Title	Strength of Titanium Joints Brazed with Aluminum Filler Metals(Physics, Process, Instrument & Measurement)
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Citation	Transactions of JWRI. 1990, 19(1), p. 45-49
Version Type	VoR
URL	https://doi.org/10.18910/5077
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Strength of Titanium Joints Brazed with Aluminum Filler Metals†

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Abstract

Joint strengths of aluminum to titanium (Al/Ti) braze joint and titanium to titanium (Ti/Ti) braze joint were investigated in relations to the filler metal composition and brazing conditions. In Al/Ti joints, Al-10Si-Mg filler metal offered better results than Al-Cu-Sn and Al-Ag-Cu filler metals. Fracture occurred within filler metals in the former filler metal and at interface between filler metal and titanium base metal in the latter ones.

In Ti/Ti joints, lap joint fractured at base metal under low temperature and short time brazing conditions. Increase of brazing temperature and time degraded the braze joint quality, decrease of strength and quality of appearance. The rate of degradation was lower in filler metal with lower intermetallic compound growth rate than filler metal with higher growth rate. Lower growth rate of intermetallic compound layer was obtained in silicon bearing filler metals. The use of commercial aluminum alloys with silicon as impurities such as 3003 is recommended as brazing filler metals for making Ti/Ti joint.

KEY WORDS : (Vacuum brazing) (Aluminum filler metals) (Titanium) (Joint strength) (Lap joint)

1. Introduction

The needs for brazing of aluminum to titanium (Al/Ti) joints and titanium to titanium (Ti/Ti) joints becomes high in recent days. Brazing with aluminum filler metals offers light joint weight, therefore, the method is useful for airplanes and space industries. Aluminum brazing filler metals for making aluminum to titanium joints in a vacuum has been developed in the previous paper[1]. The work described the spreadability and filled clearance length as parameters of brazeability, however, the joint strength is also an important factor of joint quality. In the present work joint strengths of aluminum to titanium lap joint and titanium to titanium lap joint were investigated in relations to aluminum filler metal composition and brazing condition.

2. Experimental Procedures

Pure titanium plate with 1 mm thickness and Al-1Mn (3003) alloy were used as base metals. The chemical compositions of titanium base metal is indicated in **Table 1**.

Used aluminum filler metals for joint strength test were Al-10Cu-8Sn, Al-20Ag-10Cu and Al-10Si-0.5Mg for Al/Ti joints, and commercial aluminum alloys and laboratory made high purity binary alloys for Ti/Ti joints. The amount of additional elements in high purity binary filler metal was fixed to about 1%. The filler metals were cut and polished to a size of 5 × 5 × 2 mm for clearance filling test and 0.03 g for strength test. Prior to brazing, titanium base metal was chemically cleaned by immersing into nitric acid-fluoric acid aqueous solution to remove surface oxides, and then rinsed sufficiently in tap water.

The shape and size of tensile test specimens are shown in **Fig. 1**. Figure 1(a) is Al/Ti lap joint specimen, and Ti/Ti lap joint specimen is shown in Fig. 1(b). The gap between lapped area was maintained to 0.1 mm by inserting the pure titanium wire between two base metals, the volume of a gap is one third of that of used filler metal. Accordingly, fillet formed after brazing were removed by machining. After that the specimen was subjected to tensile test by an Instron type tensile test machine with crosshead speed of 1 mm/min, the length

Table 1 Chemical compositions of titanium base metal

Base metal	Elements					
	Fe	N	O	H	C	Ti
Pure Ti	0.066	0.0038	0.074	0.0018	–	bal.

† Received on April 28, 1990

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Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan

between chucks was 45 mm.

Figure 1(c) shows the clearance filling test specimen[2,3]. The vertical and horizontal members were composed of titanium and the clearance was maintained by inserting a stainless steel rod at one edge of tee type joint.

