KnE Materials Science

MIE-2017
15th International School-Conference "New materials – Materials of innovative energy development, characterization methods and application"
Volume 2018

Conference Paper

Correlation Between the Resistance to Stress Corrosion Cracking of Steel Tubes of Gas Pipelines with Their Layerwise Texture Inhomogeneity

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Received: 21 December 2017
Accepted: 15 April 2018
Published: 6 May 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the MIE-2017 Conference Committee.

Abstract

In the present work, the influence of the tubes texture layering on their resistance to stress-corrosion cracking (SCC) is demonstrated by the example of several main gas pipelines (MGP) constructed of X70 steel tubes of different manufactures and operated under various exploitation conditions. X-ray studies of crystallographic texture and structural characteristics were implemented for external and internal layers of various tubes sections, which were cut out from MGP zones with fixed SCC defects and without them. Correlation between the depth of corrosion cracks and the thickness of the surface layer with sharply differing texture parameters is established. The system data analysis also shows that the presence of the texture component {110} <001> in the tubes surface layers can increase their resistance to the SCC.

Keywords: crystallographic texture, structure, texture layering, electron backscattered diffraction, stress corrosion cracking, main gas pipeline, hot rolling.

1. INTRODUCTION

The problem of stress corrosion cracking (SCC) of steel tubes is especially urgent in countries, which have extended system of high-pressure main gas pipelines (MGP) [1, 2]. At present moment, the combined effect of three factors is established for the cracks initiation and propagation processes: the exposure of corrosive environment, the presence of local tensile stresses and the material's susceptibility to the SCC. However, mechanisms responsible for the cracks propagation or inhibition are still insufficiently studied as well as the correlation between rate of crack propagation and tubes texture parameters.

At the same time, the hot rolling of steel sheets, used for the production of MGP tubes, leads to significant texture inhomogeneity in the pipe wall thickness [3-6]. The character of such inhomogeneity depends on technological parameters of sheets processing at certain plant, i.e. the temperature and deformation gradients etc. The higher degree of textural inhomogeneity may increase the tubes SCC resistance. This effect can be explained by the fact that the crack opening can be inhibited when achieving the layer with a changed texture due to arising of mutual misorientation of grains and the resulting necessity to change the plane of moving crack, what requires an additional increase of applied stresses [4-7].

The purpose of this study was to determine the quantitative characteristics of the texture inhomogeneity of MGP steel tubes and its contribution to the SCC cracks stabilization.

2. MATERIALS AND METHODS

We have investigated sections of various MGPs operated under different conditions. The tubes of steel X70 obtained using hot rolling by various manufacturers were exploited since construction of MGPs. Samples with fixed by eddy current testing SCC defects and without them were studied from each MGP. The MGP characteristics are presented in Table 1. The investigations were conducted on samples of two types (Fig.1):

1. samples with studied surface perpendicular to the tube axis, i.e. the rolling direction (RD) of the initial sheet (designated in Fig.1 as ⊥RD);
2. samples 15x15 mm in size for internal (half of wall thickness) and external (surface) layers of the tube, with studied surface parallel to the rolling plane of the initial sheet (denoted ||RD).

The following investigation methods were used:

1. The electron backscattered diffraction (EBSD) method using a Zeiss EVO 50 XVP scanning electron microscope (SEM) and the Oxford Instruments Nordlys EBSD detector. Local textural heterogeneity was studied in the region of the cracks tip about 50x40 μm in size at ⊥RD surface.
2. The X-ray lines profiles registration on ⊥RD samples for successive layers across the tube wall by using of the thin beam. The results were used to construct the distributions of the ratio of main texture components in the tube wall. The

registration was carried out according to a standard procedure using an X-ray diffractometer Bruker D8 DISCOVER with CuK_α radiation.

3. The texture pole figures (PF) registration on ||RD samples was used for layer-by-layer study of the tubes texture. Three incomplete direct PF: {110}, {100} and {112}, – were registered by means of standard procedure [8, 9]. Then the orientation distribution functions (ODF) were restored using LABOTEX software [9]. Texture analysis was implemented for cubic materials three-dimensional ODF cross-sections of Euler space located at constant φ_2 = 45°, using the notation developed by Bunge [10].

