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INFLUENCE OF SUBSURFACE LAYERS ON GOSS-TEXTURE DEVELOPMENT IN SECONDARY RECRYSTALLIZATION OF RGO ELECTRICAL STEEL SHEET

A. BÖTTCHER[1,2], M. HASTENRATH[1], K. LÜCKE[2]

1) Thyssen Stahl AG, D-4100 Duisburg 11,Germany
2) Institut für Metallkunde und Metallphysik der RTHW Aachen, D-5100 Aachen, Germany

ABSTRACT

Regular grain oriented (RGO) electrical steel sheet used for power transformer cores is produced by a two stage cold rolling process with intermediate annealing and a subsequent decarburizing primary recrystallization. Its beneficial magnetic properties originate from a sharp Goss-texture developed by the following secondary recrystallization. By controlled thinning of the material the sharpness of this Goss-texture will be shown to strongly depend on texture and structure of the subsurface layers of the sheet. A less intense secondary recrystallization with deteriorated Goss-texture sharpness and magnetic properties was found if a critical surface layer was removed from both sides of the sheet at any processing step, but no such effect occurred after single-sided surface removal. This result led to a new interpretation of the model of "texture inheritance".

1. INTRODUCTION

Earlier investigations of sheet thickness texture profiles being found at different processing stages suggested a model of texture inheritance /1/. It assumes that in Goss-textured material as a reason of shear deformation and recovery, which the subsurface layers are suffering during hot rolling, large amounts of Goss-oriented grains are produced. This amount would be strongly reduced by cold rolling but still be present for acting as nuclei for the subsequent recrystallization treatments to finally confirm a strong Goss-texture developed by secondary recrystallization. In a later study /2/ this model was put in question, since a final Goss-texture could be obtained even if the initial texture doesn't contain any Goss orientation. (This was achieved by cross rolling of the original hot strip during the further treatments.) By the results of the present experiments being concerned with the removal of subsurface layer material the texture inheritance model has to be reinterpreted in the sense that not the same matrix regions is kept in Goss-orientation during all the processing steps, but that a chain of texture transformations exists which must not be interrupted.

2. EXPERIMENTAL

The starting material is RGO-hot strip with 2mm thickness and the following main alloying elements (in weight percent): 3,2% Si, 0,029% C, 0,061% Mn, 0,02% S. After hot strip annealing -HSA- (1030°C / 150 s) and thickness reduction to 0,65 mm by 1st cold rolling -1CR- an intermediate recrystallization annealing -IA- (980°C / 180 s) is performed. After a subsequent 2nd cold rolling -2CR- to final thickness of 0,26 mm a decarburization annealing -DA- (840°C / 150 s) in a wet atmosphere again recrystallizes the sheet. At high temperature box annealing - HTA- secondary recrystallization is initiated during heating up very slowly to 1200°C. From all processing stages specimens were taken. The cross sectional microstructure was investigated by optical microscopy. Texture investigations were carried out at flat specimens with an automized X-ray goniometer /3/ and ODF calculations /4/.

The surface removals were realized by grinding and chemical etching to avoid surface deformations. The remaining thickness is described by the value s giving the not removed fraction of the half thickness scaled from the center ($s=0$ represents the centre layer, $s=1$ the original surface). The resulting sharpness of the final Goss-texture is judged from (110)-pole figures and from magnetic measurements. The power losses at 50 cps and 1,5 T peak induction (P1,5) as well as the induction at $H=800$ A/m magnetic field (B_8) are measured, both reacting very sensitively on any decrease of Goss-texture sharpness.

3. RESULTS

3.1 Texture and microstructure during standard processing

Figs.1.a to e demonstrate the texture development during standard processing for the layers $s=1$, $s=0,7$ and $s=0$, thus giving a thickness profile. As typical for sheet steel /5/, the ODF's of the deformation texture consist of complete gamma-fibres (common $<111>$ $\|$ ND) and incomplete alpha-fibres (common $<110>$ $\|$ RD). The ODF's of the recrystallization textures besides the gamma-fibre mainly consist of eta-fibres (common $<100>$ $\|$ RD). At hot strip, the centre layer with a flat, "pancake"-shaped deformation structure differs from the globular subsurface matrix. During 1CR the near-surface structure has changed into a longitudinal "lath"-shaped structure, whereas the central "pancake"-structure remains unchanged (Fig.2.a). A globular microstructure without thickness gradient evolves during the recrystallizing IA. No structure gradient was observed furthermore after 2CR and DA.

The sharp gradient of texture and microstructure at hot strip is also reported in /5, 7/. The thickness gradient in texture only decreases during processing but still partly remains until after DA.

3.2. Influence of surface removals

As a first attempt, after DA "window areas" on the surface were thinned by different amounts. Then secondary recrystallization was fainted inside of these window areas, no matter wether the etching was performed single- or double-sided. This means the major detrimental effect is related to the absolute sheet thickness. To observe effects truely induced by the absence of surface layers, such a thickness effect was avoided by adjusting 1CR in such a way that after removal in every experiment the same sheet thickness was obtained. Here 2CR was also kept unchanged which is essential for always obtaining the same recrystallization behaviour at DA. This modification of standard processing does not influence the materials development as has been proved.

