EBSD CHARACTERIZATION OF THE EFFECT OF WELDING PARAMETERS ON HAZ OF AISI409

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Abstract

One of the main problems during the welding of ferritic stainless steels is severe grain growth in the heat affected zone (HAZ). In the present study, microstructural characteristics of tungsten inert gas (TIG) welded AISI409 ferritic stainless steel were investigated. The effect of the welding parameters on grain size, local misorientation and low angle grain boundaries was studied. It was found that the base metal was partly in recrystallization state. Complete recrystallization followed by severe grain growth occurs after joining process due to welding heating cycle. A decrease in the number of low angle grain boundaries in HAZ was observed. Nevertheless, the welding plastic strain increases the density of local misorientation and low angle grain boundaries. This investigation shows that the final state of strain is the result of the competition between welding plastic strains and stress relieving from recrystallization but the decisive factor in determining the grain size in HAZ is heat input.

Keywords: EBSD; AISI409; Grain growth; Low angle grain boundary; Local misorientation.

1. Introduction

Stainless steels are widely used in various industries because of their resistance to corrosion .The welding of stainless steels are important in energy-related systems, for instance petrochemical refining systems. Stainless steels can be classified into three major categories based on the structure: ferritic, martensitic and austenitic [1]. AISI

409 is titanium-stabilized ferritic stainless steel although regarded as a general-purpose chromium stainless steel. The primary application for Grade 409 is in automotive exhaust systems. Its applications are those where appearance is a secondary consideration to mechanical properties and corrosion resistance and where some weldability is required [2]. One of typical welding problems in ferritic stainless steels is low toughness due to HAZ grain growth. It is well-established that grain growth phenomenon is a microstructural evolution due to the motion of grain boundaries driven by the reduction in grain boundary interfacial energy. Given sufficiently high temperatures (such resulted from welding processes) and no factors impeding grain boundary migration, a polycrystalline material will evolve towards a single crystal [3]. Obviously, lower welding heat input causes lower temperature. Therefore, grain growth can be controlled or limited using low welding heat input [1]. There are a lot attempts to develop model for grain growth. For example, Priadi *et al*. [3] used a mathematical method for modeling of abnormal austenite grain growth in Nb-containing HSLA steel. Their results showed that the increase in temperature increased the austenite grain size with a sharp gradient observed at higher temperatures.

Another important general point about the welding of engineering materials is plastic strains. Plastic strain imposed on metal by manufacturing process can make problems by increasing the sensitivity to stress corrosion cracking (SCC) in stainless steels [4]. Plastic strain can be microscopic or macroscopic. Macroscopic plastic strain

appears to be homogenous and uniform, even when it is not in welding process, but strain on a microscopic scale (hereafter, local plastic strain) is non-homogenous due to the anisotropy of crystal grains [5]. In microscopic scale, EBSD is a powerful means to measure the degree of plastic strain, utilizing either change in diffraction pattern quality or changes in local orientation. It has been shown that it is possible to know the magnitude of local plastic strain by evaluating the misorientation angle between neighboring points. The cause of local change in the crystal orientation is accumulation of stored dislocations resulted from plastic deformation. As this tool was championed by the texture analysis community in the early stages of its application to materials research, characterization of deformed microstructures has been a significant fraction of the EBSD applications research published in the open literature [6]. In the welding field, most of these studies are focused on solid state welding and specially, friction stir welding. Kang *et al*. [7] investigated the microtexture of friction stir welded Al 6061-T651 and they found that FSW produced an equiaxed fine grain structure in weld zone and the grain size of weld zone is decreased with decreasing the rotating speed. Fujii *et al*. [8] studied the effect of FSW on ultra low carbon interstitial free steels prepared by accumulative roll bonding. They found that the grain size of the stir zone was significantly affected by the initial grain size of the samples. Indeed, there are some studies on fusion welded joints. Coelho *et al*. [9] investigated the microtexture and residual stresses in dissimilar laser joints in

