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Investigation of Heat Affected Zone by Welding Simulation of Duplex Stainless Steel

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Abstract

This work is a contribution to the study of the heat affected zone of duplex stainless steel by using thermal cycle simulation. It presents the microstructures obtained after thermal cycle simulation of welding by rapid heating and cooling treatments of the base metal in a specific simulation equipment. Optical microscopy and microhardness measurements were used as characterization techniques. Microstructures and mechanical properties of the heat affected zone were determined. We have found that this thermal cycle simulation provides more details of the heat affected zone.

Keywords: welding, HAZ, duplex stainless steel , thermal cycle simulation

1. Introduction

Historically, stainless steels have been classified by microstructure and are described as austenitic, martensitic, ferritic, or duplex (austenitic plus ferritic). Duplex stainless steel (DSS), with nearly equal proportion of ferrite and austenite phase, near-perfectly combines most of the beneficial properties of austenitic stainless steel (ASS) and ferritic stainless steel (FSS), including high strength,good toughness, and excellent corrosion resistance [1-3]. Thus, DSS is increasingly being applied in various fields such as petroleum, and natural gas industries [4].

Welding processes are essential for the manufacture of a wide variety of products, such as: frames, pressure vessels, automotive components and any product which have to be produced by welding [5]. In modern pipeline technology, an appropriate selection of microstructure is the main parameter to modify the strength and toughness behaviors of the oil and gas pipeline steels [6]. Heat generated during welding induces an important temperature gradient in and around the welded area or fusion zone (FZ). The microstructure that develops in the FZ varies noticeably from region to region. The zone outside the fusion zone that is thermally affected by the welding treatment is known as the heat-affected zone (HAZ) [6].

It has been found that by improving the microstructure of the HAZ, the properties of the welded joint can be improved. Generally, the HAZ is zone with small width. For this reason, it will be interesting to study this zone by a specific technique such as weld thermal cycle simulation. This technique simulates the HAZ in a specific setup by heating the base metal at different temperature below the melting point.

This technique has been used in our previous works [7-9]. We have studied the heat affected zone by thermal cycle simulation of welded INC 738 LC alloy [7] and low carbon steel [9]. In general, we found a similarity between the microstructure obtained by thermal cycle simulation of welding and the microstructure of the HAZ of the real welded joint with more obtained details are found by the thermal cycle simulation.

Duplex stainless steel is considered as one the appropriate steel for pipeline construction. The most previous works on welding of duplex stainless steel were focused on microstructure, mechanical properties, and corrosion resistance on real welded material [1-3] and there is not a specific investigation by welding simulation which was devoted to the HAZ in duplex stainless steel. The objective of this present investigation is to study by a thermal cycle simulation the microstructures of the heat affected zone of duplex stainless steel.

2. Experimental procedure

The base metal is duplex stainless steel used in pipeline construction for the oil transport. The chemical composition of duplex stainless steel is presented in Table 1.

Table 1. Chemical composition of the base metal duplex stainless steel (wt %).

C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Cu	N
0.029	0.480	1.870	0.0239	0.004	23.189	7.078	3.018	0.01	0.07	0.09

For thermal cycle simulation study, specimens 10 mm thick $10\times 12\ mm^2$ of duplex stainless steel, were heat treated for the simulator tests TCS 1405 (Fig. 1). Simulation studies of thermal cycles consisted of resistive heating of samples. Thermal cycles were simulated at the following temperatures : 600°C, 800°C, and 1000°C (Fig. 2).

The specimens for metallographic examination were polished using different grades of emery papers. Final polishing was done using the diamond compound in the disc-polishing machine. Specimens were etched with this solution : 50% HCl + 25 % HNO_3 + 25 % H_2O, to reveal the microstructure. The etched samples were observed by optical microscopy. Vickers's microhardness testing machine was employed for measuring the hardness of the specimens with 0.3 kg load.

