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Research Paper

# OPTIMIZATION OF PROCESS PARAMETERS OF DIFFUSION BONDING IN TITANIUM WITH STAINLESS STEEL

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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 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 combination of joints is 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 analyses on diffusion bonded joints of the material combinations are in good correlation with the tensile test carried out at their joint interface.

**Keywords:** Titanium (Ti-6Al-4V), Stainless steel (SS 304L), Temperature, Pressure, Holding time

## 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 - 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 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.

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## DIFFUSION BONDING PROCESS

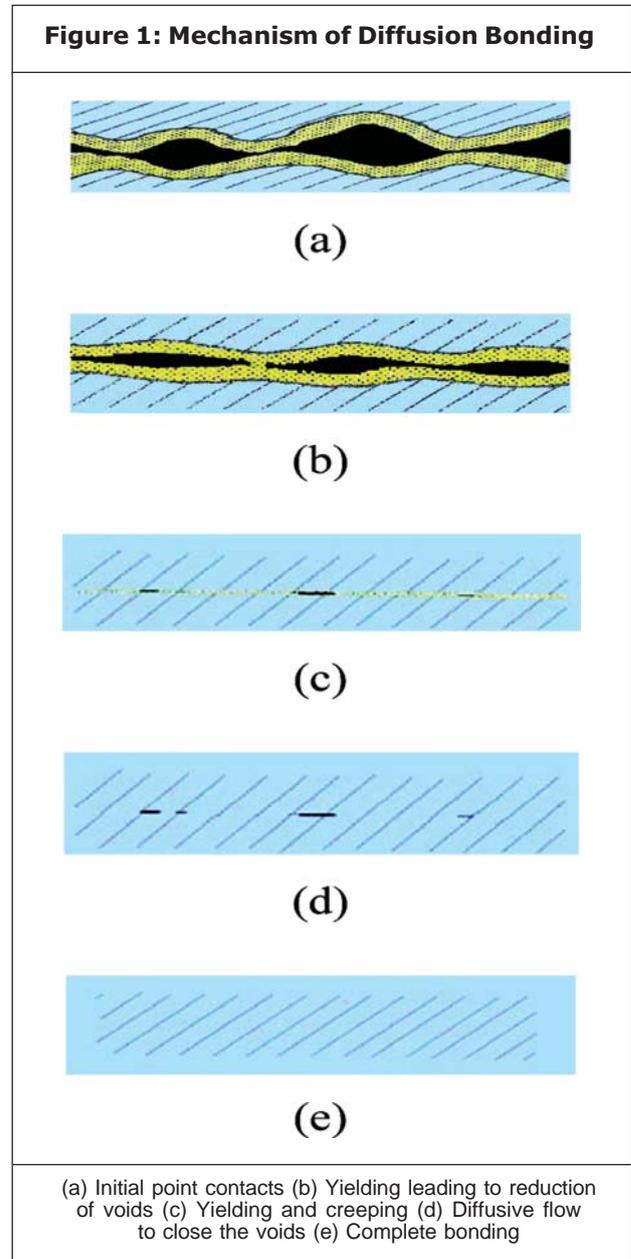
Diffusion bonding is a solid state joining process in which two metals with clean surfaces are brought into contact at elevated temperature and pressure for a predetermined time. International Institute of Welding (IIW) defines diffusion bonding as “a solid state bonding process for making a monolithic 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.



### 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 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. 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 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 1: Chemical Composition of Base Metals**

Alloy	Units	1	2	3	4	5	6	7	8	9	10	11	12
		Sn	Mo	Cu	Ni	Fe	Mn	Cr	V	Ti	Al	S	Si
Ti-6Al-4V	%	0.018	0.015	-	-	0.584	-	-	3.43	90.66	4.845	-	0.322
SS-304L	%	0.015	0.011	0.488	0.602	8.111	0.328	71.578	1.641	17.093	0.088	-	-

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

## 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.

The ultrasonic C-scan images were taken by fixing the gate region to include the Titanium on Stainless Steel diffusion bonded joint are shown in Figure 2. The C-scan images of the joints

corresponding to different process parameters 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.

