Texture Evolution in Weld Regions of SUS-304 Stainless Steel and TRIP Steel

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Abstract: Electron back-scattered diffraction (EBSD) analysis has been conducted on the bead-on-plate GMAW welding of stainless steel SUS-304 and TRIP steel. The grain size, texture evolution, misorientation distributions and CSL grain boundary of weld metal (WM), HAZ and base metal (BM) have been observed at various welding conditions. With increasing heat input, the grain size in all cases increased at weld metal. With increasing heat input, no significant textural change was observed, but the characteristics of misorientation distributions and the CSL grain boundary decreased.

Introduction

The automated Gas Metal Arc Welding (GMAW) process is widely practiced in most industries for fabrication of welds due to its high productivity and high quality of welds. It has applications ranging from joining thin sections, pipelines, etc. to joining most large metal structures such as bridges, farm equipment, cars, trains, nuclear reactors etc.

Amongst the many structural materials being used in industry, the SUS-304 stainless steel and TRIP steel are widely used due to their many desirable properties. Therefore, welding is clearly a unique and vital process in construction and maintenance of large-scale machine parts produced from these materials and hence a comprehensive understanding microstructure of weld regions is essential for their implementation in several industry sectors. Due to the intense concentration of heat in the heat source of welding, the regions near the weld line undergo severe thermal cycles. The thermal cycles cause non-uniform heating and cooling in the material, which affect on the gain size, shape, texture of weld regions.

The purpose of this study is to investigate the effect of the welding conditions on grain size, texture evolution, misorientation distributions and CSL grain boundary at weld regions by measuring the orientation data from EBSD.

Experimental procedure

The welding process selected for the experimental work was the automated gas metal arc welding (GMAW) process, that was carried out on the Pulse MIG Inverter Auto Atom 350P. The series of sheets of SUS-304 stainless steel and TRIP steel of 260 x 130 x 3mm in size were used during the experiments to make the bead-on-plate welds. The wire of stainless steel ER-308L and carbon steel ER-70S-6 of diameter of 1.2mm was used as filler materials in welding of SUS-304 and TRIP steel, respectively. Typical chemical compositions of these materials are given in Table 1. Table 2 shows the welding conditions used in this study. During the welding of SUS-304 stainless steel, the welding speed (v) was changed from 50 to 45 and 40cm/min and in the case of TRIP steel the welding current (I) was changed from 160A to 180A and 200A. Considering an arc efficiency of 0.75(η), the heat input per unit length of weld (Q) was calculated by using the relation Q = η.V.I/v
The obtained heat input for welding process of SUS-304 SS was changed from 0.207 to 0.230 and 0.259 KJ/mm and for TRIP steel from 0.360 to 0.405 and 0.450 KJ/mm. Other welding parameters as wire feed rate (680 cm/min), electrode extension (14mm) and gas flow of Argon (15l/min) were not changed in all cases during welding process.

**EBSD analysis**

For EBSD analysis the samples are cut from welded specimen, mechanically polished and electrolytically polished in a solution of 30% perchloric acid at −10°C, 30V for 40s. Fig.1 shows a schematic diagram of transverse cross section and the location of the EBSD sample. It also shows the conventional orientations for normal direction (ND), rolling direction (RD) and traveling direction (TD). The surface analyzed laid on the ND-RD plane. For present analysis, it is necessary to employ a sample from non-welded specimen in order to compare the results before and after welding.

EBSD measurements were carried out on Oxford INCA CRYSTAL from Oxford Instrument installed in high resolution SEM equipped with Schottky type Field Emission Gun. The operating accelerating voltage and probe current are 15 kV and 5nA, respectively. EBSD map was obtained on a 128x128 µm surface with 1µm steps between two measurements.