Mg alloys. Their results showed that fusion zone texture did not depend on the Al content of the Mg-alloy. Merson *et al.* [10] characterized the texture of laser welds in Ti-6246 using EBSD. The samples used for experimental wildings were heat-treated. This had been carried out for a weld that had been heat-treated for 3 hours at 550°C. At this temperature, relaxation of residual stress will occur, but changes to the microstructure will be minimal. It is planned that EBSD will now be carried out on the as received sample, and the results will be presented along with a comparison with the heat treated weld. There are few studies on measurement of plastic strain using EBSD. Kamaya *et al.* [4] used EBSD to measure the plastic strain imposed to austenitic stainless steel by tensile load. They defined a new parameter as the crystal deformation. This parameter quantifies the spread of the crystal orientation due to the plastic strain using the misorientation from a central orientation in each grain. It was confirmed that crystal deformation parameter had a good correlation with plastic strain induced by uniform tensile deformation in stainless steel, and was not affected by the data density of the crystal orientation map. In another study, Kamaya [5] used EBSD to assess the plastic strain on a microstructural scale (local plastic strain) induced in stainless steel deformed up to a nominal strain of 19.7%. He quantified the distribution of local plastic by the correlation between the misorientation and the plastic strain.

As long as the authors know, no attempt has been made on EBSD characterization of the effect of welding parameters on plastic strain during welding. Accordingly in the present study, some dissimilar joint were made between AISI409 and a plain carbon steel using tungsten inert gas (TIG) and microstructural characteristics of HAZ of stainless part of the joint were investigated. The main focus was to study the texture evolution, grain size change in the HAZ and residual plastic strain (based on grain boundary and local misorientations investigations) with respect to the welding parameters of current and travel speed.

2. Experimental procedures

Three samples with equal dimensions of 450x80x2 mm were provided and edge-cleaned before welding using acetone. Table 1 shows chemical composition of welded stainless steels according to the manufacturer. Automatic TIG (direct current electrode negative) welding process (without filler) was used to generate three but welded samples (S1, S2 and S3). The diameter of TIG electrode and arc length was 1.6 and 1 mm, respectively. Welding parameters (Table 2) were chosen according to ASM standard [11] and were varied in order to gain an effect of the heat input on grain size distribution. After welding operation, cross-sections from the middle of the welded seam were cut perpendicular to welding direction and prepared following metallographic procedures. Finally these cross-sections were analyzed by an EBSD system (Crystal, Oxford Instruments, Wiesbaden, Germany) installed into an SEM (Leo1530, Zeiss, Oberkochen, Germany). Orientation data obtained from EBSD system were reprocessed by the Channel 5 program

Table 1. Chemical composition of welded base metals

Steel	C	Si	Mn	Ni	Cr	Ti
1.4512(AISI409)	0.015	0.59	0.27	0.13	11.28	0.17
1.1005(CK4)	0.025	0.013	0.19	0.04	0.01	-

Table 2. Welding Parameters for Test Welds

Sample	Welding Speed (mm/s)	Welding Current(A)	Welding Potential(V)	Heat Input(J/mm)
S1	1.03	70	13	583
S2	3.56	105	13	284
S3	3.56	120	13	342

(HKL-technology, Hobro, Denmark) and the texture distribution, the local misorientation and grain size distribution for base metal and the HAZ were obtained. The approach used in the current study was based on the density of low-angle misorientations which had been generated through the introduction of dislocations arrays. It is worth noting that the analyses of the current study were limited to the HAZ of the stainless steel side.

3. Results and Discussion

Fig. 1 shows a color map indicating the crystallographic orientations of the base metal (a), S1 (b), S2 (c), and S3 (d). The colors determined in the stereographic triangle indicate the crystallographic orientation parallel to the RD. The base metal (a) shows the equiaxed grains which had finer grains near to surfaces. This IPF (inverse pole figure) shows that the base metal had a weak texture in <111> direction. In the welded samples, strong texture was not observed, too (b, c, d).

Fig. 2 indicates a comparison of the local misorientation of the base metal (a), S1 (b), S2 (c) and S3 (d). It can be seen that the base metal exhibited the high fraction of local misorientation angle between neighboring grains less than 7 degrees. These misorientations in the base metal seem to be concerned with the plastic deformation without complete annealing. Incompleteness of the annealing process was checked and proved by the hardness measurement, too. The measured hardness of the base metal (188HV) was greater than those of fully annealed material (175HV) [2]. It was well known that most grain boundaries in the annealed specimen were high-angle ones. As increasing strain, low angle grain boundaries generate and their densities increase [12]. Seemingly, the amount of misorientation varied through the thickness of the sheet or different amounts of recrystallization.

