MICROSTRUCTURE EVALUATION OF UNS S32205 DUPLEX STAINLESS STEEL FRICTION STIR WELDS

AVALIAÇÃO MICROESTRUTURAL DE JUNTAS SOLDADAS POR ATRITO COM PINO DE AÇO INOXIDÁVEL DUPLEX UNS S32205)

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Abstract

UNS S32205 Duplex stainless steel welds were performed with the friction stir welding (FSW). Advancing and retreating sides showed distinct characteristics in the welded joint. The advancing side shows the strongest grain refinement which it is corroborated by microhardness measurements. The microstructure characterization was carried out by optical and electron scanning microscopy. The thermo-mechanically affected zone (TMZA) displays the austenite islands deformed in the ferrite matrix. The Stir zone (SZ) showed an incomplete recrystallization of austenite, while the ferrite displayed a grain refinement more pronounced than austenite. Secondary phase precipitation was not observed in the welded joint probably due to the shorter heating times.

Resumo

Soldas de aço inoxidável duplex UNS S32205 foram realizadas com a soldagem por fricção (FSW). Os lados avançado e recuado apresentaram características distintas na junta soldada. O lado avançado mostra o mais forte refinamento de grão que é corroborada por medidas de dureza. A caracterização microestrutural foi realizada por microscopia óptica e microscopia eletrônica de varredura. A zona termomecanicamente afetada (TMZA) exibe ilhas de austenita deformada na ferrita. A zona de fricção (SZ) apresentara uma incompleta recristalização da austenita, enquanto a ferrita apresenta um refinamento de grão mais acentuado do que a austenita. A precipitação de segunda fase não foi observada na junta soldada, provavelmente devido aos tempos de aquecimento mais curtos.

Introduction

Austenitic-ferritic stainless steel also referred to as duplex stainless steels (DSS), combine many of beneficial properties of ferritic and austenitic steels. The chemical composition of duplex steels is balanced to give approximately equal amounts of ferrite and austenite in solution-annealed condition. They are most often selected for corrosion resistance and have been substituted for austenitic alloys in many applications where stress corrosion cracking and pitting corrosion are concerns. However, the DSS have a limited service temperature range, lower than 300 ºC, because a great number of detrimental secondary phases that can be formed as a consequence of the thermodynamic instability of the ferrite (Lo et alii, 2009; Lippold et alii, 2005).

Due to their low nickel content, DSS have good weldability. However, the melting and solidification associated with fusion welding process destroy the favorable duplex microstructure of these stainless steels. Moreover, detrimental intermetallic phases can be formed during the fusion welding process. Higher ferrite content and coarser grains are other factors which decrease both the corrosion resistance and the mechanical properties of welded joint (Sato et alii, 2005; Steel et alii, 2004).

Friction Stir Welding (FSW) is a solid state joining process, which shows some advantages to weld the DSS. For example, fusion welding-associated problems are eliminated. During FSW process, the material is submitted to intense plastic deformation at elevated temperature resulting in generation of fine and equiaxed recrystallized grains (Mishra et alii., 2007).

Materials and Experimental Procedure

The study was performed on a commercial grade UNS S32205 duplex stainless steel with typical chemical composition indicated in Table 1. The chemical composition was provided by the steel producer, Arcelor Mittal Inox Brazil. A common characteristic for all duplex grades is their high mechanical strength. Their yield strength is about twice that of the most common austenitic grades, and is much higher than for ferritic stainless (Paijkull et alii., 2008). Table 2 shows the mechanical properties of the steel studied in this work.

Table 1. Chemical composition (wt %) of the of UNS S32205 duplex stainless steel.

C	Mn	Si	Cr	Ni	Mo	P	S	N
0.023	1.80	0.30	22.5	5.4	2.8	0.030	0.001	0.16

Table 2. Typical mechanical properties of UNS S32205 duplex stainless steel.

Property	MPa	ksi
Yield strength (YS)	450	67
Tensile strength (TS)	620	93
YS/TS (%)	0,72	
% elongation	25	
Average microhardness ($HV_{0.2}$)	280	

Plates of 350 x 150 x 6 mm were used for the FSW samples preparation. The welds were performed normal to the rolling direction. Friction stir welds were performed of these 6.0 mm plates. The joints were performed using a dedicated TTI FSW, which allows position and force controlled welding. Downward forces of the 40 kN (force controlled process) was necessary to produce sound welds using an un-tilted PCBN tool with threaded conical shape and 6 mm long pin and convex threaded shoulder. Welding speeds were limited to keep the forces in the welding direction (x direction) at or below 5 kN in order to extend the tool life. Final parameters for UNS S32205 steel consisted of 200 rpm and 100 mm/min. An argon atmosphere was introduced through a gas cup around the tool at a flow rate of 1.68 m^3/h.

