IJERST

International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 4, No. 3
August 2015

www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 4, No. 3, August 2015

Research Paper

OPTIMIZATION OF PROCESS PARAMETERS OF DIFFUSION BONDING IN TITANIUM ON MEDIUM CARBON STEEL AND STAINLESS STEEL JOINTS

Edwin Lyonal W[1]*, Mahadevan G[2] and Senthil Kumar T[3]

Corresponding Author: **Edwin Lyonal W ✉ edwinlyonal@gmail.com*

Titanium alloys are joined to medium carbon steels for applications in aerospace engines. Titanium alloys are joined to stainless steels for nuclear applications. The main purpose of the present study is to investigate and compare the characteristics of dissimilar joining of Ti-6Al-4V with AISI 4140 Medium carbon steel and Ti-6Al-4V with SS 304L Stainless steel using diffusion bonding process. For the diffusion bonding, temperature, pressure and holding time are the key parameters. The study will also investigate the suitability of ultrasonic C-scan, a non-destructive testing method for diffusion bonded joints; the characterization tests include ultrasonic C-scan analysis, SEM-EDS. Diffusion bonding experiments for the two combinations of joints namely (i) Ti-6Al-4V with AISI 4140 Medium carbon steel; and (ii) Ti-6Al-4V with SS 304L Stainless steel were carried out by varying the temperature from 750°C to 850°C, stress from 5 to 15 MPa and time from 60 to 120 min. The results of ultrasonic C-scan analyses on diffusion bonded joints of the two material combinations are in good correlation with their joint efficiency. The results of SEM-EDS analyzes on diffusion bonded joints of the two material combinations are in good correlation with the tensile test carried out at their joint interface.

Keywords: Titanium alloys, Diffusion boding, Tensile test

INTRODUCTION

Titanium and its alloys find numerous applications in aerospace and nuclear industries due to their high strength to weight ratio and good corrosion resistance. Joining of various components is inevitable for the manufacture of machine, plant and equipment. Titanium alloys are joined with medium carbon steel alloys for aerospace engines to withstand high temperatures. Titanium-stainless steel joints are made in nuclear applications for better corrosion resistance. Conventional fusion welding is not a feasible technique to join these kinds of dissimilar joints due to the formation of chemical, mechanical and structural heterogeneities. Solid state joining is a suitable alternate to overcome the difficulties. No melting is involved in solid state welding; hence melting related defects are avoided. The joining

[1] PG student, Department of Mechanical Engineering, BIT Campus, Anna University.
[2] Assistant Professor, Department of Mechanical Engineering, BIT Campus, Anna University.
[3] Professor, Department of Mechanical Engineering, BIT Campus, Anna University.

of immiscible or partially miscible alloy systems which is cumbersome in conventional fusion welding is also possible by solid state joining. Numerous solid state joining processes have been in use on an industrial scale now-a-days.

DIFFUSION BONDING PROCESS

Diffusion bonding is a solid state joining process in which two metals with clean surfaces are brought into contact at elevated temperature and pressure for a predetermined time. International Institute of Welding (IIW) defines diffusion bonding as "a solid state bonding process for making a monolithic joint through the formation of bonds at atomic level, as a result of closure of the mating surface due to the local plastic deformation at elevated temperatures which aids inter-diffusion at the surface layers of the materials being joined".

