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DIFFUSION BONDING OF TITANIUM ALLOY TI-6AL-4V AND AISI 304 STAINLESS STEEL – AN EXPERIMENTAL INVESTIGATION

M. BALASUBRAMANIAN[1,*], G. RAMESH[2], V. BALASUBRAMANIAN[3]

[1] Department of Mechanical Engineering, RMKCET,Puduvoyal, Tamilnadu, India
[2] Department of Mechanical Engineering, Velammal Engg College, Chennai, India
[3] Department of Manufacturing Engineering, Annamalai University, Chidambaram, India
*Corresponding Author: manianmb@gmail.com

Abstract

Titanium alloy Ti-6Al-4V and AISI 304 stainless steel were diffusion bonded at various temperatures and holding times. The experimental investigation of the process parameters of the diffusion bonded coupons was carried out. Lap shear tests were performed to determine the strength of the joint, and hardness measurements were taken to understand the hardness in the diffusion region. Diffusion bonding was performed from the lower temperature to the higher temperature considering melting point of the parent material. Hardness measurement at the diffusion layer is almost equal to the parent material. Optical microscopy examination was carried out to determine the quality of the joint and XRD analysis was carried out to confirm the formation of intermetallic compounds. The highest lap shear strength of 138.3 MPa was obtained at 800˚C at 60min holding time under 5 MPa pressure.

Key words: Titanium alloy Ti-6Al-4V, AISI 304 stainless steel, Diffusion bonding, Microhardness, Diffusion layer.

1. Introduction

Diffusion bonding is a solid state joining process, in which two clean metallic surfaces are brought into contact at elevated temperatures under optimum pressure [1]. Diffusion bonding produces high quality joints without post weld machining [2]. It can be accomplished, with or without the aid of an interlayer. In order to produce a high quality joint by diffusion bonding, the two contact surfaces of the materials to be smooth, which increases the atomic diffusion between them [3,4]. Metals, alloys, ceramics and composites can be joined by diffusion bonding technique with minimum macroscopic deformation [5-7]. By diffusion bonding process the chemical heterogeneities can be minimized [8, 9].

Usual defects such as crack, distortion and segregation can be avoided with this technique [10, 11]. To produce a metallurgical joint between dissimilar metals, a faster diffusion rate accomplished by higher bonding temperature and longer holding time between the materials is necessary [12].The Titanium alloy Ti-6Al-4V is an excellent material widely used in aerospace applications and possess good fatigue life, high strength to weight ratio and better corrosion resistance [13,14]. Diffusion bonded plates of titanium alloy and stainless steel finds application in nuclear industries. In this present work Ti-6Al-4V and AISI 304 stainless steel materials are diffusion bonded and their lap shear strength and microhardness measurements were studied.

2. Experimental procedure

Titanium alloy Ti-6Al-4V and AISI 304 Stainless Steel plates were cut into dimensions of 50mmx50mm square samples. The chemical composition of Ti-6Al-4V and AISI 304 Stainless steel are referred in Tables 1 and 2 respectively. The surfaces of both materials were polished with various grades of emery paper and cleaned with acetone (Fig.1). Both the materials were placed one over the other and stacked in a die. This setup is kept in a vacuum chamber at a pressure of -29mm of Hg. The temperature, holding time and pressure is chosen as important process parameters for diffusion bonding. The specimens were heated, in the furnace at a heating rate of 25°C/min, and a pressure of 5MPa. The bonding temperature was taken in the range of 0.5 - 0.8 Tm (Tm is the absolute melting temperature) [15-17]. The samples were kept in the diffusion bonding machine shown in Fig.2 at various temperatures ranging from 750˚C to 800˚C and a pressure of 5MPa. After diffusion bonding, the samples were cooled to room temperature in the furnace itself.

The diffusion bonded samples are shown in Fig..3. Lap shear tensile test specimens were prepared from the Ti-6Al-4V/304SS diffusion bonded joint, by a wire cut electrical discharge machine as shown in Fig.5. The test was carried out in a 5ton capacity universal testing machine and the results are tabulated in Table 3. The microhardness measurement was carried out using the Wilson Wolpert micro vickers hardness tester shown in Fig.6 with a load range of 10grams to 1kg. The test was performed at a load of 0.5Kg and readings were taken at regular intervals on both sides of the interfacial regions. The microstructure of the bonded specimen is observed, using an optical microscope, as seen in the Figs.8(a-f). XRD test has been conducted to confirm the formation of intermetallic compounds.

Table 1. Chemical Composition of Ti-6Al-4V Titanium alloy.

Elements	Al	V	C	Fe	O_2	N_2	H_2	Ti
(wt%)	6.3	4	0.006	0.17	0.166	0.006	0.002	Balance

Table 2. Chemical Composition of AISI 304 Stainless steel.

C	Si	Mn	Cr	Ni	S	P	Fe
0.05	0.52	0.82	18.7	8.765	0.014	0.011	Remainder

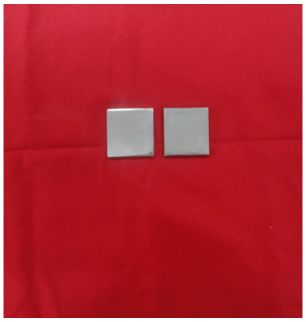


Fig. 1. Polished specimen.

