Indian Journal of Engineering & Materials Sciences
Vol. 27, June 2020, pp. 730-736

Study on microstructure and mechanical property of Ti-6Al-4V brazed joint with low temperature filler metal

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Received:02 August 2017 ; Accepted:18 October 2018

This study investigates the microstructure and mechanical properties of Ti-6Al-4V brazed joints which has been performed in a vacuum furnace using BAg-22 (Ag–16Cu–23Zn–4.5Ni-7.5Mn, wt. %) as filler metal. The microstructure of the brazed joints has been analyzed by means of optical microscope, scanning electron microscope (SEM) and X-Ray diffraction (XRD). In addition, the mechanical strengths of the joints have been evaluated by shear test and microhardness test. Brazing temperatures employed in this study are 720, 750, and 780 °C for a holding time of 30 min. By increasing the brazing temperature, a variety of intermetallic phases have been formed in the bond area, such as CuTi, $CuTi_2$, Mn_2Ti, $MnZn_2$, AgZn and Ag solid solution. Both the brazing temperature and the brazing time seem have critical factors for controlling the microstructure and the better mechanical property of the brazed joints. The maximum shear strength of 154.15 MPa has been achieved at 780 °C and a holding time of 30 min.

Keywords: Brazing, Mechanical properties, Microstructure, Ti-6Al-4V, Vacuum furnace

1 Introduction

Ti-6Al-4V is one of the most important titanium alloys and is widely used in many modern industries (especially in aerospace, Nuclear and chemical), due to their highly desirable performance characteristics, such as good strength to weight ratio, high creep, fatigue and strong corrosion resistance. Many titanium joining methods, including welding, brazing and diffusion bonding have been developed. Among those, brazing is widely applied in aerospace manufacturing for brazed titanium parts in aircrafts frames and engines [1-3].

The advantages of titanium brazing in comparison with welding are: a decrease of energy and heat input, the decrease of residual stress, a lighter weight structure and the absence of a heat affected zone. In titanium brazing technology, it is recommended that the brazing temperature does not exceed the α-β transformation temperature in order to preserve the original microstructure and mechanical property of the titanium base metal[4]. With decreasing time or temperature of brazing, erosion of the substrate and excessive growth of intermetallic phases at the interface will be significantly decreased or eliminated. As mentioned, in the brazing of Ti and its alloys, the brazing temperature should be as low as possible, in order to retard the grain growth in the base metal and joint parts. Since brazing temperature is determined by the melting temperature of the filler alloy, many experiments have been done on filler alloys with a decreased of the brazing temperature. One effective method of doing this is by adding alloying elements with various combinations of Copper, Zinc, Manganese, and Nickel to brazing filler as well as producing fillers, in shapes of powder, foil, paste, or coat [5-7].

Titanium alloys brazing, filler metals can be classified as either high temperature or low temperature. High temperature filler metals are based on either the titanium-based alloy or palladium-based alloys system. Low temperature brazing filler metals can be divided in to the following groups: silver-based alloys, aluminium-based alloys, and zirconium-based alloys system that having brazing temperature below 800 °C does not hurt mechanical properties of the base metal [8]. The intension to use low temperature brazing filler metal is not only necessary to produce strong brazed joints with desired microstructure, but also to save the energy on heating and reduce brazing time, this is critical consideration because more and more brazed titanium structures are being designed and used in outer space. Vacuum brazing offers a

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number of distinctive advantages over other brazing which includes low residual stresses in the brazed joint due to the use of silver based filler metals which act as a buffer for stresses. More ever, low pressure is required within the bonding zone during joining process [9-11].

