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INFLUENCE OF TEXTURE AND MICROSTRUCTURE INHOMOGENEITIES ON THE ORIGIN OF GOSS TEXTURE IN SILICON STEEL

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ABSTRACT

Development of texture and microstructure of commercial high permeability silicon steel during rolling and recrystallization were studied by Orientation Distribution Functions (ODFs) and optical and electron microscopy. The present results confirm former single crystal results that large {111}<112>-oriented cold rolled grains containing shear bands are the origin of the Goss texture after primary and secondary recrystallization. The formation of {111}<112>-oriented grains during intermediate cold-rolling can be explained by relaxed constraint models. In the case of iron-silicon their orientation density is still enhanced by the transformation of the shear texture in the hot band subsurface during cold rolling [1]. Formation of Goss nuclei in shear bands together with growth preference of the Goss nuclei in these grains leads to a primary recrystallization texture containing Goss grains.

INTRODUCTION

The extreme perfection of Goss texture in commercial grain-oriented high permeability (HiB) silicon steels is essentially based on the grain growth inhibition by fine AlN and MnS precipitates which allow the growth of only the Goss component {011}<100> during secondary recrystallization. But also the presence of a Goss component after primary recrystallization is necessary for this. Single crystal studies (e.g. [2]) have shown that during primary recrystallization Goss grains can nucleate in crystals with {111}<112> orientation after cold rolling with shear bands acting as preferential Goss nucleation sites.

However, the transfer of the models derived from single crystal experiments and theoretical considerations to the microstructure and texture events in polycrystalline materials is not trivial. E.g. in commercial HiB steels only in the coarse grained surface zone [2] and under special rolling conditions [3] nucleation of Goss grains in deformation inhomogeneities was observed. Thus the purpose of the present study is to present clear evidence

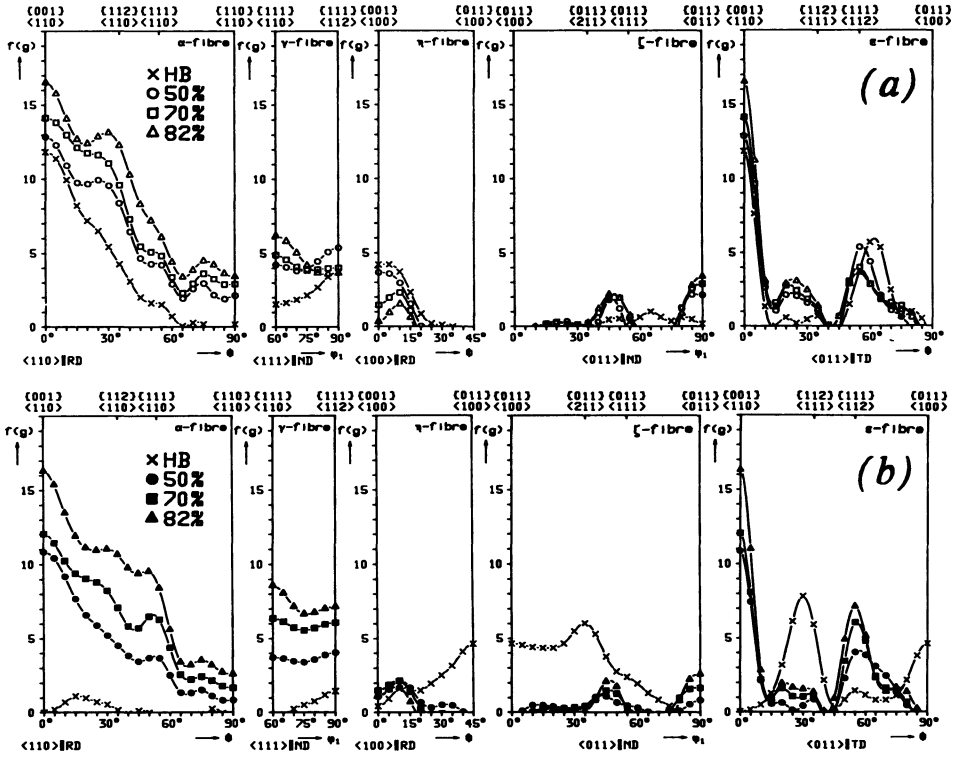

Figure 1 - Hot band texture and rolling texture as function of degree of cold rolling (a) in center layer; (b) in subsurface

of inhomogeneous deformation in commercial HiB steels and of influences of hot band structure and texture on the development of the Goss texture. Orientation distribution functions (ODFs) with their much higher resolution than pole figures will here be applied which is of special importance also in the case of weak textures.

