Two Types of Grain Boundaries in Deformed Materials

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The specific features of deformation induced grain boundaries in steels of ferritic (0.13%-C, 25%-Cr, 0.9%-Ti, Fe-balance) and austenitic (0.12%-C, 18%-Cr, 9%-Ni, Fe-balance) classes have been studied. These materials are strongly different in their stacking fault energy (SFE). Consequently, the crystal-geometric characteristics of grain boundaries assemblies formed during hot deformation differ at all stages of plastic flow. In austenitic steel the average misorientation of low angle grain boundaries increases as strain rises. This results in dynamic recrystallization (DRX). The average misorientation of low angle grain boundaries increases weakly with rising the strain in ferritic steel. The fraction of low angle boundaries with misorientation $\theta \leq 1^0$ does not change. The analysis of experimental data shows that this is attributed to a character of slip. The latter influences a type of subgranular structure formed during deformation.

INTRODUCTION

Plastic deformation of metals and alloys at high temperatures causes some changes in the initial structure. These changes consist in the appearance of deformation induced grain boundaries. In case of material with low SFE during deformation the misorientation of new formed grain boundaries increases and DRX is observed [1]. Whereas in materials with high SFE a stable substructure is formed, and misorientation of subgrains weakly changes as strain increases [2,3]. No DRX is observed. It is interesting that in one case dynamic recovery promotes DRX while in another case it retards this process. In order to predict the probability of DRX occurrence it seems useful to analyze in detail the structural evolution connected with dynamic recovery at the early stage of deformation in materials both with and without DRX occurrence. The present work is deal to investigation of specific features of structural changes at the early stage of deformation of austenitic and ferritic steels. The choice of these materials is motivated by strong difference in their phenomenology and kinetics of structure evolution during plastic deformation.

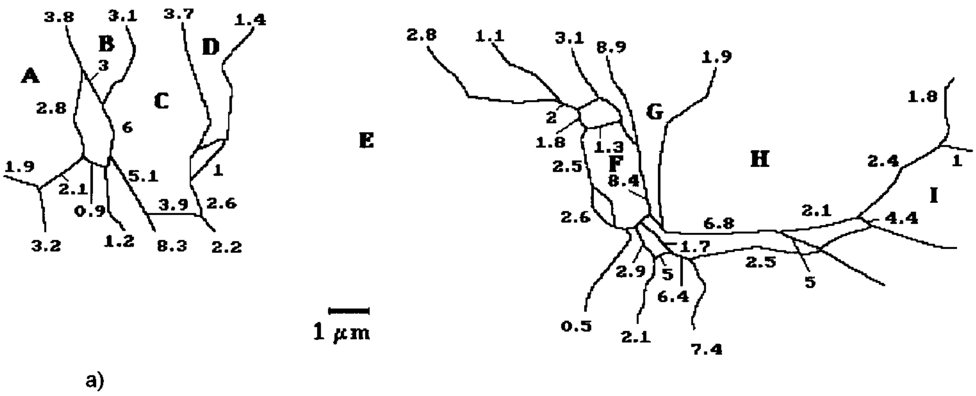
EXPERIMENTAL PROCEDURE

Stainless steels of both ferritic (0.13%-C, 25%-Cr, 0.9%-Ti, Fe-balance) and austenitic (0.12%-C, 18%-Cr, 9%-Ni, Fe-balance) classes are taken for investigations. Due to pre-heat treatment a microstructure with a mean grain size of about 250 μm was formed in both steels. Cylindrical samples, 10x12 mm in dimension, were compressed on a testing machine (Instron 1185) at a strain rate of $\varepsilon=10^{-3}$ s^{-1}. The samples of austenitic steel were deformed at 1100^{0}C, and the samples of ferritic steel were deformed at 700°C. According to the previous studies [4,5] under such deformation conditions the following basic parameters of the formed structure coincide, namely mean sizes of subgrains and recrystallized grains, as well as density of lattice dislocations. The quenching performed immediately after the end of deformation allowed to retain the high-temperature structure state. Structural investigations were conducted using optical microscopes (Neophot-32, Epiquant) and a transmission electron microscope (JEM-2000EX). The qualitative analysis of fine structure was made by the technique described in [6]. In addition to the traditional presentation of misorientations by degrees they were presented in the form of Gibbs vectors **G**=[h k l]. The rotation axis aligns with [h k l], and the misorientation angle θ is determinated by the Gibbs vector length, i.e., $\tan(\theta/2)=|\mathbf{G}|$ [6].

