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Microstructural Evolution during Solid State Diffusion Welding of X70 Steel to Duplex Stainless Steel

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Abstract

The main objective of this research work was to study the effect of solid state diffusion welding time on the joining of two dissimilar steels: low carbon steel (X70) and a duplex stainless steel. To achieve our objective, we used three characterization techniques such as optical microscopy, scanning electron microscopy, energy dispersive spectroscopy, and X-ray diffraction. The two steels were successfully welded and we were able to highlight the microstructural evolutions of the welded joint.

Keywords: Solid state diffusion; Dissimilar steels; Microstructures

Introduction

The study of welding of dissimilar metals is an important issue due to their increasing applications in many industrial fields. Actually, many welding techniques have been used for welding dissimilar metals. In particular, solid state processes which are interesting processes. Solid state welding makes it possible to create a mechanical connection in a solid phase, since the melting temperature of the materials to be welded is not reached. These processes are diffusion welding, friction welding, cold pressure welding, and explosion welding. Diffusion welding is a solid state welding process which involves the application of high pressure to the parts to be assembled, at high temperature, generally under vacuum. Diffusion welding is a solid phase joining process. It consists of positioning two surfaces opposite each other and applying strong pressure, mainly between 2 and 20 MPa. While being placed in a thermal chamber, brought to a high temperature, but remaining below the melting temperature of the material to be welded (generally 0.5 to 0.8 times its melting temperature). It is only an interatomic diffusion between the different materials present, with the creation of a common crystal lattice at the interface of the parts. The processing time can reach around ten hours [1,2]. (Figure 1a,b,c) schematizes the solid-state diffusion joining process and the mechanism from a microstructural point of view, which is mainly based on the disappearance of the cavities between the two surfaces. Contact which promotes interatomic diffusion at the contact interface and consequently new grains are formed in the contact zone. The diffusion welding parameters are the welding temperature, the pressure applied to the two samples, the surface condition of the samples to be welded, and the time required to form a joint [3]. Diffusion welding is increasingly applicable to the aerospace industry and is also used for various applications in advanced development, such as the manufacturing of honeycombs, turbine components, rocket engines, structural elements, composites and laminates [4,5]. According to literature research, many dissimilar metals have been welded by this process [6-8]. But there remain other dissimilar metals that have not been studied. The aim of our research work was to study the solid state diffusion welding time of two dissimilar steels: a low carbon steel (X70) and a duplex stainless steel. These two steels are widely used in the field of hydrocarbon transport.

Experimental Procedure

In this study, duplex stainless steel (0.02 %C, 20 % Cr, 1.54% Mn, 0.06 % Ni, 67.00 % Fe, and others elements) and low carbon steel X70 (0.07 %C, 0.20 % Si, 1.02 % Mn, 0.15 % Mo, 98.00 % Fe, and others elements) were used as base metals for diffusion welding experiments. These types of steel are used in the construction of pipelines for transporting gas and oil. The polished samples are cleaned with ethanol to put them into the solid-state diffusion welding device as shown in (Figure 2).

