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Aluminum Brazing Filler Metals for Making Aluminum to Titanium Joints in a Vacuum†

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Abstract

A spread test on Ti-base metal and a clearance filling test on Al/Ti joint were performed under vacuum condition to investigate the appropriate composition of aluminum filler metals. The spread area on Ti-base metal depended on the surface area of titanium in a brazing furnace due to an effective gettering action of titanium. Magnesium bearing brazing sheets were also effective getter materials. Al-10Si-Mg alloy was the most suitable filler metal for vacuum brazing of Al/Ti joints, and it made sound fillets at 600°C. Al-10～12.5Cu-5～8Sn and Al-20Ag-10Cu filler metals were also applicable at brazing temperatures of 600～620°C. The joint strength is however, only a half of that of the Al-10Si-Mg filler metals.

KEY WORDS : (Vacuum brazing) (Aluminum filler metals) (Aluminum to titanium joint) (Getter action) (Spread test) (Clearance filling test)

1. Introduction

Aluminum and titanium has been widely used in airplanes and space vehicles due to its small density and high specific strength. In recent days the necessity of making aluminum to titanium joints becomes high. Brazing is one of the inexpensive convenient joining methods for aluminum and titanium. The filler metals used for brazing of titanium are silver based[1-7], titanium based[8-10] brazing filler metals and copper insert metal[11-13], however, these filler metals have higher melting temperatures than that of aluminum, therefore, they are not applicable for making aluminum to titanium joint (Al/Ti joint).

On the other hand Al-Si filler metals have been used for brazing of aluminum. Ag-Al and Al-50Zn filler metals were reported to give good results for making Al/Ti joints[14], however, these filler metals have difficulties for adopting into the vacuum brazing or practical use due to their high vapor pressure and cost. From the point of view of the reduction of weight and cost, fluxless brazing of aluminum to titanium at low temperature would be satisfactory. The aim of the present work is to make Al/Ti joints with aluminum filler metals in a vacuum. For this purpose spread test on titanium and clearance filling test on Al/Ti joints were conducted.

2. Experimental Procedures

Used titanium base metal was pure titanium of 1 mm thickness, 0.066% Fe, 0.0038% N, 0.074%O, 0.0018% H, balanced Ti. Commercially pure aluminum, A1100-H14, of 3 mm thickness was used as aluminum base metal, 0.08%Si, 0.23%Fe, 0.03%Cu, 0.02%Mn, balanced Al.

Taking into consideration of the melting point of aluminum, the preferable brazing temperature will be lower than 630°C. The newly made filler metals estimated to have liquidus temperatures less than 630°C were made by addition of copper, silver and/or silicon, the elements significantly decrease the melting temperature of aluminum. The purity of aluminum and additional elements for filler metal exceeded 99.99%. The cast filler metals were cut to a predetermined volume and used for brazing tests.

The present work aims to make Al/Ti joint without applied stress, therefore, the brazability was evaluated by the spread test on titanium base metal and clearance filling test on Al/Ti joint. Spread tests were conducted on titanium base plate with $30 \times 30 \times 1$ mm, filler metal of $5 \times 5 \times 2$ mm was put on the center of base metal and heated at the predetermined temperature for 3 min.

Brazeability of Al/Ti joints was evaluated by the clearance filling specimen shown in **Fig. 1**, vertical member is aluminum and horizontal member is titanium.

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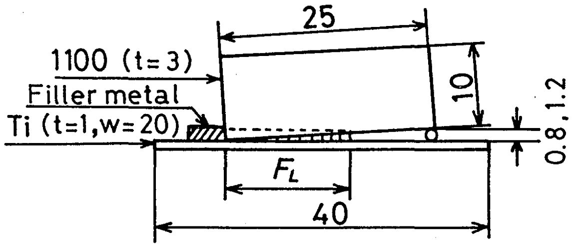

Fig. 1 Shape and size of specimen for clearance filling test of Al/Ti joint.

Stainless steel rod with 0.8 or 1.2 mm diameter (D_O=0.8 or 1.2mm) was put on one edge to make a clearance varying along the length of specimen. Tests were conducted in a vacuum level of 2.67×10^{-3} Pa.

Aluminum base metal was polished by 600 grade emery paper and titanium base metal was chemicaly cleaned in HNO_3+HF+H_2O solution for 30 min.