In this study, BAg-22 (Ag–16Cu–23Zn–4.5Ni-7.5Mn, wt. %), is chosen as the brazing filler metal according to American Welding Society[12] (AWS) because it provides good chemical compatibility in fusion reaction applications. Furthermore, it is suggested that the higher percentage of Mn is responsible for the additional improvement of its wettability, some percentage of Ni is responsible for the additional improvement of corrosion resistance at braze zone, and higher percentage of copper provides good chemical compatibility in fusion reaction applications and good wettability to many materials. It is not expensive compared to most of the other filler metals. The filler metal has solidus temperature of 682°C and liquidus temperature of 699 °C which are significantly lower than those of traditional silver brazed alloys[13-17]. Brazing temperature of conventional higher temperature filler metals are usually above the β-transformation temperature of titanium base metals that affects mechanical properties of the base metal. The higher the brazing temperature, more is the intensive reaction between the filler metal and base metal, and consequently, thicker inter metallic layer may be formed at the inter face. This brittle intermetallic layer is considered as a source of micro cracks, which may develop and propagate during the mechanical or thermal cycling of the brazed joints. The main purpose of this study is to evaluate low temperature filler metal in brazing Ti-6Al-4V plates in vacuum furnace. The effects of brazing parameters on the interfacial microstructure along with shear strength and fracture properties of the brazed joint were evaluated.

The objective of this study is to focus on the brazing of Ti-6Al-4V plate with low temperature silver based filler metal, which is not essential to produce strong joints by means of desired microstructures; however, it is also useful to cut down the total time and energy required to braze components. This has to be considered crucially, since additional brazed titanium structures are being designed and used in outer space. Hence, it is essential to develop a filler metal to join titanium with steel under a brazing temperature lower than 800 °C thereby, exhibiting sufficient strength.

2 Experimental Method

2.1 Materials

The base metal used in this work is Ti-6Al-4V (ASTM Grade 5) plate are cut into pieces with the dimension of 125 mm × 28 mm × 3 mm. The foil type filler metal BAg-22 (Ag–16Cu–23Zn–4.5Ni-7.5Mn, wt. %), with a thickness of 100μm is used. Chemical composition and mechanical properties of the materials are listed in Table 1 and Table 2, respectively. The base metals are polished through SiC papers up to 1000 grit and are subsequently, ultrasonically cleaned in acetone before brazing. The brazing foils are also cleaned with acetone before brazing and sandwiched between the overlapping areas of the base metals[18, 19].

2.2 Brazing Procedure

The joints are fixed by a stainless steel clamp and cautiously placed into a vacuum furnace. Brazing is carried out at the temperatures of 720, 750 and 780 °C and a holding times of 30 min with a vacuum of 2×10^{-5} Pa. Initially, the samples are heated up to a temperature below the solidus temperature of the filler alloy for a dwelling time of 60 min. This step is carried out to achieve the thermal equilibrium of both furnace and the brazed components. The sample is then heated up to the brazing temperature and the furnace is cooled to room temperature as shown in Fig.1.

2.3 Microstructure Observation

Selected brazed samples are cut into 10 mm×10 mm chips and mounted within an epoxy for microstructure analysis. It is polished subsequently and etched for microscopic evaluation. Then, a light optical microscope and a scanning electron microscope (SEM) are used to characterize the joints. Moreover, X-ray diffraction (XRD) analysis is carried out with the assistance of a diffractometer to recognize the phases formed on joint fracture surfaces after the shear test [20, 21].

Table 1 — Chemical compositions of Ti-6Al-4V.

	Chemical composition, wt. (%)				
Ti	Al	V	Fe	O	C
Balance	6.2	3.8	0.22	0.I7	0.01

Table 2 — Mechanical properties of the base metals and filler metal.

Materials	Yield Strength (MPa)	Tensile Strength (MPa)
Ti-6Al-4V	830	900
Filler alloy	250	300

