Journal of Metallurgical and Materials Engineering, Vol.28, No.1, 2017.

Optimum Brazing Conditions for Joining Commercially Pure Titanium to 304L Stainless Steel using BAg-8 Silver Filler Metal

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1- Introduction

Existing literature reveals that diffusion welding has been used successfully to join titanium to steel alloys. However, the great care required in the surface preparation stage and the impracticality of this method for mass production has limited the usage of this process. The difficulty of bonded titanium with other metals could be relieved by using brazing techniques. Brazing is beneficial because it involves the melting of the filler material only, thus eliminating problems that occur when fusing dissimilar metals. It has been reported that pure silver, silver-based alloys, titanium-based alloys, and copper-based alloys were used to braze titanium to steel. The melting point of pure silver is 961°C and can be greatly decreased by alloying copper into the silver matrix. Therefore, the Ag–Cu eutectic braze alloy was selected as a filler metal for vacuum brazing of titanium to steel.

The objective of this investigation is focused on brazing of CP titanium to stainless steel using silver-based alloys at their optimal brazing temperatures, which were determined in previous studies, and to compare the results in order to predict the main controlling factors, which govern the quality of the joints. Microstructures as well as mechanical properties are the main focus of the study.

2- Materials and Experimental Procedure

CP titanium and stainless steel were received in the form of plates of 2mm thickness. The chemical composition of the material, in wt.%, as indicated in the supplier's test certificate was 0.07% C, 0.18% Fe, 0.03% N, 0.16% O, 0.014% H, and balance Ti. On the other hand, the composition of stainless steel, in wt.%, was 0.03% C, 0.04% P, 0.005% S, 0.81% Mn, 0.4% Si, 8.94% Ni, 17.7% Cr and balance Fe. Specimens were cut into 125×28×2mm strips for shear strength testing and 10×10×2mm strips for microstructure analysis. Prior to brazing, one face of each specimen was processed in order to achieve a predetermined degree of roughness using 1200 mesh grinding paper. The samples were then degreased in an ultrasonic bath using acetone. Brazing was carried out using silver-based alloys. Table 1 shows the composition, thermal and mechanical properties. The brazing foils, 100-µm thick, were cleaned in acetone before brazing and then sandwiched between the overlapped areas of the parent metals.

Table 1 Composition of the investigated brazing filler

Composition (wt.%)		Thermal properties		Mechanical properties
%Ag	%Cu	Melting Point	Flow Point	UTS
72	28	779 °C	779 °C	466 MPa

The width of the titanium to steel overlap was kept at 6mm since it is recommended to use a lap width of not more than three times the thickness of the base metals to achieve high strength for the joint. The joints were fixed with stainless steel clamp, and then carefully placed into a furnace. Initially, the samples were heated up to a temperature of 50°C below the solidus temperature of the filler alloy for a dwell time of 5min. The sample was then heated up to the brazing temperature. All specimens were furnace-cooled to room temperature.

After bonding, the brazed samples were cut, mounted in epoxy, polished, and then etched by 5% HF, 20% HNO_3, and 75% glycerol for 60s for the titanium side and 3% Nital solution for the steel side. The microstructures were examined using optical and scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS). Tensile shear specimens were machined out from brazed lap joints in accordance to AWS C3.1-63. The test was carried out at room temperature and with displacement rate of 0.5mm/s.

Three samples were used to calculate the average shear strength of the joint.

3- Results and Discussion

Microstructure examination of the interface reveals the formation of reaction layers close to

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the titanium side in contrast to the steel side, which showed no reaction layer with the silver-based braze alloy. A coarse grain structure was formed at the steel boundary to the silver–brazed alloy. This structure results from diffusion growth accompanied by recrystallization of the steel substrate at high temperature. Fig. 1a displays microstructure features of the titanium/steel joint brazed at a temperature of 815 °C for 5min.

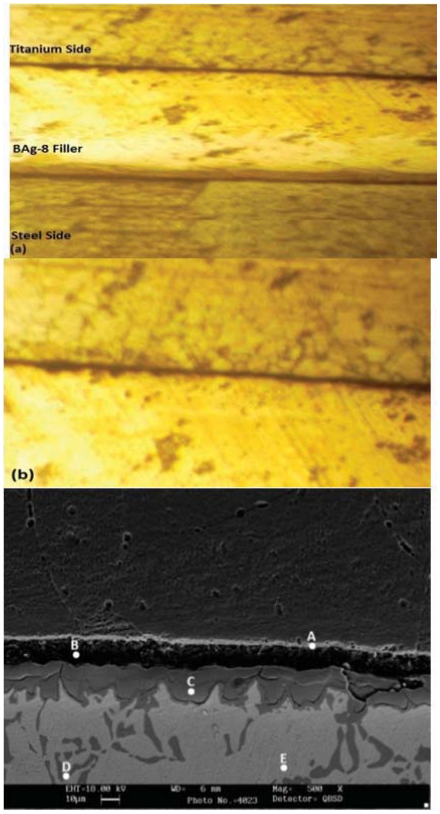

Fig. 1 a) Microstructure features of the titanium/steel brazed joint at 815 °C for 5 min using Bag-8 filler metal; b) enlarged view at the titanium/filler metal interface; c) SEM microstructure at the titanium/filler metal interface

The interfacial region can be divided into three characteristic zones. Zone I is the titanium parent metal without evidence of diffusion by elements of the brazed alloy. Table 2 shows the chemical compositions of the marked areas in Fig. 1c.

Zone II is considered to be the interaction and diffusion zone since a high amount of titanium was diffused from the titanium side to the brazed area close to the titanium substrate. The measured average thickness of zone II is about 11.2µm. Zone III is considered to be the rest of filler alloy which has not interacted directly with the parent metals.

Average shear strength observed for the joint was 102MPa and the fracture path followed interaction layers at the titanium/silver–braze alloy since it contains the most harmed structure in the joint. Fig. 2 shows the fracture path and fracture morphology for this joint.

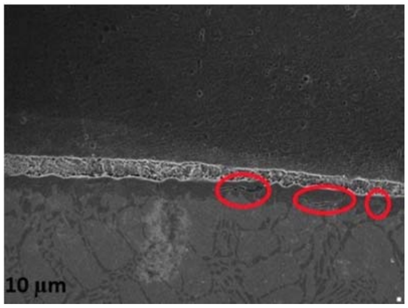

Fig. 2 Cross section of the fractured surface of the titanium/steel joint brazed at 815 °C for 5 min using Bag-8 filler metal

α–β-Ti and Ti–Cu intermetallic are the main phases formed at the titanium/filler metals interfacial region. Meanwhile, the FeTi intermetallic phase is probably the phase formed at the steel/filler metals interfacial region. The crack path, after performing shear tests, follows the location of intermetallic compounds (IMC) in the majority of joints. It was found that the fracture path follows the location of the IMC when it is thick enough to represent the weakest structure in the joint. Therefore, there is a critical thickness of the IMC layer for the maximum shear strength. At the critical IMC layer thickness, the shearing fracture occurred inside the braze. As the IMC layer thickness increases to the critical thickness, the fracture tends to occur at the substrate/IMC interface.

5- Conclusions

There is a strong relation between the thickness of IMC formed at the interfacial region, the values of shear strength of the joints, the location of the fracture or crack propagation and the brazing temperature. The smaller the thickness of the IMC, the higher the shear strength. The average shear strength of the joint showed the highest values when brazed with silver-based BAg–8 at the temperature of 815°C. An increase in the brazing temperature led to an increase in IMC thickness.