Vacuum 146 (2017) 152–158

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Effect of pressure pulsation on bond interface characteristics of 409 ferritic stainless steel diffusion bonds

Gaurav Sharma*, Dheerendra Kumar Dwivedi

Department of Mechanical & Industrial Engineering, Indian Institute of Technology Roorkee, Uttarakhand 247667, India

ARTICLE INFO

Article history:
Received 26 July 2017
Received in revised form
30 September 2017
Accepted 30 September 2017
Available online 3 October 2017

Keywords:
Pressure pulsation
Bonding ratio
Diffusion bonding
Shear strength

ABSTRACT

In present study, impulse pressure assisted diffusion bonding (IPADB) technique was applied for diffusion bonding of 409 ferritic stainless steel plates. The effect of diffusion bonding process parameters i.e. maximum pulse pressure and pressure pulses on bond interface characteristics and mechanical properties was investigated. The bonds were analyzed by field emission scanning electron microscope (FESEM) and using these micrographs interface bonding ratio was measured, which is defined as the ratio of void free interface length to the total interface length. The pressure pulsation improved the interface bonding ratio by reducing the voids at the interface. At 40 MPa maximum pulse pressure and 18 pressure pulses, 43.7% improvement in interface bonding ratio of the diffusion bonds was observed with respect to those developed at same constant pressure. Hardness and tensile shear tests were performed on the diffusion bonds. A maximum shear load of 37 kN was obtained for the diffusion bonds developed at 40 MPa maximum pulse pressure and 18 pressure pulses, having the fracture from the base metal during tensile shear testing. The fracture surface of the diffusion bonds was also studied by FESEM.

1. Introduction

Ferritic stainless steel is a candidate material for automotive exhaust systems, coal wagons and chemical industries because of its better corrosion resistance [1,2]. Generally, the fusion welding processes are used for welding of this steel. However, in fusion welding of ferritic stainless steel grain coarsening may occur in heat affected zone (HAZ), which adversely affect the weld performance [3]. To eradicate these problems, diffusion bonding can be used as a better alternative as the joint is produced at a temperature of 0.6–0.8 T_m (T_m is the absolute melting point of material) [4]. It is a process which reduces the chance of deterioration of the metallurgical and mechanical properties of the produced joint. A wide variety of materials can be easily joined by diffusion bonding in both similar and dissimilar manner [5–9]. Kurt [10] performed diffusion bonding of duplex stainless steel (DSS) and austenitic stainless steel (ASS) to low carbon steel (LCS) at 900 °C temperature, 8 MPa pressure and for 30 min bonding time. Maximum shear strength of 767 and 475 MPa for DSS-LCS and ASS-LCS joints respectively was achieved. Roy et al. [11] performed diffusion bonding brazing of high strength stainless steel using C50 and N82 filler and obtained 332 and 492 MPa bond strength respectively at 980 °C bonding temperature. In diffusion bonding highly polished surfaces are required to achieve a quality joint. In spite of the high polishing requirements diffusion bonding takes a longer time [12–14]. Literature suggests that diffusion bonding in most of the study was performed with highly polished surface using constant pressure. IPADB process is expected to reduce the polishing requirements for diffusion bonding by deforming the surface asperities and reducing the micro voids at the diffusion bond interface. The IPADB process, where the pressure pulses are used in place of the constant pressure has been successfully applied for joining of similar and dissimilar metals [15–18]. However, a limited work has been carried out on IPADB in previous years and the science and technology of the joint formation is not clearly understood. Therefore, in present work investigation of the bond interface characteristics, metallurgical and mechanical properties of the diffusion bonds of ferritic stainless was carried out and the effect of input process parameters was studied.

2. Material and method

409 ferritic stainless steel plate of thickness 4 mm was used for the study in present work. Chemical composition of the as received

* Corresponding author.
E-mail addresses: gauraviitr1992@gmail.com, gaur8.dme2014@iitr.ac.in (G. Sharma).

https://doi.org/10.1016/j.vacuum.2017.09.049
0042-207X/

base metal was analyzed using optical emission spectrometer (make: Metalvision, model: 1008i) and presented in Table 1. The samples were machined to the required size and polished by rough grade emery paper to a surface roughness (R_a) of 0.85 μm. A 3D roughness plot of the prepared samples captured by the roughness tester (make: Veeco, model: NT1100) is shown in Fig. 1. Prior to the bonding process the samples were cleaned by acetone and dried using hot air. Diffusion bonding was performed in a vacuum of 8×10^{-6} mbar using vacuum hot press (make: Mansha Vacuum equipment, model: indigenous designed vacuum hot press) having pressure pulsation capability. To study the effect of pressure pulsation the bonding was done using the process parameters presented in Table 2. For pressure pulsation, the minimum pulse pressure of the pulsation cycle was kept half of the maximum pulse pressure. Fig. 2 (a) represents a schematic of the pressure pulsation cycle.

To study microstructure, hardness testing, interface bonding ratio and void distribution, bonds were developed using 20 mm × 20 mm × 4 mm coupons. After diffusion bonding the samples were cut by abrasive cutter and polished with the help of silicon carbide papers. Etching of the polished samples was done by vilella's reagent. Analysis of the diffusion bond interface was done by the micrographs captured by FESEM (make: Carl Zeiss, model: Carl Zeiss ultra plus) equipped with energy dispersive X-ray spectroscopy (EDS). Lap joints of overlapped length 20 mm were prepared to characterize the diffusion bonds mechanically (Fig. 2 (b)) and tested using universal testing machine (make: Instron, model: 5980) at a cross head speed of 0.5 mm/min. Hardness testing of few selected samples was also done using Vickers's micro-hardness tester (make: Omnitech, model: S Auto) using 100 g load and 10 s dwell time at a regular interval of 200 μm across the bond interface.