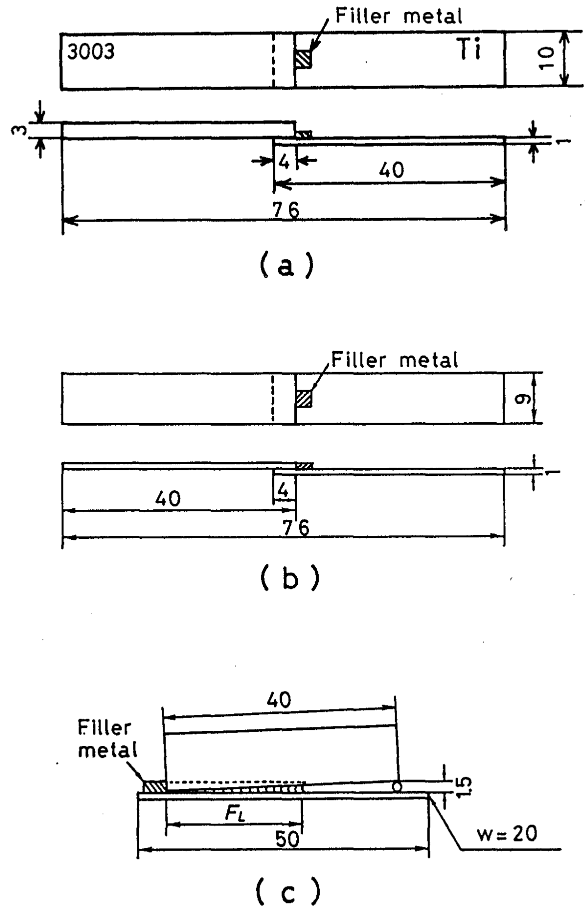

Fig. 1 Shape and size of specimens for tensile test of Al/Ti joint (a), Ti/Ti joint (b) and for clearance filling test of Ti/Ti joint (c).

3. Results and Discussions

3.1 Al/Ti Joints

Table 2 shows the Al/Ti joint strength brazed with aluminum filler metals at 600 ~ 615 C for 3 ~ 5 min. Filler metal that offers good brazeability, long filled clearance length, at low temperature, 600 ~ 615°C[1], were used for making tensile test specimens. Al-10Si-0.5Mg filler metal showed the largest value. Al-10Cu-8Sn and Al-20Ag-10Cu filler metals contains intermetallic compounds of $CuAl_2$ and Ag_2Al. The ductility of these alloys would be expected to be lower than that of Al-10Si-Mg alloys composed mainly of aluminum solid solution and silicon. The use of Al-10Si-Mg filler metal would be the best selection for making Al/Ti joints.

Figure 2 shows the scanning electron micrographs and energy dispersive X-ray (EDX) line analysis on the cross section of brazed interface at titanium base metal side.

Table 2 Results of tensile tests on Al/Ti joints and formed intermetallic compounds on titanium base metal

Filler metal (Brazing condition)	Tensile load (N)	Intermetallic compounds *
Al-10Cu-8Sn (615℃, 5 min)	1530	Al_3Ti, (Ti_8CuAl_{23})
Al-20Ag-10Cu (600℃, 5 min)	1530	Al_3Ti
Al-10Si-0.5Mg (600℃, 3 min)	2795	$Ti_7Al_5Si_{12}$, (Ti_9Al_{23})

* ( ): Only a few very weak diffraction lines (including a main peak) were observed.

