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The interface morphology of diffusion bonded dissimilar stainless steel and medium carbon steel couples

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Abstract

In the present study, a duplex stainless steel and an austenitic stainless steel were diffusion bonded to medium carbon steel. The differences of two dissimilar metal couples at the test temperature on microstructural developments across the joint region were investigated. After diffusion bonding, microstructural analysis including metallographic examination, energy dispersive spectroscopy (EDS) and shear strength tests were performed. From the results, it was seen that mutual diffusion of C and Cr was effective on the morphology of the diffusion zone that affected the shear strength of the bonds.

Keywords: Diffusion bonding; Austenitic stainless steel; Duplex stainless steel; Medium carbon steel; Interface morphology

1. Introduction

Diffusion bonding is only one of many solid-state joining processes wherein joining is accomplished without the need for a liquid interface (brazing) or the creation of a cast product via melting and resolidification [1]. In diffusion bonding process, the application of a moderate pressure causes plastic collapse of contacting asperities leading to the formation of a planar array of interfacial voids. Creep/superplasticity and diffusion processes transport atoms to the void surfaces from adjacent areas, thus reducing interfacial void volume. If sufficient time is given, the voids will be removed and an atom to atom bond across the original interface will result. As bonding does not involve melting or gross macroscopic interface distortion, the microstructure of the bond region is similar to that of regions remote from the joint and has parent metal properties [2].

Duplex stainless steels have found widespread use in a range of industries, particularly the oil and gas, petrochemical, pulp and paper, and pollution control industries. Austenitic stainless steels were developed for use in both mild and severe corrosive conditions. The fusion weld of these steels is usually the part of a system with reduced corrosion resistance and low-temperature toughness, and therefore in many cases it is the limiting factor in material application. The heat of fusion welding also leads to grain coarsening in the heat-affected zone and solidification cracking in the weld metal of stainless steels. From all this difficulties and problems, diffusion bonding does not involve melting or gross macroscopic interface distortion. Also, the lack of a fused zone is potentially attractive to the welding of alloys that are prone to localized segregation effects. Consequently, there is ongoing effort to establish whether solid-state welding processes offer significant advantages over fusion processes [3,4].

In the literature, joining of austenitic stainless steels to plain carbon steels has widely been attempted for applications in thermal power industries [5,6].

In this study, a duplex stainless steel and an austenitic stainless steel were diffusion bonded to medium carbon steel. The reason for choosing these materials is investigate the interface morphology and morphology differences of two dissimilar metal couples. The other reason for choosing these materials is to see if diffusion bonding can be used for dissimilar couple as alternative to the joining with arc welding method. It is well known that the heat of fusion welding leads to grain coarsening in the heat-affected zone and solidification cracking in the weld metal of stainless steels [7]. From this point, it was aimed with the present study to determine if diffusion bonding technique could be used for joining of this dissimilar couple.

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Table 1
Chemical composition of specimen for used diffusion bonding

Alloy	Weight % composition								
	Fe	C	Cr	Ni	Mo	Si	Mn	P	S
Duplex S.S.	Bal.	0.024	24.5	4.23	0.81	0.7	0.7	0.02	0.02
AISI 304	Bal.	0.052	19.2	8.5	–	0.87	1.8	0.035	0.03
AISI 4140	Bal.	0.42	0.87	–	0.19	0.22	0.72	0.02	0.02

2. Experimental procedure

In the study, a duplex stainless steel and an austenitic stainless steel were diffusion bonded to AISI 4140 type medium carbon steel. Table 1 shows the chemical compositions of these steels. The materials were delivered in plates. For diffusion bonding, the plates were cut into of 10 mm × 10 mm × 10 mm. Prior to diffusion bonding, surfaces of the specimens were prepared by grinding on SiC wheels followed by polishing to 3 μm surface finish. The specimens were then degreased in an ultrasonic bath using acetone. Diffusion bonding was made in an argon atmosphere in the bonding chamber equipped with an induction heating unit designed for diffusion bonding. The bonds were made a pressure of 8 MPa at a temperature of 900 °C for 30 min. The heating rate was 40 °C min^{-1}. Once the bonding process was completed the specimens were cooled to the room temperature at a rate of 15 °C s^{-1} before removal from the chamber.

Metallographic examination of the bonding area involved preparing transverse sections through the bonds followed by grinding and polishing to 1 μm diamond past. For microstructural examination, the AISI 4140 side was etched using Nital reagent. Duplex stainless steel side was etched electrolytically in a solution of 50 g KOH and 100 ml H_2O and AISI 304 stainless steel side in a solution of 50 ml HNO_3 and 50 ml pure water. Metallographic observations were performed by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The bonds were mechanically tested using a shear test apparatus. For this aim, the bonded specimens were further machined to produce 8 mm × 8 mm × 10 mm shear test specimens, to eliminate the edge effects on test data. An Instron tensile testing machine set at a crosshead speed of 0.5 mm min^{-1} was used for the shear tests.