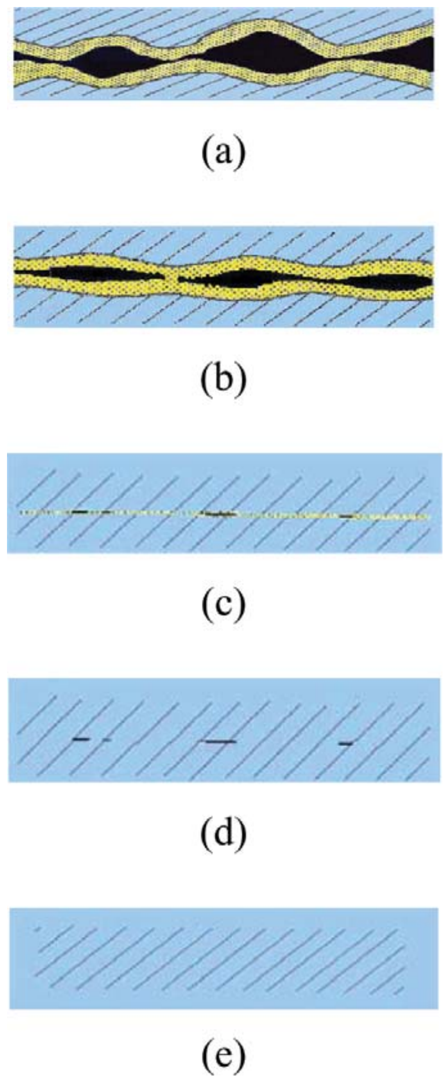
Some of the solid state joining processes like cold pressure welding needs no significant heating. But they require extensive deformation. Hence the processes are applicable only for ductile materials. Processes like friction welding, Magnetically Impelled Arc Butt welding (MIAB) and explosive welding result in significant distortion due to plastic deformation at high temperatures. But diffusion bonding gives a sound bond without any macroscopic deformation because it involves only inter-atomic diffusion with microscopic deformation at the interfaces.

Mechanism of Diffusion Bonding

The mechanism of diffusion bonding is schematically illustrated in Figure 1. During diffusion bonding, the surfaces, which are smooth and free from contaminants, are brought into intimate contact by applying sufficient pressure. First, the applied pressure causes yielding of the asperities at the interface, which establishes an intimate contact between the surfaces to be bonded. Subsequently continuous creep deformation and atomic diffusion take place leading to closure of interfacial voids followed by bonding of materials. The pressure applied will cause only deformation of asperities and not bulk deformation.

Figure 1: Mechanism of Diffusion Bonding

(a) Initial point contacts (b) Yielding leading to reduction of voids (c) Yielding and creeping (d) Diffusive flow to close the voids (e) Complete bonding



Operating Procedure of the Diffusion Bonding Unit

The samples after preparation are placed inside the heating chamber along with the spacers to adjust the height. Spacers are used to restrict the bellows movement to only 2-3 mm. The chiller unit of the vacuum system is switched on. The heating chamber is switched on and the required temperature is set. After the temperature is attained, the press is switched on and the load indicator is checked to read 0000. The required load is applied by lowering the ram of the hydraulic press; the bellows movement is minimum ensured. Starting time of the diffusion bonding experiment is noted. The temperature and the load are maintained for the predetermined process time. Ending time of the diffusion bonding experiment is noted. The heating chamber is switch off and the load of the press is also released. But the running of vacuum system and chiller unit of the heating chamber is maintained. Once the chamber temperature reaches room temperature, the vacuum system is switch off. The chamber is opened and the diffusion bonded sample is taken out**.**

EXPERIMENTAL WORK

Materials and Preparation

The chemical compositions of Ti-6Al-4V, AISI4140 Medium Carbon Steel and SS304L Stainless Steel are given in Table 1.

For diffusion bonding, the specimens were machined to dimensions of 40 mm diameter x 20 mm length. The mating surfaces of the samples were polished in a disc polishing unit with 0.5 µm diamond paste. The mating surfaces of the samples were ground to get flat surface using surface grinder.