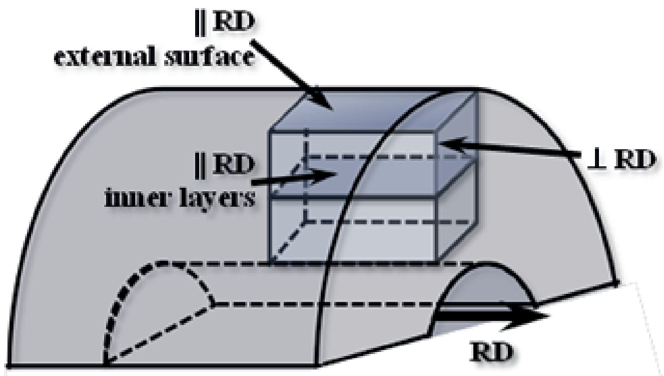

Figure 1: The scheme of sample preparation.

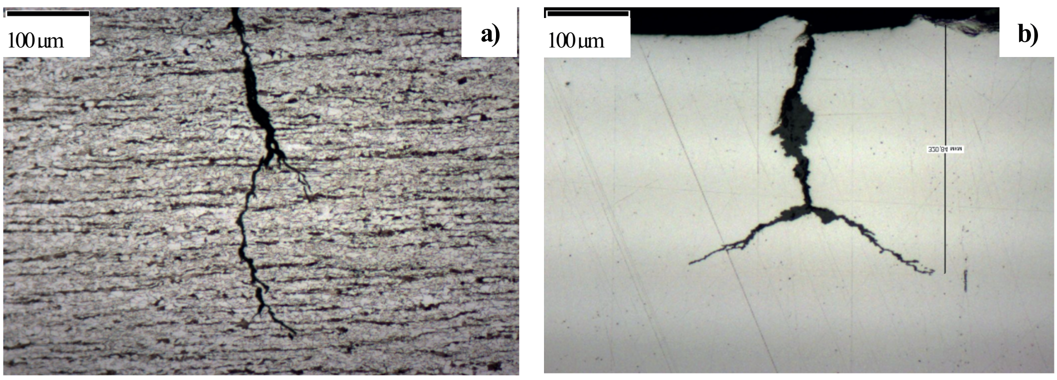

Figure 2: The different character of the propagation cracks along the pipe wall thickness of different MGPs.

3. RESULTS AND DISCUSSION

The conducted microstructure studies by SEM of MGPs ⊥RD samples revealed differences in the character of the SCC cracks propagation (Fig.2). The cracks development in some tubes occurs almost along straight line, perpendicular to the tube

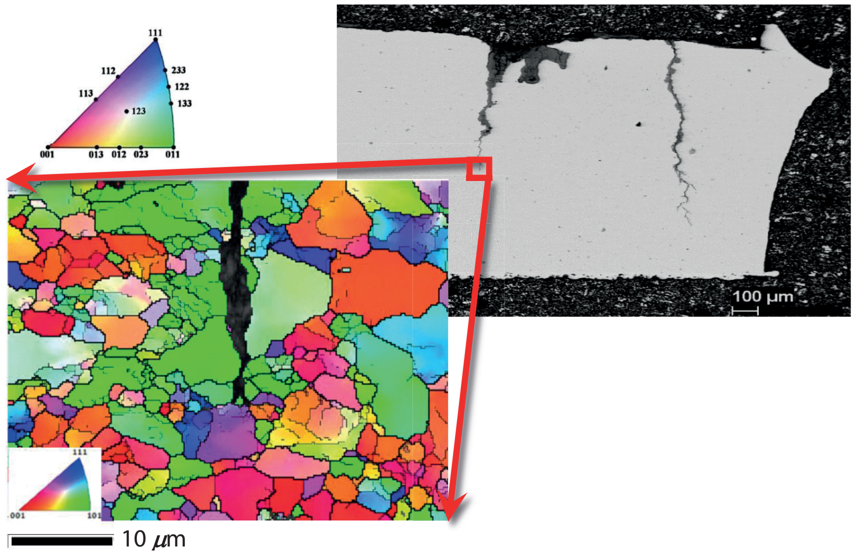

Figure 3: The grain orientation EBSD-map of the material region at the tip of the stabilized crack (⊥RD).