In this way at all processing stages single- and double-sided surface removals were carried out to s = 0.9/0.8/0.7/0.6/0.5 -layers. After final secondary recrystallization, (110)-pole figures and the magnetic properties were measured. It was found that the Goss-texture is weakened (Fig.4), the power losses (P1,5) are increased and the induction (B_8) decreased, also the secondary grain size is decreased, if at any processing step a critical layer was removed from both sides of the sheet. But no such effect occured after single-sided removals.

4. DISCUSSION

The above described development of deformation textures can essentially be interpreted by the Taylor-model /6/ and its relaxed constraints modifications. Thus for the centre layers (assuming there plain strain compression) and for moderate degrees of deformation (assuming the relaxation of e_{RN} shear, "lath-model") the model predicts as stable rolling orientations {111}<112> of the gamma-fibre and {001}<110> of the alpha-fibre, and after high reductions (additional relaxation of e_{TN} shear, "pancake-model") the orientations {111}<110> (alpha- and gamma-fibre) and {112}<110> (alpha-fibre). These predictions agree well with the observations (Fig.1); details will be discussed later /10/.

The development of annealing textures is related to a selective growth mechanisms of nuclei according to an orientation relationship of ≈27° around a common <110> axis between a growing nucleus and the deformed matrix /8, 9/. Thus the annealing texture development is characterised by transitions from strong deformation texture components to typical recrystallization texture components as e.g. {112}<110> -> {111}<112> and {111}<112> -> {011}<100>. Especially the rolling texture development at 1CR is different at centre and subsurface layers because of the different hot strip structure there, allowing at centre layers both relaxations e_{RN} and e_{TN} simultaneously, whereas at surface layers only e_{RN} can be relaxed. Since in centre and subsurface layers the rolling textures are different, also different recrystallisation textures are to be expected. On the other hand, cold rolling leads to different rolling textures in the differently textured layers at s = 0 and s = 0.8. Thus texture gradients originally stemming from hot rolling are kept, although the subsequent processes as annealing and cold rolling act homogeneously over the thickness of the sheet. (For more details see /10/.)

The above described experiments clearly show that, in order to produce a sharp Goss-texture, in no processing step the subsurface layer material may be completely removed (single-sided removal would still be allowed). This does not necessarily mean that these subsurface layers contain a certain amount of Goss-textured material from the hot strip, where it was formed by shear deformation and recovery, up to the final secondary recrystallization, where it acts as nuclei. Texture inheritance must then be interpreted in the sendose that the chain of texture transformations, beginning with the Goss-orientations at hot strip and ending with the Goss-orientations after primary recrystallization must not be interrupted in order to obtain the final secondary recrystallization leading to the very sharp Goss-texture.

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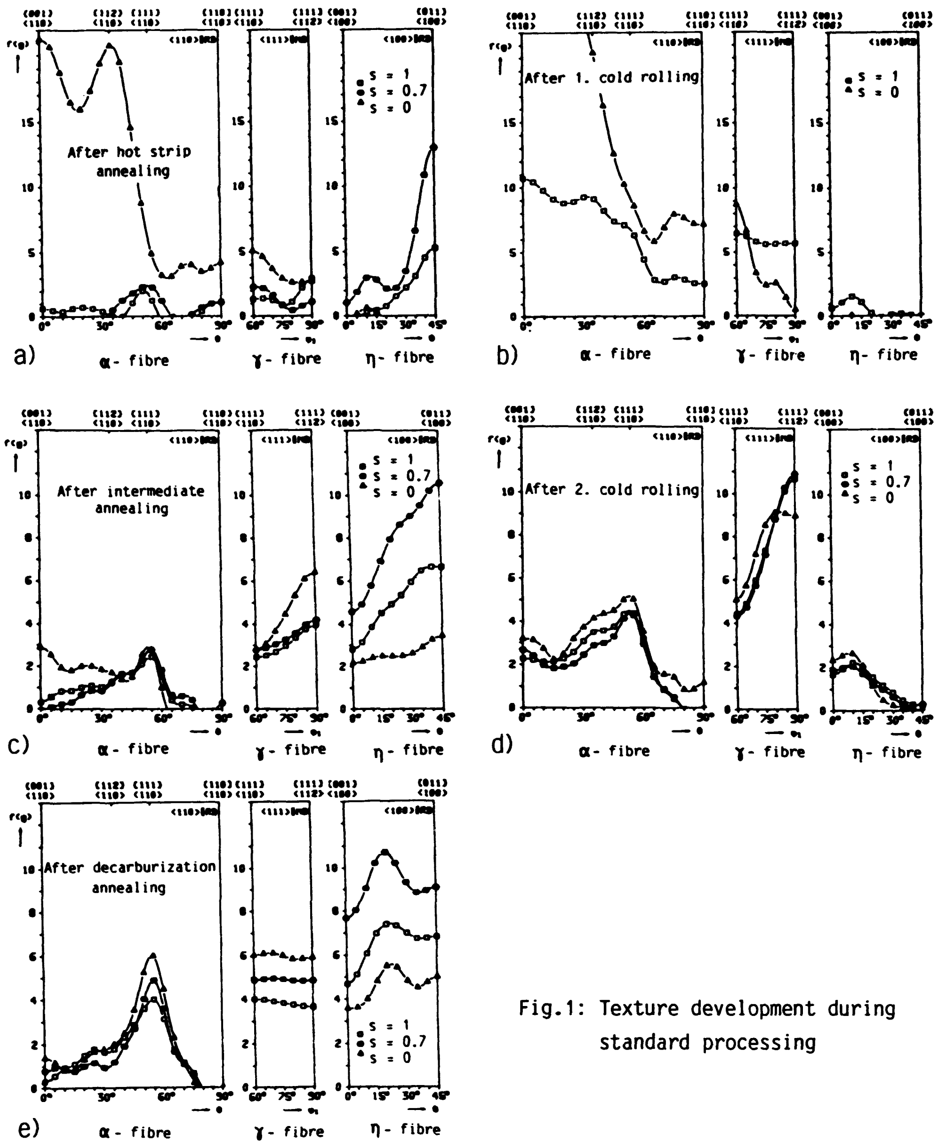