Fig. 2. Diffusion bonding machine.

Fig. 3. Diffusion bonded coupon.

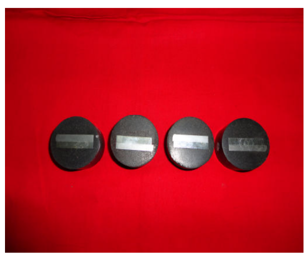


Fig. 4. Moulded sample for microscopic examination.

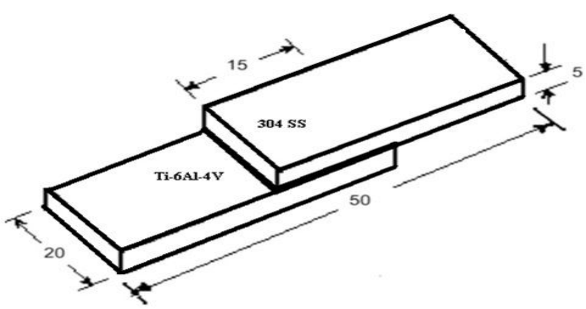


Fig. 5. Lap shear tensile specimen.

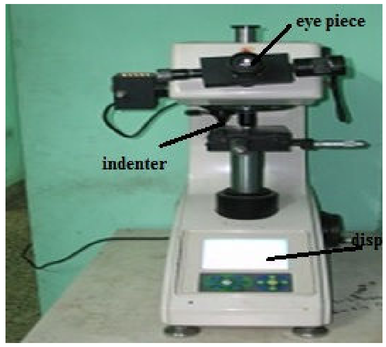


Fig. 6. Vickers Micro Hardness Tester.

3. Results and Discussion

3.1. Evaluation of the lap shear test results

The experimental results of lap shear test were presented in the Table 3. Results showed that the bonding strength is lower at lower temperatures and lesser holding time, due to the incomplete coalescence of the mating surfaces. The maximum lap shear strength of 138.3MPa was obtained for the joint No.6, bonded at 800^{0}C for 60min holding time. The diffusion layer formed at the interfacial regions confirms the formation of intermetallic compounds, which give high strength to the joints. The thickness of the diffusion layer is higher on the titanium region than the stainless steel. The bonding strength of the joints increases with the rise of temperature [18]. At a higher temperature, large number of atoms starts to migrate between the materials. When the temperature is not sufficient, the excitation of atoms on either side takes place at a minimum level, and hence, the strength of the joints is very low. However, when the temperature reaches 825^{0}C and 60min holding time, the material starts to deform slowly and leads to poor bonding strength. However the joint was not successful after 800^{0}c and failed early. Three samples were made and two samples failed during the specimen preparation for lap shear test.

Table 3. Process Parameters.

Joint number	Parameters	Lap shear in MPa
1	750^{0}C, 30min, 5MPa	102.3
2	750^{0}C, 60min, 5MPa	104.6
3	775^{0}C, 30min, 5MPa	107.3
4	775^{0}C, 60min, 5MPa	112.6
5	800^{0}C, 30min, 5MPa	123.6
6	800^{0}C, 60min, 5MPa	138.3

3.2. Hardness measurements

Figures 7(a-b) show the hardness profiles of all the joints. It is observed that the hardness value increases considerably in the diffusion region, due to the formation of the intermetallic compounds. The hardness values in the diffusion region are almost the same as that of the parent material. Its value for Ti-6Al-4V is 352 HV and that of 304Stainless steel is 252HV.

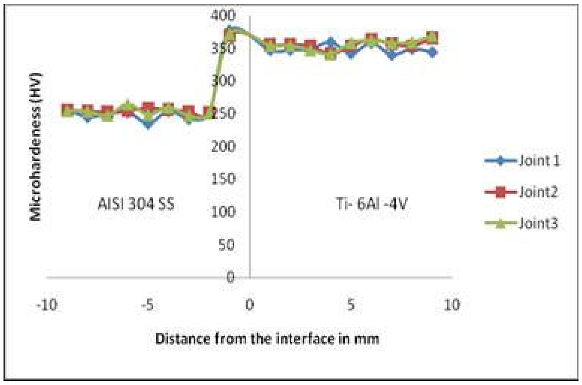


Fig. 7(a). Hardness distribution for the joints 1, 2, and 3.