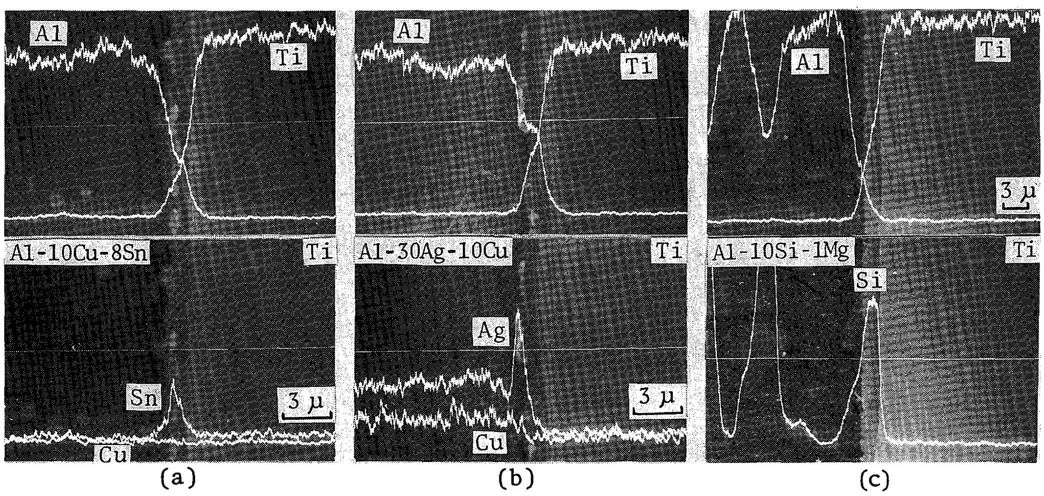

Fig. 2 Scanning electron micrographs of cross section of brazed interface at titanium side and EDX line analysis.

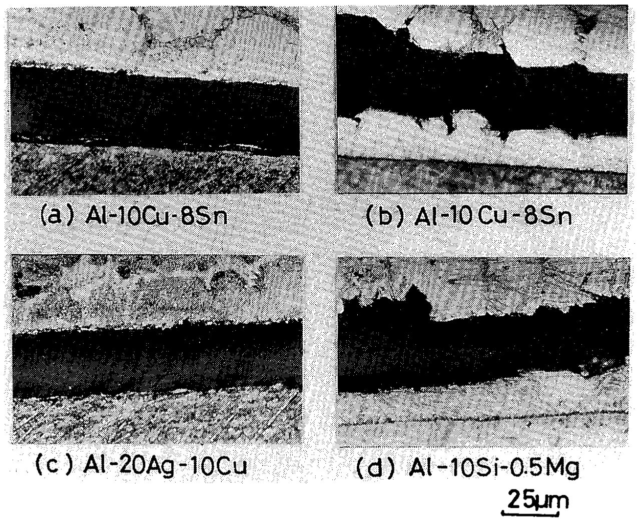

Fig. 3 Cross section of fractured specimen.

Intermetallic compounds formed on titanium base metal are listed in Table 2. Al_3Ti formed on titanium surface during brazing with Al-Cu-Sn and Al-Ag-Cu filler metals, and $Ti_7Al_5Si_{12}$ compound was mainly detected on titanium brazed with Al-10Si-Mg filler metals. Precise descriptions about the intermetallic compounds are reported in the other paper[4].

Figure 3 shows the cross section of fractured specimen. In Al-10Cu-8Sn and Al-20Ag-10Cu filler metals, specimens were fractured at interface between filler metal and titanium base metal. In Al-10Si-0.5Mg filler metal, fracture path was inside of filler metal. In Al-10Cu-8Sn filler metal fracture occurred partially in filler metal, but the path was not aluminum solid solution but intermetallic $CuAl_2$ phase at boundaries of solid solution (Fig. 3(b)). The intermetallic compounds in filler metal would acted as the initiation site of propagating cracks.

3.2 Ti/Ti joints

Figure 4 shows the filled clearance length and the thickness of intermetallic compoud layer after brazing with various aluminum filler metals. The brazing were carried out at 680°C for 3 min. The filled clearance length of each filler metal was 25 to 28 mm, indicating no dependence on filler metal composition.

On the other hand, the thickness of intermetallic compound layer was quite different with each other. Pure aluminum (99.99%) filler metal showed the largest thickness, suggesting that all additional and impurity elements in aluminum suppressed the growth of intermetallic compounds. Above all, small addition of silicon remarkably reduced the layer thickness. Accordingly, in the commercial aluminum alloys with silicon as an impurity or an additional element the growth of intermetallic layer is remarkably suppressed.