EXPERIMENTAL

Commercial hot rolled and normalized hot band Fe2.99%Si with AlN and MnS precipitates was homogeneously cold rolled up to 82% reduction on a laboratory mill. A salt bath (700°C, 300s) was used for the isochronal annealing treatment. The textures of the center layer and the subsurface were investigated with a fully automatic texture goniometer and ODFs were calculated using four incomplete pole figures [4]. The microstructures in longitudinal and surface sections were examined with optical microscopy, TEM and SEM. In some cases the micro etch pit method was applied [6,7].

RESULTS

The ODFs of normalized hot band measured in center (s=0) and sub-

surface layer (s=0.8) are representative for the strong through-thickness variation of texture (Fig.1). The texture in s=0 (Fig.1a, crossed symbols) consists of an α-, γ- and η-fiber with a maximum at {001}<110> , {111}<211> and {001}<100>, respectively. The subsurface texture (Fig.1b, crossed symbols) is mainly characterized by single peaks around {011}<211>, {112}<111> and {011}<100>. After 82% cold rolling reduction (Fig.1) the α-fiber ({100}<011>, {112}<011>, {111}<011>), and γ-fiber ({111}<011>, {111}<112>) are strengthened for s=0 and are formed also for s=0.8 even with an intensity significantly higher along the γ-fiber than for s=0.

Fig.2 shows the microstructure in a 82% cold rolled sheet. The longitudinal sections display shear bands lying in an angle of about 35° to the rolling plane (Figs.2a,c). In sections parallel to surface traces of shear bands are lying perpendicular to the rolling direction (Fig.2b). Microstructure after a short anneal are represented in Fig.3. In longitudinal as well as in surface section small recrystallized grains appear along shear bands (Figs.3a,b). Etch pits reveal a preference of Goss-oriented recrystallized grains along the shear bands in large {111}<112> oriented cold rolled grains (Fig.3c).

The textures of the fully recrystallized specimen after 82% rolling reduction can be seen in Fig.4. As found generally they mainly consist in a γ-fiber with strong {111}<112>. In the subsurface a significant orientation

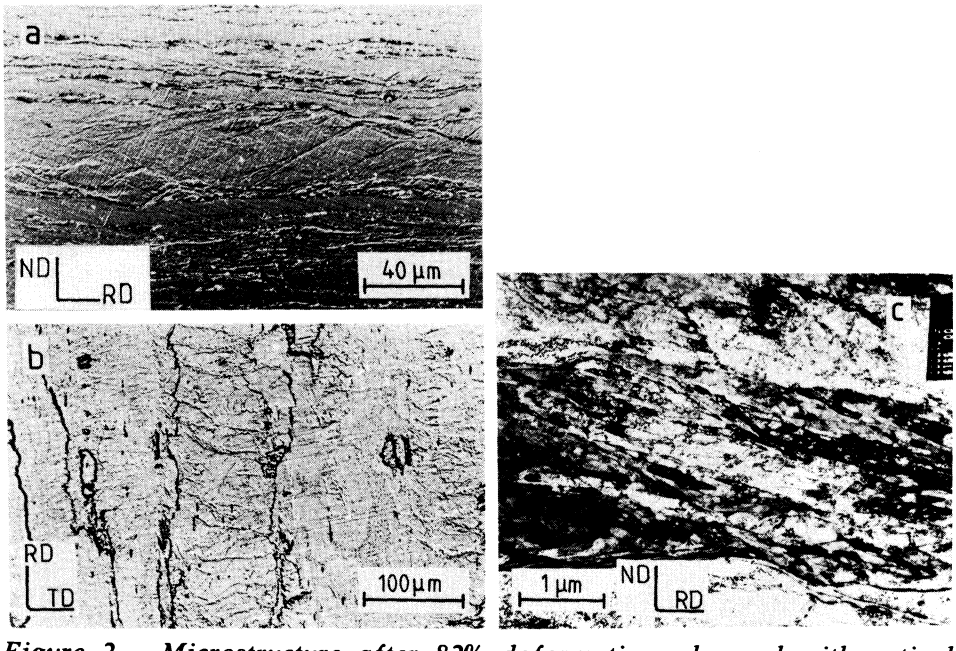

Figure 2 - Microstructure after 82% deformation, observed with optical microscope: (a) longitudinal section , (b) surface section; observed with TEM: (c) longitudinal section

