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Friction stir welding of 430 ferritic stainless steel

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1- Introduction

Ferritic stainless steels are categorized as a group of engineering materials which are widely used in different technical fields such as automotive industry because of their high corrosion resistance and excellent mechanical properties. Therefore, welding of these types of alloys are strongly requested in the industry. Common traditional welding techniques break up the initial microstructure of the material by re-melting of the welded material and develop a new microstructure with new possible defects such as the formation of large dendritic grains, sensitization, martensite formation and grain growth. Therefore, FSW process with less heat input is considered as alternative technique for traditional welding processes.

2- Experimental

In this study, the as-received 2 mm thick 430 FSS material was FS welded in a bead-on-plate configuration along the rolling direction of the material at a welding speed of 50 mm/min and a rotational speed of 400 rpm. The welding tool was a WC-based material with a conical geometry. The tool was designated with a shoulder diameter of 16 mm, pin base diameter of 4.5, pin tip diameter of 3.5, and height of 16 mm. The pin insertion depth into the material was held constant at 1.8 mm during welding procedure. EBSD evaluations were performed on a cross-section perpendicular to the welding direction. The EBSD specimen was mechanically pre-polished with 1 and 0.25 µm diamond pastes, electro-polished with a solution of 700 mL ethanol, 120 mL distilled water, 100 mL glycerol, and 80 mL perchloric acid at ambient temperature and a voltage of 35 V for 10 s.

3- Results and Discussion

Fig. 1 shows the microstructure of the different regions of the weld zone. It is observable from the figure that the rotating tool break up the initial microstructure of the material and generated a new fine microstructure with three distinct of the stir zone (SZ), the thermo-mechanically affected zone (TMAZ), and the base metal (BM). In the TMAZ grains are highly deformed and elongated in the direction of applied strain. It is also observable that a very fine equiaxed microstructure developed in the SZ. The presence of elongated grains in the TMAZ and fine grains in the SZ resulted a distinct interface between them. Similar results were reported from the FS welds of pure iron, duplex stainless steels, austenitic stainless steels, and FSSs.

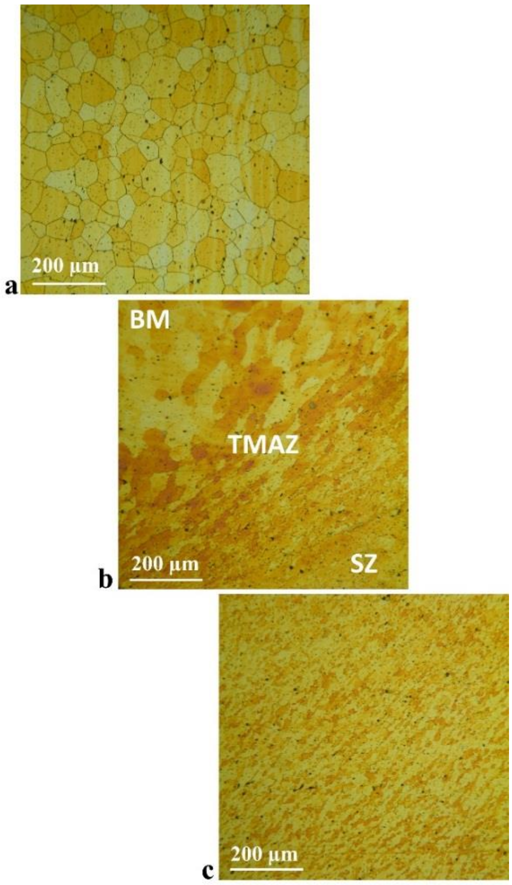

Fig. 1 Optical microstructures from; a) BM, b) TMAZ, and c) SZ

Fig. 2 depicts the EBSD data obtained from the cross section (ND-TD) perpendicular to the rolling direction (RD). Based on this figure, ferrite is composed of rough equiaxed grains with average grain size of 56 µm. each grain was colored regarding their crystallography orientation with respect to the RD of the welded sample. Moreover, it is obvious from figure that the elongated grains of the TMAZ are replaced with fine equiaxed grains in the SZ. The increase of strain from the TMAZ towards the SZ resulted the formation of recrystallized grains in the SZ.

Grain boundary maps and grain boundary character distribution (GBCD) of BM, TMAZ, and the SZ in the Fig. 3 and Fig. 4 indicate that the majority of total grain boundaries of the BM (about 65%) are recognized to be high angle grain boundaries (HAGBs) and 14 % is recognized to be coincidence site lattice (CSLs) boundaries. The presence of large amount of low angle

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grain boundaries (LAGBs about 21 %) along with the formation of HAGBs implies that the BM has experienced the annealing phenomenon during the production process. According to this figure, the frequency HAGBs decreased to 45% and higher amount of LAGBs (about 45%) formed in the TMAZ. The formation of such high frequency of LAGBs is more likely related to the occurrence of the dynamic recovery during the welding procedure. The formation of subgrain boundaries (or LAGBs) is commonly starts with the start of straining through the interactions taken place between the generated dislocations during the welding at high temperatures. Accordingly, dislocations with opposite signs effectively are eliminated the microstructure is left with only one type of dislocations. Sub-structures form by the rearrangement of such dislocations into low energy boundaries (LAGBs).

