LA-UR- 98-2560

Approved for public release; distribution is unlimited.

Title: INFLUENCE OF ORIENTATION PINNING ON THE GOSS-TEXTURE IN Fe-3%Si ELECTRICAL STEEL

CONF-980645--

Author(s): O. Engler
F. Friedel

Submitted to: ICGG 3
Pittsburgh, PA
6/15-19/98

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos
NATIONAL LABORATORY

Form 836 (10/96)

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LA-UR- 98-2560

INFLUENCE OF ORIENTATION PINNING ON THE GOSS-TEXTURE IN Fe-3%Si ELECTRICAL STEEL

O. Engler, F. Friedel[#]

Los Alamos National Laboratory, Center for Materials Science,
Mail Stop K765, Los Alamos, NM 87545, USA

[#]) Thyssen Krupp Stahl, Forschung, Zentrales Qualitäts- und Prüfwesen, Duisburg, Germany

Abstract

Despite a large number of investigations on the formation of the Goss-texture in Fe-3%Si electrical steels, the exact mechanisms leading to the preference of this particular orientation are not completely understood so far. As an alternative to the standard explanation of a favored growth of Goss-oriented grains during secondary recrystallization, recently the concept of 'orientation pinning' has been proposed, which considers that the growth of grains with special orientation relationships corresponding to low-angle and twin grain boundaries is disfavored. The present paper present preliminary EBSD-results on the growth of Goss-grains during secondary recrystallization in high-permeability (HiB) transformer steel sheets. A semi-quantitative model to simulate the effect of orientation pinning on the evolution of the Goss-texture is introduced.

Introduction

The magnetic properties of Fe-3%Si electrical steel sheets are mainly determined by their crystallographic textures. Alignment of the magnetically weak <001>-directions parallel to the rolling direction (RD) of the sheets gives rise to a high permeability to maximize flux passage in the easy magnetization direction and, consequently, to low core loss in applications such as electrical transformers. In most commercial applications, a texture with a preferred {011}<100>-orientation – called Goss-orientation – is produced during the final decarburization anneal of the cold rolled and recrystallization annealed sheets (e.g. [1,2]).

The final Goss-texture forms by discontinuous growth of Goss-oriented grains which pre-exist in the primary recrystallization texture, i.e., by secondary recrystallization. Thus, to obtain the aspired sharp Goss-texture, continuous grain growth must be restrained. In the so-called regular grain oriented (RGO) material this is achieved by finely dispersed MnS-inhibitor phases [3]. Higher permeability can be achieved by introduction of additional AlN-precipitates in combination with a higher level of deformation (high permeability grain oriented, HGO or HiB, material) [4].

The preference of the Goss-orientation during secondary recrystallization has been attributed to its approximate 35°<110> orientation relationship to {111}<112>, the major recrystallization texture component. This orientation relationship is close to the 27°<110> orientation relationship which often is assumed to depict maximum growth rates [5]. More recent studies attempted to correlate the Goss-orientation to its preference of so-called special or coincidence-site-lattice (CSL or low-Σ) grain boundaries, in particular Σ5 (37°<100>) and Σ9 (39°<110>) [6-9]. As such CSL-boundaries are assumed to have lower energy than ordinary high-angle grain boundaries, they would be less frequently affected by precipitates and, consequently, would be more mobile than other high-angle grain boundaries.

The present paper presents an opposite approach to explain the dominance of the Goss-orientation which often is based on the concept of 'orientation pinning' [10,11], that has recently successfully been applied to account for growth selection during primary recrystallization of Al-alloys [12]. Rather than assuming that certain grains are *favored* by a special orientation relationship, it is considered that growth of grains with some orientation relationships is *disfavored.* It is generally known that low-angle grain boundaries with misorientation angles below 15-20° (Σ1) as well as coherent twin grain boundaries (Σ3) are characterized by a very low, almost negligible, mobility. Thus, if upon secondary recrystallization a growing grain encounters other grains with a similar or twin orientation, immobile grain boundary segments result which will act as obstacles to the moving grain boundary and, consequently, will pin it (Figure 1). In the long run, grains which are distinguished by a low probability of being pinned by creating immobile grain boundaries to the primary recrystallized structure are preferred and would eventually predominate in the final texture.

