Titanium Brazing for Manufacturing Titanium Heat Exchangers

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Introduction

Titanium is well known as high corrosion resistance material so that it is often selected as an appropriate structural metal of the heat exchangers for under corrosive environment. Conventional titanium heat exchangers are welded type or gasket type. We recently developed brazed type titanium heat exchangers with titanium based filler metal and reported our prior study.

The most important key of manufacturing titanium heat exchangers is the brazing filler metal. For mass production of the heat exchangers in the industry, it is necessary to manufacture the brazing filler metal in large volume. Atomize process is now applied producing titanium based filler metals. The other key is brazing process. Titanium heat exchangers are brazed in industrial production furnace. However, no effort has been made to understand the interfacial reaction related to joint strength under manufacturing process condition.

In this study, commercially pure titanium is brazed with commercially produced atomized brazing filler metal powder in industrial vacuum furnace. We investigated the joint strength by shear strength test and the microstructure at the brazed joint by SEM. This investigation has lead to further insight into the interfacial reaction related to joint strength.

Experimental Procedure

CP-Ti (Grade 2) which consists of titanium heat exchangers was selected as a base metal. 4 types of brazing filler metals which currently manufactured were used in this study. Chemical composition of brazing filler metals was show in table 1. These atomized filler metal powders were in making paste with mixing particular amount of organic binder. Fixed amount 0.3g of brazing filler metal was supplied at the joint and specimens were fixed by fixture.

Schematic diagram of the specimen was shown in Figure 1. The specimens were polished to particular roughness and then dip ultrasonic washed in the acetone.

Brazing was done in the industrial vacuum furnace with high purity shield gas process (Carrier gas process: Ref. 1). This process is to supply particular amount of high purity Ar gas (99.9995%) into the vacuum furnace chamber during vacuuming in order to prevent vaporization of filler metal and to carry the out gas from the chamber, fixture or specimen. Brazing temperature was selected at 880°C and 950°C considered melting point of the brazing filler metals. Brazing time were varied 5, 30, 60min.

Appearances of the specimens after brazing were observed by visual inspection. The joint strength was evaluated by shear strength test. The shear strength test jig was shown in figure 2. Autograph was used for shear strength test. The crosshead speed was set up 1mm/mm and the test was done at the room temperature. Maximum load divided brazed area was determined as a shear strength. The number of specimen was n=8 and the average strengths were defined as joint strength. Cross-section of brazed joint was observed by optical microscope and SEM.

Table 1 Chemical composition of brazing filler metals.

Type	Chemical Compositions (mass%)				Melting Range (°C)
	Ti	Zr	Cu	Ni	
1510	Bal.	37.5	15	10	842(eutectic)
2020	Bal.	20	20	20	810 - 867
2500	Bal.	37.5	25	-	861(eutectic)
5000	Bal.	25	50	-	810 - 860

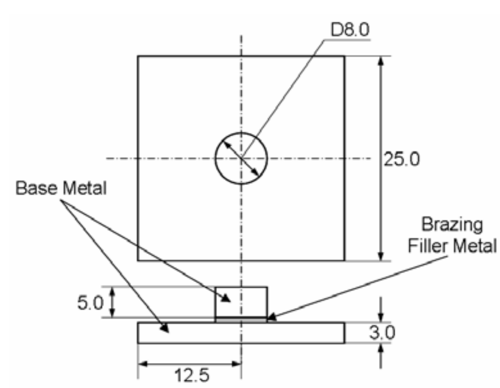

Figure 1 Schematic diagram of shear strength test specimen.

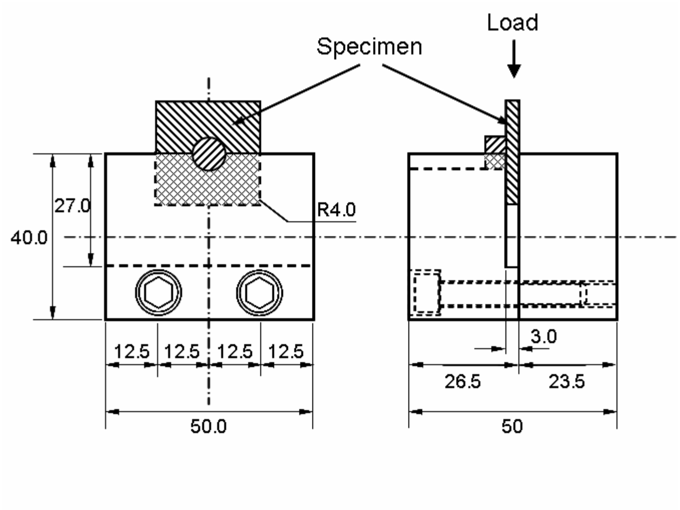

Figure 2 Image and schematic diagram of shear strength test jig.

