Indian J.Sci.Res.1(2) : 615-622, 2014 ISSN:2250-0138(Online)
ISSN : 0976-2876 (Print)

EFFECT OF FRICTION STIR BRAZING PARAMETERS ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF DISSIMILARALLOYSJOINT

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ABSTRACT

In the present study,microstructure, metallurgical and mechanical properties of friction stir brazing of the lap joint Ti-6Al-4V and 321 stainless steel were investigated. Ag-Cu braze alloy was used as braze alloy. The bonds were characterized by optical microscopy(OM), scanning electron microscopy (SEM), X-Ray diffraction (XRD) and energy dispersive spectroscopy(SEM-EDS). Also shear test and microhardness were carried out as mechanical experiments.Anumber of intermetallic phases such as TiCu, Ti_2Cu and Fe–Cu–Ti have been identified. Both traverse and rotational speed are critical factors to control the microstructure and hence the mechanical properties of the brazed joints. It showed that, increasing of rotating speed and decreasing of advancing speed, increasing the thickness of intermetallic layer. At this condition average of shear strength of joints were decreased and microhardness were increased.

KEYWORDS:Friction stir brazing, Ti-6Al-4V, 321Stainless steel.

Dissimilar joining between titanium alloys and stainless steels has attracted great interest in the aerospace, nuclear and chemical industries due to the high mechanical properties and corrosion resistance of them (Elrefaey, 2009).Formation of brittle intermetallic compounds resulting from the limited solubility of Fe in α-Ti is the major drawback for joining these metals, with a greater complexity for austenitic stainless steels due to the possible development of complex phases involving Ti, Fe, Cr and Ni (Elrefaey, 2009). Fusion welding is readily associated to the formation of these intermetallics, and thus solid state welding has emerged as a viable alternative(Sidyakin, 2004).

One of the best joining process for titanium to steel is brazing. Because in brazing, just braze alloy melt and problems of intermetallic phases forming almost disappeared. But However, there are two major problems in brazing dissimilar materials. First, residual thermal stresses are usually developed after brazing due to thermal expansion mismatch between the joined alloys. Second, brittle intermetallic compounds are formed, especially at the interface between braze alloy and substrate after brazing. Both the above problems will be encountered in brazing Ti-6Al-4V and 304SS(Liu, 2002).

It has been reported that pure silver, silver-based alloys, titanium-based alloys, and copper-based alloys were used to braze titanium to steel (Yue, 2008).However, reported that silver based alloys have the most capability fortitanium and steel joining among abovementioned alloys. Melting point of pure silver is 961℃ and thistemperature significantly decreased by alloying with copper, so that melting point of utectic alloy of $Ag - Cu$ is below 780°C. This provides idle condition for most of the brazing processes(Liu, 2002).

On the other hand, friction stir welding (FSW) is a modern process to joining of metals. But in an effort is tried to use the process within brazing(Fazel-Najafabadi, 2010). According to application procedure Estimated that the process has unique feature compare to other brazing processes such as torch and furnace brazing(Shiue, 2006). In this paper, joining of titanium alloy Ti-6Al-4V with stainless steel 321 has investigated by means of silver-copper braze (BAg-8) with friction stir brazing (FSB) process. Also the effects of this brazing parameters(traverse and rotational speed) on the formation of intermetalic phases during this process were investigated(Ganjeh, 2011).

EXPERIMENTAL PROCEDURE

MATERIALS

Ti-6Al-4V sheet and 321 stainless steel sheet were used as base metals. Both of them were 2mm thick, 125mm long and 150mm wide. Chemical composition and mechanical properties of the materials are listed in Tables 1 and 2, respectively.

Table 1.Chemical composition of the parent materials and braze alloy

Material	Element(wt.%(											
	Ti	Al	V	Fe	C	Mn	Cr	Ni	Mo	Ag	Zn	Cu
Titanium alloy (Ti–6Al–4V(	Bal.	5.5	4.5	0.25	0.08	-	-	-	-	-	-	-
Stainless steel (321 SS(	0.4	-	-	Bal.	0.08	2.0	18.0	9.0	-	-	-	-
Filler alloy (BAg-8)	-	-	-	-	-	-	-	-	-	72.0	-	28.0

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[1]Correspondingauthor

Table 2.Mechanical properties of the parent materials at room temperature.