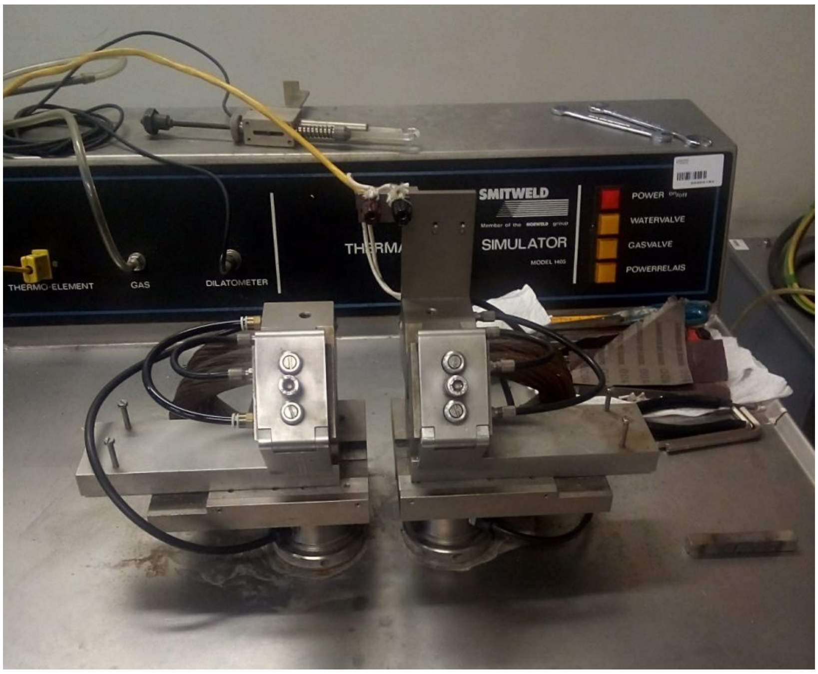


Fig. 1. Smitweld thermal cycle simulator in application

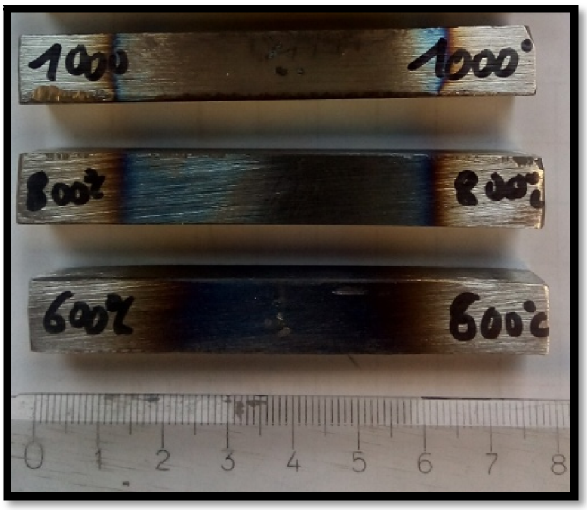


Fig. 2. Samples obtained after thermal cycles simulation.

3. Results and Discussion

Fig.3 presents the microstructure of the base metal which is typically of ferrite and austenite phase. Duplex stainless steels (DSS) are Fe-Cr-Ni alloys having an approximately volumetric fraction of 50% ferrite and 50% austenite in their microstructures, therefore they combine some characteristics of each of these phases. Their main feature is that they compromise the favorable corrosion resistance of austenitic stainless steels with good mechanical properties.

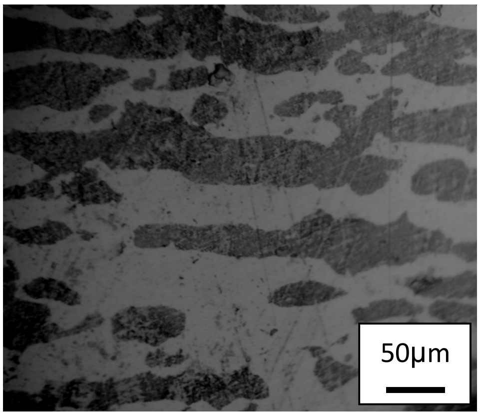
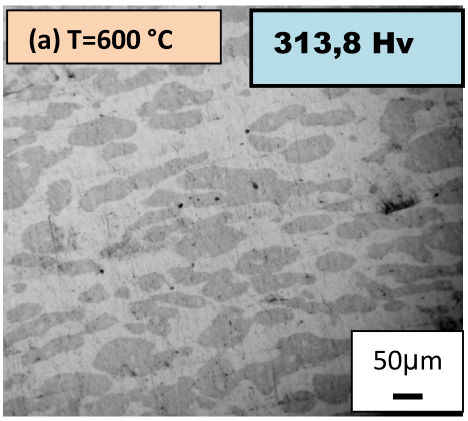


Fig. 3. Smitweld thermal cycle simulator in application.

Fig. 4 shows microstructures of duplex stainless steel obtained after different thermal cycles with the corresponding hardness value. There is not phase transformation such as development of new phases or grain growth reaction after the three the thermal cycles. This means that the heat affected zone formed between 600 and 1000 C correspond typically to the base metal. However, with the increase of temperature, the hardness HV decreases. This mechanical changing can be due some hidden transformations which are not observed by an optical microscopy. Because, various types of precipitate may form at temperature in the range 550- 1000°C: σ, χ, ε, R phases, carbides and nitrides. the producers and manufacturers of these steels have to be aware of these phase transformations because they may occur either during production or during welding when the material is exposed to elevated temperature for shorter or longer times. We can deduce from these results that the HAZ is not a homogeneous structure but it is formed with different subzones which differ on their mechanical properties.



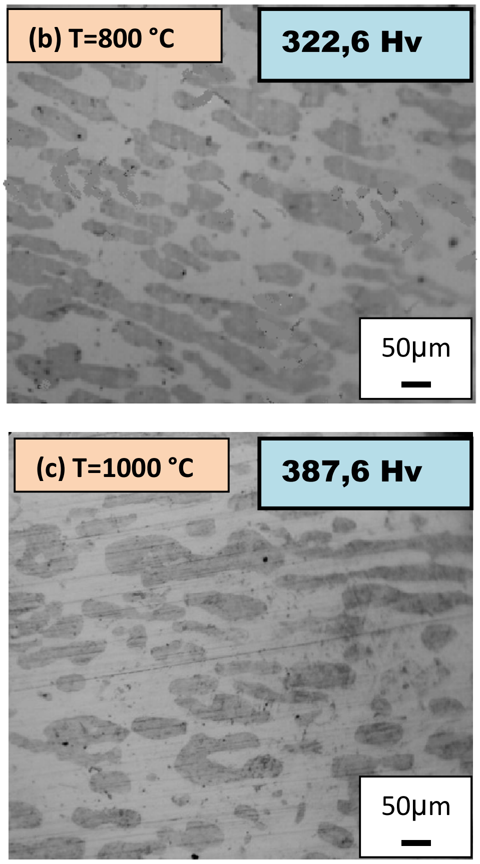


Fig. 4 Microstructures of duplex stainless steel after simulation welding process and their plotted temperature-time during the welding thermal cycle.

4. Conclusion

In this investigation, heat affected zone of duplex stainless steel was investigated by the thermal cycle simulation of the base metal. This technique simulates the HAZ in a specific setup by heating the base metal at different temperature below the melting point. From thermal cycle simulation technique, the increase of temperature leads to hardness increase of the steel. However, there was not an observed phase transformation of the base metal after thermal cycle simulation but some hidden transformation were developed such as precipitation of sigma phase.

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