Results and Discussions

Brazing by High Purity Shield Gas Process

As a result of appearance observation, there is no discoloration by oxidation on base metal and at the fillet. It is proved that the vacuum furnace and high purity shield gas process in this study was effective.

Joint Strength

Typical shear strength test results, for example brazed with 1510, were shown in Figure 3. As brazing time increased, joint strength was slightly increased on brazing temperature at 880°C. In the case of brazing temperature at 950°C, joint strength became almost same in any brazing time. On the brazing time of 60min, joint strength showed almost same regardless of any brazing temperature. The difference of shear strength was indicated in the error bar in the figure and the difference became smaller as increasing of the brazing time and brazing temperature.

In order to give further discussion of the reliability of joint strength, relationship between Weibull and shear strength was shown in Figure 4. Then Weibull slope was calculated by method of least squares from Weibull distribution in Figure 4. It is understood that the reliability of average number can be evaluated from the Weibull slope. In generally, higher Weibull slope means smaller difference of joint strength and the reliability of average number becomes better.

Figure 5 shows the effect of brazing time on Weibull slope. The Weibull slope was rose according to increasing of brazing time on both brazing temperature at 880°C and 950°C. In other words, reliability of joint strength becomes higher according to increasing of brazing time and temperature. No appearance different was involved any other brazing filler metals in this study.

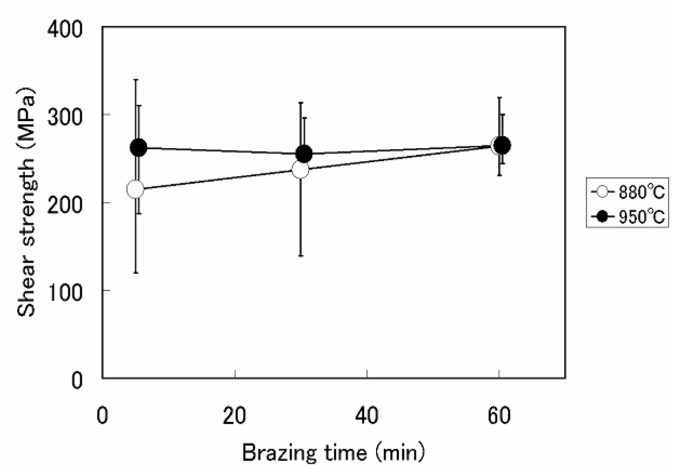

Figure 3 Effect of brazing condition on shear strength test. (Brazed with 1510)

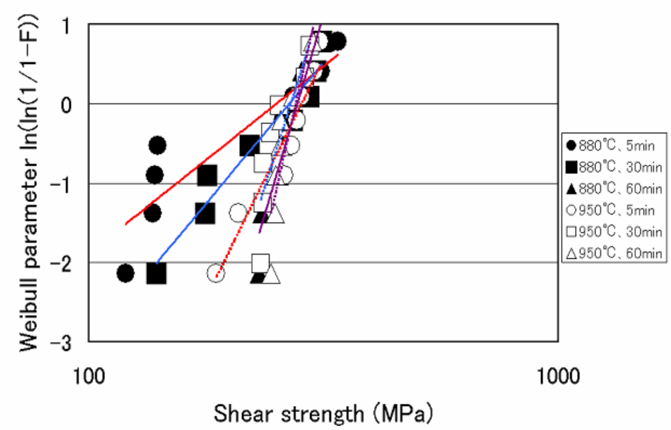

Figure 4 Relationship between Weibull and shear strength. (Brazed with 1510)

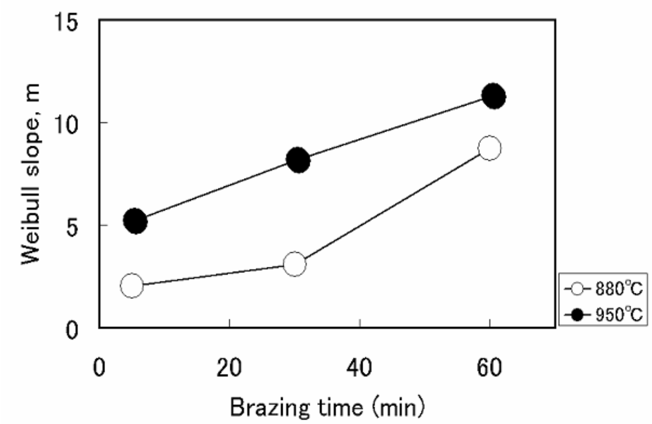

Figure 5 Effect of brazing time on Weibull slope. (Brazed with 1510)

Micro Structures of Joint

No joint failures such as voids and cracks were observed at the brazed joints of all specimens in this study.