**Table 1. The chemical composition [w%]**

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
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<tr>
<td>SUS-304</td>
<td>0.048</td>
<td>0.46</td>
<td>1.06</td>
<td>0.026</td>
<td>0.002</td>
<td>8.21</td>
<td>18.32</td>
</tr>
<tr>
<td>ER-308L</td>
<td>0.02</td>
<td>0.38</td>
<td>1.85</td>
<td>0.018</td>
<td></td>
<td>9.8</td>
<td>19.8</td>
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<tr>
<td>TRIP</td>
<td>0.16</td>
<td>1.80</td>
<td>1.49</td>
<td>0.005</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER-70S-6</td>
<td>0.07</td>
<td>0.85</td>
<td>1.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. The welding Condition**

<table>
<thead>
<tr>
<th></th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Speed (cm/min)</th>
<th>Heat input (KJ/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS-304 SS</td>
<td>23</td>
<td>100</td>
<td>50; 45; 40</td>
<td>0.207; 0.230; 0.259</td>
</tr>
<tr>
<td>TRIP steel</td>
<td>25</td>
<td>160; 180; 200</td>
<td>50</td>
<td>0.360; 0.405; 0.450</td>
</tr>
</tbody>
</table>

![Fig. 1. Schematic diagram of the samples used in the EBSD study.](image-url)
Results

Grain size: Fig. 2a shows the change of grain size during welding of SUS-304 stainless steel. The equivalent circle diameter (ECD) of grains increased from 52\(\mu\)m to 55.20\(\mu\)m and 57.92\(\mu\)m for weld metal region and from 15.74 \(\mu\)m to 17.76\(\mu\)m and 19.45\(\mu\)m for HAZ with increasing heat input from 0.207 to 0.230 and 0.259 KJ/mm, respectively. In comparison with grain size of 15.29\(\mu\)m before welding, EBSD mapping results show the significant increases in grain size after welding. In the case of TRIP steel as shown in Fig. 2b, with increased heat input from 0.360KJ/mm to 0.405KJ/mm and 0.450KJ/mm, the ECD of grains in the weld metal region was 4.04\(\mu\)m, 5.52\(\mu\)m and 7.74\(\mu\)m and in HAZ it was increased from 3.45\(\mu\)m to 3.74\(\mu\)m and 3.89\(\mu\)m and, respectively. In comparison with grain size value before welding (2.5\(\mu\)m), the results show that there is a 38%, 50% and 56% increase in ECD for the grains in HAZ region. It can be understood that with increasing heat input the cooling rate decreases and the grain size increases. Fig. 3, 4, 5 are the misorientation maps showing the bulk change in grain shape and size (only the high angle boundaries are marked).

![Grain Characteristics of SS](image1)

![Grain characteristics of TRIP](image2)

Fig. 2. Change of grain size characteristics.

![Fig. 3. The grain characteristics of Stainless steel-Weld Metal.](image3)

Fig. 3. The grain characteristics of Stainless steel-Weld Metal.

![Fig. 4. The grain characteristics of TRIP steel-HAZ.](image4)
Texture: The major phases of stainless steel SUS-304 and TRIP steel are $\gamma$-austenite phase and $\alpha$-ferrite phase, respectively. Fig. 6 and Fig. 7 show the inverse pole figures for normal direction obtained from measured orientations at HAZ of stainless steel and TRIP steel, respectively. As shown in Fig. 6a), the SUS-304 base metal before welding shows a random texture. After welding process at various heat input, the inverse pole figure shows random textures, even though the HAZ of stainless steel was undertaken melting and solidification. It can be expected that the HAZ has a solidification texture, but in these given range of heat input all the texture of weld metal show random texture. Fig. 7a) shows a strong alignment of mixture of [111] + [001] texture before welding, representing the $\alpha$-fiber from cold rolling of TRIP steel. $\alpha$-fiber is the typical cold rolling texture of $\alpha$-ferrite steel. After welding process, the inverse pole figure shows that the texture at HAZ becomes random. The HAZ undergoes the melting, solidification, phase transformation and the final texture can be related the phase transformation of $\gamma$-austenite to $\alpha$-ferrite. It is reported that the typical texture of heat-treated TRIP steel is random texture [6].