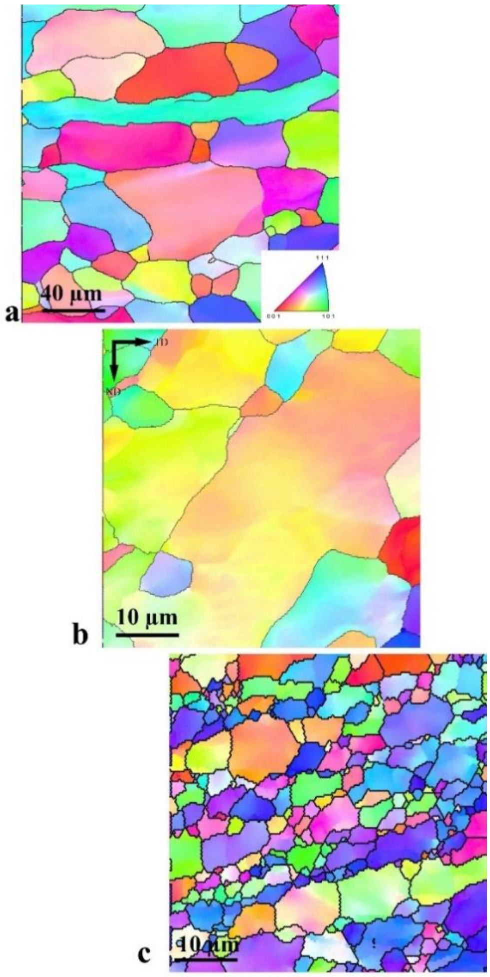

Fig. 2 Orientation maps; a) BM, b) TMAZ, and c) SZ

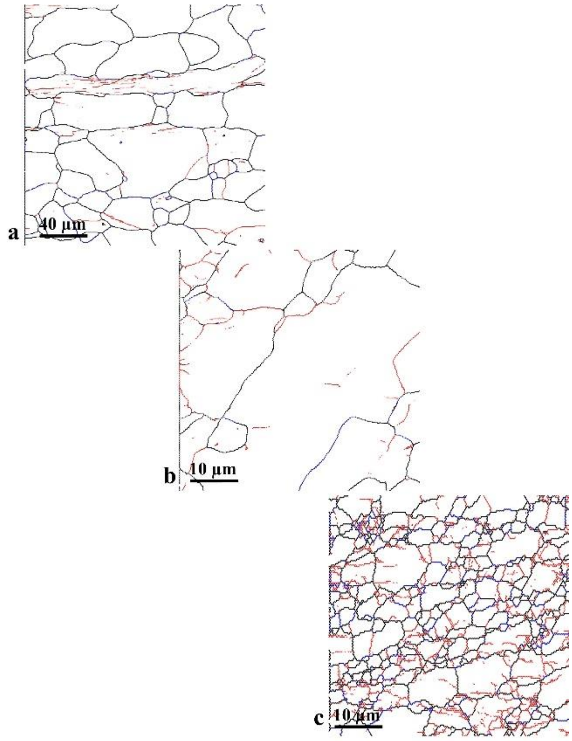

Fig. 3 Grain boundary maps; a) BM, b) TMAZ, and c) SZ

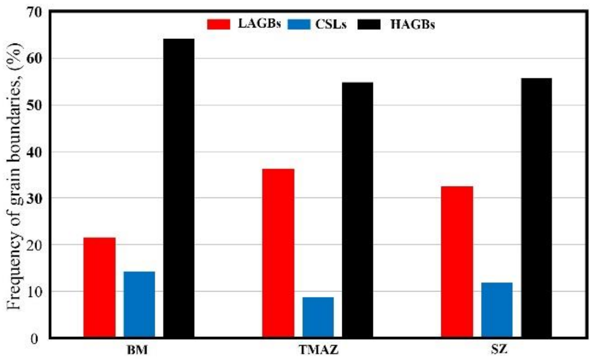

Fig. 4 Grain boundary character distribution

4- Conclusions

Microstructure of FS welded 430 ferritic stainless steel was examined in this study. High frequency of LAGBs formed during the occurrence of dynamic recovery in the TMAZ. Severe grain refinement took place through the dynamic recrystallization in the SZ.