SEM of typical microstructure of brazed joint with 1510 at 880°C for 5 min was shown in figure 6. Brazing filler metal was partially remained at the center of the brazed joint.

Reaction layer which assumed primary crystal of Ti-Zr solid solution was formed at the filler metal side of the interface. An aciculate microstructure formed of lamellar microstructure between thin black phases was observed at the base metal side of the interface.

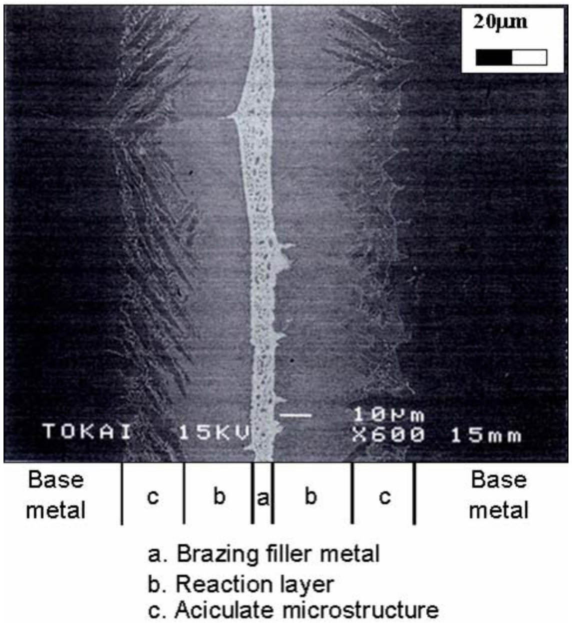

Figure 6 Typical microstructure of brazed joint with 1510 at 880°C for 5 min.

SEM of typical microstructure of brazed joint with 1510 at 880°C for 60 min was shown in figure 7. As brazing time increased, brazing filler metal layer was disappeared and only reaction layer and an aciculate microstructure were observed at the interface. An aciculate microstructure remarkably grew up compared with the microstructure of brazing time 10 min. As same as the result of joint strength, no appearance different was involved any other brazing filler metals in this study. It is assumed that different formation of microstructure effected Weibull slope.

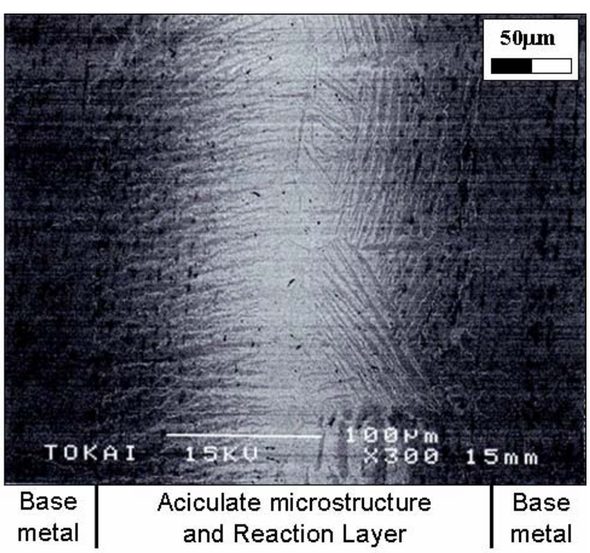

Figure 7 Typical microstructure of brazed joint with 1510 at 880°C for 30 min.

Conclusions

In this study, all specimens were well brazed under industrial condition including commercially produced atomized brazing filler metal powder in industrial vacuum furnace by high purity shield gas process.

Joint strength was examined by shear strength test and reliability of joint strength was evaluated by calculation of Weibull slope. It is understood that reliability of joint strength becomes higher according to increasing of brazing time and temperature.

Microstructure of brazed joints was observed. Brazing filler metal layer was partially remained at the center of the brazed joint for 5 min, but it was totally disappeared for 60 min. Different formation of microstructure effects Weibull slope, which is same as reliability of joint strength.

It is understood that sufficient brazing time is necessary to improve mechanical properties of titanium heat exchangers.

References

[1] New Industrial Furnace Handbook, Japan Industrial Furnace Manufacturers Association, (1997) pp. 265-266