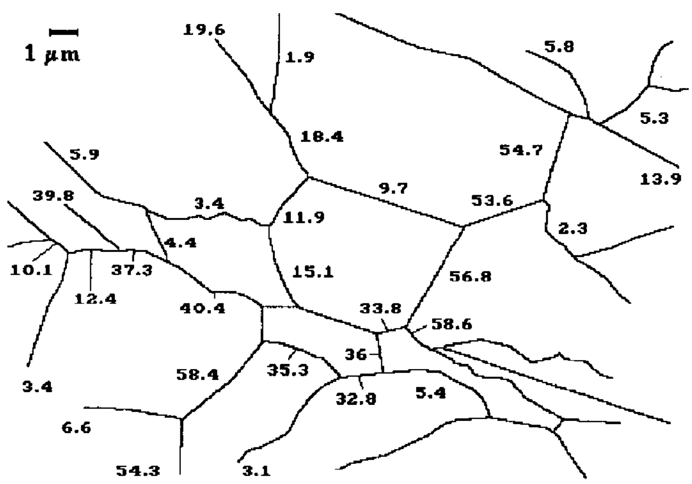
RESULTS

Austenitic stainless steel.

At the early stage of plastic deformation (ε=15%) a subgrain structure is formed inside initial grains. The misorientation of subboundaries constitutes, on average, 2-4^0 (Fig.1a). A typical area of such structure with evidence of low angle grain boundary misorientations is shown in Fig.1a. A subgrain size ranges from 0.5 to 10 μm. The scalar density of free dislocations inside subgrains constitutes about $\rho=2\times10^{9}$ cm^{-2}. One should note that misorientation of separate boundaries considerably exceeds a mean value of subboundary misorientation. For instance, the misorientation of boundaries between subgrains F and G exceeds that of the majority of boundaries presented in Fig.1a by more than twice. These boundaries locate in the regions of elevated density of subboundaries.



a)



b)

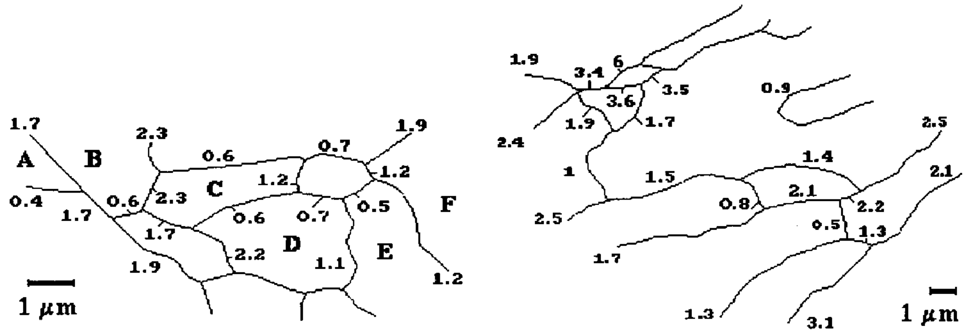
Fig. 1. The scheme of fine structure segment of austenitic stainless steel with grain misorientation in degrees: (a) - ε=15%, (b) - ε=75%.

An increase in strain leads to subdivision of coarse subgrains by low angle boundaries. As a result, the maximum subgrain size decreases to 6 μm. At the same time the minimum size increases up to 1 μm. The substructure becomes more homogeneous. The average misorientation of subgrains increases. After high strain (ε=75%) the formation of a large amount of high angle grain boundaries is observed (Fig.1b). DRX occurs. As a result, a fine-grained structure with a mean grain size of about 15 μm is formed in austenitic steel. The equiaxed subgrain structure with subgrains from 1 to 5 μm in size is typical of both unrecrystallized regions and newly formed grains.

Ferritic stainless steel.

At the initial stage of deformation (ε=15%) a substructure with a subgrain size of 1-5 μm is formed (Fig.2a). The misorientation of subgrains is about 0.5-2°. The scalar density of free dislocations inside subgrains constitutes 5×10^{9} cm^{-2}. With increasing strains the subgrains acquire an elongated shape but their mean grain size does not almost change. After strain ε=75% no considerable increments in misorientation of adjacent subgrains are observed (Fig.2b). Formation of high angle grain boundaries is not observed either.

The elongation of initial grains after high strain in the direction of the material flow creates favorable conditions for occurrence of the so-called geometric DRX. However, the geometric DRX fails to provide a large amount of recrystallized grains after the studied strains. The volume fraction of recrystallized grains does not exceed 2%.



a) b)

Fig. 2. The scheme of fine structure segment of ferritic stainless steel with grain misorientation in degrees: (a) - ε=15%, (b) - ε=70%.

DISCUSSION

The presented results show that structural evolution at the initial stage of deformation is characterized by development of dynamic recovery. However, phenomenology and kinetics of dynamic recrystallization in steels of ferritic and austenitic classes are different. Unlike the ferritic steel, in the austenitic steel the development of dynamic recovery at the early stages of deformation does not retard the development of DRX with strain increase. The influence of dynamic recovery is connected with specific features of the subgranular structure formed at the early stages of plastic deformation. Let us consider in detail the character of misorientations of adjacent subgrains formed after low strains in both steels and their influence on microstructural evolution. The investigated areas of fine structure had a size of about a recrystallized grain size.