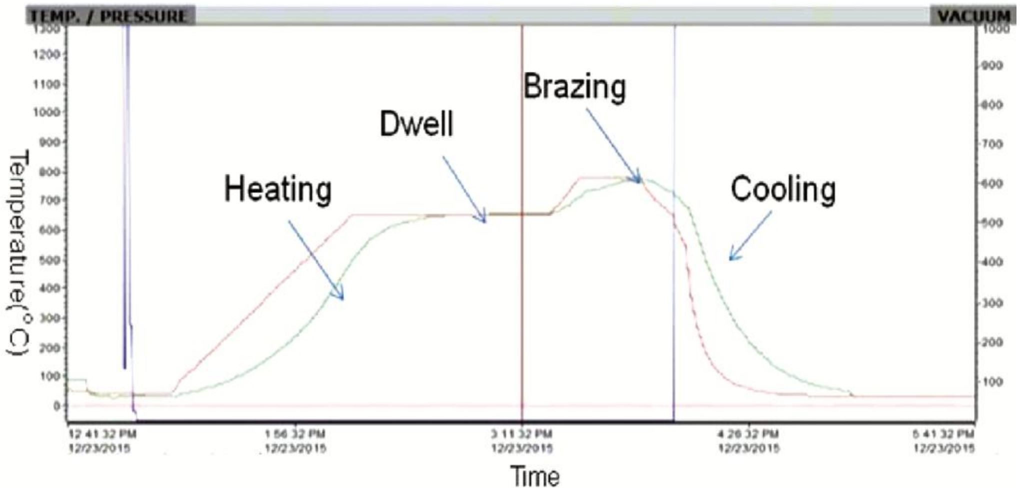

Fig.1 — Time-temperature plot showing the schedule for brazing temperature is 780 °C, and time is 30 minutes.

Fig. 2 — Tensile test specimen.

2.4 Mechanical Testing

Single lap shear samples of 13 mm width within the reduced cross-section are brazed by over lapping 9 mm (3t) in accordance to AWS C3.1-63 (Standard Test for Brazed Joints) by wire cutting machine. The test is carried out at room temperature in addition to displacement rate of 0.5 mm/s. Three samples are used to compute the average shear strength of the joint. Figure 2 demonstrates a specimen meant for the shear test. The hardness measurement is performed through the assistance of a Vickers hardness testing machine with 25-s impressing time[22].

3 Results and Discussion

3.1 Microstructure Observations

Brazed joints are successfully joined for all the studied combinations of brazing temperature range and holding time 30 min. Sound joints are obtained without any voids or cracks are observed along all joints. It is noted that the microstructure of the brazed joints is changing slightly with an increase in brazing temperature. Even though the brazing filler metal could melts at a brazing temperature of 720°C which is near the liquids temperature of the filler metal. In addition, a variations in microstructure can be observed in the joint area, they almost originate from an evaporation of zinc content within the braze alloy. The joint cracks absence is probably due to the joint ductility where as good wettability provides the pore absence. This result is agreement with optical microstructure and SEM images as shown in Figs 3 and 4, respectively.

Figure 4c shows the SEM image at 720°C for 30 min. The microstructure of the brazed joints changed significantly with decreasing brazing temperature, melting of the brazed alloy took place only at the interface because the temperature matches the melting temperature exactly. After melting, the liquid fills voids formed by the unequal of the mating surfaces and the melting point depressant elements in the brazing alloy diffused into the base metal. Generally, titanium diffused more in the filler alloy. Macdonald (1998)[23] and Elrefaey (2009)[2] suggested that the mutual diffusion of elements at the interfacial layer resulting in isothermal solidification as in the case of transient liquid phase bonding.

To confirm the presence of different phases especially those directly at the fracture surface. The experimental results demonstrate that the characteristics reflection of Ag and Ti are widely observed in the X- ray data. Meanwhile, copper and manganese are difficult to be detected due to their reaction with other elements and formation of several new compounds. In addition, most of the intermetallic compounds in the diffusion zone have been confirmed by XRD techniques. XRD not only confirmed the presence of Cu-Ti intermetallic compounds like CuTi, and $CuTi_2$,

