

Local texture of microstructural inhomogeneities in rolled microalloyed steel

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Abstract. Specific inhomogeneities consisting of coarse-grained bainite are observed in the microstructure of low carbon microalloyed steels after hot rolling. Earlier a special etching method has been developed allowing to reveal that these inhomogeneities markedly affect a fracture toughness of steels. In the present work their crystal geometry was studied using EBSD technique, and orientations of former austenite grains were reconstructed. The austenite, from which the coarse-grained bainite regions have been produced, is shown to have orientations concentrated predominantly within the brass component of austenite rolling texture. The inhomogeneities of steel microstructure are promoted by orientation dependency of the deformation substructure of heavily deformed austenite grains.

1. Introduction

Mechanical properties of low carbon steels for pipeline productions were shown to depend on an appearance of specific structural inhomogeneities [1]. When using optical metallography, these inhomogeneities manifest themselves as regions with non-polygonal or even lath-like bainite structure [1]. As it was shown by EBSD analysis [2], crystallites within these regions have relatively low-angle misorientations and, as a result, form very coarse “effective grains”. Large size of these effective grains promotes propagation of trans-granular cleavage cracks from one high-angle boundary to another, leading to degradation of toughness [3].

It was suggested that the regions with lath-like structure were formed by a transformation of abnormally coarse austenite grains [2,4]. At the same time, even coarse austenite grains are known to be subdivided by highly misoriented bainite blocks on a rather fine scale due to a great number of variants of orientation relationship between α and γ phases [5,6]. Therefore, strong variant selection is needed to form a coarse effective grain. Actually, a nonrandom variant selection takes place in the case of plastically deformed austenite [7] due to anisotropy of its deformation substructure, which is known to be dependent on grain orientation [8]. One can thus suggest that not only large size but also specific orientation of a former austenite grain plays a role in formation of structural inhomogeneities considered. The aim of the present work is to verify this hypothesis.

2. Experimental

Industrially processed low-carbon microalloyed steel was investigated. Its chemical composition is 0.06C-1.7Mn-0.2Si-0.2Mo-0.1(V+Nb+Ti) (wt pct). Steel plate was hot rolled from 300 mm slab to 27.7 mm under industrial conditions. Seven initial passes were conducted in the temperature range from 1010 to 930°C. Then a plate was hold at the temperature about 930°C during 20 minutes that is sufficient for recrystallization. Subsequent passes were conducted at temperatures 750±40°C. For the steel investigated a recrystallization does not occur within this temperature range. True strain accumulated at this later stage is about 1.6. After rolling, the steel was cooled with a mean rate about 10 K/s. The samples were prepared from a central region of steel plate. The longitudinal section was examined. EBSD analysis was carried out by SEM Quanta 3D FEG using the EDAX Pegasus system with a step size 0.5 μ m. The data were treated using MTEX software. Evaluation of orientation relationship (OR) between α and γ phases was performed, as distinct from the



earlier works [9,10], on a base of misorientations between α -phase crystallites only without reconstruction of austenite. After that, statistics of inter-variant misorientations was determined and orientations of former austenite were reconstructed. The methods of OR evaluation and austenite reconstruction will be described elsewhere.

3. Results and discussion

3.1. General characterization of microstructure

As it is seen in Fig. 1, the steel examined has non-uniform microstructure: one can observe very coarse-grained regions along with fine-grained ones. The regions of different microstructure are separated by much extended high-angle boundaries. Supposedly these are boundaries of former austenite grains subjected by severe deformation. Acicular morphology is predominant in the coarse-grained regions, but polygonal – in some fine-grained ones. It is to be noted that fields 1 and 2 do not represent a typical microstructure: they were chosen for examination of the structural inhomogeneities.