Liquidus and solidus temperatures of laboratory made filler metals were measured by differential thermal analysis (DTA). Cast filler metals were put in a graphite crucible, DTA were made during cooling stage of molten filler metal in an air atmosphere. Pure aluminum (99.99%) was used as a standard material.

3. Experimental Results

3.1 Effect of surface area of titanium

Titanium has been known as a getter material that react with impurities such as oxygen and moisture in a vacuum furnace, therefore, the surface area of titanium in vacuum brazing furnace would give some influences on brazability. **Figure 2** shows the effect of titanium surface area on spread area of aluminum filler metal on titanium base metal after heating at 630°C for 3 min. The surface area is the total of the surface area of spread specimen and additional getter titanium plate, the indicated area is only the surface area at upside. The arrow means that the contact angle exceeded 90°, poor wetting, the plotted spread area of 25 cm^2 was the initial contact area between filler metal and base metal.

In all filler metals, spread area increased with increasing the surface area of titanium indicating the effectiveness of getter action of titanium. **Figure 3** shows the appearance of spread test specimen, filler metal spread smoothly in larger titanium area, whereas the insufficient spread area in smaller titanium area. In Al-Si system filler metal, the addition of magnesium improved spreadability. In Al-Cu system filler metal, spreadability was improved by addition of lithium. The results indicate that the surface area of titanium affected the spreadability. Accordingly in the brazing test of

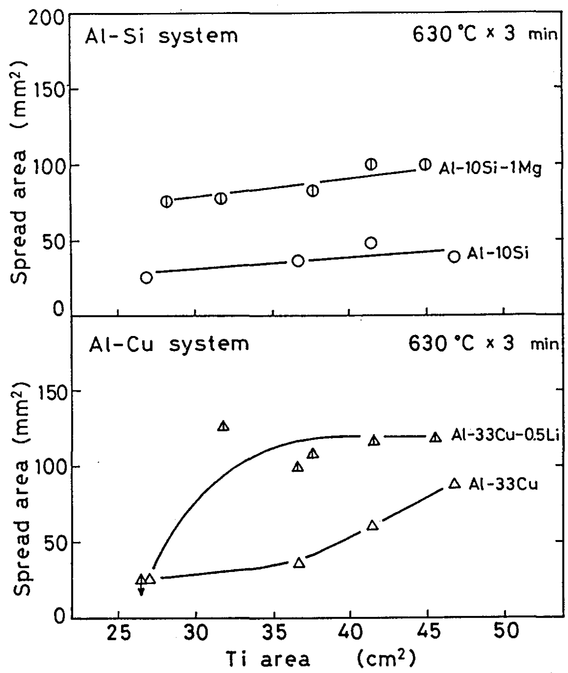

Fig. 2 Effect of titanium area in brazing furnace on spread area of aluminum brazing filler metals on titanium base metal.

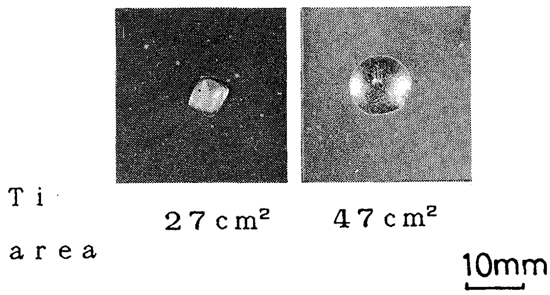

Fig. 3 Appearance of spread test specimen tested at different surface area of getter titanium plate.

titanium the surface area of titanium should be maintained at a constant. In the following test, the surface area of titanium was fixed to 47 cm^2, sufficiantly large from Fig. 2.

3.2 Selection of aluminum filler metals

To select the appropriate brazing filler metals for making Al/Ti joints, various filler metals that would have liquidus temperature less than 630°C were made. The results of spread test of these candidate filler metals are indicated in **Fig. 4**.

Good appearance was obtained in the specimen with spread area more than 80 cm^2, therefore, silver based, Al-Cu-(Sn), Al-10Si-1Mg, pure tin, Al-Ag-Cu system are the most promising filler materials. Pure tin and silver based alloys were rejectable from the point of view of high cost and high density. In the following tests, brazeability of

Al-Cu-Sn, Al-Cu-Ag and Al-Si-Mg filler metals were investigated using clearance filling test specimen.

The Al-30Ag-1Mn filler metals that has been reported to make good titanium brazed joints at 650 ~ 660°C[15] showed insufficient spread area of less than 80 cm^2.