3. Results and discussion

3.1. Microstructural analysis

The microstructure of the as received base metal and for diffusion bonds corresponds to minimum and maximum tensile shear load carrying capacity are represented in Fig. 3. FESEM micrograph of as received base metal shows ferritic grains with randomly distributed carbide along the grain boundaries (Fig. 3 (a)). The EDS analysis for the base metal was also performed to check the elemental composition and represented in Fig. 3 (d). The size of ferritic grains of the base metal and diffusion bonds was also measured by the Mat lab software using line cut program. For base metal, the average size of the ferritic grains was 20.4 ± 5 μm. The FESEM examination in secondary electron mode for diffusion bond developed at 850 °C temperature and 20 MPa maximum pressure and zero pressure pulses (without pressure pulsation) showed large number of micro voids present at the diffusion bond interface (Fig. 3 (b)). However, the microstructure of the diffusion bond interface was similar to the base metal having average size of ferritic grains as 19.7 ± 6 μm. The diffusion bond developed at 40 MPa maximum pressure and eighteen pressure pulses was found free from any defect at the diffusion bond interface (Fig. 3 (c)). The average size of the ferritic grains in this condition was reduced to 16.8 ± 5 μm after diffusion bonding.

Table 1
Chemical composition of the ferritic stainless steel base metal measured by optical emission spectrometer.

Elements (weight %)							
C	Cr	Mn	Ni	Si	S	P	Fe
0.03	11.8	0.8	1.5	1	0.03	0.05	Balance

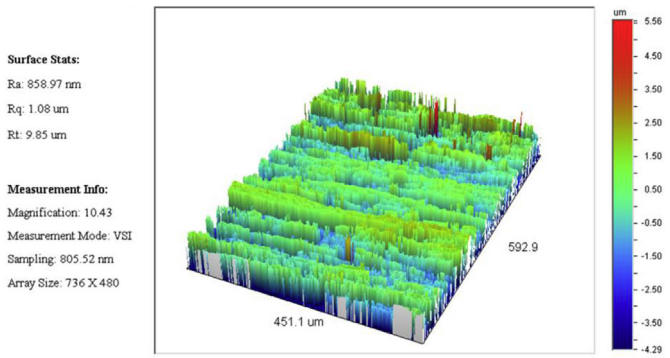

Fig. 1. Showing 3 D roughness plot of the prepared samples for diffusion bonding.

Table 2
Impulse pressure assisted diffusion bonding (IPADB) process parameters.

Sr. No.	Process parameter	Bonding condition
1	Diffusion bonding temperature (°C)	850
2	Total bonding time (s)	1800
3	Maximum pulse pressure (MPa)	20, 30 and 40
4	Pulse duration (s)	15
5	Number of pressure pulses	0, 6 and 18
6	Surface roughness (μm)	0.85

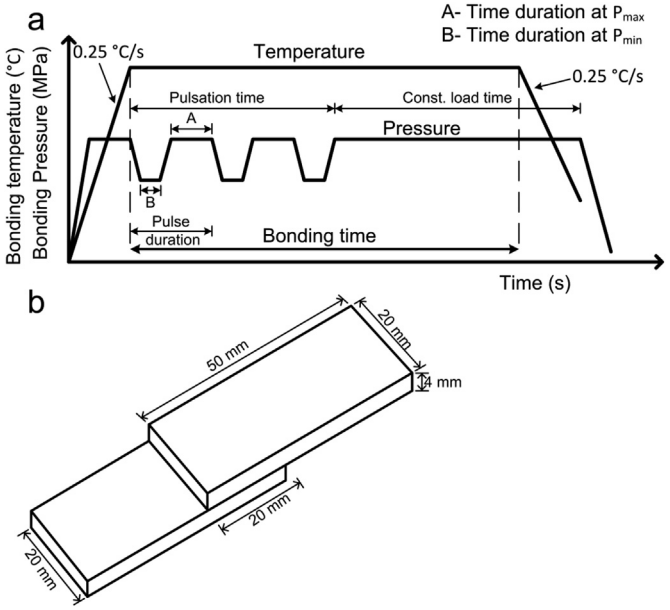

Fig. 2. Schematic: (a) pressure pulsation cycle of the diffusion bonding and (b) lap joint specimen.

It was also observed that the diffusion bonds developed using pressure pulsation possesses relatively finer grains near the bond interface than those developed at 20 MPa maximum pressure and zero pressure pulses (without pressure pulsation). Fig. 4 shows the variation of the grain size across the diffusion bond interface for the diffusion bond. From the figure it is clear that for the diffusion bond developed at 20 MPa maximum pressure and zero pressure pulses, no change in the grain size was observed across the diffusion bond interface whereas it was reduced to 14.5 μm for the diffusion bond developed at 40 MPa maximum pressure and 18 pressure pulses. The pressure pulsation produces compressive deformation of the surface layers at the diffusion bond interface which facilitates