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Abstract

During pipe making, mechanical properties of pipeline steel change from strip to bare pipe to coated pipe. In this paper, microtexture evolution at outer surface, outer quarter, centre, inner quarter and inner surface positions for hot rolled strip, bare pipe and coated pipe of X70 pipeline steel was investigated. The results showed that the textures at the inner quarter, centre and the outer quarter positions remained the same from strip to bare pipe to coated pipe. The surface textures changed from strip to bare pipe but remained the same from bare pipe to coated pipe. It can be concluded that there was texture change during the pipe forming process but not in the coating process.

Keywords: microtexture, strip, bare pipe, coated pipe

1. Introduction

In order to protect steel line pipe from corrosion, fusion-bonded epoxy (FBE) coating is usually applied on line pipe before pipeline construction. During the coating process, the pipe is usually heated to a certain temperature, typical of 220 °C to 260 °C for a single-layer FBE coating [1-3]. A large number of experiments have shown that this thermal coating process changes the mechanical properties of line pipe steels: an increase in yield strength and the yield strength to tensile strength ratio, a decrease in uniform elongation and a change in the shape of the tensile curve [4-6]. This phenomenon is known as strain ageing. Generally, strain ageing in low carbon steels is due to the...
diffusion of interstitial solute atoms to free dislocations generated during plastic deformation [7]. But the effect of strain ageing on texture is still unclear. In this paper, microtexture evolution at surface, quarter and centre positions of hot rolled strip, bare pipe and coated pipe were characterized to investigate the evolution of texture during pipe forming and FBE coating.

2. Experimental investigation

The testing materials were API 5L X70 pipeline steels supplied by Baoshan Iron & Steel Co., Ltd. The strip, bare pipe and coated pipe sections were obtained from pipe production. Samples for microtexture characterization were cut from these three materials along the ND (normal direction)-TD (transverse direction) plane. The samples were subjected to mechanical grinding and polishing, and then were electropolished in a 95 % acetic acid and 5 % perchloric acid electrolyte for 12 s at 30 V using Struers Lectropol-3. Electron backscatter diffraction (EBSD) were conducted on a JEOL JSM-7001F field emission gun-scanning electron microscope (FEG-SEM) using the Oxford Instruments AZtec acquisition software and operating at 15 kV, ~ 5 nA and 24 mm working distance.

EBSD measurements were taken at five thickness positions for each sample: outer surface, outer quarter, centre, inner quarter and inner surface (as indicated in Fig. 1). The size of each map is 75 µm by 60 µm and a step size of 0.1 µm was used for all the maps. The surface maps were taken within 100 µm from the inner and outer surfaces. The post-processing of the maps was undertaken using Oxford Instruments Channel-5 software. The orientation distribution function (ODF) of ϕ2=45° sections were calculated by imposing orthorhombic sample symmetry and were depicted using Bunge’s notation.

3. Results and discussions

Fig. 2 shows the ϕ2=45° ODF sections of the microtexture along the thickness direction of the strip, bare pipe and coated pipe. It can be seen that the surface textures are different from the textures at other positions. The textures at the inner quarter, centre and the outer quarter positions for all the three types of materials are similar and exhibit typical body-centred cubic (BCC) transformation textures from deformed austenite. This indicates that the textures measured at these three locations can represent the bulk texture of the materials and the bulk texture stays the same from strip to bare pipe to coated pipe. The schematic representation of the most important orientations in BCC metals in the ϕ2=45° section is shown in Fig. 2(p). The higher intensity is located along the α fibre in the vicinity of \{211\}<011> component, which is corresponding to the transformed austenite copper component, as well as in the vicinity of \{554\}<225> component, which is corresponding to the transformed austenite brass component. Rotated Cube \{100\}<011> component also has relatively high intensity.

