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Texture and structure formation of low-carbon low-alloy pipe steel after TMCP and heat treatment

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Abstract. The structure and texture of low-carbon low-alloy pipe steel after Thermo-Mechanical Controlled Processing (TMCP) and subsequent isothermal quenching were studied by the method of Electron Backscatter Diffraction (EBSD) analysis. The texture, obtained after TMCP, was formed mainly by two strong scattered orientations from $\{112\}\langle 110\rangle$ and two weaker scattered orientations from $\{110\}\langle 223\rangle$ and one weak orientation (001)[110]. Complex multicomponent textures were observed after heat treatment. The regions with "ferrite" and martensitic structures were identified and analyzed using Oxford Instruments HKL software. Orientations, constituting textures for both selected areas types, are associated with the basic orientations of the initial deformed austenite grains, formed during the hot deformation by orientation relationships (OR), transitory between Kurdjumov-Sachs OR and Nishiyami-Wasserman OR.

1. Introduction

Low-carbon low-alloy steels with ferritic, ferritic-bainitic and bainitic structure are used for the production of pipes applied for the transportation of gas and oil products. An important feature of these steels is a high level of strength properties and a high level of crack resistance [1, 2].

Thermo-Mechanical Controlled Processing (TMCP) is used in the manufacturing of main pipeline sheets. It allows to decrease a metal intensity (pipe wall thickness) and increase the reliability of main pipelines under construction [3]. The transition from ferritic-pearlitic microstructures to structures with a predominance of intermediate transformation products is realized through the application of the accelerated cooling [2, 4].

A crystallographic texture is an additional resource that allows to attach products an improved complex of physicomechanical properties in certain directions. The emergence and development of texture occurs at the stage of manufacturing the product with the direction of deformation and thermal effects on the material [5]. Accounting patterns of texture formation allows you to optimize the production of materials due to the rational choice of temperature-time and deformation intervals of technological operations [6].

In [7–9], it is shown, that a significant role in the processes of pipe steel sheet destruction is played not by the integral texture of the product, but by one of its weak components – (001)[110]. The presence of sufficiently extended regions with a corresponding orientation along the entire length exceeding the critical crack size is important for the development of a crack.

This paper is devoted to the study of the features of the structural-textural state formation in low-carbon low-alloy sheet steel, after heat treatment and TMCP, as a result of which a ferrite-martensitic mixture is formed.



2. Research Methodology

As materials for research, we used samples of low-carbon low-alloyed tube steel 06G2MB with predominantly bainitic structure after TMCP, characterized within the strength class (X80) by similar levels of mechanical properties ($\sigma_{0.2}$ in the direction of deformation $\sim 575 - 585$ H/mm²). Samples were heat treated in laboratory muffle furnaces and tank furnaces. The process of austenitization was carried out at 1000 °C. Some samples were water quenched. Another part of the samples was transferred to the tank furnace at a temperature of 700 °C, where they were aged for 10 and 20 minutes and then water quenched. Metallographic thin sections on the RD-ND plane were prepared on the samples (where RD is the rolling direction at TMCP, ND is the normal direction to the rolling plane).

The electron microscopic study of the structure was carried out on a ZEISS CrossBeam AURIGA scanning microscope with an accelerating voltage of 20 kV. EBSD HKL Inca prefix with the Oxford Instruments analysis system was used to determine the orientation of individual grains and analyze the local texture. Scanning step – 0.1 microns. The error in determining the orientation of the crystal lattice is no more than $\pm 1^\circ$ (on average $\pm 0.6^\circ$). Low-angle boundaries between crystallites were built on orientation maps with misorientations of $2 - 7^\circ$ (the thickness of the boundaries in the figures is 1 pixel) and $8 - 15^\circ$ (thickness is 2 pixels); high-angle boundaries were drawn with misorientations $\geq 15^\circ$ (3 pixels thick). The texture was studied using the construction of orientation distribution functions (ODF). The analysis of the coincident site lattice (CSL) between the individual grains was carried out by constructing them on orientation maps, taking into account the Brandon standard $\pm \Delta\Theta$ criterion incorporated in the software. It constitutes a specific value for each boundary: $\Delta\Theta = 15^\circ/(\Sigma n)^{1/2}$, where Σn is the number of coinciding nodes when three-dimensional crystal lattices are superimposed.

3. Results and Discussion

The initial samples after TMCP were characterized by a predominantly bainitic structure (grain size $5 - 30$ μm) formed within the limits formed during isothermal hot rolling of deformed austenite grains (ND size $10 - 30$ μm) [7]. The texture of the initial samples consisted mainly of the same scattered components: two strongly pronounced orientations of $\{112\}\langle 110\rangle$, two weaker orientations of $\{110\}\langle 223\rangle$ and weak orientation $(001)[110]$ [7].

A package structure characteristic of martensite consisting of alternating plates with a thickness of 0.5 to 2 μm and a length of up to 20 μm was observed in the samples in the case of water quenching [10]. About $2 - 3$ crystallographic orientations of crystallites were observed within the limits of one martensitic package. The spectra of the intercrystalline boundaries corresponded to a martensitic structure [11, 12]. Only CSL boundaries were fixed in the spectrum of special boundaries: $\Sigma 3$, $\Sigma 11$, $\Sigma 25\text{b}$, $\Sigma 33\text{c}$, $\Sigma 41\text{c}$. In [12], it was shown that the appearance of this spectrum is the result of a shear phase transformation in accordance with the orientation relations (OS) intermediate between the Kurdumov-Sachs (K-S) OS and the Nishiyama-Wasserman (N-W) OS.