Material	Yield strength (MPa)	Tensile strength (MPa)
Titanium alloy (Ti–6Al–4V)	827	896
Stainless steel (321 SS)	276	621

After polishing the surfaces to be joined by waterproof abrasive paper (grain size 400), the stainless steel sheet was placed at the top and Ti-6Al-4V at the bottom for lap joining. A BAg-8 foil with 10mm width and 0.1mm thickness was preplaced at the interface between the stainless steel sheet andTi-6Al-4V sheet. Then this set was puttedin designed fixture (see fig.1).

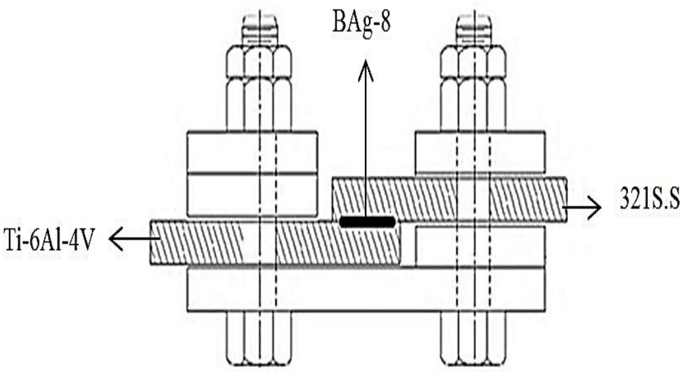

Fig.1.Schematic of designed sampling fixture

BRAZING CONDITION

FSB process was conducted on a conventional vertical milling machine in this study. A cylindrical tool made of hot working steel tool (AISI H13) with a shoulder of 25mm diameter, but without pin, was used, and the tool was tilted at 3 deg to enhance the forging effect of shoulder. Process was done with 1500 and 2500 rpm of rotational speed and 50 and 100mm/min traverse speed as shown in Fig.2.

Microstructure Observation And Mechanical Testing

Figure 3 shows the appearance of as–friction stir brazed Ti-6Al-4V/321 SS.After bonding, the brazed samples were cut, mounted in epoxy, polished, and then etched by Kroll`s reagent for the titanium side and Marbel`s reagent for the steel side. Table 3, Shows the Chemical composition of the Etchants. The microstructures were examined using optical and scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS).

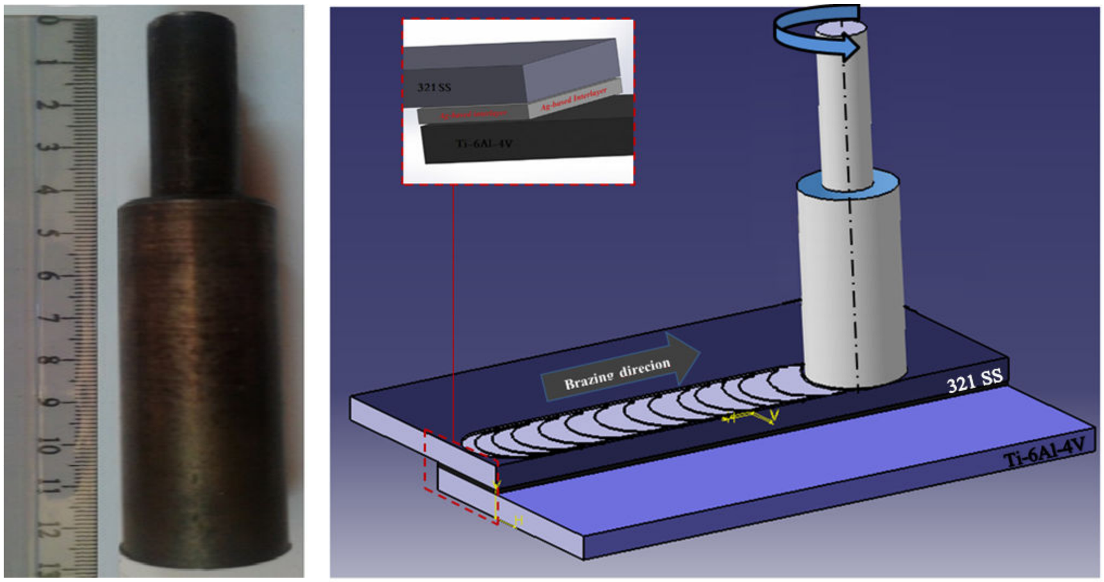

Fig.2.Schematic diagram of FSB technique

A hardness measurement was performed with the help of a Vickers hardness testing machine with 25s impressing time.Tensile shear specimens were machined out from brazed lap joints in accordance to AWS C3.1-63 (Standard Test for Brazed Joints). The test was carried out at room temperature and with displacement rate of 0.5 mm/s. Three samples were used to calculate the average shear strength of the joint.