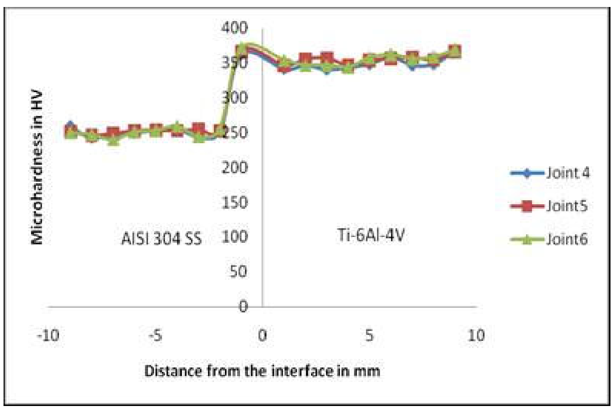
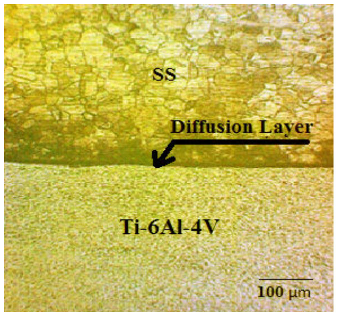


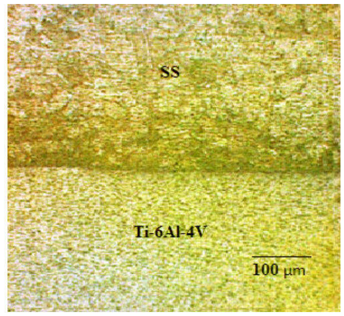
Fig. 7(b). Hardness distribution for the joints 4, 5, and 6.

3.3. Metallurgical studies

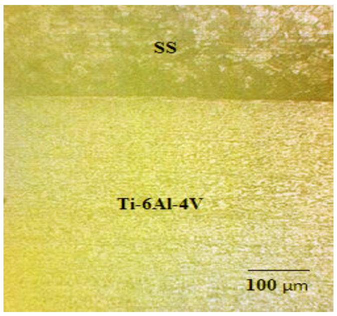
Figure 4 shows the molded samples for microscopic examination. It is observed that the atoms migrate in all directions, and a diffusion layer is formed at the center. The diffusion layer thickness is found to be 12 µm, as evidenced in Fig.8 (f). The thickness at 800˚C, 30mins, 5MPA is higher when compared to the other conditions. This is due to the formation of intermetallic compounds in the diffusion layer. Intermetallic compounds like FeTi, Fe_2Ti were formed at the interface which was confirmed by XRD Test as shown in the Fig.9. This result is also in good agreement with the literatures [19, 20]



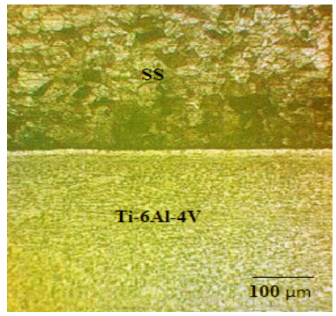
a. Joint-1(750^{0}C, 30mins, 5MPa)



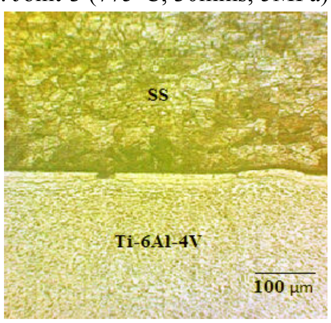
b. Joint-2(750^{0}C, 60mins, 5MPa)



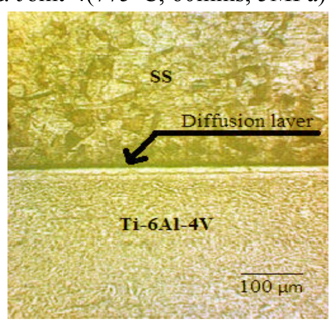
c. Joint-3 (775^{0}C, 30mins, 5MPa)



d. Joint-4(775^{0}C, 60mins, 5MPa)



e.Joint-5(800^{0}C, 30mins, 5MPa)



f. Joint-6(800^{0}C, 60mins, 5MPa)

Fig. 8. Microstructure of bonded specimen.

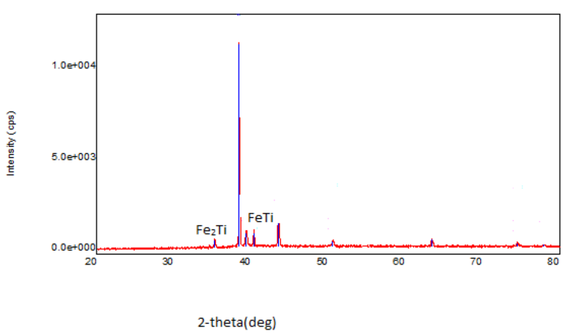


Fig. 9. XRD diffraction pattern at the interface.

4. Conclusions

In the present study, the properties of diffusion bonded Ti-6Al-4V and AISI 304 Stainless Steel were investigated. Bonding was carried out at temperatures from 750°C to 800°C, for holding times of 30 and 60 minutes, under 5 MPa load in a vacuum atmosphere. Based on the experimental investigation and subsequent testing, the following conclusions were drawn.

- Joints fabricated at 800°C, 60min and 5MPa have the maximum lap shear strength, due to the better coalescence of the mating surfaces.
- The lap shear strength is high at the interface, due to the formation of intermetallic compounds and it increases with an increase in temperature.
- However, the shear strength decreases after 800˚C,with increase in holding time further, because the width of the brittle intermetallic compounds increases considerably, which acts as a barrier to the strength of the joints.
- The micro hardness value at the interface is almost equal to that of the base material.

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