Design of Experiments

The design of experimental activity is to get the maximum information about a system with the minimum number of well-designed experiments as shown in Table 2. An experimental program recognizes the major “factors” that affect the outcome of the experiment. The factors may be identified by looking at all the quantities that may affect the outcome of the experiment. The most important among these may be identified using a few exploratory experiments or from past

Table 1: Chemical Composition of base metals

Alloy	Units	1	2	3	4	5	6
		Sn	Mo	Cu	Ni	Fe	Mn
Ti-6Al-4V	%	0.018	0.015	-	-	0.584	-
SS-304L	%	0.015	0.011	0.488	0.602	8.111	0.328
AISI 4140	%	-	0.199	0.232	0.127	96.135	0.591
Alloy	**Units**	7	8	9	10	11	12
		Cr	V	Ti	Al	S	Si
Ti-6Al-4V	%	-	3.43	90.66	4.845	-	0.322
SS-304L	%	71.578	1.641	17.093	0.088	-	-
AISI 4140	%	1.02	0.036	-	-	0.076	0.589

experience or based on some underlying theory or hypothesis. The next thing one has to do is to choose the number of levels for each of the factors. The data will be gathered for these values of the factors by performing the experiments by maintaining the levels at these values. Suppose we know that the phenomena being studied is affected by the pressure maintained within the apparatus during the experiment. We may identify the smallest and the largest possible values for the pressure based on experience, capability of the apparatus to withstand the pressure and so on. Even though the pressure may be varied “continuously” between these limits, it is seldom necessary to do so. One may choose a few values within the identified range of the pressure. These will then be referred to as the levels. Experiments repeated with a particular set of levels for all the factors constitute replicate experiments. Statistical validation and repeatability concerns are answered by such replicate data.

Table 2: Design of Experiments

Temperature(°C)	Pressure(MPa)	Time(min)
750	5	60
800	10	90
850	15	120

$$\text{DOE} = (\text{Level})^{\text{Factors}} = 3^3 = 27$$

RESULTS AND DISCUSSION

This chapter deals with the results of the different experiments conducted as well as the analysis of the same. The main scope of study is to analyze the effect of process parameters of diffusion bonding on the joint quality of the chosen dissimilar combinations.

Table 3: Parameters used for Diffusion Bonding of Titanium on Medium carbon steel and Stainless Steel

Experiment No.	Temperature (°C)	Pressure (MPa)	Time (min)
1	750	5	60
2	750	10	90
3	750	15	120
4	800	5	90
5	800	10	120
6	800	15	60
7	850	5	120
8	850	10	60
9	850	15	90

The ultrasonic C-scan images were taken by fixing the gate region to include the Titanium on Medium carbon steel and Stainless Steel diffusion bonded joint are shown in Figure 2. The C-scan images of the joints corresponding to different process parameters in Table 3 are taken for wire cut EDM to perform the tension test. The variation in the intensity of the ultrasonic waves that is reflected from the surface depends on the quality of the bonding.

Figure 2: Ultrasonic C-Scan systems

Tension Test

Tension test was carried out on diffusion bonded samples of titanium on medium carbon steel and stainless steel joints to find out the ultimate tensile strength of the bonds. The average UTS values obtained are given in Table 4 and Table 5.

Regression Equation

For Titanium and Stainless Steel Combination, Regression Equation

TENSILE STRESS = -780 + 3.73 P + 0.361 t + 1.05 T

Table 4: Ultimate Tensile Strength for Diffusion Bonding of Titanium on Medium carbon steel

Ex.No.	Temp(°C)	Pressure(MPa)	Time(min)	Ultimate Tensile Strength (MPa)
1	750	5	60	178
2	750	10	90	156
3	750	15	120	165
4	800	5	90	128
5	800	10	120	17.6
6	800	15	60	215
7	850	5	120	65
8	850	10	60	140
9	850	15	90	132

Table 5: Ultimate Tensile Strength for Diffusion Bonding of Titanium on Stainless steel

Ex.No.	Temp(°C)	Pressure(MPa)	Time(min)	Ultimate Tensile Strength (MPa)
1	750	5	60	198
2	750	10	90	164
3	750	15	120	175
4	800	5	90	142
5	800	10	120	68
6	800	15	60	235
7	850	5	120	85
8	850	10	60	163
9	850	15	90	148