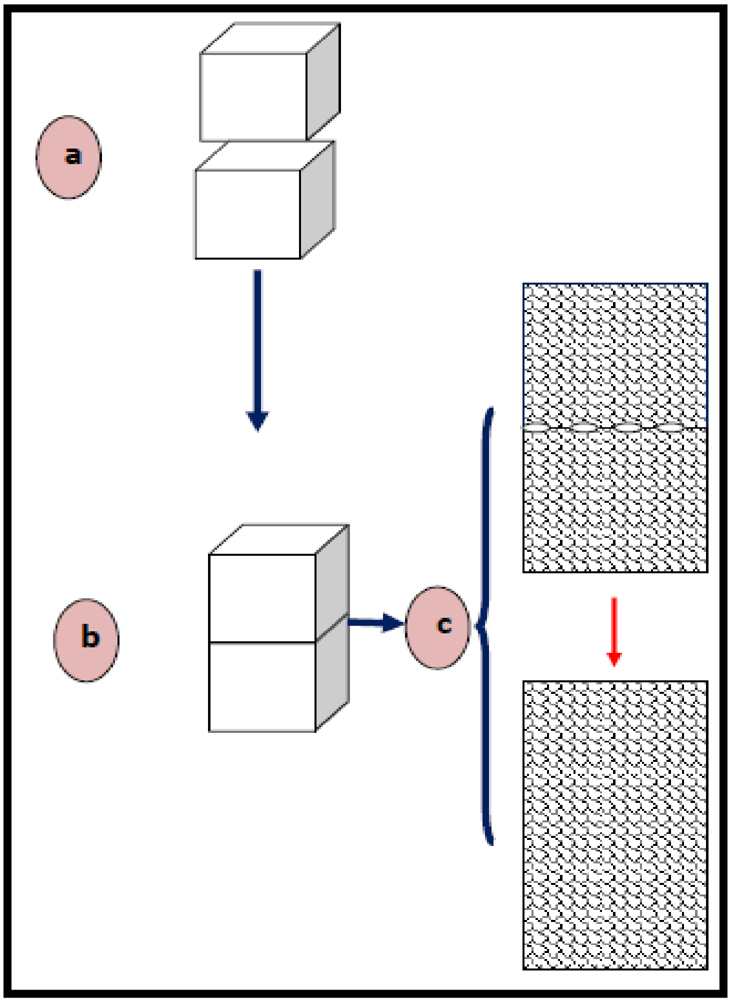

Figure 1: *Schematic representations of the solid-state diffusion joining process.*

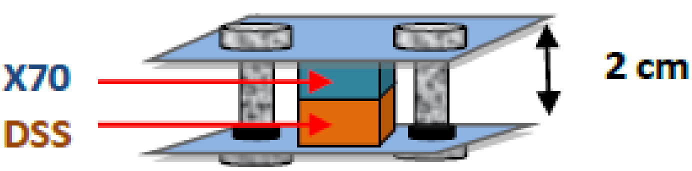

Figure 2: *Schematic configuration of diffusion welding of dissimilar steels.*

The diffusion welding was carried out at 1150°C in a vacuum chamber for different holding time (45 min, 120 min, 300 min, and 1200 min.). For metallographic observations and other characterization techniques, the welded samples were cut perpendicular to the joining surface (interface) and then polished using the different abrasive papers: 240, 400, 600, 800 and finish 1000, 1200, 2400, and 3000. The final polishing step is carried out using 3 µm diamond paste until a well-polished (mirror) surface is obtained. For the microstructural examination, the X70 steel was etched with 2% Nital for 20 s, on the other hand the duplex stainless steel was etched with a chemical solution containing 5 g of CuCl2, 100 ml of HCl and 100 ml of alcohol for 10 s. For characterization; we used an Olumpus type metallographic microscope, an Empyrean diffractometer (XRD) with Cu-Kα monochromatic radiation (λ= 1.541838 Å) a voltage of 40 kV and a current of 20 mA, and a Prima E type scanning electron microscope which is equipped with energy dispersive spectroscopy (EDS).

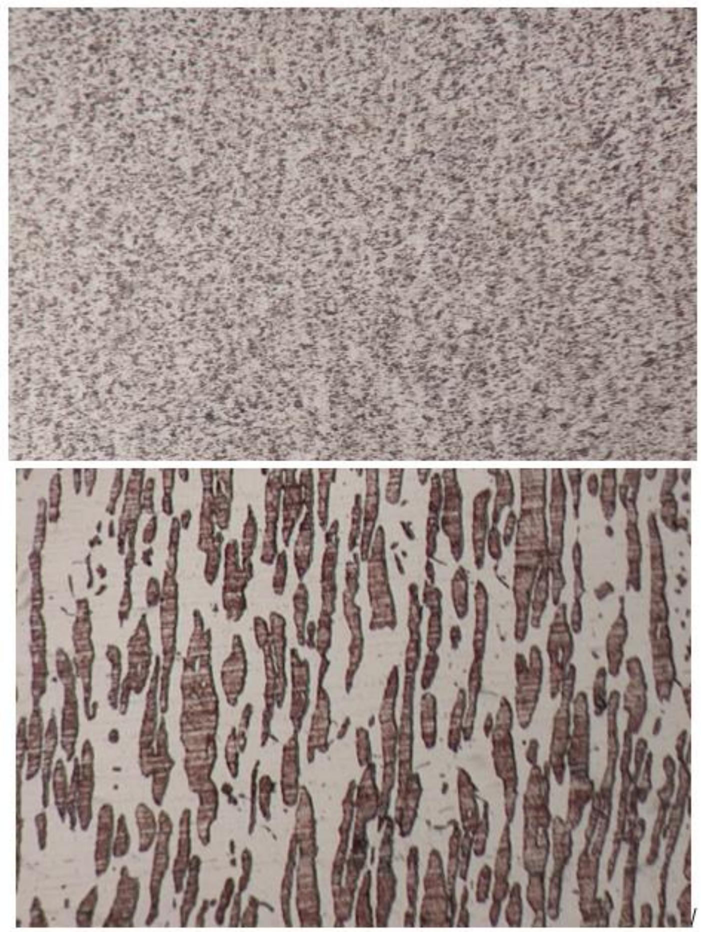

Figure 3: *Microstructure of base metals, (a) X70 steel, (b) duplex stainless steel.*