RESULTS AND DISCUSSION

Microstructure And Phase Analysis

Fig. 5 shows the optical microstructures of Ti-6Al-4V/321 Stainless Steel joint bonded.The interfacial region can be divided into three characteristic zones. Zone A is considered to be the interaction and diffusion zone since a high amount of

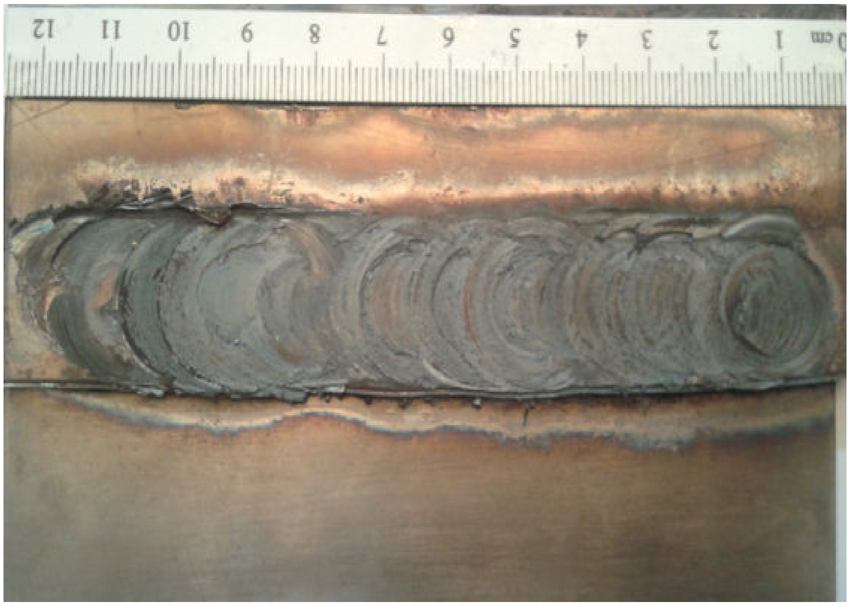

Fig. 3.Top views of dissimilar Ti-6Al-4V/321 SS lap brazing

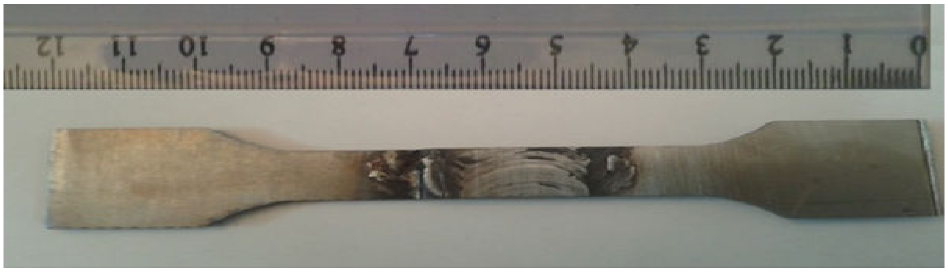

Fig.4. Shear test specimen after the bonding process

Table 3. Chemical composition of the Etchants

Material	Chemical composition
Ti–6Al–4V	92 ml Distilled water + 6 ml Nitric acid + 2 ml Hydrofluoric acid
321 SS	50 ml Water + 50 ml Hydrochloric acid + 10 gr $CuSO_4$

Ti was diffused from the titanium side to the brazed area close to the titanium substrate. Zone C is the narrow diffusion layer in interface of 321 stainless steel and filler metal. Zone B is considered to be the rest of filler alloy which has not interacted directly with the parent metals. This zone consists of three phases. The eutectic Ag–Cu phase, silver rich solid

Observation with SEM revealed that several interaction layers were formed in the brazed area with different chemical analyses as shown in Fig. 6 and Table 4. The interpretation of the EDS reveals the interface includes collection of phases that

solution phase which formed duo to the consumption of Cu by Cu–Ti phases in the main alloy, and some scattered Cu2Ti phase. Theses phases are also marked in Fig. 5. These results are in agreement with those of previous research work (Liu, 2002).

their compositions are different from composition of braze alloy. This expresses that brazing alloy reacted with surface of joining metals. But it seems, most of reactions has occurred between titanium and filler metal.