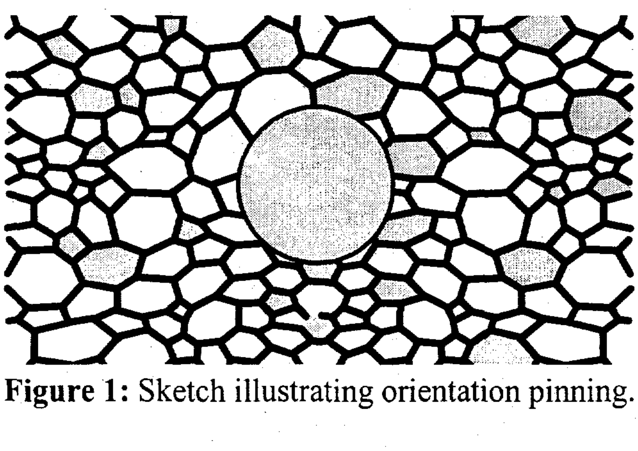


Figure 1: Sketch illustrating orientation pinning.

Experimental Procedure

To follow the evolution of the Goss-texture out of the primary recrystallized microstructure, different samples taken from a commercially cold rolled and recrystallization annealed Fe-3%Si HGO electric steel sheet with 0.23mm thickness were subjected to a laboratory annealing treatment. Samples were extracted at different temperatures and water quenched so as to produce various intermediate states during secondary recrystallization [13]. The progress of secondary recrystallization was characterized by microstructural investigation, conventional X-ray texture analysis and by statistical electron back scattering diffraction (EBSD), as will be described in more detail in a subsequent paper [14].

Results

Figure 2a shows the X-ray texture after primary recrystallization, i.e. prior to the onset of grain growth. In this diagram, the texture is represented in form of iso-intensity lines in the section with φ_2=45° through the three-dimensional orientation space defined by the Euler angles φ_1, Φ, φ_2 [15]. As indicated in Figure 2b, this section contains all important orientations that may occur in Fe-3%Si sheets. During the primary recrystallization of bcc steels the orientations along the so-called γ-fiber – comprising orientations with a common {111}-axis parallel to the sheet normal direction (ND) – typically grow at the expense of the α-fiber orientations (<110>//RD) in the rolling textures (e.g. [16]). Furthermore, an ND-rotated cube-orientation with the approximate Miller-indices {001}<310> as well as weak intensities of the Goss-orientation {011}<100> were observed (Figure 2a).

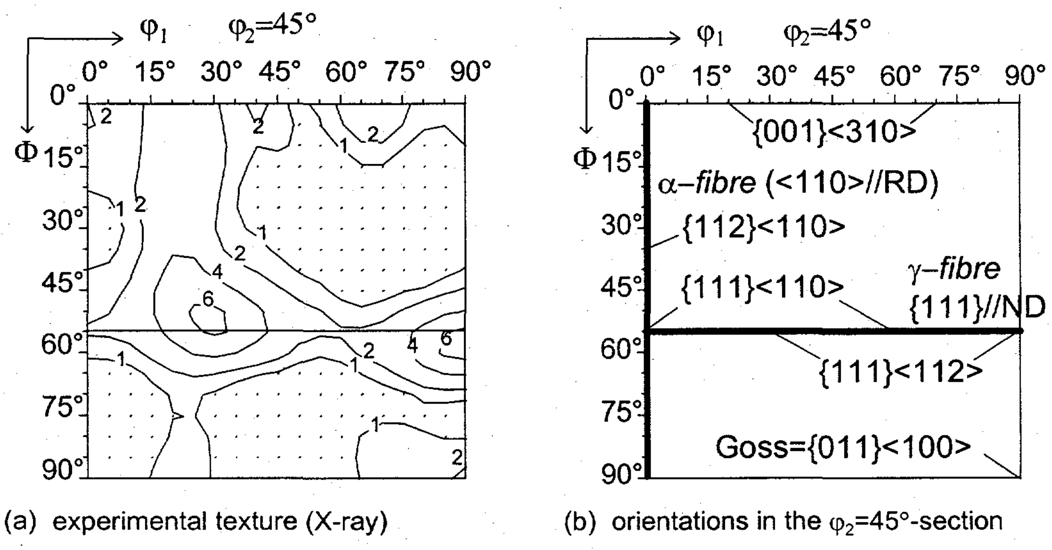


Figure 2: Texture after primary recrystallization.