3.3 Filled clearance length

3.3.1 Al-Cu-Sn filler metals

Figure 5 shows the effect of tin content in Al-10Cu-Sn filler metals on filled clearance length, F_L, at $D_O = 0.8$ mm. Erosion of aluminum base metal was remarkably large under the brazing temperature over the liquidus of filler metal, therefore, the experiments were carried out at liquidus temperature of each filler metal indicated in Fig. 5 and maintained for 5 min. The liquidus lowered with tin content, and F_L at liquidus increased with tin content. The addition of tin was found to be effective to lower the brazing temperature and to enhance brazeability.

Figure 6 shows the effect of copper content in Al-Cu-5Sn filler metals on F_L. The liquidus lowered with copper content, F_L also decreased with copper content, the results showed large scattering at 15% Cu.

These results indicate that Al/Ti joints can be made at 610~620°C by using Al-10~12.5Cu-5~8Sn filler metals.

3.3.2 Al-Ag-Cu filler metals

Figure 7 shows the effect of silver addition to Al-10Cu filler metals on F_L, D_O=0.8 mm. Liquidus temperature significantly decreased with increasing silver content. F_L remains constant up to 20% Ag and decreased remarkably at 30% Ag, where the filler mtetal scarcely penetrated. Even in 30% Ag filler metal, test at 630°C gave sufficient F_L as indicated in Fig. 7, however, brazing over the liquidus temperature resulted in severe erosion, the use of this filler metal over lquidus is not recommended.

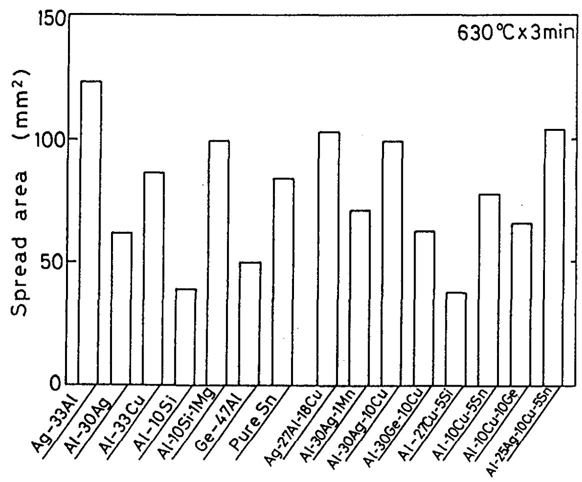

Fig. 4 Spread area of various aluminum brazing filler metals on titanium base metal.

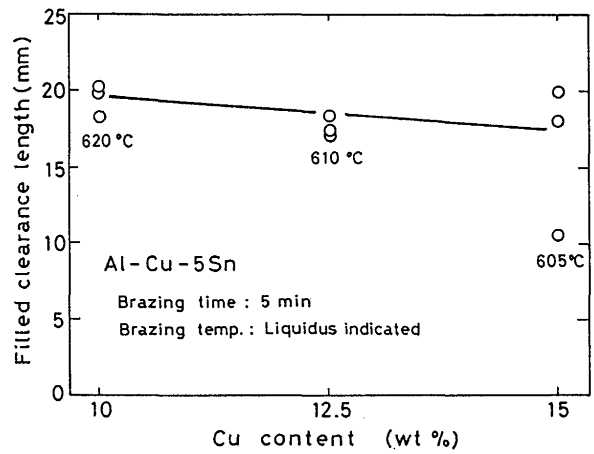

Fig. 6 Relation between copper content in Al-Cu-5Sn filler metals and filled clearance lengths of Al/Ti joints brazed at liquidus temperatures of filler metals.

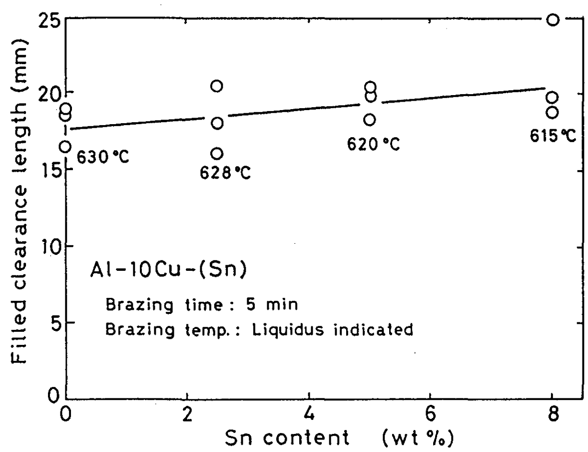

Fig. 5 Relation between tin content in Al-10Cu filler metals and filled clearance lengths of Al/Ti joints brazed at liquidus temperatures of filler metals.