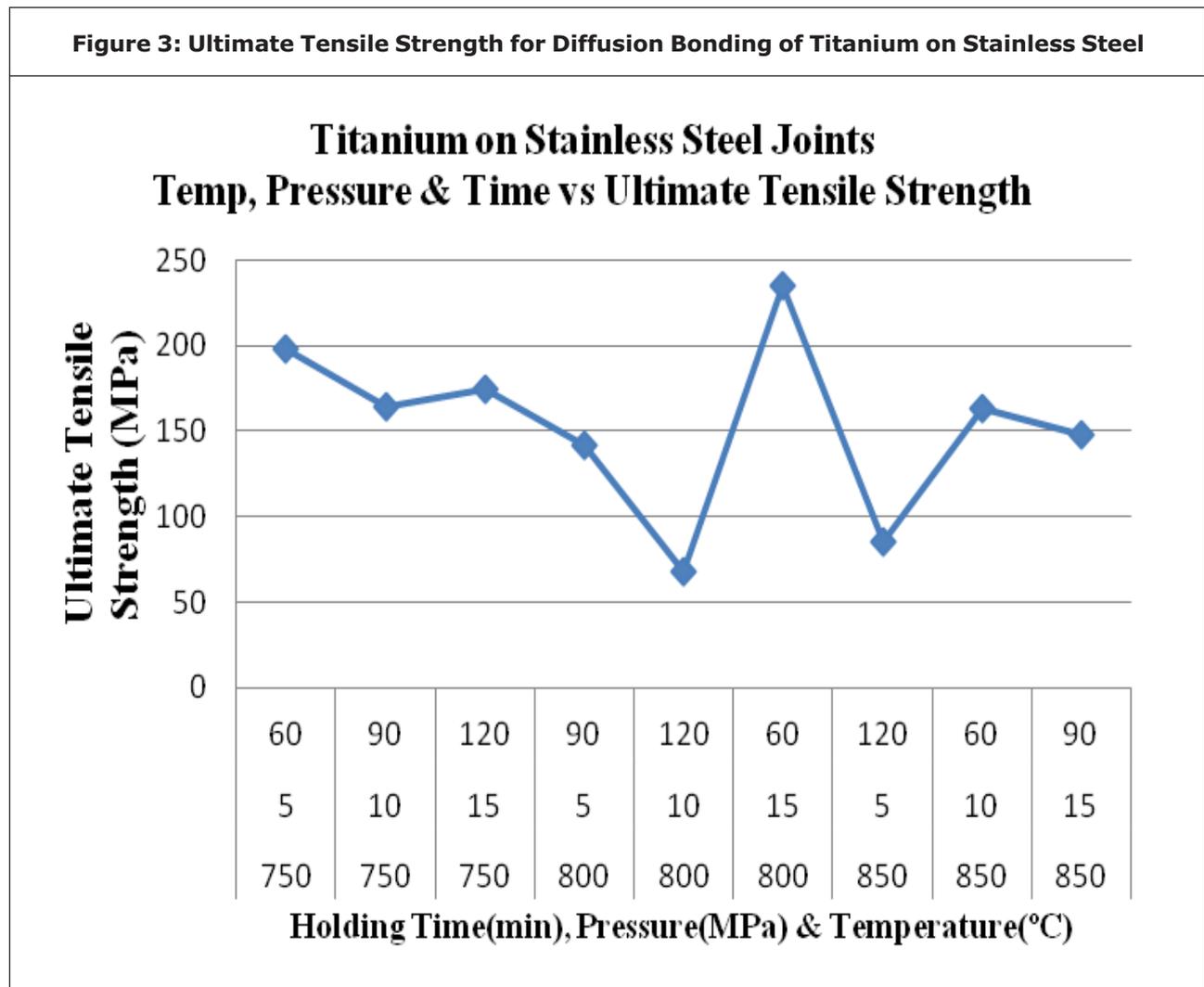
### Tension Test

Tension test was carried out on diffusion bonded samples of titanium on stainless steel joints to find out the ultimate tensile strength of the bonds. The average UTS values obtained are given in Table 3.

**Figure 2: Ultrasonic C-Scan system**



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



## 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.
- 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 material combinations are in good correlation with the transverse hardness survey carried out at their joint interface.

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