Table 6: Regression analysis of Titanium Ti-6Al-4V with Medium Carbon Steel

EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
1	800	15	120	109.18
2	850	5	90	82.76
3	750	10	60	207.84
4	800	5	120	62.18
5	850	5	60	130.34
6	800	10	60	180.84
7	750	15	90	183.76
8	800	5	60	157.34
9	750	5	90	136.76
10	850	15	60	177.34
11	850	15	120	82.18
12	750	10	120	112.68
13	750	15	60	231.34
14	850	10	120	58.68
15	800	10	90	133.26
16	850	10	90	106.26
17	800	15	90	156.76
18	750	5	120	89.18

For Titanium and Medium Carbon Steel combination, Regression Equation

TENSILE STRESS = 661 + 4.70 P - 1.586 t - 0.540 T

where

P = Pressure

t = Holding time

T = Temperature

By using the above regression equation, we have to find the ultimate tensile strength for the remaining 18 designs in the Table 6 and Table 7.

Optimization

The necessity of using optimized process parameters for effective joining of dissimilar materials is rapidly growing throughout the world. It is essential to have a complete control over the relevant process parameters to maximize the strength on which the quality of a joint is based. Therefore, it is very important to select and control

Table 7: Regression analysis of Titanium Ti-6Al-4V with Stainless Steel

EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
1	800	15	120	159.27
2	850	5	90	163.64
3	750	10	60	66.46
4	800	5	120	121.97
5	850	5	60	152.81
6	800	10	60	118.96
7	750	15	90	95.94
8	800	5	60	100.31
9	750	5	90	58.64
10	850	15	60	190.11
11	850	15	120	211.77
12	750	10	120	88.12
13	750	15	60	85.11
14	850	10	120	193.12
15	800	10	90	129.79
16	850	10	90	182.29
17	800	15	90	148.44
18	750	5	120	106.77

Table 8: Full Factorial design for Titanium and Medium Carbon Steel

EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
1	800	15	120	109.18
2	850	5	90	82.76
3	750	10	60	207.84
4	800	5	120	62.18
5	850	5	60	130.34
6	800	10	60	180.84
7	750	15	90	183.76
8	800	5	60	157.34
9	750	5	90	136.76

Table 8 (Cont.)				
EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
10	850	15	60	177.34
11	850	15	120	82.18
12	750	10	120	112.68
13	750	15	60	231.34
14	850	10	120	58.68
15	800	10	90	133.26
16	850	10	90	106.26
17	800	15	90	156.76
18	750	5	120	89.18
19	750	5	60	178
20	750	10	90	156
21	750	15	120	165
22	800	5	90	128
23	800	10	120	17.6
24	800	15	60	215
25	850	5	120	65
26	850	10	60	140
27	850	15	90	132

Table 9: Full Factorial design for Titanium and Stainless Steel				
EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
1	800	15	120	159.27
2	850	5	90	163.64
3	800	5	90	142
4	750	10	60	66.46
5	800	5	120	121.97
6	850	5	60	152.81
7	750	5	60	198
8	850	15	90	148
9	800	10	60	118.96

Table 9 (Cont.)

EXPERIMENT NO.	TEMPERATURE(°C)	PRESSURE(MPa)	HOLDING TIME (Minutes)	TENSILE STRENGTH(MPa)
10	750	15	90	95.94
11	800	5	60	100.31
12	750	5	90	58.64
13	850	15	60	190.11
14	850	15	120	211.77
15	750	10	120	88.12
16	750	15	60	85.11
17	850	10	120	193.12
18	750	10	90	164
19	800	10	90	129.79
20	800	10	120	68
21	850	10	90	182.29
22	850	5	120	85
23	800	15	90	148.44
24	800	15	60	235
25	750	5	120	106.77
26	850	10	60	163
27	750	15	120	175

Figure 3: Ultimate Tensile Strength for Diffusion Bonding of Titanium on Medium carbon steel