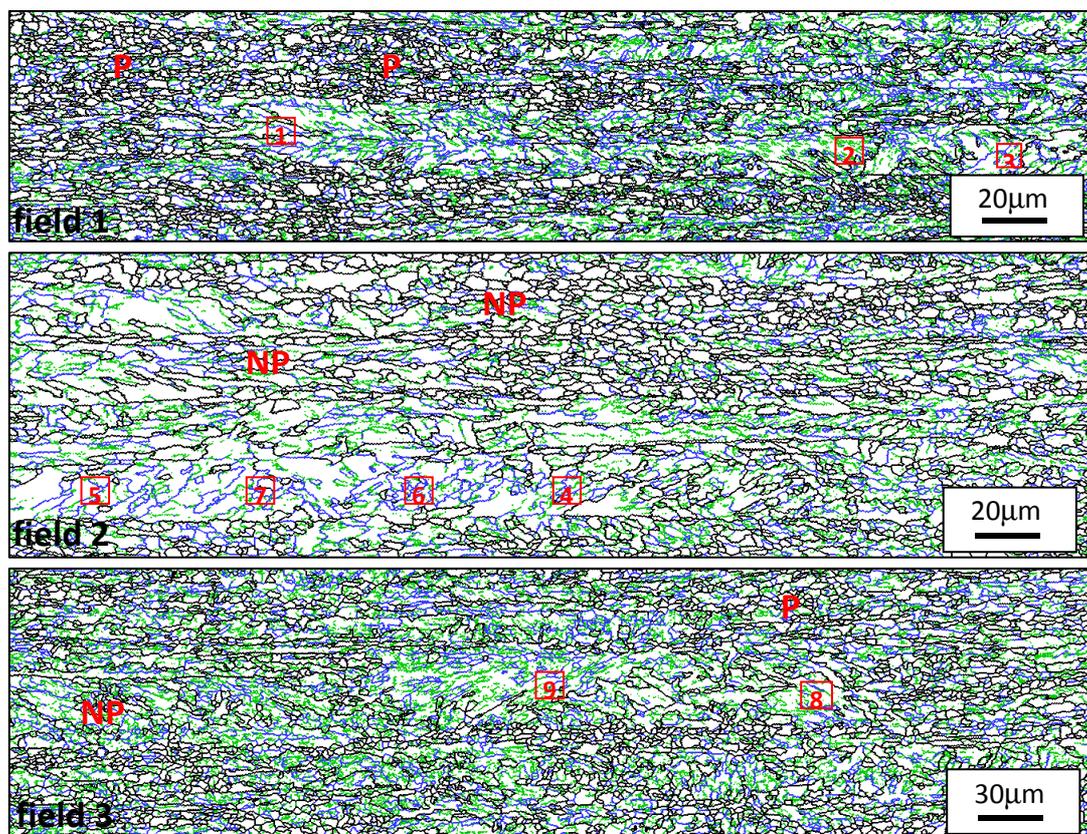


Fig. 1. Boundary maps of specimen examined. The boundaries are drawn by green ($2^\circ < \theta < 5^\circ$), blue ($5^\circ < \theta < 15^\circ$) and black ($\theta > 15^\circ$) lines.

Usually the structure of industrially processed hot-rolled microalloyed steels is characterized as ferrite-bainite [1]. Since it is complicated to differentiate bainite and quasi-polygonal ferrite of microalloyed steel by their morphology only, crystallographic analysis can be used for this purpose. OR determined for above three fields are presented in Fig. 2a by help of deviation angles of close-packed planes and directions. Here the Greninger-Troiano (G-T) OR and the ORs reported by Takayama et al [11] are shown for comparison also. The latter ORs are obtained for a bainite of low carbon steel formed during isothermal holding (the holding temperatures are indicated at the plot). Assuming similarity of bainite crystallography in low carbon steels [6,10], one can conclude from the comparison that we deal with upper bainite formed at relatively high temperatures in the steel examined. As judging from morphological features, certain fraction of α -phase in the fine-grained regions may relate to a polygonal

ferrite, but this fraction seems to be small since the OR fulfills much less strictly for a ferrite than for a bainite [12]. Above conclusion is supported by the spectrum of inter-variant boundaries (Fig. 2b), where the low-angle boundaries, V1/V4, V1/V8 and V1/V11&V13 (nomenclature of variants corresponds to generally accepted one [11]), are predominant in accordance with the results obtained for bainite formed both isothermally [11] and by continuous cooling [13].

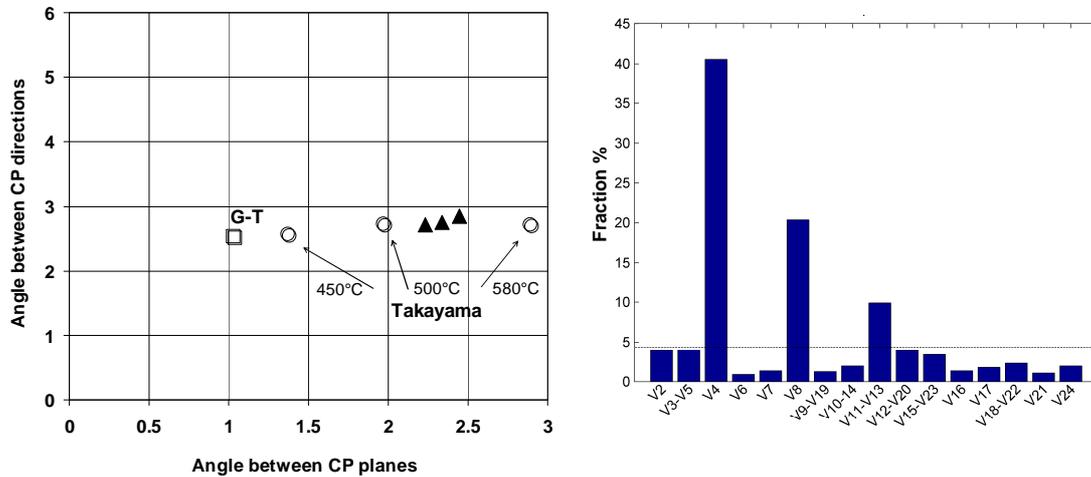


Fig. 2. Crystallographic characterization of specimens shown in Fig. 1: ORs presented by angles between planes $\{111\}_\gamma$ and $\{110\}_\alpha$ as a function of angles between directions $\langle 110 \rangle_\gamma$ and $\langle 111 \rangle_\alpha$ (black triangles) together with Greninger-Troiano OR and the ORs reported by Takayama et al [11] (a); length fractions of inter-variant boundaries (b).