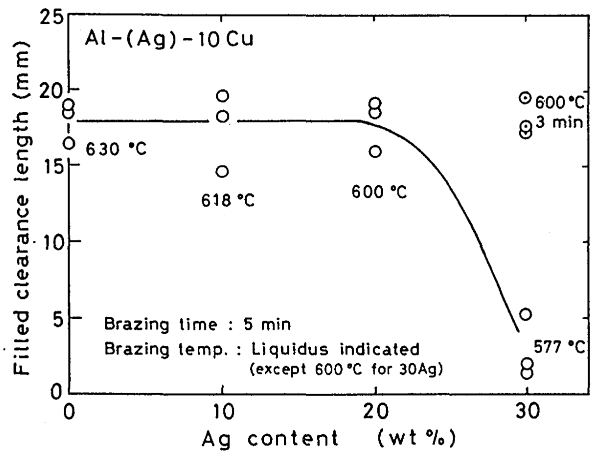

Fig. 7 Effect of silver content in Al-10Cu filler metals on filled clearance lengths of Al/Ti joints brazed at liquidus temperatures of filler metals, except 30Ag at 600°C.

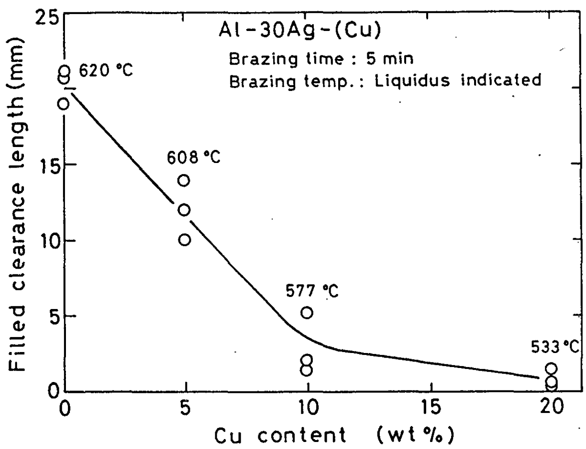

Fig. 8 Changes of filled clearance length of Al/Ti joints with addition of copper to Al-30Ag filler metals, brazed at liquidus temperatures of filler metals.

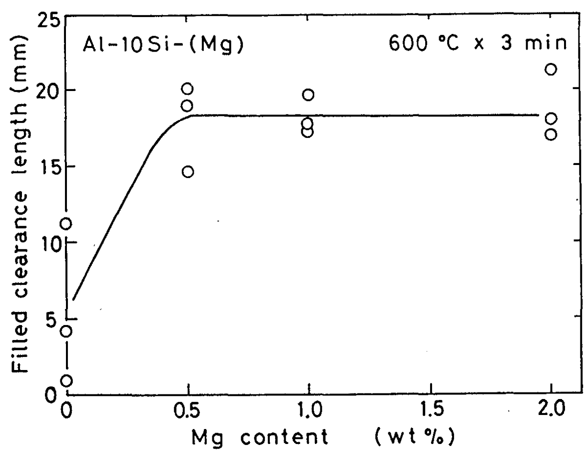

Fig. 9 Effect of magnesium content in Al-10Si filler metals on filled clearance length of Al/Ti joints brazed at 600°C.

Figure 8 shows the effect of copper addition to Al-30Ag filler metals on F_L. The liquidus temperature and F_L decreased drastically with copper content. In 10% Cu and 20% Cu filler metals molten filler metal could not penetrate into gaps between aluminum and titanium base metals and sound fillet was not obtained.

The results indicate that Al/Ti joints could be obtained at 600°C by using Al-20Ag-10Cu filler metals.

3.3.3 Al-10Si-Mg filler metals

Figure 9 shows the effect of magnesium content on F_L,D_O = 1.2 mm. The liquidus temperature of the filler metals are ranging between 590°C and 596°C[16], and the erosion of aluminum base metal was very small. Accordingly, the clearance filling tests were conducted at 600°C for 3 min. Short F_L and large scattering in F_L was observed in Al-10Si filler metal without magnesium. In filler metals with 0.5～2% Mg, F_L increased to about 18 mm and the scattering became narrow. Al-10Si-Mg filler metal gave same F_L at lower temperature and shorter holding time than in the former Al-Cu-Sn and Al-Ag-Cu filler metals, therefore, the use of Al-10Si-Mg would be the best selection for making Al/Ti joints from the point of view of brazeability. Joint strength[17] and intermetallic compounds formed between aluminum filler metal and titanium base metal[18] are described in the separate paper.