Welds and base metal (BM) were sectioned and polished for optical metallography. The metallographic preparation consisted on sanding and polishing with 1-μm grain diamond paste; final polishing was performed in the Vibromet® vibratory polisher with a 0.25-μm alumina solution. Electrolytical etching was used in order to reveal the microstructure. The etching solution consisted of 60%vol. HNO_3 in distilled water. Voltage and etching time were 1.50 V and 75 s, respectively.

An Olympus microscope with a PAXCam digital camera attached to it was used for all optical microscopy performed in this study. PAX-it!® software was used for capture the images. The volumetric fraction of BM was measured by PAX-it. The scanning electron microscope (SEM) analyses were carried out using JEOL JSM 5900 LV

Vickers microhardness map was performed through LECO® microindentation hardness testers using a load of 1.96 N (200 gf) for 15 s.

Results

In the friction stir welding (FSW) system there is a hole, in which is possible to insert the thermocouple into the tool head that is attached to the FSW machine. This thermocouple positioned by the tool shoulder does not provide the exact tool temperature at its interface with the processing material within the stir zone. However, due to the high thermal conductivity of PCBN, it provides a comparative value for different welding parameters and final microstructures (Steel et alii., 2004). The highest temperature in PCBN tool was 705 ºC

Figure 1 shows the welded joint microhardness map. In the cross section, the left- and right-hand sides of the weld center are consistent with retreating and advancing sides of the rotating tool, respectively (Sato et alii, 2005). The advancing side shows the higher hardness than others regions. The advancing side indicated the strongest grain refinement.

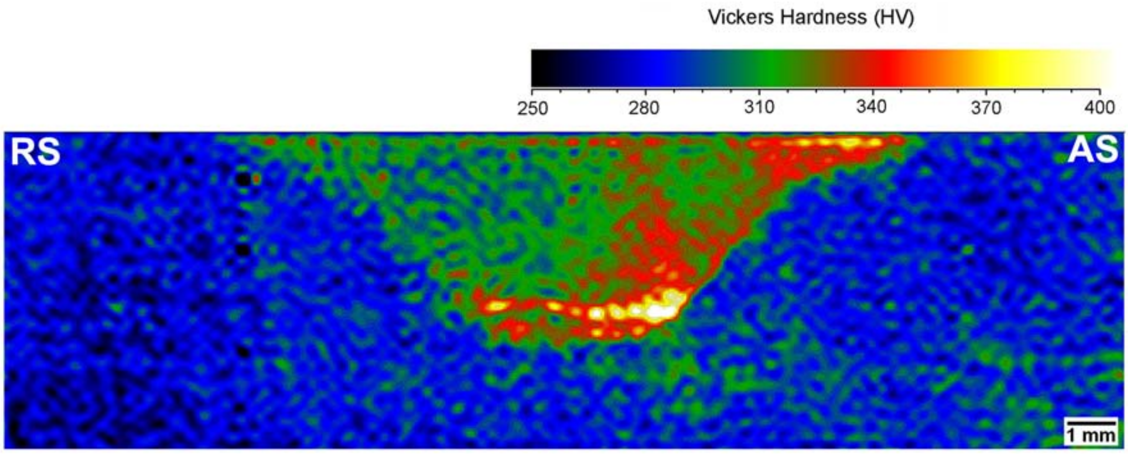

Figure 1. Microhardness map of the welded joint.

The microstructure of the welded joint can be classified into three distinct regions including the SZ, the TMAZ, and BM. The heat affected zone (HAZ) was not clearly observed. Figure 2 displays macro- and microstructures of the cross-section at different regions of welded joint.

Figure 2 (a) shows the macrostructure of the welded joint. Some thermocouples were positioned near to the TMAZ and SZ. These data have been analyzed, and in the future they will help to understand the microstructural changes. Several regions are indicated in Figure 2. The BM is shown in the Figure 2 (b), the microstructure consists islands of austenite in the ferritic matrix. TMAZ near to retreating side (RS) is shown in the Figure 2 (c), it was observed deformed austenite grains, grain grow significant was not observed.

Figure 2 (d) displays the SZ center. The austenite grain appear more deformed than ferrite ones. In the case of the duplex alloys both phases deform differently and recrystallize according to distinct kinetics. Although, the austenite has a higher recrystallization potential, the diffusion in the ferrite phase is quicker than the austenite one. Thus, the ferrite has fully recrystallization and grain grow while the austenite shows only partial recrystallization.

Figure 2 (e) shows the strongest grain refinement in the advancing side of the welded joint. Steel el alii. (2004) and Sato et alii. (1999) working the FSW of UNS S32750 welds showed stronger grain refinement in the SZ (advancing side) of the friction stir welds. Figure 2 (f) shows the SZ/TMAZ interface.