Figure 3 shows the microstructure at an intermediate state during the secondary recrystallization. In that state, a few large Goss-oriented grains appear to have consumed already part of the as-recrystallized microstructure. Not surprisingly, EBSD-analysis during progressing secondary recrystallization proved a growth of the Goss-orientation at the expense of the components of the primary recrystallization texture, in particular {111}<112>. However, it turned out that the Goss-grains did not grow homogeneously into the primary recrystallized structure, but that some grains seemed to be more stable than others [14,17,18]. The magnetic quality of the final material depends on the extent to which these 'stable' grains will eventually be consumed by the large Goss-oriented grains [13]. In that context, several characteristic features have been identified, which will be summarized in terms of one example here (further

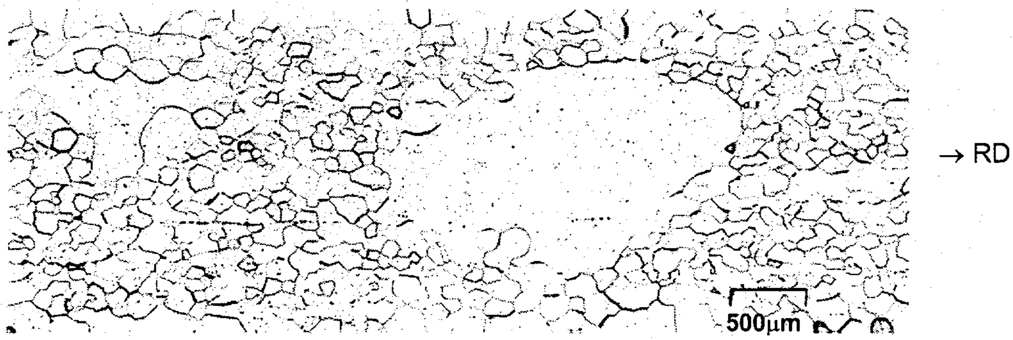
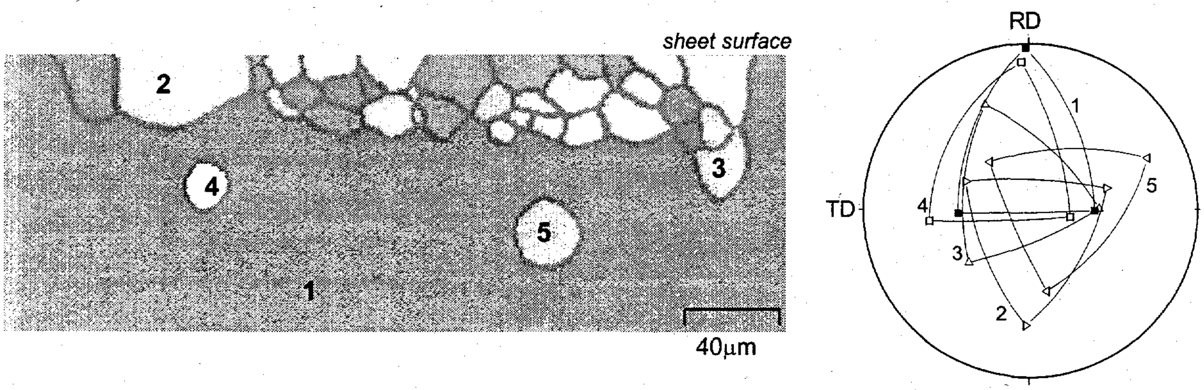


Figure 3: Microstructure during secondary recrystallization.

examples will be given in Ref. [14]). The microstructure of a region adjacent to a growing grain has been redrawn and the grains have been shaded according to their crystallographic orientation (Figure 4a); the orientations of some of the grains are further presented in a {100}-pole figure in Figure 4b. The large grain 1 with an orientation very close to the Goss-orientation obviously grows into the primary recrystallized structure at the upper part of the micrograph. Typically some large non-Goss oriented grains can be observed, preferably at the sample surface (e.g. grain 2 in Figure 4a). Furthermore, some grains in the sample interior, e.g. grain 3, seemed to be particularly resistant to being consumed by the Goss-grains (cf. [17,18]).



(a) microstructure

(b) individual orientations of a)

Figure 4: Example of several grains which are resistant to consumption by a Goss-grain.

