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Texture Evolution during the Processing of Electrical Steels with 0.5% Si and 1.25% Si

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The development of the crystallographic texture in the processing of a 0.5 % Si semi-processed steel sheet has been investigated. The results were also compared with those of a steel with 1.25 % Si and 0.22 % Al, to verify the effect of the chemical composition. The texture was examined after the following steps: i) hot band ii) 80–90 % cold reduction iii) annealed iv) after skin pass v) after final annealing. The texture is very similar for both chemical compositions. The hot band presents an almost random texture. After 80–90 % cold reduction, a typical rolling texture of steels is observed, containing the fibers ⟨110⟩//RD and ⟨111⟩//ND. After annealing, the fiber ⟨111⟩//ND is the most important component, but now with maximum at {111}⟨112⟩. After skin pass and final annealing, the main components are the fiber {111}⟨uvw⟩ and Goss (110)[001]. The results indicate that the Goss intensity tends to increase for smaller values of skin pass (where final grain size also increases). The change of Si content (from 0.5 % up to 1.25 % Si) and of Al (from ~0 upto 0.22 %) did not produce significant variation about the texture components.

KEY WORDS: electrical steels; texture; recrystallization.

1. Introduction

The ideal texture for non-oriented electrical steels is {100}⟨0vw⟩. Nevertheless, there is no commercial (low-cost) method able to attain that texture. So, the usual procedure for texture optimization in non-oriented electrical steels is by avoiding grains with orientation such as {111} or {211}, *i.e.* planes without easy magnetization direction parallel to the plane of the sheet, trying to replace them by grains like {100} or {110}.

Electrical steel texture development has been investigated[1–9] and the effect of the hot band grain size has been the subject of several studies.[6–8] But, more specifically, the effect of silicon on the texture development of semi-processed electrical steels was not studied in depth. Among the reports on this subject are those of Kestens *et al.*[1] that discussed the recrystallization texture in high Si steels and Hou,[2] which found more favorable recrystallization textures for steels with higher Si content. Few data is available about the effect of Si on deformation texture, and one of the rare studies is that of Sudo *et al.*,[9] often mentioned in reviews.[10,11]

The aim of this work is examining the texture in all steps of the processing of semi-processed electrical steels, and providing data about both, the deformation and recrystallization textures in Si steels.

In this study, we follow the change of crystallographic texture of a 0.5% Si steel sheet during processing. The results are also compared with those of a 1.25% Si and 0.22% Al steel sheet, to acquire data about the effect of chemical composition. The texture data come from the steps: i) hot band, ii) after 80–90% cold reduction, iii) annealed, iv) after skin pass, v) after final annealing and recrystalization.

2. Experimental

Steel samples were processed in such way to reproduce typical conditions of industrial production. The A and B alloys permit us follow the evolution of texture during the processing of semi-processed electrical steels with different Si and Al content. The composition of the alloys are presented in **Table 1**.

A and B samples were submitted to the following processing:

Hot rolling to 2.7 mm: soaking temperature of 1 150°C, finishing temperature 900°C, plus 5 h at 750°C, producing grain size of 18±2 μm (alloy A) and 16±2 μm (alloy B).

Table 1. Chemical composition and electrical resistivity of alloys A and B.

Alloy	%Si	%Al	%Mn	%P	%S	N (ppm)	ρ (μΩ.cm)
A	0.54	0.04	0.31	0.045	0.006	53	20.5
B	1.25	0.22	0.3	0.01	0.005	54	32

Table 2. Codes for the different samples of alloys A and B.

name	Step
HB	Hot band
CR	Cold rolled, ~80% reduction
N	After intermediary annealing under nitrogen
V	After intermediary annealing under vacuum
XX%	Skin-pass reduction
FA	Final Annealed

Those samples will be named A-HB and B-HB (where HB means "hot band").

The same samples were, in a further step, cold rolled from ~2..7 mm down to ~0.53 mm of thickness, a 80% reduction. The cold rolled samples will receive the denomination A-CR and B-CR. These samples were submitted to two different types of intermediate annealing: one under nitrogen and other under vacuum.

