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# Stability of Dislocation Structure During Plastic Deformation of B.C.C. Metals

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Single crystals of Fe-0.5wt.%Si and Fe-0.9wt.%Si oriented for single slip were predeformed cyclically or in tension to develope various dislocation structures. Work-hardening, slip line structure and dislocation arrangements were investigated after change of deformation mode. Deformation processes observed during subsequent deformation are discussed on the basis of stability of dislocation structures. Dislocation arrangements formed during tensile deformation are relatively more stable then the structures formed by cyclic deformation.

## 1. Introduction

Tensile and cyclic deformation behaviour studies of Fe-Si alloys are reported elsewhere (see e.g. [1−3]). The results in many aspects appear to be more similar to the behaviour of f.c.c. metals than to those of the pure b.c.c. metals, mainly at cyclic deformation.

The cyclic hardening curves show two stages (the rapid hardening stage and the saturation stage). In the rapid hardening stage typical vein dislocation structure occurs, which consists of primary edge dipoles in dislocation rich veins and low density of screw dislocations in dislocation pure channels. In the saturation stage localization of plastics deformation in persistent slip bands takes place, in which cell structure is observed.

The tensile hardening curves show two distinct stages denoted as stage I and stage III [3]. Homogeneous glide is typical in stage I, slip traces are relatively straight and dislocation arrangement is formed by braids consisting of edge multipoles of primary dislocations. In stage III strain localization in slip bands occurs, dislocation structure is transformed to the dislocation sheets parallel to primary slip plane, formed by primary and secondary dislocations of high density.

To obtain more information about deformation processes in various dislocation structures it is convenient to study the stability of these structures. One type of such

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experiments is combination of cyclic and unidirectional deformation [4]. In this paper such an investigation behaviour of Fe-Si single crystals predeformed to various stages of cyclic or tensile hardening curve is reported.

## 2. Experimental

Cylindrical specimens with gauge diameter of about 3.5 and gauge length of 10 mm were prepared from single crystals of Fe-0.5wt.%Si and Fe-0.9wt.%Si alloys oriented for single slip (for detail see [1]). Symmetrical tension-compression tests were performed at constant plastic strain range of $1 \times 10^{-3}$ and $2 \times 10^{-3}$ at room temperature and constant frequency of 0.1 Hz at constant total strain rate in each cycle.

Tensile tests were performed at room temperature at constant strain rate of $5 \times 10^{-5}$ $s^{-1}$. Specimen surfaces were examined by optical microscopy using Nomarski interference contrast. Dislocation structures were studied by TEM. Thin foils were cut from deformed specimens parallel to primary and secondary slip planes.

## 3. Experimental results

Cyclic predeformation (Fe-0.5%Si).

The cyclic hardening curve of Fe-0.5%Si single crystals is shown in Fig. 1. The rapid hardening stage transfers to the saturation stage at cumulative deformation of about 2. The specimens were cyclically predeformed to various stages of cyclic hardening curve, marked by points 1 to 5 in Fig. 1. After then, the specimens were deformed in pure tension up to 10 % of plastic strain. Tensile deformation curves are shown in Fig. 2. (numbering corresponds to Fig. 1.).

The slip line structure observed after cyclic deformation is described in detail in [1]. The slip in the rapid hardening stage is relatively homogeneous whereas high localization of slip in the persistent slip bands is typical for saturation stage. The volume fraction of PSBs at $\Delta\varepsilon_{pl} = 2 \times 10^{-3}$ is about 20 %. The development of slip line structure during tensile deformation depends on predeformation. Generally at tensile stresses below 140 MPa the slip is homogeneous, at stresses above 140 MPa strain localization occurs and the new formed slip bands succesively cover the whole specimen surface. The arrows in Fig. 2. mark the beginning of strain localization process. In rapid hardening stage the vein dislocation structure was found [1]. This dislocation structure transforms at tensile stresses below 140 MPa to the dislocation braids typical of tensile deformation. On the other hand at stresses above 140 MPa activation of secondary dislocations occurs and dislocation sheets parallel to primary slip plane form.