density along the η-fiber including Goss {011}<100> can be observed (Fig.4b). Concerning the variation of recrystallization texture with the degree of cold rolling, it is important to notice a maximum orientation density along the η-fiber which occurs at 70% cold rolling in the subsurface (Fig.4b) and surprisingly at 50% cold rolling in the center (Fig.4a).

DISCUSSION

The reason of texture inhomogeneity in hot band is a shear deformation occurring during hot rolling in the near surface layers. This can be concluded from the fact that in these layers mainly grains with shear orientation like {011}<211>, {112}<111> and {011}<100> are present whereas in the center normal rolling orientations like {001}<110>, {112}<110>, {111}<110> and {111}<112> are found [1,6]. Additional hot band inhomogeneities in texture and microstructure originate from the α-γ-α-transformation which occurs in volume fraction up to 30%. In this volume parts transformation produces small grains, a high precipitation density and weak texture compared to the large grains which are the ones having no phase transformation and thus still possess a pronounced rolling texture in s=0 and shear texture in s=0.8.

The texture evolution by cold rolling (Fig.1) can be interpreted by applying Taylor-type theories with full and relaxed constraints (FC and RC) [5,8]. In the large non-transformed hot band grains of the subsurface the

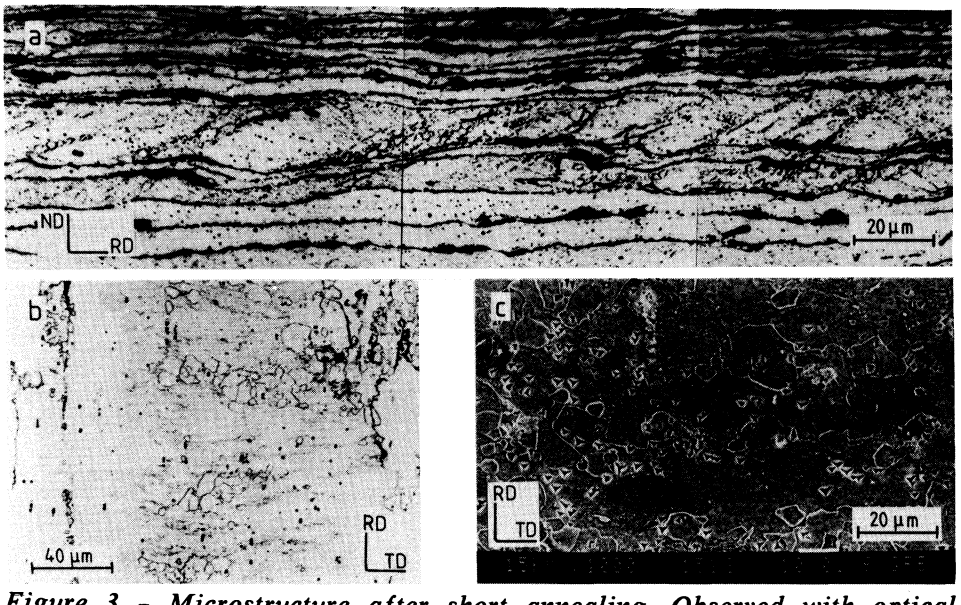

Figure 3 - Microstructure after short annealing. Observed with optical microscope: (a) longitudinal section, (b) surface section; observed with SEM: (c) surface section