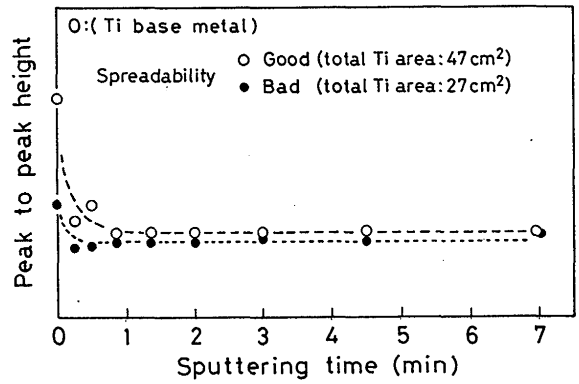

Fig. 10 Auger peak to peak height of oxygen (arbitrary units) of titanium base metals.

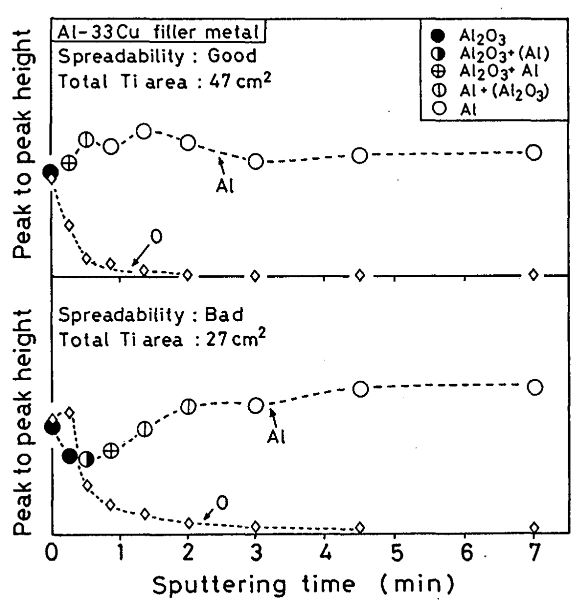

Fig. 11 Changes of Auger peak to peak height of oxygen and aluminum (arbitrary units) of Al-33Cu filler metals.

4. Discussions

4.1 Effect of titanium getter

The present work revealed the placement of titanium plate in a vacuum brazing furnace improved spreadability of aluminum filler metals on titanium base metal. The placed titanium removes the detrimental elements such as oxygen and moisture in vacuum furnace by reacting with them, thus the growth of oxide on titanium base metal and aluminum filler metal is suppressed.

Figures 10 and **11** show the results of Auge spectroscopy on the titanium base metal surface. The peak to peak hight of oxygen at surface is higher in the specimen that showed better result. At inside the height is not so different with each other, and the corelation between spreadability and oxide on titanium surface was not found.

On the other hand, the difference in thickness of oxide is pronounced on the surface of aluminum filler metal, Fig. 10, where the state of aluminum judged from the shapes of Auger spectra was also indicated. On the specimen with titanium getter (surface area of titanium is 47 cm^2), oxide films thinner than that without getter. The sputtering time that required to change the spectra from oxide to aluminum is reduced to about 1/3 by using titanium getter. The placement of titanium getter reduced the growth of oxide film of aluminum filler metal, thus the molten filler metal can extrude from thin oxide film.

The results of Auger spectroscopy showed that titanium getter suppressed mainly the growth of oxide on aluminum than films on titanium base metal. Especially, the new clean surface produced by cracking of the oxide films due to the differnce in thermal expansion coefficient between oxide and aluminum is protected from oxidation by impurities. This effect is the same as the role of magnesium in Al-Si filler metals for vacuum brazing. Added magnesium vaporizes during heating in a vacuum and react with harmful impurities in furnace[19,20].

The effectiveness of titanium getter with larger oxide formation energy than that of aluminum is attributable to the diffusion of oxygen in oxide and matrix and large occlusion of oxygen in titanium.

4.2 Effect of magnesium getter

Magnesium has found to be an effective additional elements in filler metals to enhance the brazeability of Al/Ti joints as already indicated in vacuum brazing of aluminum[22].