In saturation stage cell structure is observed in PSBs and vein structure between them. During tensile deformation (specimen 5) the vein structure transforms to

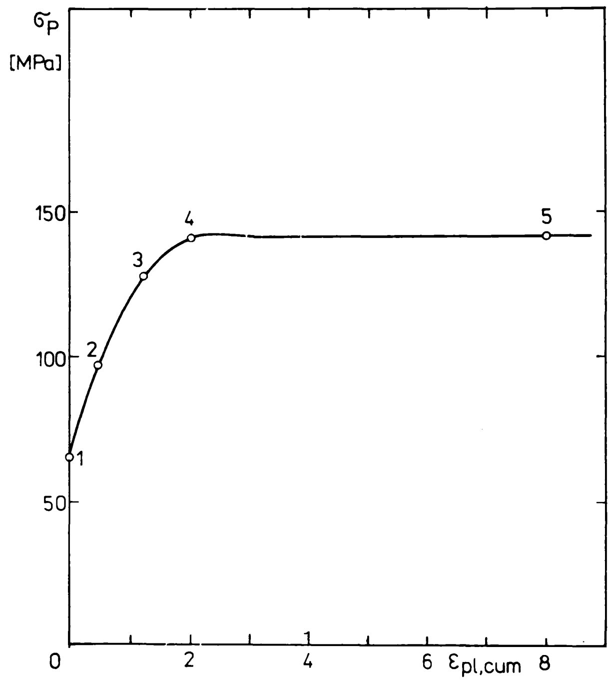


*Fig. 1.* Cyclic hardening curve at $\Delta\varepsilon_{pl} = 2 \times 10^{-3}$, 295 K, for Fe-0.5%Si single crystal

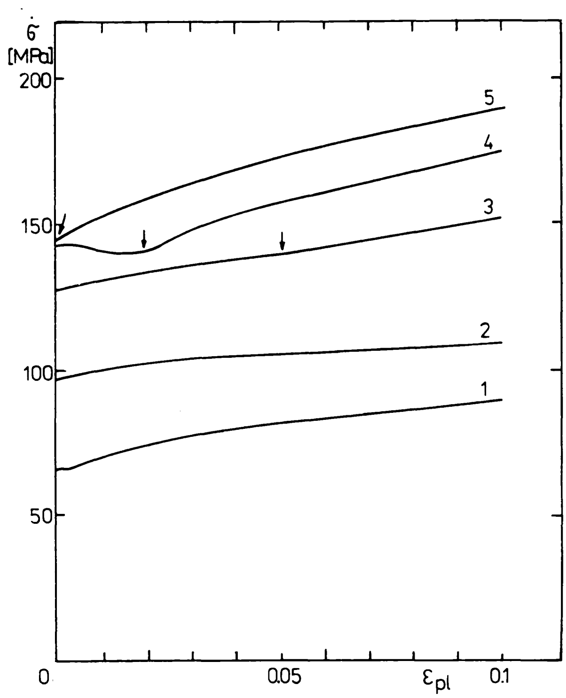


*Fig. 2.* Tensile stress-strain curves after various cyclic predeformation for Fe-0.5%Si single crystals.

dislocation sheets, while dislocation cells are only elongated in the primary slip direction.

Tensile predeformation (Fe-0.9%Si).

Single crystals of Fe-0.9%Si were predeformed in tension 1, 3, 10 and 25 % of plastic strain. As the stage 1 for this alloy is relatively long (about 30 %) only predeformations to the stage I were reached.

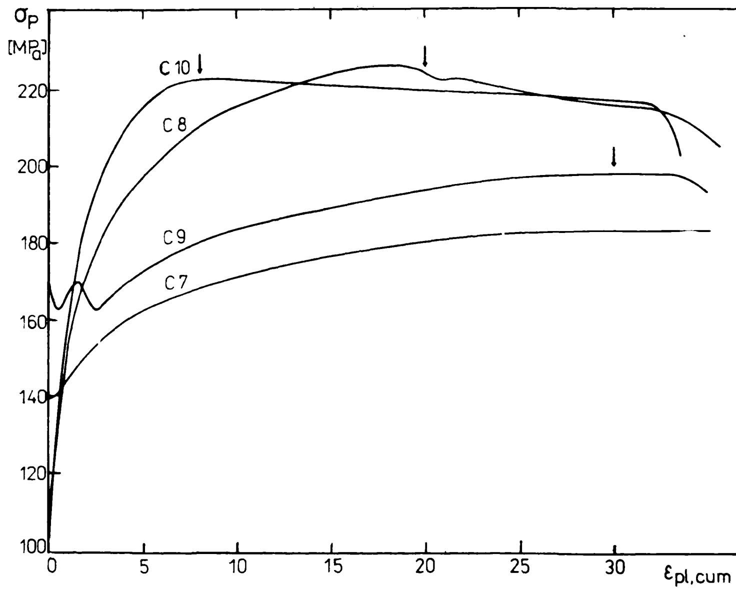


*Fig. 3.* Cyclic hardening curves for Fe-0.9%Si single crystals after tensile prestrain 0, 1, 10 and 25 %, denoted C10, C8, C7 and C9, respectively.