The rolling process caused an inhomogeneous distribution of plastic deformation. As a result, the microstructure expected in base metal was the dislocation cell structure and these cells remained metastable as the subgrains inside grains when there is not the succeeding complete recrystallization. Then, the low angle boundaries were developed in base metal, especially near the surface of the sheet. The
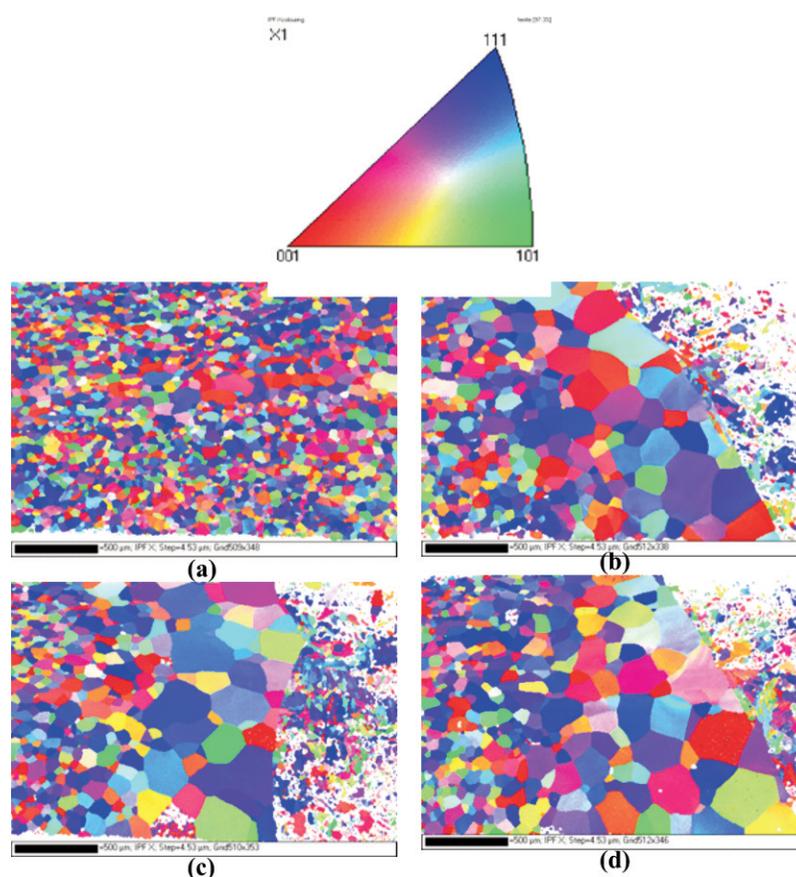
Fig 1. IPF of the base metal (a) S1 (b) S2 (c) S3 (d).