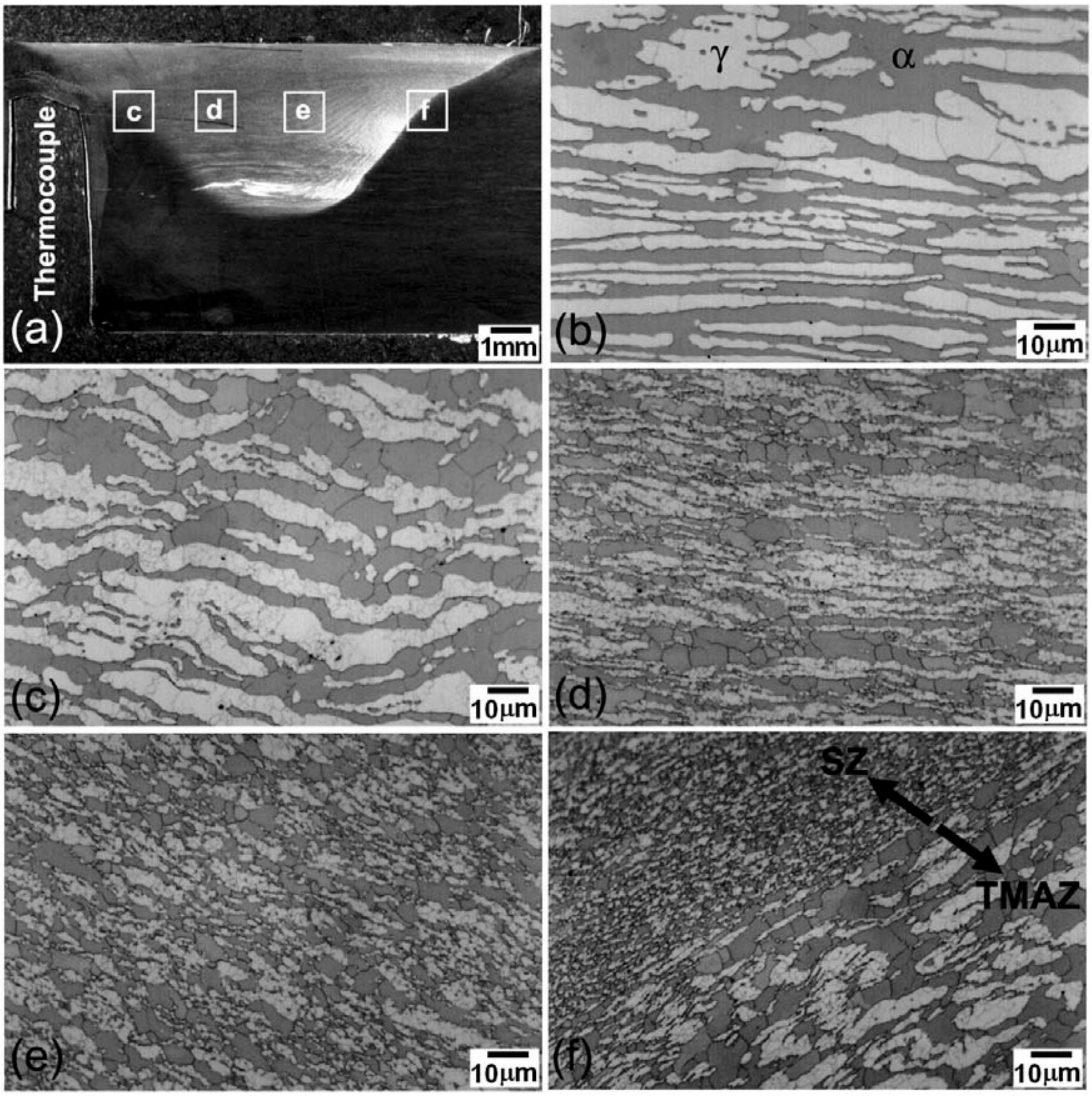

Figure 2. Macro- and microstructures of FS weld showing various microstuctural zones in UNS S32205: (a) FS weld macrograph, (b) BM, (c) ZTMA near to RS, (d) SZ near to RS, (e) SZ center and (f) SZ/TMAZ interface. Optical microscopy.

Figure 3 shows the microstructure in the retreating and advancing sides of friction stir welds stir zone. In the AS, it is possible to observe the refinement grain stronger than RS side.

Discussion

Figure 2 (c) and (f) it is possible to observe that the border between the SZ and the TMAZ is very distinct on the advancing side. The austenite grain size is lower than ferrite grain size, probably due to the ferrite achieved complete recrystallization, while the austenite had partial recrystallization.

