INFLUENCE OF STRUCTURAL AND TEXTURAL STATES OF LOW-CARBON STEELS ON THE CRACKING RESISTANCE OF TUBE PRODUCTS

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INTRODUCTION

The thermomechanical controlled processing (TMCP) of low-carbon, low-alloy pipe steel, which consists of controlled rolling with subsequent accelerated cooling, has reached a new level thanks to the introduction of specialized 5000 rolling mills at russian metallurgical plants JSC Severstal, PJSC Magnitogorsk Iron and Steel Works (MMK) and United Metallurgical Company (OMK) [1–3]. By means of TMCP, thick sheet (including sheet for pipelines) may be produced with distinctive combinations of strength, plasticity, cold strength, and weldability [4–6]. This may be attributed to the great variability in the combinations of ferrite, bainite, and martensite structures obtained in the steel and to their morphological characteristics [1–7].

Research has shown that a feature of bainitic steels of strength classes X70 and X80 is the critical role of formation within a fracture (during tensile, impact bending, static crack resistance tests) of secondary cracks, i.e., separations, propagating perpendicular to the main crack plane. It is important to note that separations are observed in contemporary large diameter pipes with ductile crack propagation [8, 9].

In the destruction of pipe steel sheets, an important role is played not by the integral texture but by a single weak component (001)[110], as shown in [10–13]. Crack development depends on the presence of extended regions with consistent orientation over a distance exceeding the critical crack size. In thermomechanical controlled processing, texture formation is mainly the result of two successive processes: hot deformation of austenite; and shear phase transformation with controlled cooling.

In this paper, we investigate the mechanisms of the formation of structural and texture states (bainite, ferrite) in sheets of low-carbon, low-alloy steel pipe obtained by TMCP, which allow crack propagation upon fracture.

RESEARCH METHODS

We investigate sheet samples of 06Mn2MoNb low-carbon, low-alloy pipe steel, containing 0.056 wt % C, 1.7 wt % Mn, ~ 0.05 wt % Nb, and ~ 0.05 wt % Mo. (The remainder is Fe and unavoidable impurities.) The steel consists primarily of bainite structure after thermomechanical controlled processing. It corresponds to strength class X80, with $\sigma_{0.2}$ ~ 575–585 N/mm^2 in the direction of deformation. At the end of isothermal hot rolling in TMCP, the temperature is close to the Ac^3 value for the given steel (~ 830 °C).

Electron microscopic study of the structure was carried out using Tescan Mira3 scanning microscope with a field emission cathode at accelerating voltage of 20 kV (Fig. 1). EBSD HKL Inca attachment with Oxford Instruments analysis system was used to determine orientations of individual grains and analyze local structure. Scanning interval was 0.1 μm. An error of lattice orientation determination was not more than plus or minus 1° (plus or minus 0.6°, on average). The texture has been investigated using of direct pole figures (DPF).

Detection of coincidence site lattice (CSL) boundaries between grains is carried out by orientation mapping regarding standard Brandon criterion plus or minus ΔΘ preset in the software. It is of a certain value for each CSL boundary: $\Delta\Theta=15°/(\Sigma n)^{1/2}$, where Σn is the number of coincidence sites under overlapping of three-dimensional crystal lattices.

RESULTS AND DISCUSSION

In certain stress–strain conditions during controlled isothermal rolling with more than 90% reduction, structure consisting of deformed austenite grains extended in the direction of rolling is formed over the whole sheet thickness. This structure is characterized by same orientations that are stable for the FCC lattice: {112}<111>, {110}<111>, <110}<112>, {110}<001> [14].

The EBSD technique allowed to define the structurally ferrite in the samples and analyse the texture (Fig. 1). All indicated orientations of the ferrite formed at hot rolling: {001}<110>, {11k}<110>, are stable deformation orientations of the BCC lattice [14, 15]. It should be noted that, taking into account the crystal-geometric characteristics of structurally ferrite (orientation, shape and size of grains), it can be considered as the defect. Propagation of longitudinal cracks will be predetermined in the crystallographic planes {001} of elongated ferrite grains [10–13]. Obviously, the elongated ferritic grains formed during hot rolling at temperatures below Ac3.

Analysis of the crystallographic relationship of the texture components and the structures obtained after TMCP shows that they may all be obtained, in accordance with orientation relations intermediate between the Kurdjumov–Sachs and Nishiyama–Wasserman types, on the basis of the main textural orientations of rolled austenite [10, 16]. The appearance of a limited number of orientations as a result of shear γ→α transformation in material with initially complex multicomponent texture suggests the presence of structural factors that significantly limit the expression of all possible crystallite orientations in phase recrystallization [17–19].