There is slight difference concerning the different cycles:

Nitrogen:

slow heating holding at 680°C for 5 h, slow cooling

Vacuum:

heating at 1 000°C/h, holding 720°C during 5 min, cooling at 200°C/h

After these cycles, the measured grain size was (N: 14–15±2 μm) (V: 11–12±2 μm).

The samples after intermediate annealing will be called of A and B (followed by N or V, according to the kind of annealing).

After the intermediate annealing, A and B samples suffered skin-pass between 4 to 20% reduction. After all, they were recrystallized. Thus, the number XX%, refers to skin-pass, and FA means they were submitted to final annealing at 760°C for 2 h under a decarburizing atmosphere. The codes applied for the samples are given in **Table 2**.

The crystallographic texture was evaluated by means of ODFs calculated with harmonic method from X-ray pole figures[12] obtained in a Philips X-Pert XRD diffractometer equipped with texture goniometer.

3. Results and Discussion

3.1. Texture Evolution during the Processing of a 0.5% Si Electrical Steel (Alloy A)

In the sample A-HB (**Fig. 1**), we note a very random texture. The planes {110} are slightly more prominent, with Goss (110)[001] as the most important component in this weak texture.

We note in sample A-CR (**Fig. 2**) a typical rolling texture, often found in steels. The texture of sample A-CR has as main components the fibers ⟨110⟩//RD (with maximum at (211)[0$\bar{1}$1]) and ⟨111⟩//ND (with maximum at {111}⟨110⟩).

In the sample A-N (**Fig. 3**) fiber ⟨111⟩//ND is still present after recrystallization, but now with maximum at {111}⟨112⟩. Other important component is a fiber {100}⟨0vw⟩ with maximum at {100}⟨011⟩. It is very important to note that several of recrystallization components tend to appear in a range with orientation difference between 15° to 35° when compared with the components in the parent situation (sample A-CR, Fig. 2).

For sample A-V (**Fig. 4**), an almost identical trend of sample A-N (Fig. 3) is followed, fiber ⟨111⟩//ND.

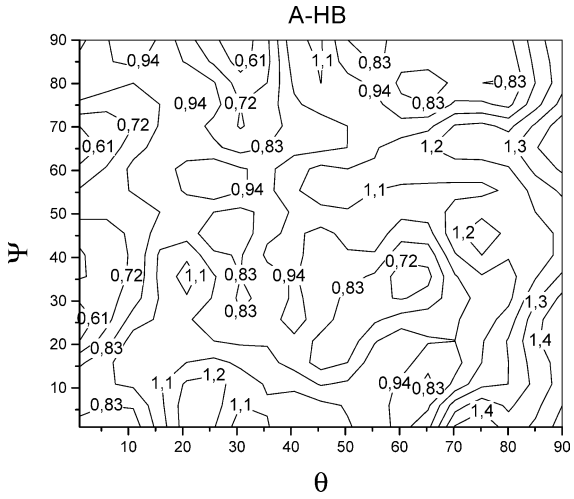

Fig. 1. Sample A-HB. ODF, section Φ=45°. Roe Notation.

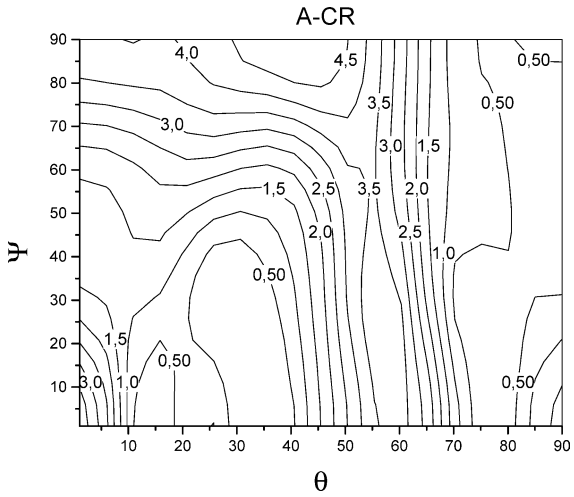

Fig. 2. Sample A-CR. ODF, section Φ=45°. Roe Notation.