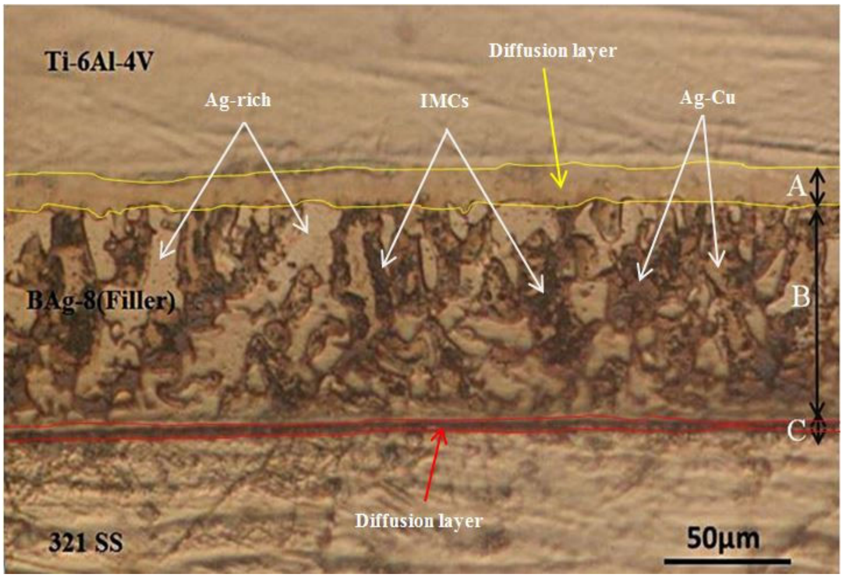

Fig.5.Optical microstructures of Ti-6Al-4V/321 Stainless Steel joint bonded

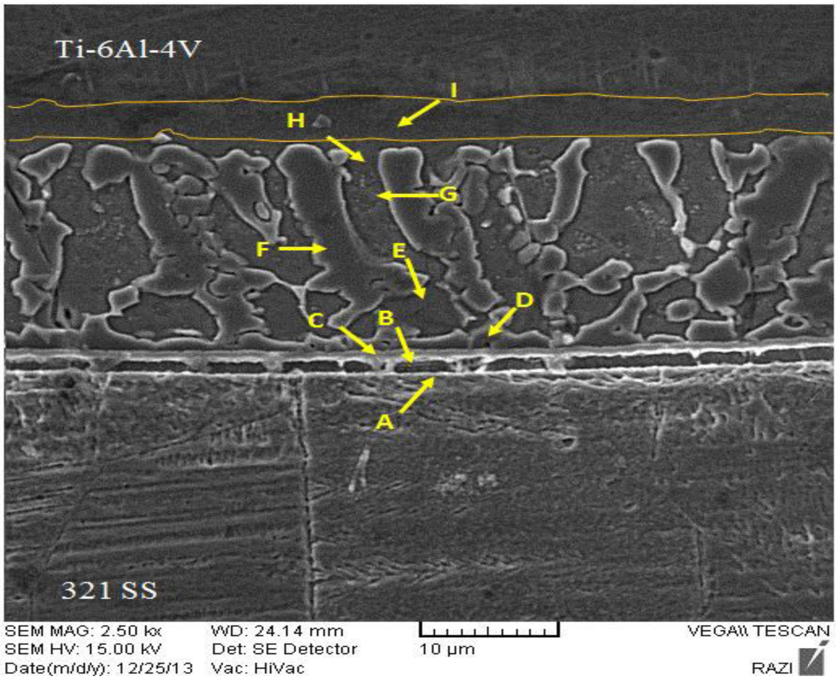

Fig. 6.SEM image of the brazed joint

Table 4.EDS results of the marked areas in Fig. 6 for the brazed joint

Point	Elements(at.%)										Probablecompound
	Ag	Cu	Fe	Cr	Si	Mn	Ni	Ti	Al	V	
A	0.05	1.20	69.12	15.65	0.64	1.70	10.74	0.94	-	-	321 stainless steel
B	0.20	6.12	49.21	10.03	0.20	-	4.08	30.12	0.03	0.01	TiFe
C	2.20	3.23	52.22	12.35	0.90	-	2.82	24.25	1.51	0.42	Ti-Fe-Cr
D	0.50	11.01	23.90	5.94	0.64	-	3.29	50.89	2.93	0.91	Cu-Ti-Fe
E	1.12	44.03	5.80	2.07	0.64	0.38	2.12	42.29	1.03	1.00	TiCu
F	92.26	3.12	2.28	0.33	0.01	-	0.67	0.30	0.69	0.27	Ag-rich
G	60.90	38.11	1.08	0.41	0.07	0.47	0.11	-	-	-	Ag-Cu
H	1.21	32.04	1.58	1.03	0.61	-	0.18	63.50	3.16	1.59	Ti_2Cu
I	50.01	0.04	0.03	0.23	-	-	0.30	46.02	1.83	2.08	TiAg

PointA is basically Fe-Cr-Ni alloy. Points B and C are the reaction layer mainly comprised of Ti, Fe and Cr, and point D is the reaction layer mainly comprised of Ti, Fe and Cu. There is a thick Cu-Ti-Fe reaction layer (point D) at the interface between BAg-8 and 321SS.