Based on the orientation data obtained, local textures were calculated. It turned out that the local texture of field 3, which has quite typical microstructure, has the features inherent for the transformation texture developed from the plastically deformed austenite [16]. The texture of fields 1 and 2, where the coarse structure is predominant, has less usual character.

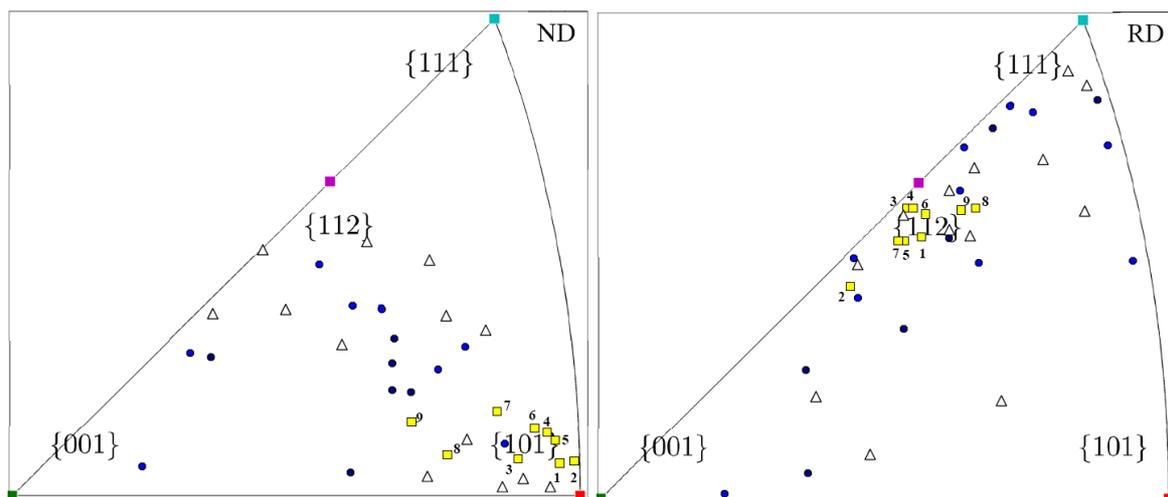


Fig.3. IPF for normal direction (ND) and rolling direction (RD) obtained from former austenite orientations determined in the regions with fine polygonal (circles), nonpolygonal (triangles) and coarse-grained structure (squares). Numbering corresponds to Fig. 1.

3.2. Reconstruction of former austenite microtexture

Orientations of former austenite were determined for the regions of three types: (1) the regions of fine-grained polygonal structure (marked by **P** in Fig. 1; corresponding poles are

marked by circles in Fig. 3); (2) the regions of more coarse nonpolygonal structure with visible extended boundaries of former austenite grains (marked by **NP** in Fig. 1; the poles are marked by triangles in Fig. 3); (3) the coarse-grained regions associated with the structural inhomogeneities (regions are numbered in Fig. 1; the poles marked by squares).

As one can see from Fig. 3, the orientations of austenite correspond well to a rolling texture of FCC metals; the most of them belong to the β -fiber. The austenite, from which the regions of first and second type were produced, has orientations distributed rather uniformly within the β -fiber, mainly around the S-component. However, the austenite producing the regions of third type differs considerably: its orientations are concentrated around the brass component.

One can suggest that this observation relates to an orientation dependency of former austenite deformation behavior. Actually, during plastic deformation crystals are known to be subdivided (fragmented) to misoriented cells, cell blocks or subgrains. The misoriented regions therewith form bands, often extended along active slip planes [8]. Additionally to this regular band substructure, the bands of localized shear appear at medium to high strains. In the study of cold rolled Al it was shown that grains of near-brass orientations have minimal values of misorientations among other orientations belonging to β -fiber [14]. Additionally, it was revealed that single crystals having the brass orientation show less shear localization compared to crystals of the S and copper orientations [15].

Note that occurrence of regular band substructure promotes variant selection at nucleation and growth of bainitic ferrite, and this variant selection results in an increase of bainite packet size [7]. On the other hand, both high-angle misorientations and localized shear nonuniformities promote nucleation of different variants of bainitic ferrite. Therefore, peculiarities of the brass orientation – lower level of misorientations and greater homogeneity – lead to a more strict variant selection during phase transformation and, as a result, promote formation of larger bainite packets as well as formation of bainite blocks with low misorientations. Since the packets of upper bainite formed at a relatively high temperature contain mostly low-angle inter-variant boundaries [11,13], the bainite characterized by extraordinary coarse effective grain size arises from the deformed austenite grains of near-brass orientation.

4. Conclusion

Structural inhomogeneities observed in the industrially processed low carbon steels appear to consist of upper bainite containing blocks and packets with low-angle misorientations. The coarse-grained constitution of these regions is predetermined by specific deformation substructure of heavily deformed austenite grains having near-brass, $(110)[\bar{1}\bar{1}2]$, orientation.

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