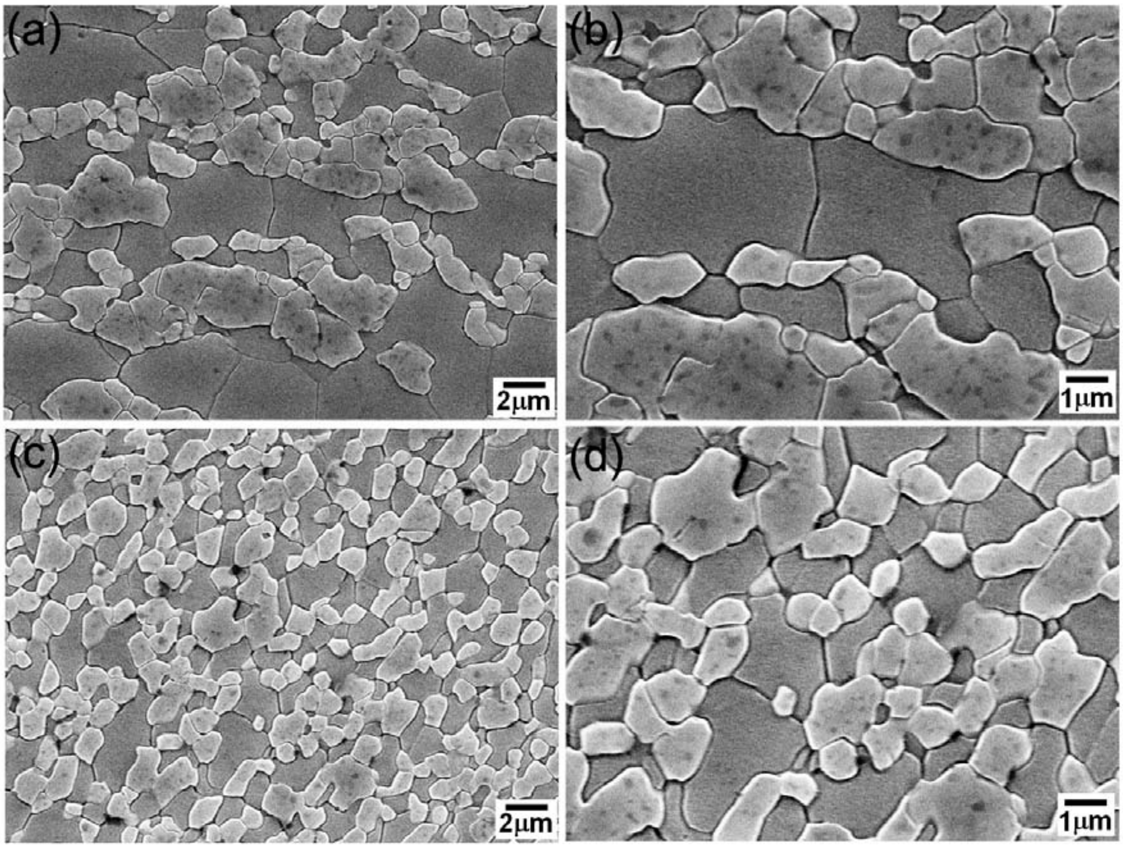

Figure 3. Duplex microstrucutures in the (a) retreating side and (c) advancing side. In (b) and (d) figures are shown the details of the RS and AS regions, respectively.

The major hardness occurred in the advancing side of friction stir welds stir zone due to lower austenite grain size. The increase of hardness in the stir zone suggests that the hardness is related to the grain sizes of ferrite and austenite phases in the weld. The morphology of austenite islands in the stir zone was much distinct from that of the base metal one. This effect has been reported to the intense plastic strain during FSW which the austenite was submitted (Sato et alii, 2005)

It is possible to observe in Figure 3 the equiaxial grain of austenite and ferrite. However, the ferrite grain size is clearly higher than austenite ones. Secondary phases were not observed in any regions of the welded joint. Escriba et alii (2009) studied S32205 DSS heat treatment in the range between 700 and 750 ºC submitted to a thermal cycle for 1 and 2 h and indicated the presence of intermetallic phases. Although during the FSW these temperatures were achieved, secondary phase precipitation was not observed in the welded joint probably due to the shorter times. Saeid el alii (2008) working the UNS S32205 duplex stainless friction stir welds did not observe any detrimental intermetallic phases.

Conclusions

The present study examined the microstructure and mechanical properties of FSW in UNS S32205 duplex stainless steel. FSW using PCBN tool produced high-quality welds in the duplex stainless steel.

An incomplete recrystallization of austenite was observed, while the ferrite shows the complete recrystallization due to the higher diffusion rates in its structure.

Secondary phase precipitation was not observed in the welded joint probably due to the shorter heating times. More careful analyses will be performed using a transmission electron microscope.

The advancing side shows a higher microhardness than other regions due to a stronger grain refinement, which is the mean mechanism of strength increase in this welded joint.

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