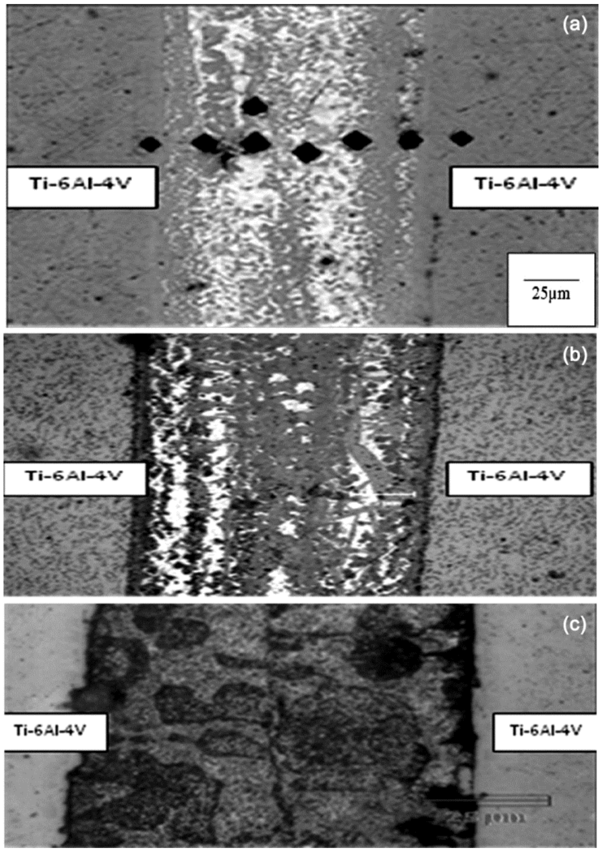

Fig. 3 — Microstructure of the brazed joint (a) Joint brazed at 780 °C, (b) Joint brazed at 750 °C and (c) Joint brazed at 720 °C.

but also suggested the presence of different phases such as Mn_2Ti, AgZn and Ag. XRD analysis of the joint achieved shown in Fig. 5.

Du & Shiue (2009)[24] discussed the infrared brazing of Ti-6Al-4V using 72Ag-28Cu and 95Ag-5Al two silver based brazed alloys. Microstructure of the brazed joints examined using a Hitachi 3500H scanning electron microscope with the accelerating voltage of 15kv. Quantitative chemical analysis was performed using a JEOL JXL-8600SX electron probe analyser with an operation voltage of 20kv and minimum spot size of 1µm. For the 72Ag-28Cu brazed specimen, Ag-rich matrix, eutectic Ag-Cu and Cu-Ti interfacial reaction layers were observed in the experiments. For the 95Ag-5Al brazed specimen, Ag-rich matrix, interfacial TiAl or Ti_3Al are found in the joint.

3.2 Mechanical Properties of Joints

Figure 6 represents the average shear strength of the joints at different brazing temperatures. The average shear strength of the joint showed the highest value (154.15 MPa) at the brazing temperature of

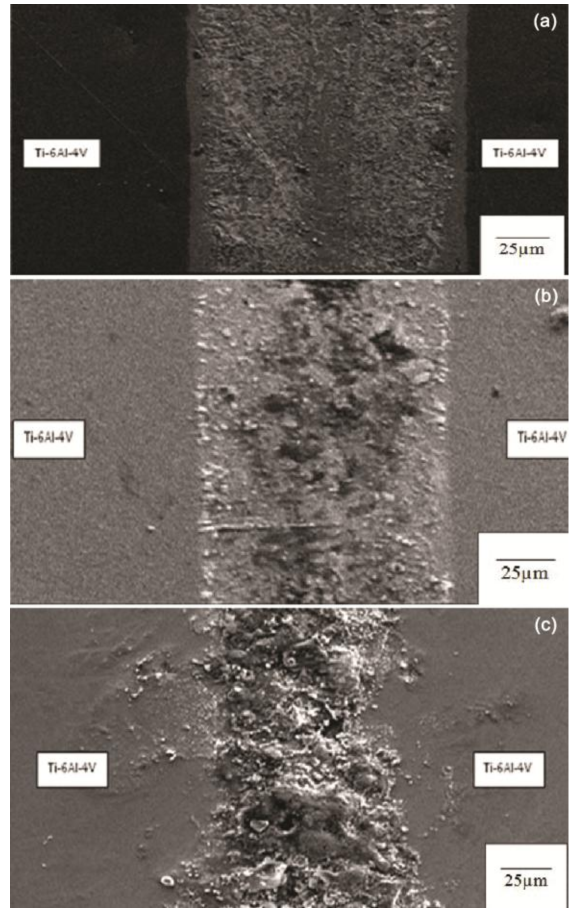

Fig. 4 — SEM images of the brazed joints (a) Joint brazed at 780 °C, (b) Joint brazed at 750 °C and (c) Joint brazed at 720 °C.