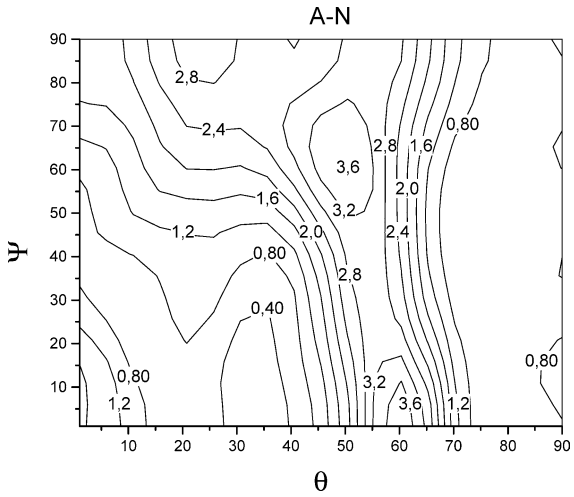

Fig. 3. Sample A-N. ODF, section Φ=45°. Roe Notation.

Two samples A-V received different skin-passes, 4% and 17%. After final anneal, sample A-V 4% FA presented grain size of 360 μm, while the grain size was 48 μm in sample A-V 17% FA.

The grain size of sample A-V 4% FA is too large, thwarting the sampling due to the small number of grains

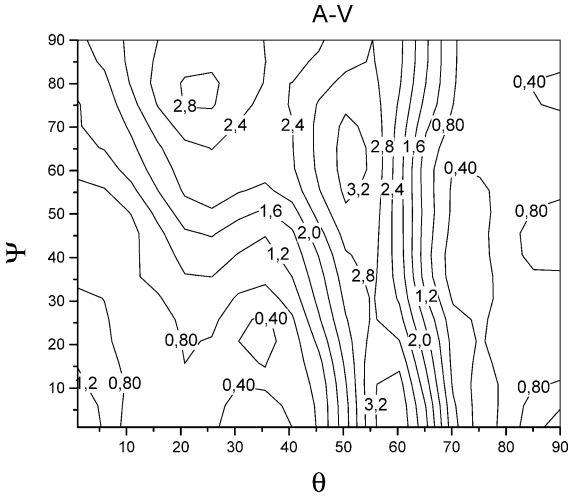

Fig. 4. Sample A-V. ODF, section Φ=45°. Roe Notation.

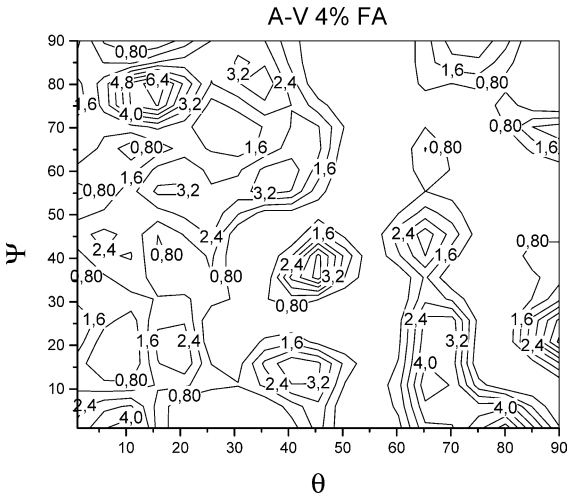

Fig. 5. Sample A-V 4% FA. ODF, section Φ=45°. Roe Notation.

measured to produce pole figures. Thus, this data may not be representative. The main components (**Fig. 5**) are near {100}⟨011⟩ and {110}⟨001⟩.

In the sample A-V 17% FA, we also note the tendency of "inversion" of the maximum of the fiber ⟨111⟩//ND (now with the maximum at {111}⟨110⟩) after recrystallization, see at sample A-N (compare **Fig. 6** with Fig. 4). The fiber ⟨110⟩//RD is also present, with maximum at {211}⟨011⟩. Goss (110)[001] has high intensity, but the component {100}⟨011⟩ is also very important. This texture is very similar to that of Fig. 2 (except the presence of Goss), showing that texture components may "reappear", after the process of annealing + rolling + annealing (but now as a recrystallization texture).