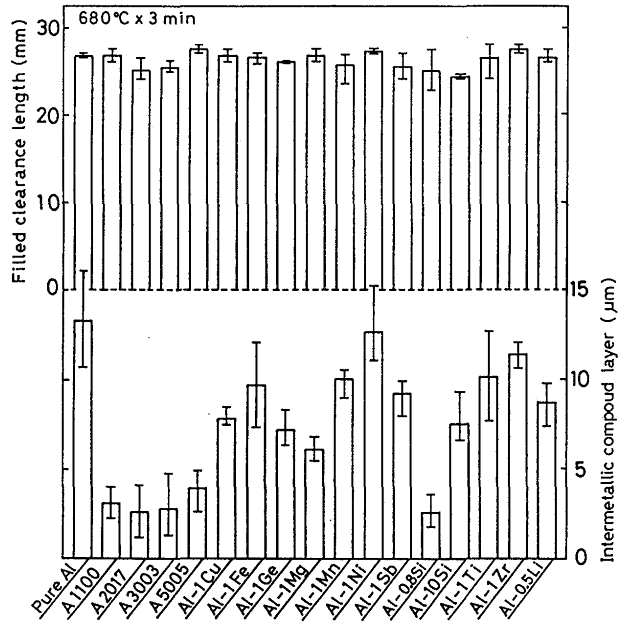

Fig. 4 Filled clearance length and thickness of intermetallic compound layer at brazed interface with various aluminum filler metals, brazed at 680°C for 3 min.

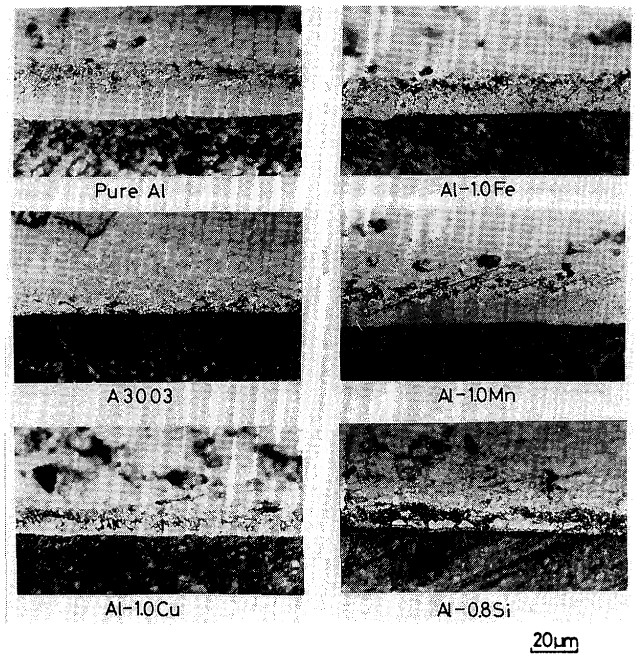

Fig. 5 Cross section of clearance filling test specimen at center of filled clearance length.

Figure 5 shows the cross section of Ti/Ti joints at the center of filled clearance length. Large intermetallic compound layer of Al_3Ti was found in pure aluminum, in commercial 3003 alloy and Al-0.8Si alloy the growth of compound layer was greately suppressed. Growth rate of intermetallic compound layer and the precise discussions were reported in the separate work[4].

Figure 6 shows the appearance of Ti/Ti joint. All specimens showed smooth surface and homogeneous fillet was formed. In pure aluminum and Al-1%Mg filler metal, molten filler metal spread relatively widely on base metal surface.

Lap joint strength of Ti/Ti joint was investigated using pure aluminum and Al-0.8%Si filler metals that showed quite different thickness of intermetallic compound layer. **Figure 7** shows the strength of Ti/Ti joint. Holding time at brazing temperature was 3 min. Fractured area is also indicated in the figure, joint fracture i.e., fracture at brazed joint is indicated by open symboles and base metal fracture is expressed by semi-solid symboles. At lower temperatures of 670 and 680°C, ratio of base metal fracture was high, especially in Al-0.8%Si filler metal. The ratio of base metal fracture decreased with increasing brazing temperature, also the joint strength decreased with the rise of brazing temperature, the tendency is more pronounced in pure aluminum that made thicker compound layer.