For the surface positions, it can be seen that the inner and outer surface textures for all the three types of materials are completely different from the typical BCC transformation textures. The texture intensities at the surface positions
are also significantly smaller than those at the other positions, as shown in Fig. 3. For the strip, the inner and outer surface textures are similar, with a high intensity at \{110\}<001> component, indicating that the texture in the strip is symmetric. For the bare and coated pipes, the inner and outer surface textures are different and are both different from the surface texture of the strip. At inner surface, both the bare and coated pipes have a high intensity near \{110\}<112> component. At outer surface, the higher intensity is located in the vicinity of \{211\}<111> component as well as \{110\}<112> component for both the bare and coated pipes.

<table>
<thead>
<tr>
<th>Inner Surface</th>
<th>Bare Pipe</th>
<th>Coated Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strip (a)</td>
<td>(b)</td>
<td>(c)</td>
</tr>
<tr>
<td>Inner Quarter</td>
<td>(d)</td>
<td>(e)</td>
</tr>
<tr>
<td>Centre</td>
<td>(g)</td>
<td>(h)</td>
</tr>
<tr>
<td>Outer Quarter</td>
<td>(j)</td>
<td>(k)</td>
</tr>
</tbody>
</table>

Fig. 2. \(\phi_2=45^\circ\) ODF sections of the hot rolled strip, bare pipe and coated pipe at (a-c) inner surface, (d-f) inner quarter, (g-i) centre, (j-l) outer quarter, (m-o) outer surface, and (p) the ideal body-centred cubic rolling texture components and fibres [8].

Fig. 3. The maximum texture intensities of the hot rolled strip, bare pipe and coated pipe at different thickness positions.

The evolution of the major orientations along \(\alpha\) and \(\gamma\) fibres can be seen in Fig. 4 for the different thickness positions. It can be seen from the fibres that at quarter and centre positions, the strip, bare pipe and coated pipes show similar characteristics, with higher intensities near \{113\}-\{112\}<110> and \{111\}<112> orientations. The surfaces exhibit near random texture for all the three materials.

It can be seen from the orientation intensities along the two major fibres that though the general features of the orientations at the quarter and centre positions are similar, there are certain shifts in maximum intensities along the fibres as well as maximum intensities outside the major fibres. This may be caused by the limited number of grains obtained from the EBSD map, so the measured microtexture does not represent the macrotexture at these thickness positions. To improve the measurement accuracies, macrotexture measurement at the same thickness positions using X-ray diffraction will be conducted in future.
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![ODF sections](image)

**Fig. 2.** $\phi_2=45^\circ$ ODF sections of the hot rolled strip, bare pipe and coated pipe at (a-c) inner surface, (d-f) inner quarter, (g-i) centre, (j-l) outer quarter, (m-o) outer surface, and (p) the ideal body-centred cubic rolling texture components and fibres [8].

![Maximum texture intensities](image)

**Fig. 3.** The maximum texture intensities of the hot rolled strip, bare pipe and coated pipe at different thickness positions.
Fig. 4. The α and γ fibres measured at different thickness positions for the strip, bare pipe and coated pipe.

The results indicate that there is a texture change at both the inner and outer surfaces during the pipe forming process, and the changes are different for the two surfaces, whilst the bulk texture remains the same, judging from the textures at the quarter and centre positions. This is reasonable since the plastic strain focuses on the strip surfaces during the pipe forming process. The strain is compressive at the inner surface and tensile at the outer surface which induces the different textures at the inner and outer surfaces. However, there is no obvious texture change after the FBE coating. It indicates that the temperature of FBE coating is not high enough to cause texture changes.

4. Conclusions

Samples from hot rolled strip, bare pipe and coated pipe were chosen to investigate the effect of pipe forming and ageing on microtexture evolution. The following conclusions can be made:

(1) The textures at the inner quarter, centre and the outer quarter positions remain the same from strip to bare pipe to coated pipe; the surface textures change from strip to bare pipe, but remain the same from bare pipe to coated pipe.

(2) The different pipe forming strains imposed on the inner and outer surfaces result in different textures at the two surfaces; the coating temperature is not high enough to cause texture changes.

Acknowledgements

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