A ferritic-martensitic mixture was fixed in the structure in the samples after quenching from a temperature of 700 °C in the case of isothermal exposures during 10 and 20 minutes (Figure 1, a–c). In this case (Figure 1, a, b), martensite differed from the “direct” quenched martensite in greater dispersion and a higher level of microstresses, expressed by a high density of low-angle boundaries. Obviously, this is due to the increased amount of carbon in this martensite compared with martensite, formed from austenite, the chemical composition of which corresponded to the concentration of elements in steel. Ferritic grains in ferritic-martensitic structure (Figure 1, a, c) had a size slightly smaller compared to the pure ferritic structure obtained in the work [10] after cooling with furnace to room temperature.

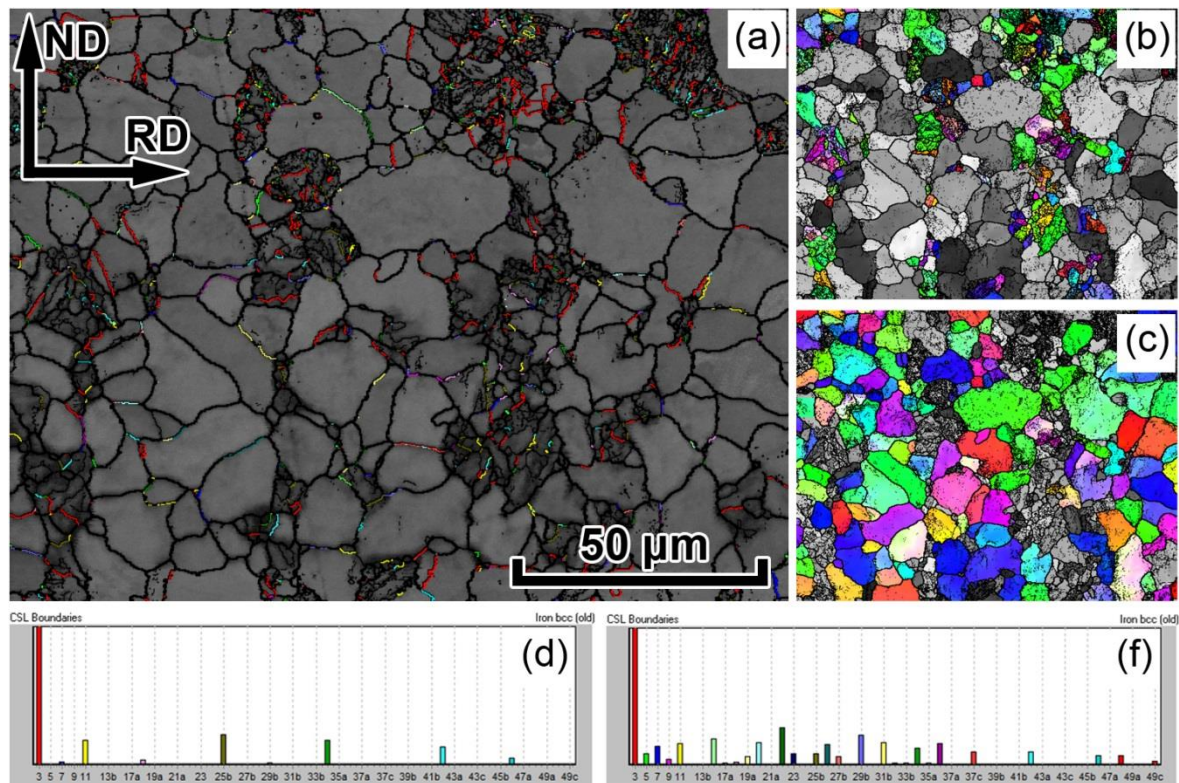


Figure 1. The microstructure of 06G2MB steel after isothermal quenching with 20 min exposure at the temperature of 700 °C obtained by EBSD: a - orientation map with CSL boundaries; b - orientation map, colored martensite; c - orientation map, colored ferrite; d - spectra of CSL boundaries in martensite; f - spectra of CSL boundaries in ferrite

Martensitic and ferritic structural components were separated and individually analyzed almost “manually” using Oxford Instruments HKL software (Figure 1, b, c). Martensitic regions differed from ferritic in size, more elongated shape and increased number of low-angle boundaries. During processing of orientation maps using software tools, areas revealed as a result of boundaries detection were identified and summarized by the presence of several characteristic features. The resulting combined regions (Subsets in software) were collections of martensitic or ferritic texture components for which ODFs were built. Areas that were in doubt (not part of any of the sets) were discarded.

Interestingly, the distribution of intergranular and special boundaries of misorientation angles defined separately for martensitic and ferritic structures constituting substantially repeated spectra corresponding in the martensite and hardening ferrite [10] obtained during the isothermal exposure (Figure 1, d, f).

It is important to emphasize that crystallographic textures obtained in samples as a result of shear and diffusion transformation demonstrate significant similarity, while repeating the bainite texture that existed before heat treatment (Figure 2). All components of these textures can be obtained in accordance with the intermediate between the OS K-S and N-W from the main orientations of rolled austenite (that is, a material with FCC lattice): $\{112\}\langle 111\rangle$, $\{110\}\langle 111\rangle$, $\{110\}\langle 112\rangle$, $\{110\}\langle 001\rangle$ [13]. Obviously, the severity of individual texture components in different samples is explained by the relatively small EBSD survey areas containing a small amount of crystallites.