The chemical compositions of point E and H in Fig. 6 mainly consist of Cu and Ti. According to the phase diagram shown in Fig. 7, the stoichiometry of Cu/Ti ratio at point H is close to Ti2Cu intermetallics. Similarly, the stoichiometry of Cu/Ti ratio at point E is close to TiCu intermetallic compound. The growth rate of TiCu is much faster than that of Ti2Cu at 890◦C. However; the consumption of Cu by both CuTi and Cu2Ti phases resulted in a silver rich phase as indicated by region F in Fig. 6. Region G represents the eutectic Ag–Cu. Between the interfacial compound layer and Ti substrate, a thick light shaded layer is observed(region I). EDS analysis of this layer reveals a composition of Ag (50.01 at.%) and Ti (46.02 at.%). According to the Ti–Ag phase diagram, this is a TiAg intermetallic compound layer.

These results are in agreed with those of previous research work (Liu, 2002).

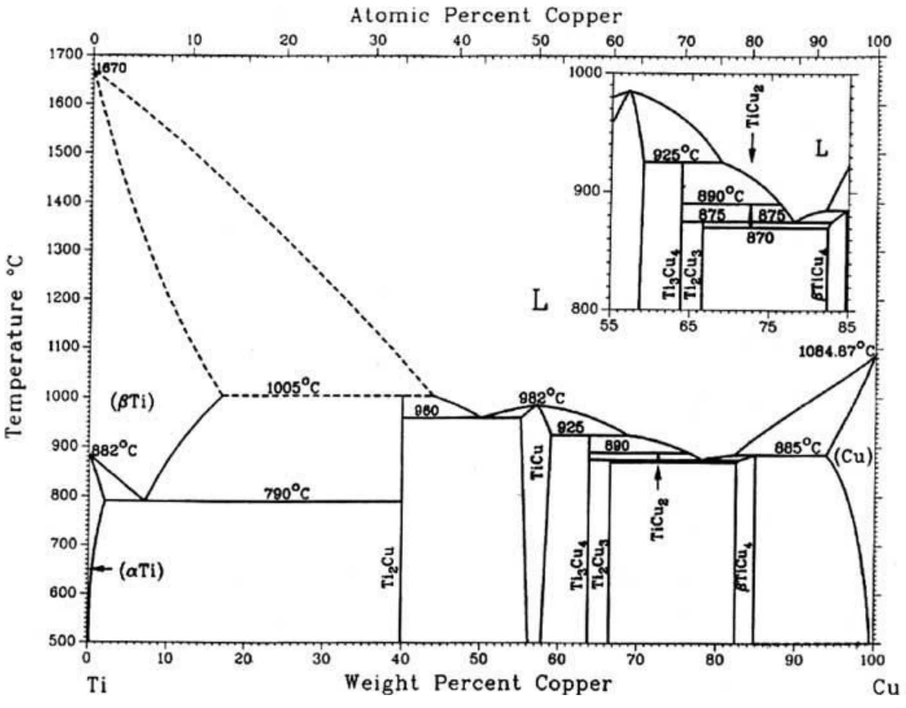

Fig. 7.The Cu–Ti binary phase diagram

Fig. 8 shows the XRD results of the brazed joints. For the XRD analysis, the fractured surface of the brazed joints was used. As it is seen there was consistency of the results achieved by XRD and EDSchemical analysis. It was reported that in the friction stir brazing of Ti–6Al–4V and stainless steel, some reaction layers can be formed in the substrate/braze alloy interfaces and also the Cu–Ti intermetallic compound can be formed at the interface.