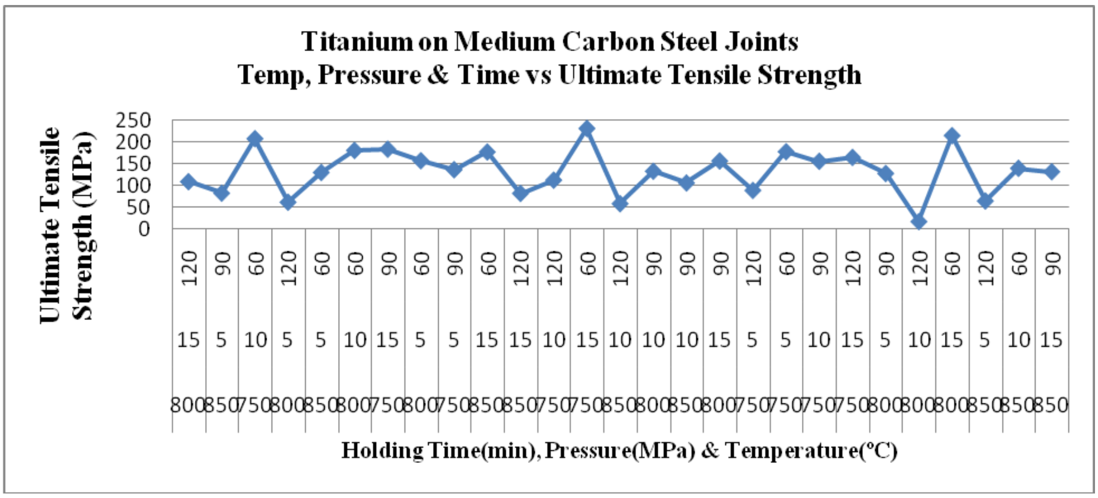
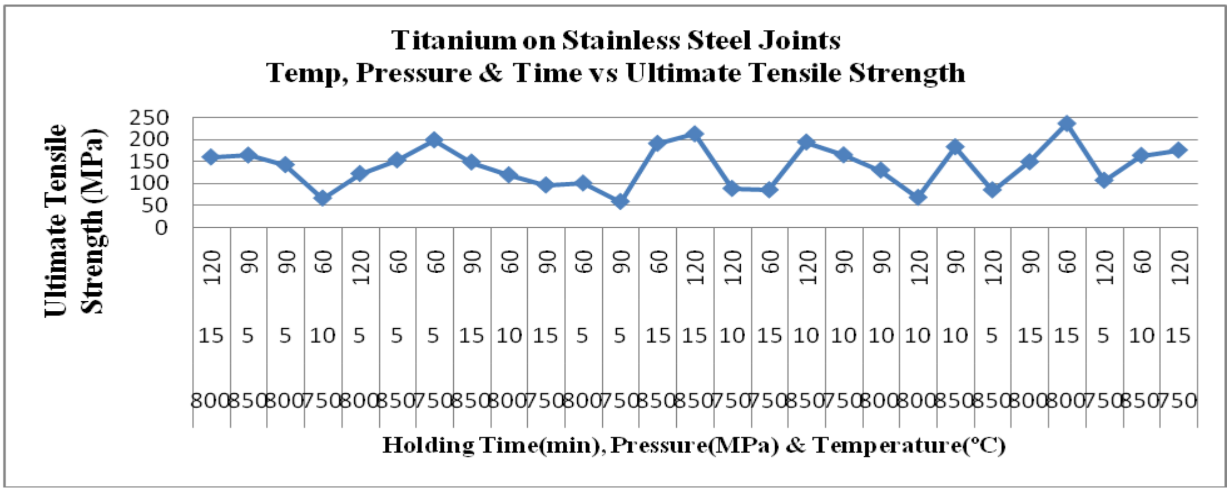


Figure.4.Ultimate Tensile Strength for Diffusion Bonding of Titanium on Stainless steel



the welding process parameters for obtaining maximum strength from the Table 8 and Table 9. In order to achieve this various prediction methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables.