Boundary Characteristics: Fig. 8 shows the boundary misorientation distributions in HAZ during welding of SUS-304 stainless steel and TRIP steel. For SUS-304 stainless steel (Fig. 8a), before welding the number of high angle boundary and low angle boundary are 1749 and 102, respectively. After welding, they are 1630 and 371 (with heat input 0.207KJ/mm); 1558 and 189 (0.230KJ/mm); 886 and 173 (0.259KJ/mm). Welding process decreases the number of high angle boundary and increases the number of low angle boundary. The increase of ECD after welding shows the total grain boundary area decreases, leading to the decrease of sum of high angle and low angle boundaries. The ratio of low angle to high angle boundaries increases after welding at various heat input with increasing welding heat input. In the case of TRIP steel the EBSD data show that the welding process increases both of the number of high angle and the number of low angle. With increasing heat input, the number of high angle and the number of low angle decreased as shown in Fig. 8b. Even though the ECD increases, the total amount of grain boundary increases. These increases can be related with phase transformation from $\gamma$-austenite to $\alpha$-ferrite.
a) Non-welded  

b) 0.360KJ/mm  
c) 0.405KJ/mm  
d) 0.450KJ/mm

Fig. 7. ND Inverse Pole Figure of TRIP Steel-HAZ.

a) SUS-304 Stainless steel  

b) TRIP Steel

Fig. 8. Boundary misorientation distributions.

**CSL boundary:** Fig. 9 shows the change of CSL boundary of stainless steel and TRIP steel at HAZ and weld metal. Most of CSL boundary in stainless steel and TRIP steel is a $\Sigma 3$ boundary. From Fig. 9a shows that in the weld metal region of SUS-304 the welding process decreased the $\Sigma 3$ from 761 to 241 and 152 according to heat input 0.207KJ/mm, 0.230KJ/mm or 0.259KJ/mm, respectively. The same results were obtained for the HAZ region as shown in Fig. 9b, showing the decrease of $\Sigma 3$ from 3343 before welding to 2577; 2451 and 1815 in accordance to heat input 0.207KJ/mm, 0.230KJ/mm or 0.259KJ/mm, respectively. With increasing heat input, the $\Sigma 3$ boundary decreased.

In the case of TRIP steel, the EBSD results also show that the total number of $\Sigma 3$ decreased with increasing of heat input. In Fig. 9c for weld metal region, the $\Sigma 3$ boundary decreased from 636 to 423 and 333 and in Fig. 9d for HAZ region, the decrease of $\Sigma 3$ is from 543 to 407 and 377 with the same increasing of heat input from 0.360KJ/mm to 0.405KJ/mm and 0.450KJ/mm, respectively. But in comparison with the number of $\Sigma 3$ boundary of 254 before welding, the $\Sigma 3$ after welding increased.

**Conclusions**

EBSD analysis gives ECD and boundary characteristics and grain morphology of the grains in the weld regions. The grain size in the weld metal and HAZ of SUS-304 stainless steel and TRIP steel increased with increasing heat input during welding process and in the case of SUS-304 stainless steel the welding process had no changed in texture. The random texture before welding remained after welding. For TRIP steel the textures of $\alpha$-ferrite phase were $[111] + [001]$ before welding, and those were changed on the random texture after welding. In the case of SUS-304 stainless steel, the welding process decreased the number of high angle boundary and increases the number of low angle boundary. For TRIP steel, the welding process increased both of them - the number of high angle and low angle boundaries. But at various heat input, both of SUS-304 and TRIP steel had the same behavior that with increasing heat input the numbers of high angle and low
angle boundaries significantly decreased at all. In both cases of SUS-304 and TRIP steel with increasing heat input the total number of $\Sigma 3$ boundary decreased.

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References