distributions of low angle boundary less than 5° obtained under the various welding conditions of current and welding speed are shown in Fig. 3. As it can be seen, there is a decrease in the number of low angle grain boundaries in HAZ of all welded samples. The amount of this decreasing and width of HAZ area depended on welding parameters. These distributions of low angle boundary enable us to give shape to HAZ. Comparing the results for S1 with other samples showed that as the welding speed decreased cooling rate in the specimen slowed down and material would remain at higher temperatures for longer time. As a consequence, the recrystallization, grain growth and strain relaxation would overcome welding plastic strains .Comparison between low angle grain boundaries for S2,S3 showed that at the constant welding speed, as welding current increased the welding plastic strains would dominate. It can be concluded that heat input alone cannot be a good criterion to judge on the effect of welding process on final state of strain in HAZ, and both welding speed and current should be taken into account, too. During the welding process, there will be plastic strain in HAZ, which causes the introduction of many dislocations and the grain subdivision. On the other hand, the welding heat input provides the driving force
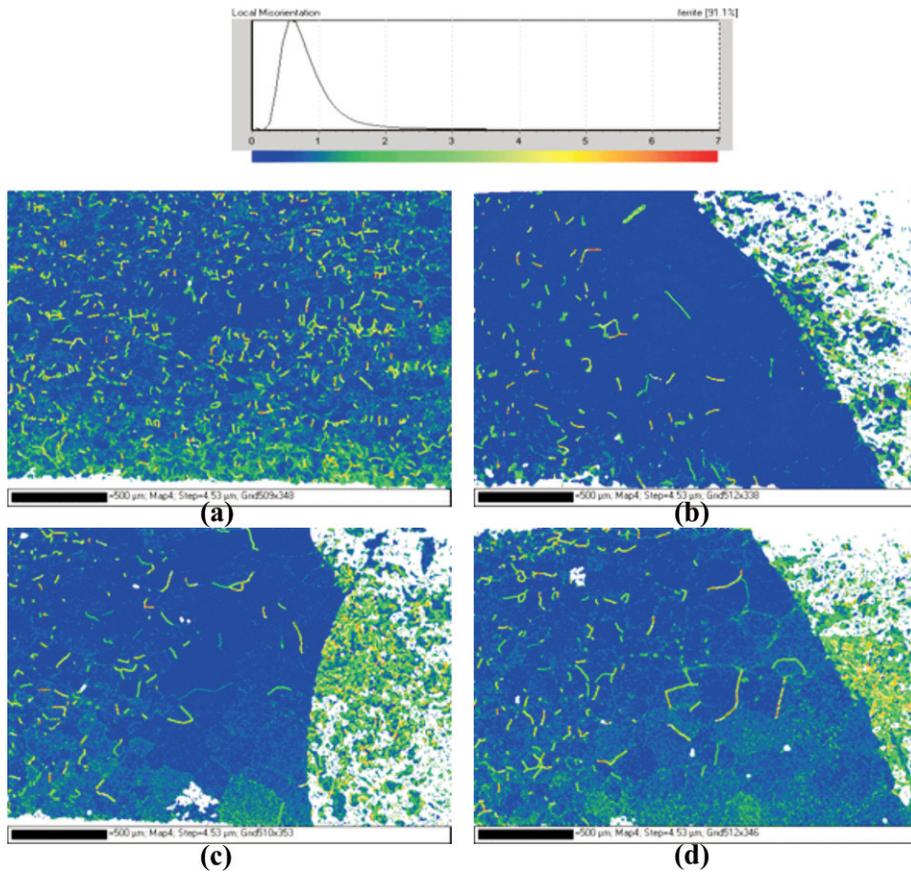
Fig 2. Local misorientation of base metal (a) S1 (b) S2 (c) S3 (d).
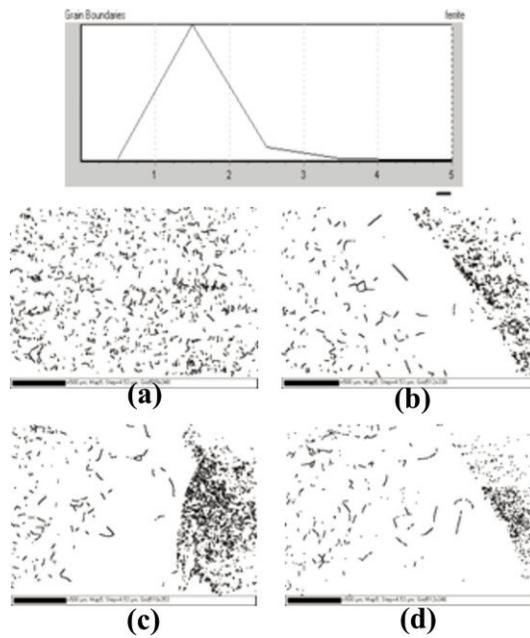
Fig 3. Distribution of low angle grain boundary (less than 5o) for base metal (a) S1 (b) S2 (c) S3 (d).

of the recrystallization and grain growth. Of course, the low thermal conductivity of this material decreases the rate of heat transfer.

4. Conclusion

In this work, microstructure in HAZ of stainless part of a dissimilar weld between CK4 and AISI409 was investigated. Experimental measurements employing EBSD were conducted to assess the effect of process parameters on local misorientation, low angle grain boundaries and grain size distribution. The results showed that:

Base metal and all welded samples did not show strong texture.

Base metal exhibited the high fraction of local misorientations that seems to be concerned with the plastic deformation without complete recrystallization.

Heat input alone was not a good criterion to judge about the effect of welding process on final state of strain in HAZ and both of welding speed and current should be taken into account concurrently.

The final state of strain was the result of the competition between welding plastic strains and stress relieving from recrystallization.

5. Acknowledgement

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