In [20], using Cr18Ni9 steel as an example, it was shown that bainite crystallites takes exactly recrystallization twin regions in γ-phase. The first γ→α transformation nuclei are generated not within the one austenitic grain, but in neighboring grains, divided by crystallographically determined CSL Σ3 boundary, at the same time. As a result, elongated homogeneous regions of ferrite crystals will be formed connected by twin misorientation (or close to it). In this way the orientation relationship of the textural components of the initial material and the structure obtained by heat treatment may be explained in terms of the onset of phase transformations (both shear and diffusional transition) at crystallographically determined boundaries (including special boundaries) that are similar to the Σ3 and Σ11 CSL boundaries [18–20].

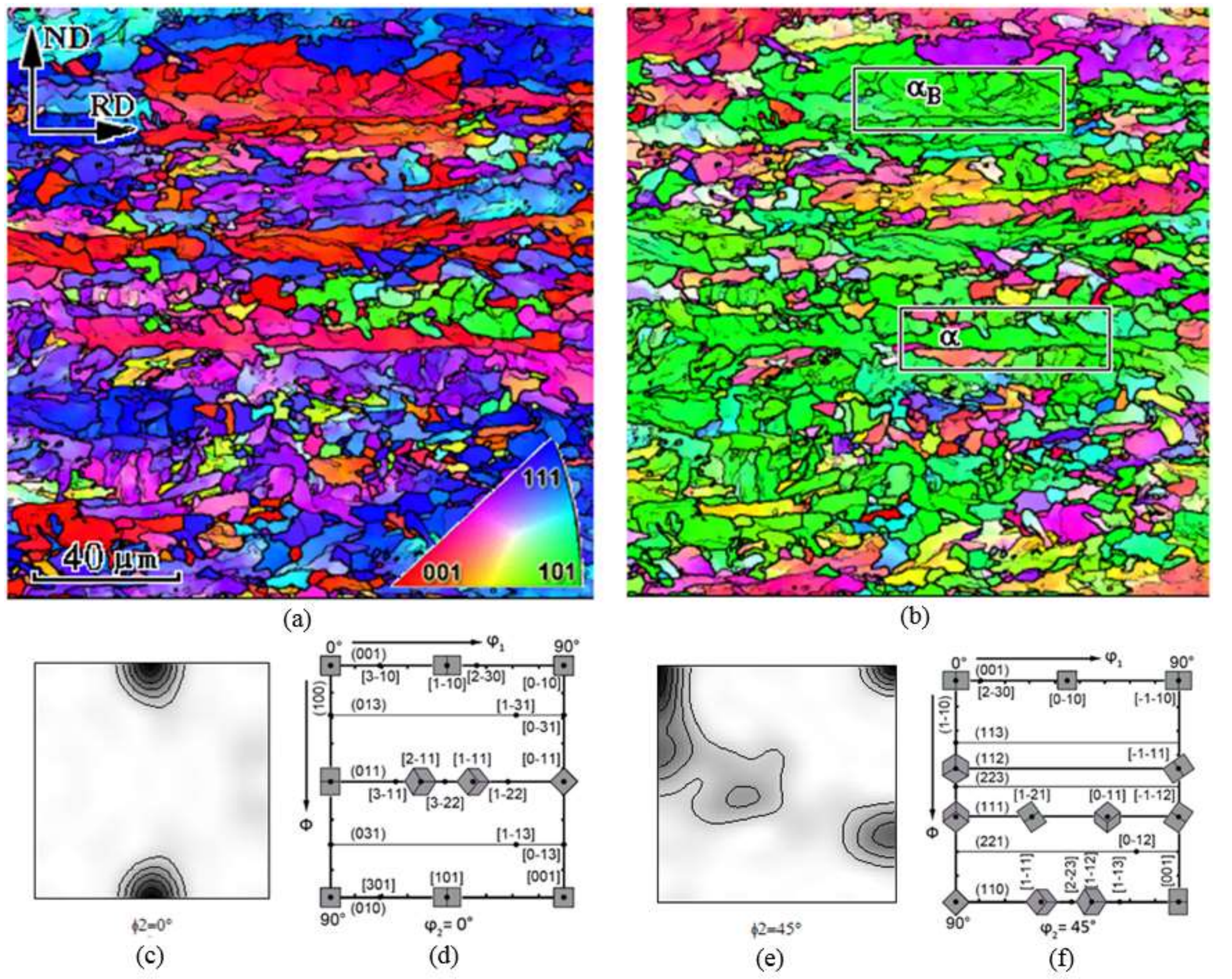

FIGURE 1. Microstructures in reflected backscattered electrons (a, b) and texture as ODF sections (c, d) of the steel in the TMCP; d, f – schematic orientations from the direction perpendicular to the RD-ND plane; α – ferrite, α_B – bainite.

CONCLUSION

We have shown two possibilities for the formation of areas of easy crack propagation along the product obtained by TMCP.

1. There is the formation of ferritic grains during hot rolling below the temperature of Ac^3.

2. There is the formation of bainitic grains at special boundaries separating the deformed austenitic grains during steel cooling after hot rolling.

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