3.2. Texture Evolution during the Processing of a 1.25% Si Electrical Steel (Alloy B)

The texture observed for the samples of alloy B, **Figs. 7** up to **10** is quite similar to the textures of alloy A samples, presented in Figs. 1 to 4. The difference between the samples of A and B alloys are the Si and Al content (Table 1). Thus the obtained results allow us to infer that, in this case (*i.e.* for this specific experiment) the change of Si content almost did not affect the texture.

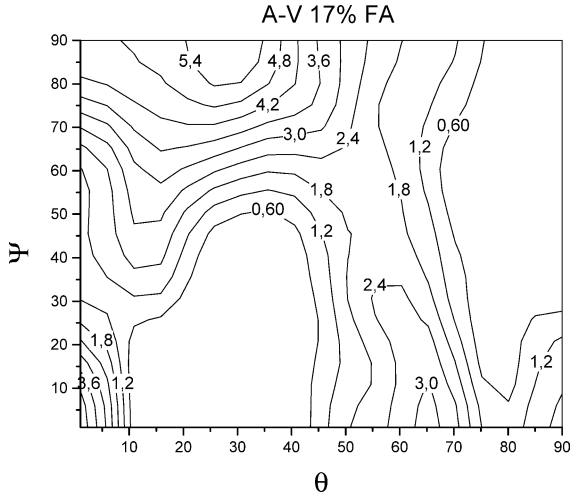

Fig. 6. Sample A-V 17% FA. ODF, section Φ=45°. Roe Notation.

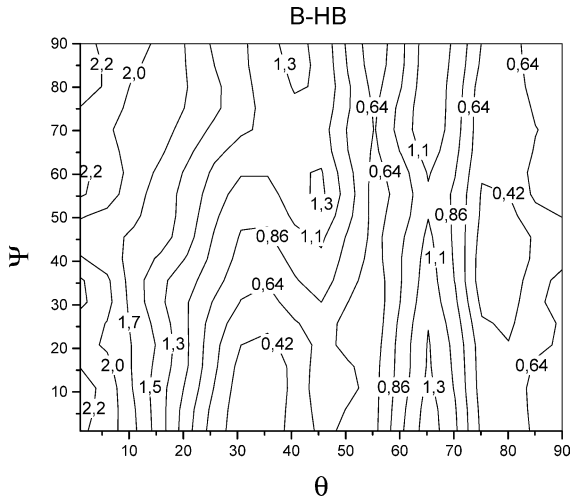

Fig. 7. Sample B-HB. ODF, section Φ=45°. Roe Notation.

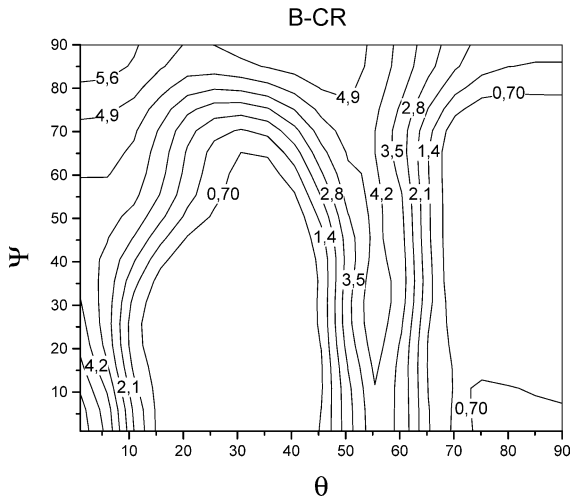

Fig. 8. Sample B-CR. ODF, section Φ=45°. Roe Notation.