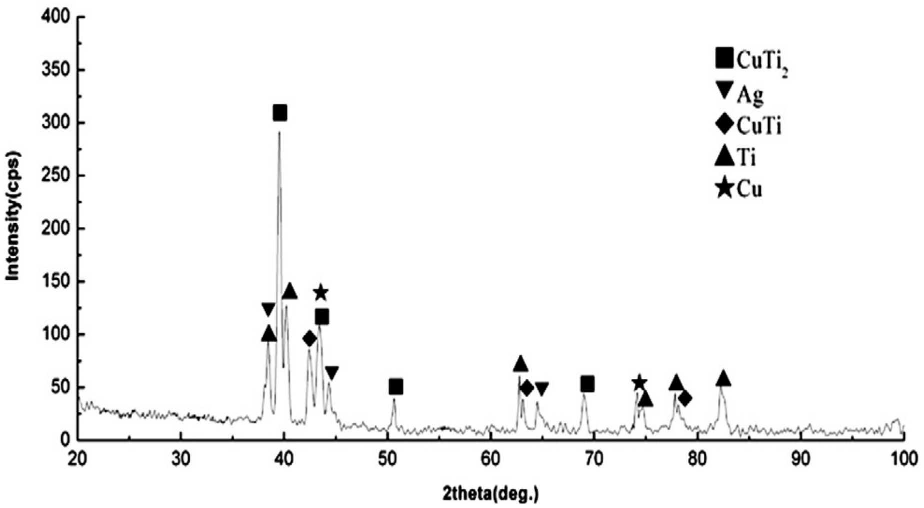

Fig. 8.X-ray diffraction analysis of the brazed joint prepared

Mechanical Properties

Fig. 9 shows the shear strength of the brazed joint with the AgCu filler metal. Shear strength of the coupons was in the range of 60–95 MPa. The study showed that the shear strength decreased with increasing rotational speed and decreasing traversespeed.It may be caused by increasing the amount of Fe–Cu–Ti brittle intermetallic compound and existence of brittle intermetallic compounds such as FeTi, Cu_2Ti in the interface (see Fig. 6). These phases are considered sensitive to initiation of cracks during loading in the shear test. The rotational and traverse speed has a critical role in the formation of the reaction layers and intermetallics. By increasing the rotational speed and decreasing traverse speed, diffusion coefficient increases and higher reaction energy would be produced. Higher reaction energy can give rise to the production of higher amount and variety of brittle intermetallic compounds. The higher brittle intermetallic compounds would result in creating a lower joint shear strength.

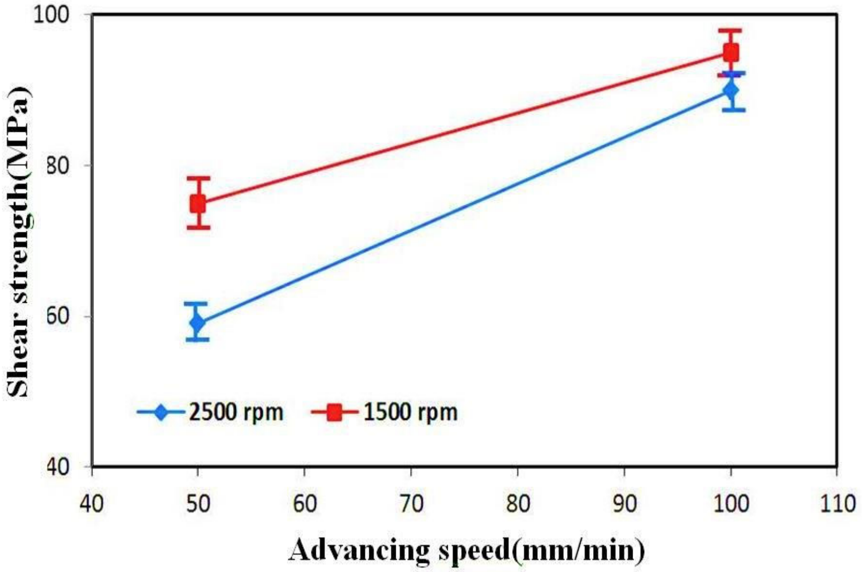

Fig.9.The shear strength of the joints prepared by AgCu braze alloy at different rotating speed