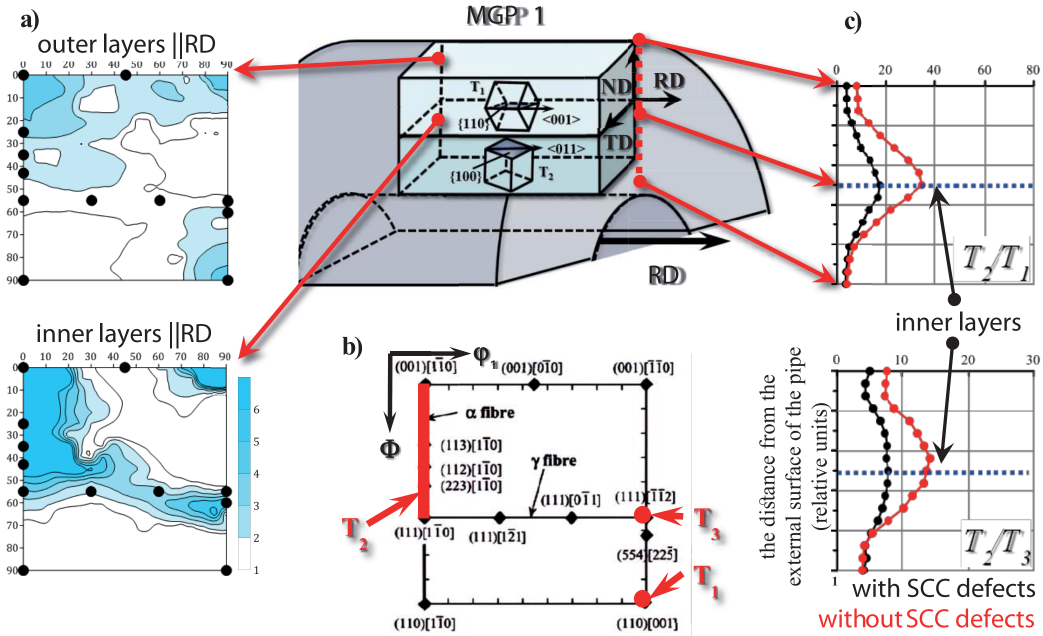

Figure 4: ODF cross sections characterizing the texture inhomogeneity of the outer and inner layers (a) and the ODF cross section for φ_2 = 45° with the main texture components (b) characteristic for cubic materials; Distribution of the relationships of the main texture components along the pipe wall thickness of MGP 1 (c).

surface, the crack propagation plane practically does not change (Fig.2a). Fig. 2b shows the cracks branching, which takes place in other MGPs. This difference of the crack propagation mechanism is determined by the degree of the texture and structure inhomogeneity along the tube wall. Since transgranular cracks propagate only along certain crystallographic planes, such heterogeneity can promote the reduction of the cracks propagation rate up to their complete stopping. This is due to necessity of the

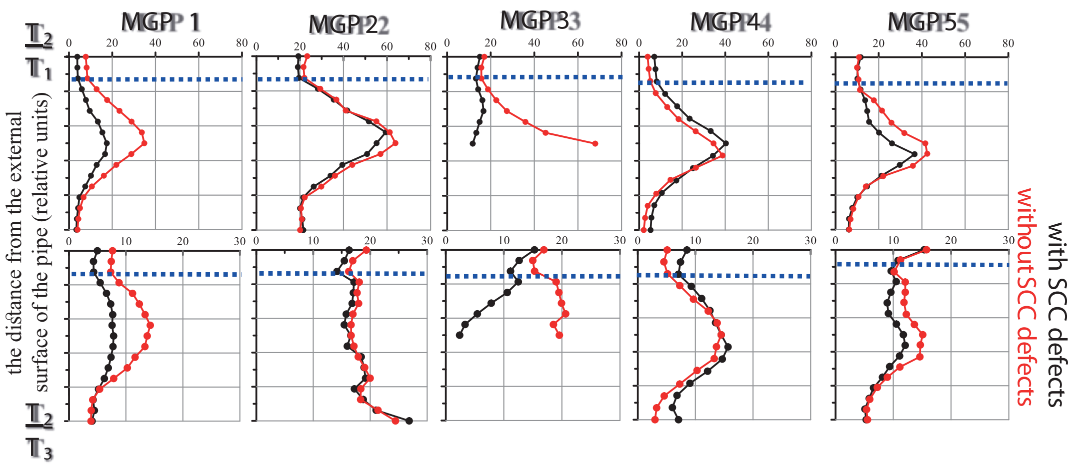

Figure 5: Distribution of the volume fractions ratio of texture components along the pipe wall thickness.

Table 1: The main gas pipelines characteristics.

MGP	⌀ × t tube thickness, mm	Operational tangential stresses σ_T MPa	Depth crack, mm
1	1420×16.5	~240	0.5-2.0
			not detected
2	1420×16.5	~240	0.5-1.5
			not detected
3	1420×18.7	~265	1.7-2.5
			not detected
4	1020×14.0	~205	1.0-2.0
			not detected
5	1020×16.0	~210	0.6-2.0
			not detected

Table 2: The depth of detected defects of the SCC and the thickness of the layer with a modified texture.