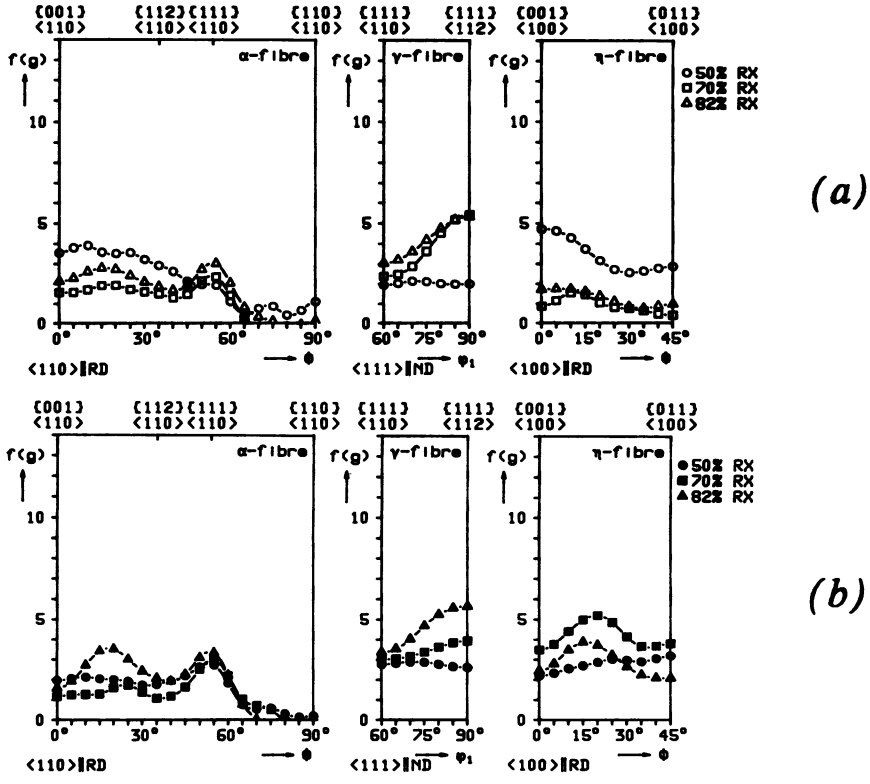

Figure 4 - Recrystallization texture as function of degree of proceeding cold rolling: (a) center layer (s=0), (b) subsurface (s=0.8)

shear orientations {011}<100> and {112}<111> rotate mainly into {111}<112> and those of the center layer of the strong {001}<110> component slowly around <110>∥RD into {112}<110>. In the irregularly oriented small hot band grains the usual α- and γ-fiber are formed . Of special importance is the presence of a pronounced {111}<112> component. It is found (i) by rotation of the shear components in the subsurface (as just mentioned), and/or (ii) by relaxing the shear parallel rolling direction (ε_{RN}). According to the RC model (e.g. [8]) the latter takes place after the grains, due to rolling, have assumed the shape of thin bands and is observed at s=0 at about 50% and at s=0.8 at about 70% reduction. Thus {111}<112> first increases with deformation. But with further reduction it decreases again, since then the shear parallel rolling direction (ε_{TN}) comes into play leading to increasing {111}<110>. The main texture results after primary recrystallization (Fig.4 and [7]) exhibit a weak texture with distinct peaks at {111}<112> and {011}<100> in the subsurface and mainly {111}<112> in the center layer. More thorough studies of the correlation between rolling and primary recrystallization textures for various rolling degrees yielded the important result that the Goss component appears in reasonable strength by primary recry-

stallization only if the cold rolling texture contains a pronounced {111}<112> component either in the surface or center layer.

The development of shear bands is well known in materials with large grains and a sufficient amount of solute atoms like carbon or nitrogen (e.g. [9]). In commercial silicon steels large hot rolled grains exist as a result of only partial transformation in normalized hot band. Present conventional metallographic studies can show that, in contradiction to other investigations [2], shear bands exist in the majority of large grains over the whole sheet thickness, only excluding {001}<110> oriented grains (as identified with micro-facet etch figures). On this basis the formation of the Goss component can be explained by oriented nucleation and oriented growth of Goss nuclei in large cold rolled {111}<112> oriented grains containing shear bands. At the beginning of primary recrystallization in which Goss nuclei are formed in the shear bands of {111}<112> grains (matrix-shear band 35° around <011> ‖ TD [2]), the Goss nuclei can grow along the former shear bands and because the preferred growth orientation relationship ≈30°<110> is fulfilled, thus consuming the whole grain. In grains with orientations different from {111}<112> also preferred nucleation at shear bands takes place (matrix-shear band 35° around <uvw> ‖ TD), but it is not followed by preferred growth.

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