Cyclic hardening curvex at $\Delta\varepsilon_{pl} = 1 \times 10^{-3}$ are shown in Fig. 3. Tensile predeformation suppress the cyclic hardening rate in rapid hardening stage. At higher tensile prestrain the saturation stress decreases. The number of cycles to rupture (life time) is about 3500 for all specimens investigated. Slip line structure in rapid hardening stage is relatively homogeneous independently of predeformation level. The arrows in Fig. 3. indicate the beginning of observed strain localization. On specimen C7 no strain localization was observed, the slip is relatively homogeneous and activity of both primary and secondary slip systems was observed.

## 4. Discussion

Plastic deformation of Fe-Si alloy single crystals leads to the formation of various dislocation arrangements. Vein structure and cell structure develop during cyclic deformation, while dislocation braids and sheets are formed by tensile deformation. Stability of these dislocation structures were studied by the change of deformation mode after predeformation.

Vein dislocation structure.

Primary dislocation dipoles forming dislocation rich regions in vein structure contribute to the plastic deformation as were shown in [5]. High cyclic hardening rate in rapid hardening stage of Fe-Si alloys (in contrast to fcc. metals and Fe-Cr alloys) can be explained by relatively low rate of dislocation annihilation. The sphae of tensile curves after cyclic predeformation depends on stress level at which they start. Particularly the hardening rate is influenced essentially by the stress level. It means that predeformed structures harden similarly to the dislocation structures formed during pure tensile test at the same stress level.

At stresses below 140 MPa (prior to the activation of secondary dislocations) the vein structure transforms if consequence of tensile deformation to dislocation bundles consisting of primary multipoles.

Above 140 MPa (secondary dislocations are activated) mechanisms typical of stage III takes place and dislocation sheets form. The process of transformation between different dislocation structures seems to be quick – about 1 % of plastic strain, which is illustrated on curve 4 in Fig. 2.

Cell dislocation structure.

Stability of dislocation arrangements in specimen cyclically deformed to saturation is different for cell structure in PSBs and vein structure around them. TEM study has shown that the vein structure transforms to dislocation sheets while dislocation cells are more stable and only some cell walls perpendicularly to slip plane are dissolved. This effect brings about the prolongation of cells along primary slip plane. Strain localization in slip bands spreads out over the whole specimen, however distance between slip bands is inhomogeneously distributed. In places of old PSBs is about 5 $\mu$m, while for the new formed bands is lower – of 1.8 $\mu$m, the same as for stage III in pure tension.

Dislocation braids.

The tensile prestrain creates dislocation braids, multipolar structure of primary dislocations of various density in dependence upon the level of prestrain.

When this structure is cyclically deformed the stress needed for activation of secondary dislocations and transformation to vein structure is expected. The experimental results, however, show a marked influence of tensile prestrain on cyclic deformation. The main effect is the decrease of cyclic hardening rate, which implies a higher annihilation rate of dislocations.

Additional effects occur after tensile prestrain — the hardening rates in the peaks of hysteresis loops are higher in comparison to pure cyclic deformation and assymetry between/tensile and compressive peak stresses remains until the saturation (tensile peak stresses are higher). It implies that internal stresses distribution is influenced by tensile prestrain. We assume that the transformation of dislocation braids to veins is not complete until the saturation and the creation of PSBs starts from different dislocation structures. An exception yields specimen C7 due to predeformation oriented for double slip. The character of cyclic deformation is similar to double slip oriented samples also in saturation in this case.

## 5. Conclusions

Single crystals of Fe-0.5%Si were cyclically predeformed to various stages of cyclic hardening curve. Stability of created dislocation structures were investigated by change of deformation mode. Vein dislocation structure transforms easy to dislocation braids at stresses below saturation stress (before activation of secondary dislocations). After activation of secondary dislocations dislocation sheets typical of stage III tensile hardening are formed. Dislocation structures in saturation — cell structure transforms to elongated cells, vein structure between PSBs transforms to dislocation sheets. The cell structure is relatively stable.

Single crystals of Fe-0.9%Si were predeformed in tension. Stability of braids dislocation structure typical of stage I tensile hardening was investigated. Braids structure does not transform completely to the vein structure. In comparison to the pure cyclic deformation the annihilation rate of dislocations after tensile prestrain slows down and lower cyclic hardening is observed. Effect of tensile prestrain remains observable until the saturation the beginning of which is shifted to higher number of cycles with increasing tensile prestrain. However, the life time is not significantly influenced by tensile prestrain.

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