780 °C for 30 min compared to the joint brazed at a temperature of 750 °C and 720 °C. Increasing the temperature also led to a increasing in the shear strength of the joints, because the microstructure contained the depletion of the copper element from the molten braze due to the formation of the interfacial Cu-Ti intermetallics results in absence of silver matrix elements from the brazed joint (Soltani Tashi R 2013)[6]. The joint prepared at temperatures 750°C, the shear strength slightly decreased may be caused by increased amounts of Cu-Ti intermetallics like as brittle Cu_2Ti in the interface comprised with Ag rich matrix. The joint prepared at temperatures 720 °C, the shear strength decreased significantly may be caused by the melting of the brazed alloy took place only at the interface, because the temperature matches the melting temperature exactly. After melting, the liquid fills voids formed by the unequal of the mating surfaces and the melting point depressant elements in the brazing alloy diffused into the base metal.

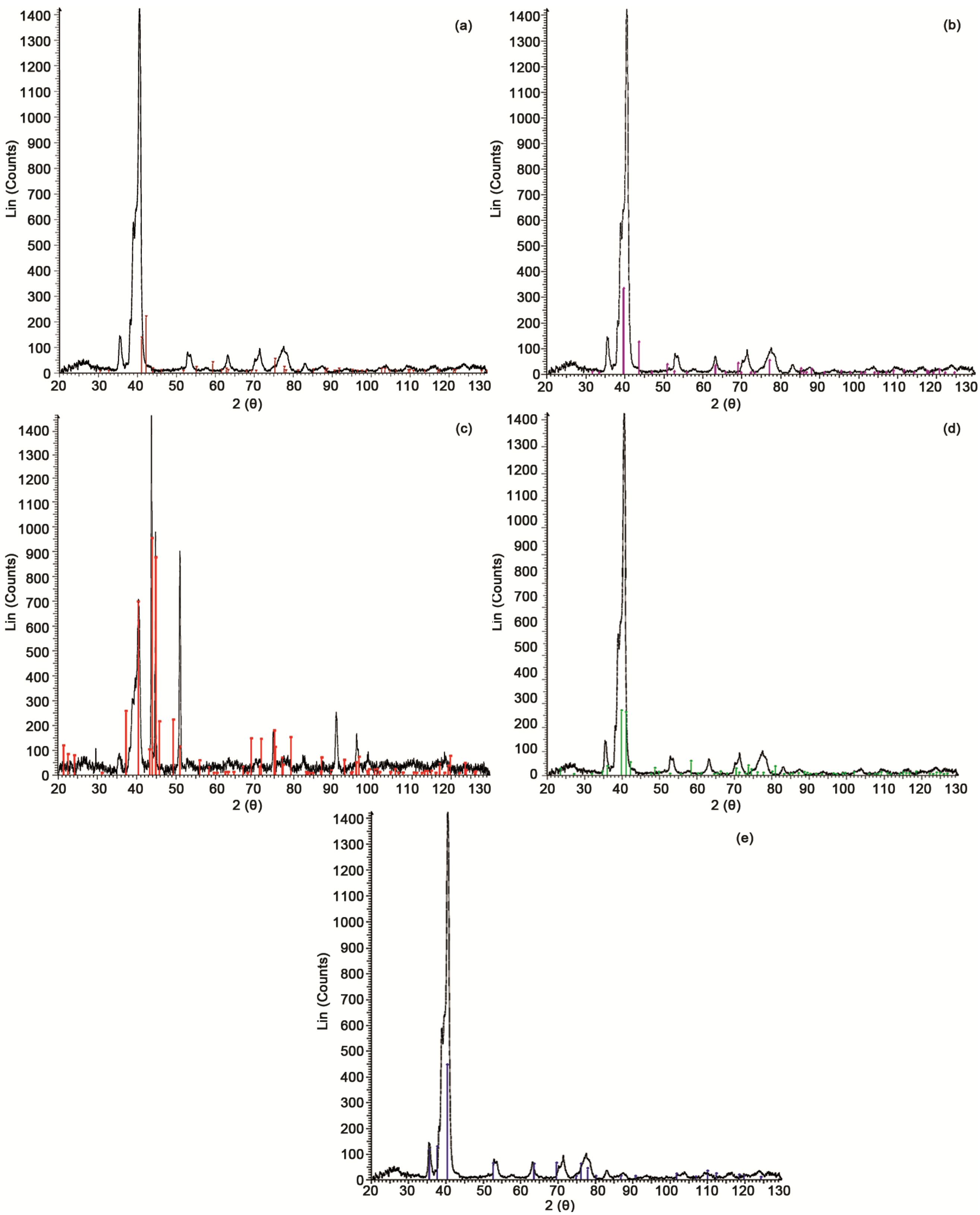

Fig. 5 — XRD pattern of the brazed joint at 780°C (a) CuTi, (b) CuTi2, (c) Mn2Ti, (d) AgZn and (e) Ag.