Fig.1: Texture development during standard processing

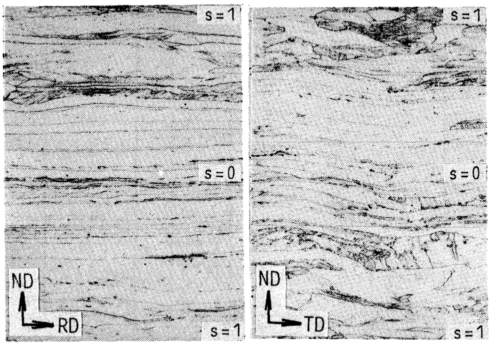


Fig.2: Cross sectional microstructure
a: after 1CR (X100)

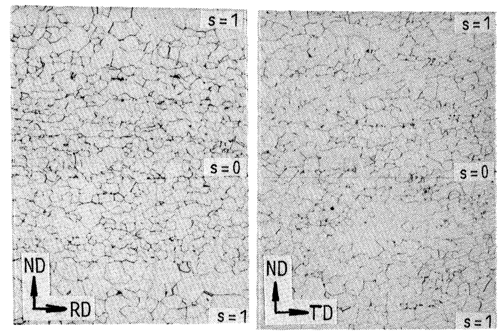
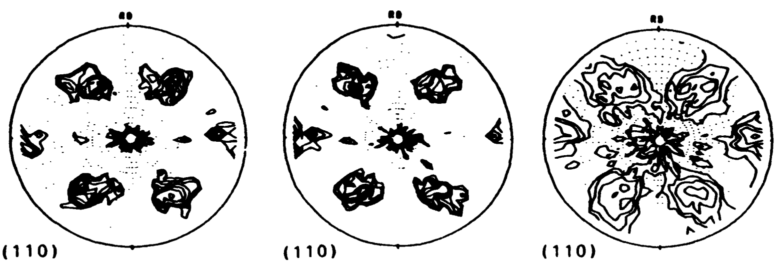


Fig.2: Cross sectional microstructure
b: after IA (X100)



(110) without surface removal

(110) single-sided removal (1X s=0.5)

(110) double-sided removal (2X s=0.5)

Fig.3: Deterioration of Goss-texture sharpness
after secondary recrystallization by surface removal

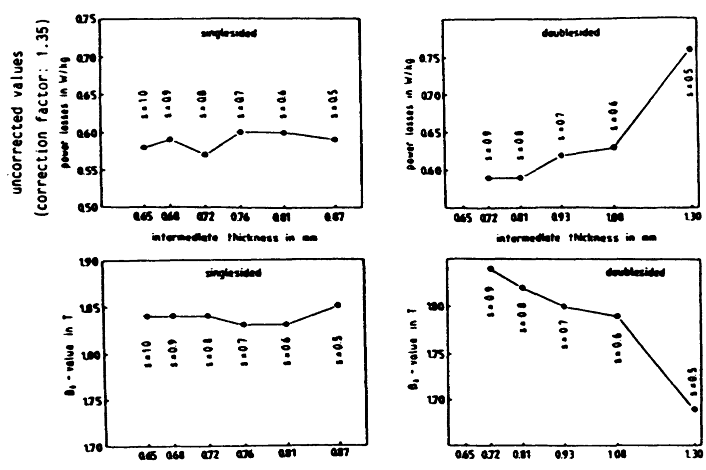


Fig.4: Magnetic properties after surface removal
at decarburized sheet