpston and D. M. Jacobson, Principles of Soldering and Brazing, ASM International, Materials Park, Ohio,1993

[20] N. Lashko and S. Lashko, Brazing and Soldering of Metals, MIR Publishers, Moscow,1979

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