Results and Discussion

Shows the microstructure of the two base metals: X70 steel and duplex stainless steel. The microstructure of X70 steel reveals a mixture of ferrite and pearlite (Dark color) (Figure 3a). And that duplex stainless steel presents a two-phase microstructure (ferrite and austenite) (Figure 3b). The ferrite phase appears dark in color Figure 4 presents the microstructural evolutions caused by diffusion welding carried out at a temperature of 1150 °C for

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different holding times. The interface is straight and does not contain any defects such as pores or cracks (Figure 4a-d)). We note that after 45 minutes of holding (Figure 4a), a very thin layer is observed throughout the interface. This proves the weldability between the two dissimilar steels. Additionally, microstructural changes were observed in both base metals, in all samples. After 300 minutes of holding (Figure 4c).

***Figure 4:** Microstructures of welded joints at 1150°C: (a): 45 min, (b): 120 min, (c): 300 min, and (d): 1200 min.*

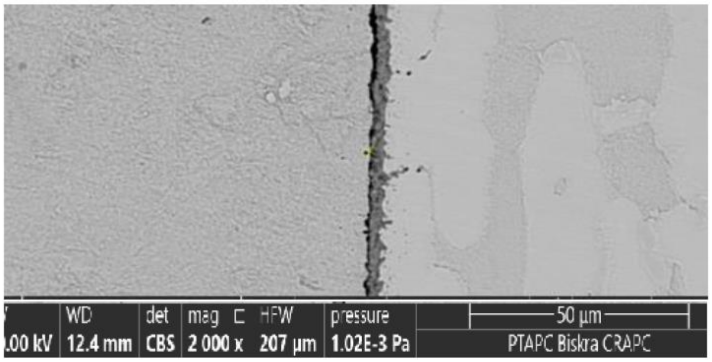

***Figure 5:** Microstructures of welded joints at 1150°C for holding time of 120 min.*

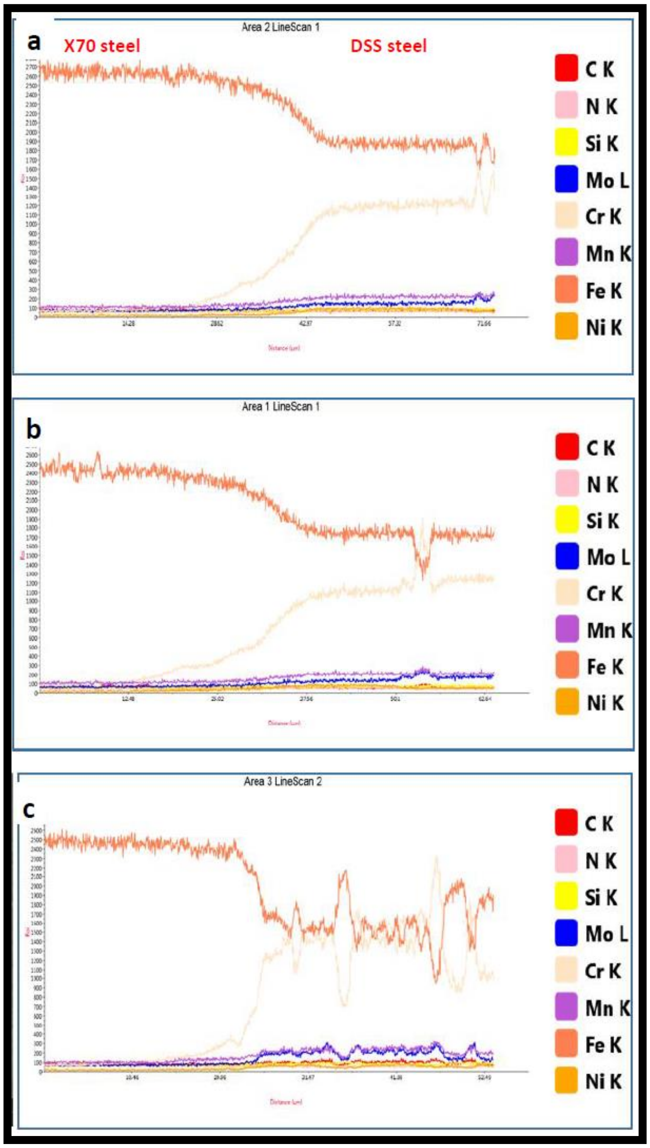

***Figure 6:** EDS analysis across the interface of dissimilarly jointed duplex stainless steel with X70 steel, welded by a solid-state diffusion bonding process at 1150°Cfor holding time : (a) : 45 min, (b) : 120 min, and (c) : 1200 min.*