3. Results and discussions

The scanning electron micrographs of the bonded specimens at 900 °C are shown in Figs. 1 and 2. Fig. 1 shows the interface of duplex stainless steel and medium carbon steel couple. This interface exhibits a good bonding along the interface and it is free from discontinuities and microcracks. Also from this micrograph four distinct regions are observed corresponding to (I) parent AISI 4140 with ferrite + pearlite structure, (II) ferrite stabilized region in carbon steel side containing Cr, (III) carbide network region in stainless steel side, from EDS analysis, (IV) parent duplex structure (ferrite and austenite) of stainless steel. Fig. 1b clearly shows carbide network in the stainless steel side and chromium carbide layer in interface. From EDS analysis (Fig. 1b), it is seen that the carbide network consists of 6.4% C–18.9% Cr–72.5% Fe–2.2% Ni and the chromium carbide layer consists of 6.74% C–18.4% Cr–71.9% Fe–3.37% Ni, respectively. These compositions were determined to be chromium carbide by Fe–Cr–C ternary phase diagram [8]. Diffused C into duplex stainless steel formed chromium carbide around austenite grains in ferrite phase. Diffusion rate of C is higher in ferrite than in austenite phase. Therefore, C diffuses longer in ferrite phase and on cooling C atoms leaves ferritic structure and binds Cr. As a result, chromium carbide network zone about 60 μm in width in the stainless steel side and chromium carbide layer of approximately 2 μm in interface were occurred. The diffused Cr into carbon steel stabilized ferrit phase creating a ferrite stabilized zone and spheroidized cementites as clearly seen from SEM micrograph in Fig. 1b. It is known that the addition of only 0.4 wt.% of Cr to steel stabilizes ferrite in two phase region [9].

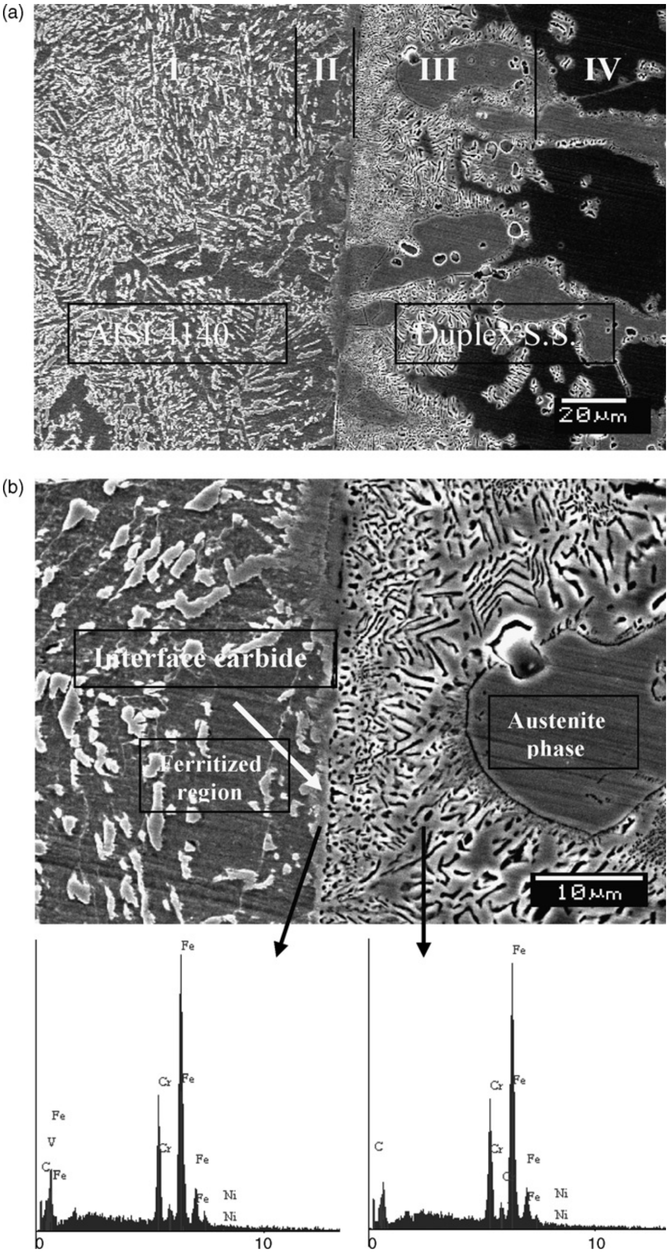

Fig. 1. SEM micrographs of the bond interface of the duplex/AISI 4140 steel couple.

The SEM micrographs in Fig. 2 show the interface microstructures of the bonded austenitic stainless steel and medium carbon steel couple. Photos demonstrate a good bonding along the interface of the bonded couples and the interface is free from discontinuities and microvoids. Fig. 2 also shows that chromium carbide begins to form in the interface region and grain boundaries of austenitic stainless steel by diffused C from medium carbon steel side. From EDS analysis it can be esti-