Figure 8 shows the effect of holding time at 700°C on joint strength. Joint strength decreased with holding time especially drastically in pure aluminum. After holding for 30 min all specimens brazed with pure aluminum separated themselves before tensile test. Appearance of joint also degraded by the wide spread of filler metal on base metal. In Al-0.8%Si filler metal strength also decreased with holding time, however, the decrement rate was not so drastic as pure aluminum.

The decrement of joint strength during holding is attributable to the decrease of molten filler metal volume

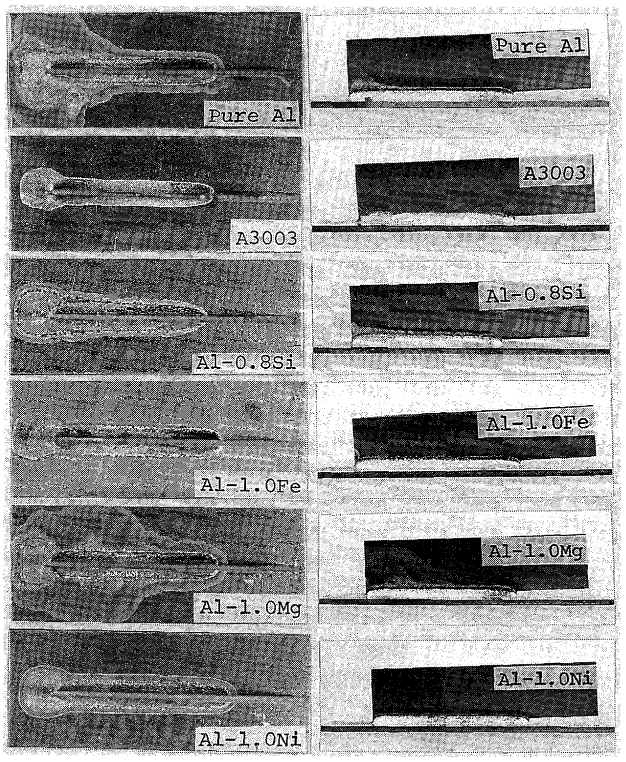

Fig. 6 Appearance of filled clearance test specimens brazed at 680°C for 3 min with various aluminum filler metals.

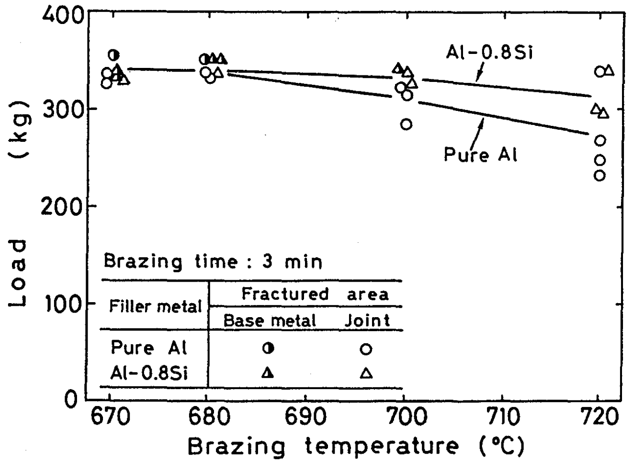

Fig. 7 Effect of brazing temperature on tensile load of lap joints with 9 mm width.

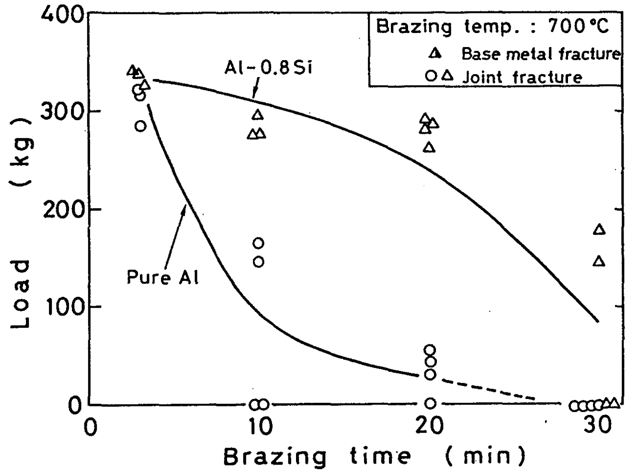

Fig. 8 Effect of brazing time at 700°C on tensile load of lap joints with 9 mm width.