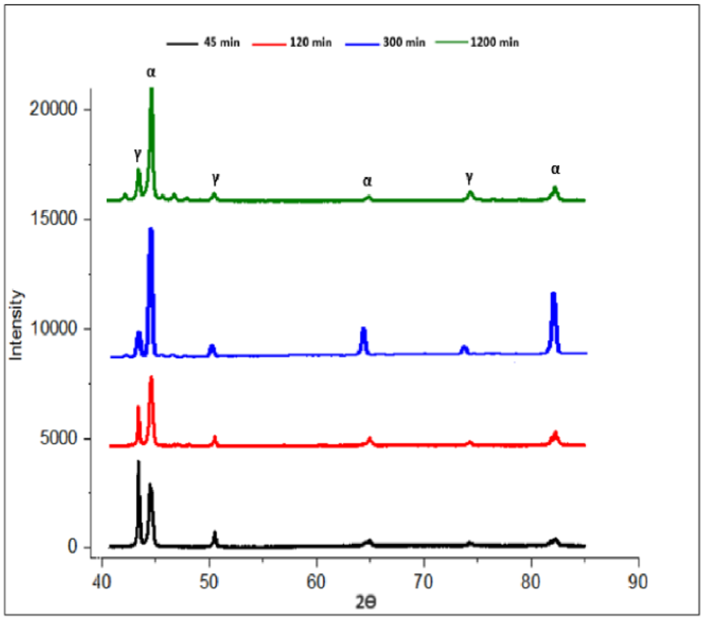

Figure 7: *X-ray diffractograms of the stainless steel side near the interface of the welded joint at 1150 °C for 45 min, 120 min, 300 min, and 1200 min.*

It was observed in the duplex stainless steel side that the grains did not retain their elongated shape and became equiaxed with a grain size of around 50 µm. It was also observed that the majority of existing pearlite colonies in the X70 steel underwent dispersion in the ferritic grains. Furthermore, after a long holding time of 1200 minutes (Figure 4d). A free zone is observed near the interface. This phenomenon can be attributed to a carbon diffusion reaction over this zone. All these phenomena are due to the welding temperature which is considered a high temperature and therefore it accelerates the diffusion process. Shiwei et al [9]. Noticed also the effect of welding temperature on microstructural change in base metals. Observation with a scanning electron microscope revealed the interface of the welded joint between the two dissimilar steels (Figure 5). This interface appears with a dark color and a thickness of approximately 2 µm. Figure 6 presents the variation curves of five chemical elements across the interface of the welded joint of the two dissimilar steels. First of all, from the three concentration variation curves, the diffusion of silicon, molybdenum, manganese, and nitride is almost negligible (Figure 6). However, iron and chromium diffuse significantly across the interface. As shown in Figure 6, when the welding time is increased, the diffusion of Fe and Cr increases (Fig.6c). It means that the holding time favors the mechanism of diffusion of atoms across the interface. Figure 7 shows the X-ray diffractograms of the stainless steel side near the interface of the welded joint at 1150 °C for a holding time 45 min, 120 min, 300 min and 1200 min, respectively. For diffusion welding for a holding time of 45 min, only the peaks of two phases were revealed, namely ferrite and austenite and which are the initial phases of the base metals. Other weak peaks appear on the X-ray diffractogram when the welding time increases up to 120 min. These new peaks are located in low diffraction angles. These peaks can be attributed to the formation of certain carbides such as chromium carbides (Figure 7). With increasing time to 300 or 1200 minutes, the intensity of the peaks of these carbides increases.

Conclusion

Based on the results obtained, our main conclusions are as follows:

- The welding was carried out successfully for the welding times adopted at the beginning of this research work.
- Analysis by optical microscopy revealed the good quality of the joint, as no visible defects such as pores or cracks were observed.
- Chemical analysis by EDS revealed the inter-diffusion of elements belonging to the two basic steels such as chromium, iron and nickel.
- X-ray diffraction revealed the formation of carbides but in small quantities.

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