Sometimes even island grains remained within the Goss-grains (e.g. grains 4 and 5). In the example shown in Figure 4, the misorientation angle between the Goss-grain 1 and the island grain 4 is 16°, which can still be assumed to represent a low-mobility grain boundary. Thus, this constellation reflects an – unfavorable – example of orientation pinning of a growing Goss-grain. To quantify these findings, from about 120 such stable grains an orientation distribution function (ODF) was computed. The resulting ODF (Figure 5) comprises intensities close to the Goss-orientation. Furthermore, some intensities of {111}<112> and, particularly, {001}<310> were observed to remain stable against consumption.

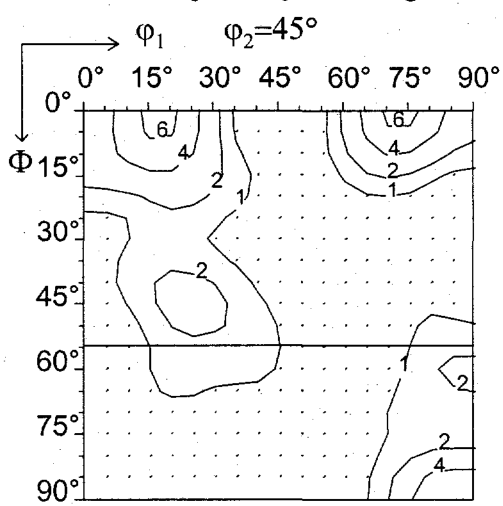


Figure 5: Orientation distribution of the resistant grains (EBSD).

Influence of Orientation Pinning on the Goss-Texture

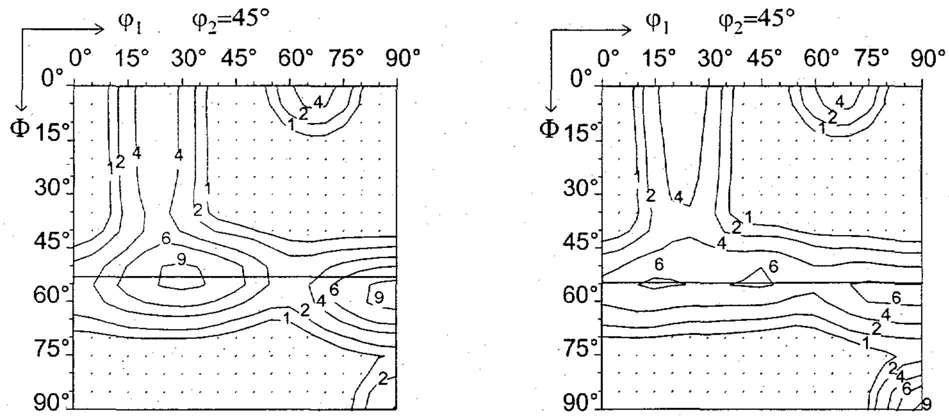
For an assessment of the impact of orientation pinning on the evolution of the Goss-texture during secondary recrystallization, information on the fraction of immobile low-angle grain boundaries, x_{LAGB}, and twin grain boundaries, x_{TB}, between the growing grains and the primary recrystallization texture is required. For that purpose, the recrystallization texture of the Fe-3%Si sheet (Figure 2a) was decomposed into a set of ~1000 individual orientations with different weight factors. Then, the misorientations between the orientation of interest and each orientation of the discretized recrystallization texture were calculated and the factors x_{LAGB} and x_{TB} derived. Grain boundaries with misorientations below 15° were considered as low-angle grain boundaries; twin grain boundaries were defined as having a misorientation within 7.5° of the ideal twin relationship, 60°<111>. Table 1 lists data of x_{LAGB} and x_{TB} for several orientations typically found in the primary recrystallization texture of Fe-Si. As could be expected, the main texture components would have a rather large probability of up to 10% of meeting grains with similar, or twin, orientations. The Goss-orientation, on the other hand, has a much lower probability of only ~3% to form immobile low-angle or twin grain boundaries to grains of the recrystallized structure.

Orientation			
Miller indices {hkl}<uvw>	Euler angles φ_1 Φ φ_2	x_{LAGB} [%]	x_{TB} [%]
{011}<100>	0° 45° 0°/90°	2.8	0.3
{001}<310>	23° 0° 0°/90°	4.7	0.1
{111}<110>	60° 55° 45°	2.0	0.8
	70° 55° 45°	3.1	1.2
	80° 55° 45°	6.2	2.2
{111}<112>	90° 55° 45°	7.6	2.6

Table 1: Fraction of low-angle grain boundaries x_{LAGB} and twin grain boundaries x_{TB} for several orientations.