Fig.3 represents the results of measurements of boundary misorientations between subgrains **A**, **B**, **C**, **D**, **E**, **F**, **G**, **H**, **I** (look Fig.1a). Misorientations are presented in the form of Gibbs vectors. It is interesting that directions of the majority of misorientations are close to crystallographic direction [3 2 2]. As a result, accumulation of misorientations occurs with increasing of the distance between subgrains. This makes up the total misorientation between the first and the last regions equal to 20°. The vector sum of misorientations between subgrains **A**, **B**, .., **I** constitutes 75% from a scalar one.

This means that in austenitic steel the strain results in a directed turn of a lattice. Since the directions of misorientations of low angle grain boundaries within one recrystallized grain size scale coincide with each other, one can suppose that the Burgers vectors of dislocations accumulated in such microregions and, consequently, the operation slip systems are similar. Correspondingly, recombination of formed subgranular boundaries does not lead to an essential decrease in their number [7]. Misorientations of some low angle grain boundaries become larger due to collision of migrating grain boundaries consisting of dislocations of one sign. The boundary between subgrains **F** and **G** arranged in the area of high subboundary density can be an example of such boundaries. On the other hand, small subgrains disappear. Homogenization of the subgranular structure occurs. A size of subgrains decreases to some equilibrium value. Dynamic equilibrium between the amount of forming subboundaries and that of recombining grain boundaries takes place. This provides a rapid shift of the deformation induced grain boundaries spectrum toward misorientation angles Θ>12. Dynamic recrystallization occures.

Other situation is observed in the ferritic steel. Vectors of misorientations between subgrains **A**, **B**, **C**, **D**, **E**, **F** (look Fig.2a) are presented in Fig.4. It is seen that the direction of misorientation of each next region very strongly deviates from the direction of the previous one. The misorientation direction of the first subboundary is almost opposite to that of the last. The vector sum of misorientations between subgrains **A**, **B**, .., **F** constitutes 40% from a scalar one. The vector sum of misorientations between adjacent regions when moving from point **A** to point **F** is smaller by a factor of 2 than the scalar sum.

In ferritic steel no considerable turn of the crystalline lattice of initial grains is observed. Misorientation of initial grain microregions is substantially compensated. The vector sum of misorientations between consecutively arranged subgrains is less than a scalar one by more than twice. The difference in misorientations of adjacent grains is attributed to the fact that a large amount of sources of dislocations with opposite Burgers vectors act in microregions. Consequently, formed subgrain boundaries of opposite dislocation content migrate in opposite direction and eventually collide thereby annihilating part of their dislocation content [7]. Due to that, the growth of misorientations of deformation induced grain boundaries occurs very slowly, that does not allow to reveal evidences of DRX at the studied strain.

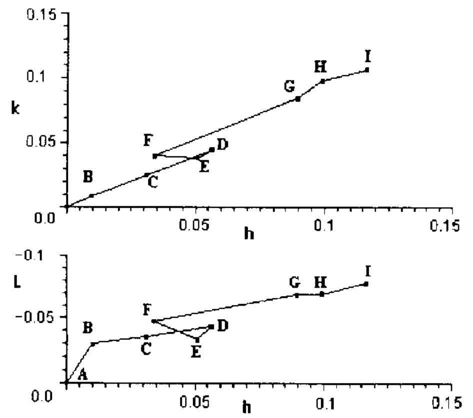


Fig. 3. The misorientation of subgrain in austenitic stainless steel presented as Gibbs vectors.

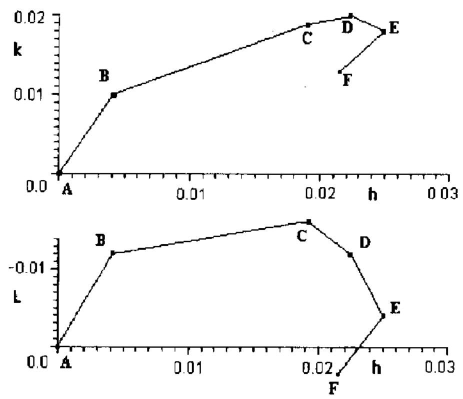


Fig. 4. The misorientation of subgrain in ferritic stainless steel presented as Gibbs vectors.

CONCLUSION

It has been shown that differences in the character of structural changes in austenitic and ferritic steels are caused by differences in the character of slip. Within the microregions of initial grains the volume fraction of dislocations with opposite Burgers vectors is much larger in the ferritic steel than in the austenitic one. As a result, the basic crystallogeometric parameters of intercrystalline boundaries induced by deformation are different in these two steels.

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