Abdel et al. (Elrefaey, 2009) reported that in the brazing of CP Ti and low carbon steel with Ag-based filler alloy, shear strength can be in the range of 25–50 MPa. Furthermore, they reported that with increasing brazing temperature, the shear strength tends to be decreased. The result of the shear strength for the present investigation shows the same trend in the reduction of the shear strength of the bonds prepared at different temperatures. However, in this study the value of shear strength is about 30 MPa greater than that achieved by Abdel et al. (Elrefaey, 2009).

Figure 10 shows microhardness measurements of the interfacial microstructure. As it is shown, the lowest hardness values were observed at the center of the joint; this hardness value was about similar to that of the AgCu braze alloy. Moreover, The results of the microhardness shows hardness increased with increasing rotational speed and decreasing traverse speed.

The study showed that the magnitude of the hardness of the interface was between that of the base metals and braze alloy.

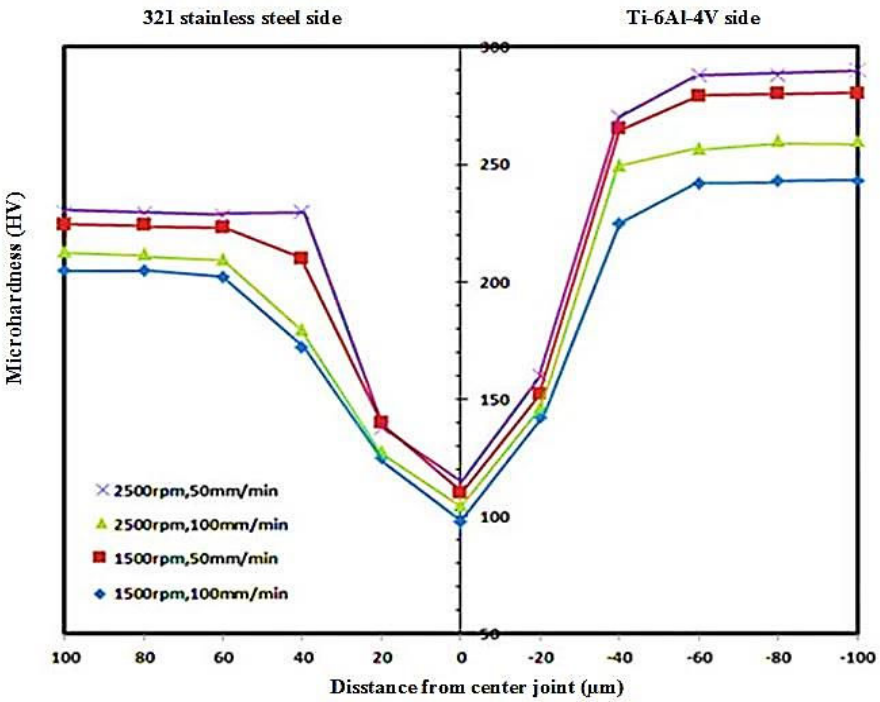

Fig.10.Microhardness test of the interfacial microstructure

ACKNOWLEDGEMENTS

The authors acknowledge Mr. Baqerie, the workroom specialist of Payam-Noor university of Esfahan, due to his cooperation for applying the research.

CONCLUSIONS

(1) Titanium Ti-6Al-4V and stainless steel 321 joining was effectual by friction stir brazing process.Microstructural observation showed that the existence of a soft phase such enriched with silver was helpful to produce a joint without any cracks.

(2) By increasing the rotational speed and decreasing traverse speed, the amount of the intermetallic compounds was increased. These intermetallic compounds mainly consisted of TiCu, Ti_2Cu and Fe–Cu–Ti. However, the TiAg intermetallic compound in the bonded area was given more ductility to the joints.

(3) Mechanical observation showed that the shear strength of the joints prepared by the AgCu filler decreased with increasing the rotational speed and decreasing traverse speed, also microhardness were increased.

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