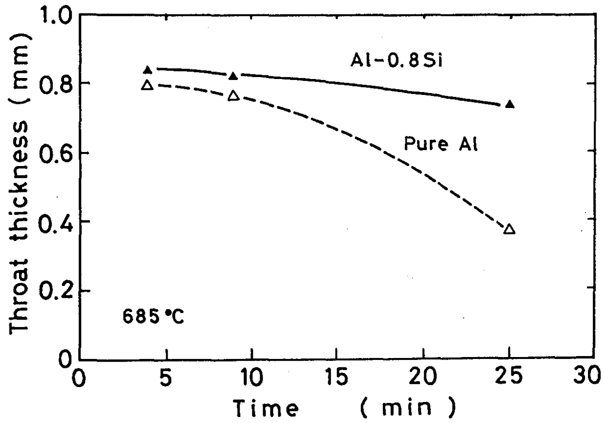

Fig. 9 Changes of throat thickness during holding at brazing temperature of 685°C.

in a joint gap due to the increase of intermetallic compound layer thickness and spreading over the base metal as indicated in Fig. 6. **Figure 9** shows the decrease of fillet size with holding time at 670 and 685°C. Fillet size was measured by the throat thickness of fillet[5] at the center of filled clearance length. Reduction of formed fillet was faster in pure aluminum filler metal than in Al-0.8%Si filler metal. In the present work no pressure was applied during brazing, therefore, formed voids in the gap decreased the quality of joint. In pure aluminum filler metal, spread area and growth rate of intermetallic compounds were larger than those in Al-0.8%Si, therefore, remarkable decrease in strength was observed with increasing the brazing temperature and time.

In view of the joint strength short time brazing at low temperature is preferable. Pure aluminum is not suitable to braze large components that require long brazing time to heat up to brazing temperature, the use of silicon bearing filler metals such as 3003 commercial alloy is recommended.

4. Conclusions

The joint strength of Al/Ti and Ti/Ti joints brazed with aluminum filler metals in a vacuum was investigated. The obtained results are summarized as follows.

(1) In Al/Ti joint, Al-10Si-Mg filler metal showed about twice higher joint strength than Al-Cu-Sn and Al-Ag-Cu filler metals. Brazed Al/Ti joints fractured within filler metals brazed with Al-10Si-Mg. On the other hand fracture occurred at interface between filler metal and titanium base metal brazed with Al-Cu-Sn and Al-Ag-Cu filler metals.

(2) In Ti/Ti joints, the filled clearance length was almost the same irrespective of the aluminum filler metal composition, whereas the thickness of intermetallic compound layer greatly depended on the filler metal composition. Pure aluminum filler metal exhibited the maximum intermetallic compound layer thickness, and the addition of other elements reduced the layer thickness. Above all, small addition of silicon in aluminum filler metal remarkably reduced the layer thickness.

(3) In Ti/Ti joint, lap joint fractured in base metal at low temperature and short time brazing. Increase of braing temperature and time lowered the joint strength and the ratio of base metal fracture. Al-0.8%Si filler metal showed superior joint strength to pure aluminum under the higher brazing temperature and longer brazing time. Decrement of joint strength with increase of brazing time and temperature is lower in Al-0.8%Si filler metal than in pure aluminum. The use of Al-0.8%Si or commercial aluminum alloy with silicon is recommended.

Acknowledgment

Thanks are extended to Dr. T. Nishimura at Kobe Steel Co. Ltd., for presentation of titanium plate, and to Mr. H. Kawase for presentation of aluminum.

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