CONCLUSION

Based on the experiments and test results of the work, it is concluded that:

- The Ti-6Al-4V – SS 304L Stainless Steel joint dissimilar materials are weldable using diffusion bonding process. A maximum tensile strength of 235 MPa is achieved corresponding to the process parameters temperature 800°C, pressure 15 MPa and time 60 min. as shown in Figure 4.
- The Ti-6Al-4V – AISI 4140 Medium Carbon Steel joint dissimilar materials are weldable using diffusion bonding process. A maximum tensile strength of 231.34 MPa is achieved corresponding to the process parameters temperature 750°C, pressure 15 MPa and time 60 min. as shown in Figure 3.
- On comparing Ti-6Al-4V – SS 304L Stainless Steel and Ti-6Al-4V – AISI 4140 Medium Carbon Steel the maximum tensile strength is achieved for the Titanium with Stainless Steel Joints.
- The results of ultrasonic C-scan analyses on diffusion bonded joints of the two material combinations are in good correlation with their joint efficiency.
- The results of SEM-EDS analyses on diffusion bonded joints of the two material combinations are in good correlation with the transverse hardness survey carried out at their joint interface.

REFERENCES

1. Aslan Miriyev, David Barlam, Roni Shneck, Adin Stern and Nachum Frage (2014), “Steel to titanium solid state joining displaying superior mechanical properties”, Vol. 214, pp. 2884 –2890.

2. Aslan Miriyev, Michael Sinder and Nachum Frage (2014), “Thermal stability and growth kinetics of the interfacial TiC layer in the Ti alloy/carbon steel system”, Vol.75, pp. 348–355.

3. Bulent Kurt and Adnan Calik (2009), “Interface structure of diffusion bonded duplex stainless steel and medium carbon steel couple”, Vol. 60, pp. 1035-1040.

4. Dunkerton S B and Stephenson D J (1991), “Diffusion Bonding”, Springer Netherlands.

5. Elrefaey A and Tillmann W (2009), “Solid state diffusion bonding of titanium to steel using a copper base alloy as interlayer”, Vol. 209, pp. 2746-2757.

6. Evren Atasoy and Nizamettin Kahraman (2008), “Diffusion bonding of commercially pure titanium to low carbon steel using a silver interlayer”, Vol.59, pp. 1481–1490.

7. Kazakov N F (1985), “Diffusion Bonding of Materials”, Mir Publishers.

8. Kundu S, Anand G, and Chatterjee S (2013), “Diffusion Bonding of 17-4 Precipitation Hardening Stainless Steel to Ti Alloy With and Without Ni Alloy Interlayer:Interface Microstructure and Mechanical Properties”, Vol. 44A, pp. 2196-2211.

9. Kundu S and Chatterjee S (2007), “Mechanical properties of diffusion bonded joints between titanium and stainless steel with nickel interlayer”, Vol. 23, pp. 1167-1172.

10. Kurt B, Orhan N and Hasc Alik A (2007), “Effect of high heating and cooling rate on interface of diffusion bonded gray cast iron to medium carbon steel”, Vol.28, pp. 2229-2233.

11. Qin B, Sheng G M, Huang J W, Zhou B, Qiu S Y and Li C (2006), “Phase transformation diffusion bonding of titanium alloy with stainless steel”, Vol. 56, pp. 32-38.

12. Vigraman T, Ravindran D and Narayanasam R (2012), “Effect of phase transformation and intermetallic compounds on the microstructure and tensile strength properties of diffusion-bonded joints between Ti–6Al–4V and AISI 304L’”, Vol. 36, pp. 714-727.

13. Xuan X J, Sheng G M, Qin B, Huang W Z and Zhou B (2008), “Impulse pressuring diffusion bonding of titanium alloy to stainless steel’, Vol. 59, pp. 930-936.

International Journal of Engineering Research and Science & Technology
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: editorijlerst@gmail.com or editor@ijerst.com
Website: www.ijerst.com

ISSN 2319-5991