To get more quantitative information on the impact of orientation pinning on the Goss-texture, such calculations had to be performed for an orientation distribution representing the primary recrystallization texture. For that purpose, an orientation spectrum was composed of 20 orientations with equal weights (Figure 6a), which, despite the low number of orientations, strongly resembled the recrystallization texture in Figure 2a. For each of these 20 orientations, the misorientations with respect to the discretized recrystallization texture were computed and the fractions of low-angle grain boundaries x_{LAGB} and twin boundaries x_{TB} were evaluated. In Figure 6b, the results are presented in form of an 'ODF' by assigning each of the 20 orientations a weight factor $1/(x_{LAGB}+x_{TB})$. As already apparent from Table 1, the Goss-orientation has a low probability of forming low-angle and twin grain boundaries and, consequently, forms a strong maximum in the modeled texture. The main recrystallization texture component {111}<112>, on the other hand, is much weaker than before. It must be emphasized, however, that the applied normalization tends to overestimate the impact of orientation pinning [12]. Therefore, the present model, though being well suited to visualize the effect of orientation pinning on the resulting textures, is not capable of predicting the textures in a quantitative manner.

According to the above model, Goss-grains have a low probability of being pinned by immobile grain boundaries. This is consistent with experimental observations that Goss-grains are less surrounded by Σ1- and Σ3-CSL grain boundaries in the recrystallized microstructure than grains with other orientations [6,7]. Hence, the Goss-orientation – present with weak intensity in the primary recrystallization texture – is strongly enhanced to the disadvantage of {111}<112>, the major recrystallization texture component. These results strongly suggest that orientation pinning indeed contributes to the preference of the Goss-orientation during secondary recrystallization.



(a) spectrum of potentially growing grains (a) modeled texture after secondary recrystallization

Figure 6: Influence of orientation pinning on the Goss-texture.

Besides the preference of the Goss-orientation, the model predicts the orientation {001}<310>, which turned out to be the main accompanying texture component in material of poorer magnetic quality [13,14]. Thus, this orientation, as well, is little affected by orientation pinning and, therefore – if present as minor component in the recrystallization texture – experiences a good growth prospect into the primary recrystallized structure.

Acknowledgments

The authors would like to thank Mr. H.J. Schmitz (RWTH Aachen) for performing the EBSD-measurements and Dr. B. Hammer (Thyssen Krupp Stahl) for valuable discussions. The work by one of the authors (OE) has been supported by the U.S. Department of Energy and by the Alexander von Humboldt-Foundation (Bonn) through a Feodor Lynen Research Fellowship.

References

1. S. Taguchi, Trans. ISIJ 17 (1977), 604-615.
2. M. Matsuo, ISIJ Int. 29 (1989), 809-827.
3. J.E. May, and D. Turnbull, Trans. AIME 212 (1958), 769-782.
4. S. Taguchi, et al., J. Magn. Magn. Mater. 2 (1976), 121-131.
5. G. Ibe, and K. Lücke, Archiv für das Eisenhüttenwesen 39 (1968), 693-703.
6. J. Harase, and R. Shimizu, Acta metall. mater. 38 (1990), 1395-1403.
7. N. Rouag, G. Vigna, and R. Penelle, Acta metall. mater. 38 (1990), 1101-1107.
8. K.T. Lee, and J.A. Szpunar, Canad. Metall. Quart. 34 (1995), 257-263.
9. N. Abe, Y. Ushigami, and N. Takahashi, Mat. Sci. Forum 204-206 (1996), 581-586.
10. D. Juul Jensen, Proc. 16th Risø Int. Symp., eds. N. Hansen et al., (Roskilde, Denmark: Risø Nat. Lab., 1995), 119-137.
11. R.D. Doherty, Prog. Mater. Sci. 42 (1997), 39-58.
12. O. Engler, Acta mater. 46 (1998), 1555-1568.
13. B. Hammer, et al., J. Magn. Magn. Mater. 112 (1992) 162-164.
14. F. Friedel, B. Hammer, and O. Engler, in preparation
15. H.J. Bunge, Texture Analysis in Materials Science (London: Butterworths, 1982).
16. L. Seidel, M. Hölscher, and K. Lücke, Textures and Microstructures 11 (1989), 171-185.
17. Y. Inokuti, and F. Saito, Trans. JIT 33 (1992), 480-486.
18. Y. Hayakawa, M. Muraki, and J.A. Szpunar, Acta mater. 46 (1998), 1063-1073.