For the sample B-HB (Fig. 7), we observe an almost random texture with a fibers {100}⟨0*vw*⟩ and ⟨111⟩//ND of weak intensity. The sample B-CR (Fig. 8) presents, again (as in Fig. 2), a typical rolling texture with the fibers ⟨110⟩//RD and ⟨111⟩//ND, this last one with maximum at

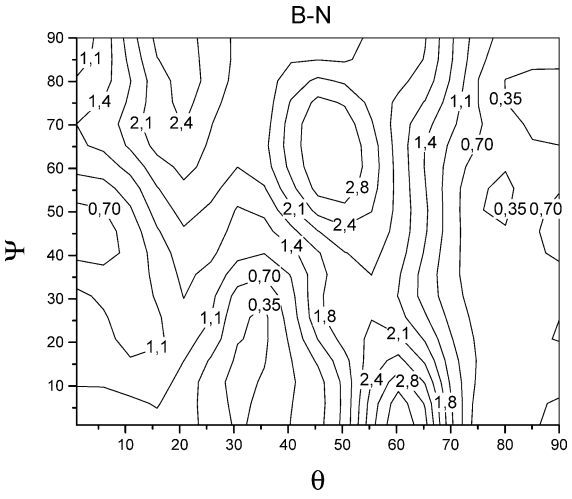

Fig. 9. Sample B-N. ODF, section Φ=45°. Roe Notation.

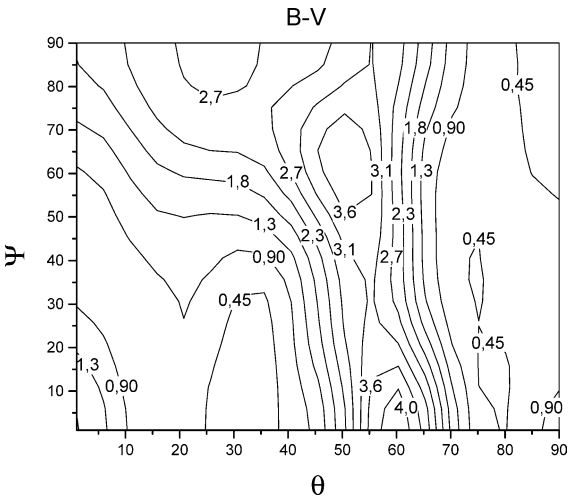

Fig. 10. Sample B-V. ODF, section Φ=45°. Roe Notation.

{111}⟨110⟩.

Cold rolled samples show fiber ⟨110⟩//RD, with maximum at {211}⟨011⟩ and significant {100}⟨011⟩ (Fig. 8). Intermeadiate annealing samples B-N (Fig. 9) and B-V (Fig. 10) present the same texture components seen at samples A-N (Fig. 3) and A-V (Fig. 4). Both samples B-N and B-V have strong fiber {111}⟨uvw⟩ with maximum at {111} ⟨112⟩. We note again that several components of intermediate anneal show differences of orientation around 15° to 35° to the texture components of the cold rolled sample (sample B-CR, Fig. 8).

4. Final Remarks

Comparing the data for alloys A and B (A: 0.54% Si, 0.04% Al) (B: 1.25% Si, 0.22% Al) we may discuss the effect of Si on texture.

The recrystallization textures of samples A-V, A-N, B-V and B-N are similar to those previously found for the specific case of small (~20 μm) hot band grain size.[8,13] The deformation textures found for the Si-steels evaluated in this study are also in accordance with those reported in literature for the case of low carbon steels with no silicon.[14–16]

There is lack of data in the literature about the effect of Si on texture of steels. Concerning deformation texture Sudo *et al.*[9] mention that an increase of Si content would provide a small increase on the intensity of fiber ⟨110⟩//RD (alpha fiber). Similar trend is observed when comparing Figs. 2 to 8. However, a definitive conclusion about the possible effect of Si on deformation texture is not possible, because the difference between samples A-CR and B-CR is very small.

It seems that some differences could be noted when sample A-HB (see for example the very weak fiber {110}⟨uvw⟩, Fig. 1) is compared with sample B-HB (see for example the weak fiber {100}⟨0vw⟩, Fig. 7). The different chemical compositions of alloys A and B imply in some important differences: the hot rolling finishing temperature 900°C is below Ar1 transformation temperature for sample A (0.54% Si) and above Ar1 transformation temperature for sample B (1.25% Si and 0.22% Al). Nevertheless, both alloys A and B resulted in hot bands with similar texture, near to the random.

We conclude that, in general, it is very difficult to identify any significant effect of Si content on the texture development during the processing.