Figure 12 shows the effect of surface area of brazing sheet on spread area of Al-33Cu filler metal on titanium base metal. The brazing sheet was consisted of 3003 core material of 1 mm thickness and Al-10Si-0.5 and 2.3Mg clad materials with 0.1 mm at one side. The surface area of titanium was 27 cm^2, at this value filler metal did not spread, Fig. 2. The area of titanium in Fig. 12 means the area of additively placed getter titanium plate.

The use of brazing sheet with magnesium is found to be effective to promote spreadability, and the required surface area is reduced by the use of brazing sheets with higher magnesium content. Larger spread area was obtained by using magnesium bearing brazing sheets than the use of titanium getter plate.

Figure 13 is the plot of spread area against calculated amount of magnesium used in the test in Fig. 12. After brazing magnesiun was scarcely observed[23], therefore, the horizontal axis corresponds the vaporized amount of magnesium. In BS-1 with less magnesium content, good spreadbility could be achieved in smaller magnesium than in BS-3 with more magnesium. In BS-1 large surface area is needed to obtain the same magnesium amount, therefore, under same magnesium amount magnesium vaporizes at wider area than in BS-3, giving higher frequency of reaction between vaporized magnesium and impurities in a vacuum furnace.

In Fig. 12 spread area became constant values depending on the getter material. The spread area of magnesium getter gave larger spread area than that of

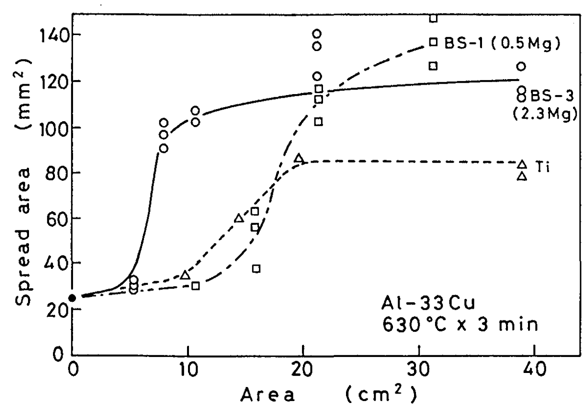

Fig. 12 Effect of brazing sheet surface area on spread area of Al-33Cu filler metal on titanium base metal.

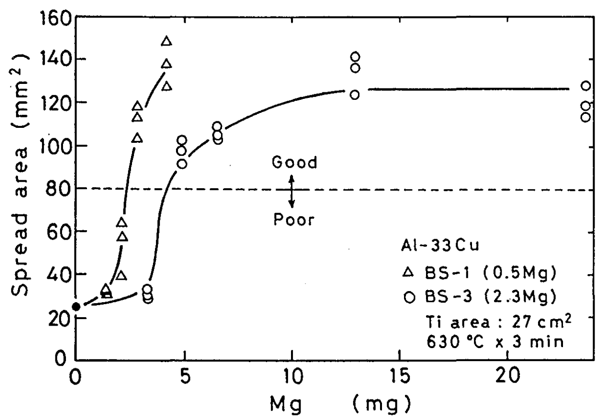

Fig. 13 Relations between magnesium content in brazing sheet getters and spread area of Al-33Cu filler metal on titanium base metal.

titanium getter. This would be attributable to that the free energy of oxide formation is smaller in magnesium than in titanium, and the role of titanium getter is mainly the prevention of growth of aluminum oxide film on filler metal, therefore the vaporization of magnesium from filler metal would effective to enhance the frequency of reaction of magnesium and impurities in furnace.

5. Conclusion

The obtained results are sammarized as follows.

(1) Spreadability of aluminum filler metals on titanium base metal was found to depend closely on the surface area of titanium that gave getter action in vacuum furnace. Placement of titanium and also the brazing sheets containing magnesium as a getter was effective to improve the brazeability of Al/Ti joint.

(2) Titanium getter improved spreadability by prevention of the growth of oxide on aluminum filler metals rather than the prevention of the oxidation of titanium base metal.

(3) Al-10Si-Mg filler metal gave the best filled clearance length in Al/Ti braze specimen, and the addition of magnesium was found to be effective to improve the brazeability

(4) Al/Ti joints could be made at 610～620°C in Al-10～12.5Cu-5～8Sn filler metals, 600°C in Al-20Ag-10Cu and Al-10Si-Mg filler metals.

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