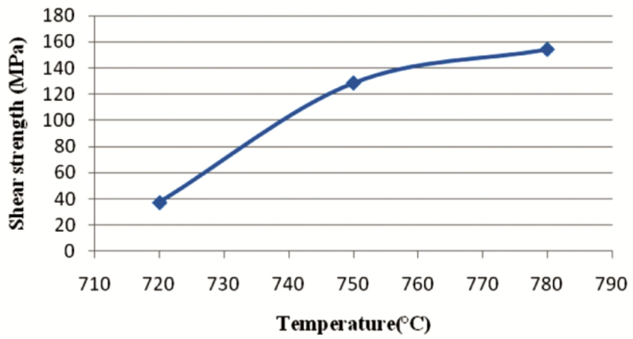

Fig. 6 — Shear strength of brazed joints.

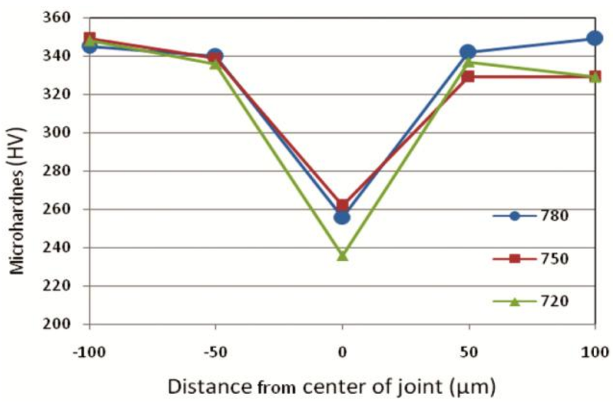

Fig. 7 — Microhardness test for the interfacial microstructure.

Elrefaey & Tillaman (2008)[9] focused on the shear strength of the joints at different temperatures. The Furnace brazing was used to produce joints between commercially pure titanium and low carbon steel with copper based filler metal (Cu-12Mn-2Ni) in the temperature range of 930 °C to 1000 °C. Shear specimens were machined according to AWS C3.1-63. The test was performed at room temperature, and the displacement speed is 0.5mm/s. The hardness measurement was performed with the help of a Vickers hardness testing machine with 25mm-s impressing time. The maximum shear strength of 61MPa is obtained for the coupled bonded at 1000°C due to better coalescence of the mating surfaces. At a lower temperature of 930°C, the bond strength was also low due to incomplete coalescence of the mating surfaces.

Figure 7 shows microhardness results of the brazed joints. Hardness values are approximately similar to that of the BAg22 filler alloy. The study showed that the magnitude of the hardness of the interface is between that of the base metal and filler alloy. As it described earlier, according XRD results between Ti-6V- 4Al and BAg22 interfaces, the reactions are produced. This might be the reason for increasing the hardness of interface in comparison to that of the joint centre.

4 Conclusions

Vacuum furnace brazing of Ti-6Al-4V base metals using BAg22 silver based filler alloy is performed in the experiments. The important conclusions are listed below.

(i) Sound Ti-6Al-4V brazed joints are obtained by the silver based filler alloy at a temperature of 750 °C and 780 °C, while the temperature of 720 °C , the melting of the brazed alloy took place only at the interface, because the temperature matches the melting temperature exactly.

(ii) Several intermetallic compounds such as CuTi, $CuTi_2$, Mn_2Ti, AgZn, and Ag are detected and confirmed by XRD analyses at brazing temperature of 780°C for 30 min.

(iii) The average shear strength of the joint showed the highest values at the temperature of 780 °C for 30 min compared to joints brazed at 750 °C and 720 °C. The joint prepared at temperatures 720 °C, the shear strength decreased significantly may be caused by the liquid fills voids formed by the unequal of the mating surfaces and the melting point depressant elements in the brazing alloy diffused into the base metal.

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