It is also important to note that the presence of Goss components in final anneal (FA) texture (as showed in Fig. 6) will result in large anisotropy of magnetic properties.[17,18] This situation (strong presence of Goss components) is typical in commercial non-oriented electrical steels.[17]

The texture of the two steels evaluated in this study are far from the ideal {100}⟨0vw⟩. There is, however, significant space for improvements. We believe that the main tendencies of optimization of texture in electrical steels should focus in two main directions:

i) Replacement of {111} or {211} grains by {0kl} grains;
ii) Reduction of anisotropy.

It is presumable that both paths will require more steps during processing (and, thus resulting in a longer and more complex process), thwarting the economic viability of commercial application.

5. Conclusions

For both alloys (0.5% Si and 1.25%Si+0.22%Al), the texture situation of hot band is very similar: we observe a random hot band texture. After 80–90% of cold reduction, a typical BCC rolling texture develops. This texture is often found for low carbon steels, and presents the fibers ⟨110⟩// RD e ⟨111⟩//ND. After annealing, we note again the presence of a fiber ⟨111⟩//ND, but now with maximum at {111} ⟨112⟩. After skin-pass and final annealing, we find, among the main components the fiber {111}⟨uvw⟩ and Goss component (110)[001]. The results indicate that Goss intensity tends to increase when the skin pass is reduced (and the grain size increases). We did not find significant difference on the texture condition when the Si content (from 0.5 to 1.25% Si) and Al content (up to 0.22%) were increased. It was observed a very interesting result from one of the samples: texture components may "reappear", after a complex process that includes annealing + rolling + annealing.

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REFERENCES

1) L. Kestens, J. J. Jonas, P. van Houtte and E. Aernoudt: *Metall. Trans. A*, **27A** (1996), 2347.
2) C.-K. Hou: *J. Magn. Magn. Mater.*, **162** (1996), 280.
3) J. Park, J. A. Szpunar and S. Cha: *Mater. Sci. Forum*, **408–412** (2002), 1263.
4) M. Shiozaki and Y. Kurosaki: *Textures Microstruct.*, **11** (1989), 159.
5) S. W. Cheong, E. J. Hilinski and A. D. Rollett: *Metall. Trans. A*, **34A** (2003), 1311.
6) H. Yashiki and A. Okamoto: *IEEE Trans. Mag.*, **23** (1987), 3086.
7) C.-K. Hou: *ISIJ Int.*, **36** (1996), 563.
8) M. F. de Campos, F. J. G. Landgraf, R. Takanohashi, F. C. Chagas, I. G. S. Falleiros, G. C. Fronzaglia and H. Kahn: *ISIJ Int.*, **44** (2004), 591.
9) M. Sudo, S. Hashimoto and I. Tsukatani: Proc. of 6th ICOTOM–Int. Conf. on Textures of Materials, ISIJ, Tokyo, (1981), 1076.
10) R. K. Ray, J. J. Jonas and R. E. Hook: *Int. Mater. Rev.*, **39** (1994), 129.
11) A. D. Rollet, S. I. Wright: Texture and Anisotropy, ed. by U. F. Kocks, C. N. Tomé and H.-R. Wenk, Cambridge University Press, Cambridge, (1998), 178.
12) R.-J. Roe: *J. Appl. Phys.*, **36** (1965), 2024.
13) F. J. G. Landgraf, R. Takanohashi, F. C. Chagas, M. F. de Campos and I. G. S. Falleiros: *J. Magn. Magn. Mater.*, **215–216** (2000), 92.
14) B. Hutchinson: *Philos. Trans. R. Soc.* (*London*) *A*, **357** (1999), 1471.
15) H. Inagaki: *Z. Metallkd.*, **78** (1987), 431.
16) H. Inagaki: *ISIJ Int.*, **34** (1994), 313.
17) M. Emura, M. F. de Campos, F. J. G. Landgraf and J. C. Teixeira: *J. Magn. Magn. Mater.*, **226-230** (2001), 1524.
18) M. F. de Campos, F. J. G. Landgraf and A. P. Tschiptschin: *J. Magn. Magn. Mater.*, **226-230** (2001), 1536.