	MGP 1	MGP 2	MGP 3	MGP 4	MGP 5
The depth of detected defects of the SCC, mm	0.5-2.0	0.5-1.5	1.7-2.5	1.0-2,0	0.6-2.0
The depth of the thickness of the layer with a modified texture, mm	1.6-2.0	1.6-2.0	1.9-2.9	1.4-2.1	1.6-2.4

crack plane changing when reaching the layer with a modified texture, what requires additional tensile stresses.

The EBSD data (Fig.3) show that the crack stops when reaching a grain with orientation differing from initial one. Since the EBSD method by study of texture gives a very local information, the X-ray methods were used to increase the data statistical significance of obtained data.

Texture analysis of MGPs by ODF cross sections indicates a significant texture inhomogeneity of investigated tubes (Fig.4a, b). The inner layers of all MGPs are characterized by main components typical for the steel rolling texture {001-111} <110> (so-called α-fiber), {111} <112-110> and the additional one {554} <225>. The external layers of MGPs are characterized by the same texture components, but with another their ratio. Moreover in the external layers the {110} <001> component can also appears. This component is known to form when the deformation passes within the ferrite phase saturated with interstitial impurities, for example at the sheet's surface layers cooled down by rollers. Such impurities block the dislocation slip, so their collective climb activates due to the so-called dynamic deformation aging [11, 12]. Thus, the significant texture inhomogeneity is present across the tubes wall and promotes an increase of tubes resistance to the SCC.

For texture inhomogeneity characterization we used ratios of X-ray lines intensities, registered on ⊥RD samples for crystallographic directions aligned ||RD attributed to appropriate texture components. The most interesting is behavior of values T_2/T_1 and T_2/T_3 (Fig.4c). The first is the interrelation of volume fractions of α-fiber and the {110} <001> component in accordance with the texture data. The second – the ratio of α-fiber and the sum of textural components {111} <112> and {554} <225> because of their close arrangement in the orientation space. Fig.5 shows such distributions for studied MGPs.

The analysis of texture data and volume fractions of different texture components shows that texture inhomogeneity of MGP1 and MGP3 sections without SCC defects (red line) is much higher than with them (black line). This confirms the assumption about increasing of the resistance to SCC with increasing of texture inhomogeneity. The inhomogeneity of MGP2 tubes is of the similar character, but it is much sharper, e.g. the T_2/T_1reaches the value of 60 in the inner layers, while it is less than 40 in the MGP1 even for sample without cracks. As one can see the cracking character for MGP2 shows branching of the cracks propagation path (Fig.1b) and smaller depth of their penetration (Table 2), what is less dangerous for the further exploitation of the MGP. The same situation is in the MGP4 and MGP5.

A layer located approximately at 0.10-0.15 of the tube wall thickness (Fig.5, blue dotted line), where the sharp changing of texture components ratio occurs, can be identified for all MGPs. When passing through this layer, the T_2/T_1 ratio, which initially was almost constant, begins to increase. What is more, areas without SCC defects have a sharper inflection. Values equal to 0.1-0.15 of the tube wall thickness are comparable to the maximal depth of cracks found in these areas (Table 2). This confirms the hypothesis of the cracks stopping when they reach a layer with a modified texture.

Thus, on the basis of a systematic analysis of the texture heterogeneity, it is possible to identify tubes with increased susceptibility to the SCC, and also to estimate the maximal depth of cracks, which would not pose a hazard due to rapid development since their further growth was suspended by boundary between successive texture layers.

4. CONCLUSIONS

1. A significant layerwise texture inhomogeneity of steel tubes, obtained by various manufacturers, was revealed. It was shown that the texture of tubes from steels, belonging to the same strength class, essentially varies depending on the specific rolling regimes. The cracks development into the inner layers of the tube is prevented with higher degree of layerwise texture inhomogeneity.

2. The type and degree of texture layering have an influence on susceptibility of tubes to SCC. A significant difference in textures of inner and surface tubes layers promotes lowering of their propensity to SCC, since a high mutual misorientation of grains in these layers requires changes of the crystallographic plane, where cracks moved by their passage from the surface layer up to the interlayer boundary.

3. A revealed depth of SCC cracks, equal to 10-15% of the tube wall thickness, was found to be correlated with a thickness of the layer with the surface texture.

4. Intensifying of the layerwise texture inhomogeneity in steel sheets leads alternatively to branching of SCC cracks, changing of the direction of their propagation and slowing of their growth.

ACKNOWLEDGMENT

This work was supported by the MEPhI Academic Excellence Project (agreement with the Ministry of Education and Science of the Russian Federation of August 27, 2013, project no. 02.a03.21.0005).

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