Influence of cubic texture intensity of hot rolled ferritic non-oriented electrical steels on the microstructure and texture in the final processed material

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Abstract. The magnetic properties of non-oriented electrical steels are determined by the microstructure and texture of the material. Besides optimum grain size (microstructure) for low values of specific magnetic losses, a high intensity of θ-fibre texture and low intensity of γ-fibre and α-fibre texture is desirable. Each of the processing steps influences the intensity of the θ-fibre in the final processed material. In this paper the interplay of the various processing steps on the intensity of the θ-fibre is regarded for ferritic Iron-Silicon steels with 2.4 wt.% Si and 3.0 wt.% Si.

1. Introduction

Ferritic Iron-Silicon (FeSi) steels form the basis for low loss grades of non-oriented electrical steels. As well known the magnetic properties of electrical steels generally depend on the crystallographic direction and structural heterogeneity. In bcc iron the <100> direction is the easiest direction of magnetization. For excellent magnetizing behaviour a high intensity of θ-fibre (〈100〉||ND) and a low intensity of α- and γ-fibre is preferable. FeSi steels with a silicon content higher than 2 wt.% and a carbon content of less than 0.002 wt.% exhibit no phase transformation [1]. Therefore, no homogenisation of the microstructure during hot rolling takes place. Besides the specific technological rolling parameters, the existing gradients of strain and temperature affects much more the resulting microstructure and texture at the production of the hot strip compared to steels with a phase transformation [2-4]. It was found that higher intensities of θ-fibre can be obtained in the hot strip. It was also observed that higher intensities of the preferable θ-fibre texture of the hot strip result in a higher intensity after cold rolling. The results of previous studies indicate that there is an interaction between the microstructure and texture of the various processing steps: hot rolling, optional hot strip annealing, cold rolling and final annealing [3].

2. Experimental procedure

The hot rolled material, see Table 1, was prepared on the four stand hot rolling pilot line at the Institute of Metal Forming (IMF), TU Bergakademie Freiberg. An additional hot strip annealing was performed with sample E and F (T_{max} = 900°C for 120 s, heating rate 4 K/s, cooling rate 20 K/s). Cold rolling was realised on a two-high cold rolling mill at the IMF within 5 passes with a total reduction of 70% to 75%. Final annealing was done in an annealing furnace at the IMF for the simulation of a continuous annealing line.

Table 1: Parameters of hot rolling

| Sample | d (mm) | Si (wt.%) | RT (°C) | FT (°C) | Rapid cooling to °C | A-T °C | A-t min | Cooling to °C with K/h |
|--------|--------|-----------|---------|---------|---------------------|--------|---------|-----------------------|
| A      | 1.1    | 3.0       | 1250    | 645     | -                   | -      | -       | 200°C, 270 K/h        |
| B      | 2.3    | 3.0       | 1150    | 690     | -                   | -      | -       | 200°C, 130 K/h        |
| C      | 1.3    | 2.4       | 1250    | 1000    | 925                 | 750    | 20      | 200°C, 50 K/h         |
| D      | 1.3    | 2.4       | 1250    | 930     | 700                 | -      | -       | 200°C, 50 K/h         |
| E      | 2.0    | 2.4       | 1150    | 1010    | 950                 | 750    | 270     | 200°C, 50 K/h         |
| F      | 2.0    | 2.4       | 1150    | 820     | 400                 | -      | -       | -                     |

d – thickness after hot rolling; RT – Reheating temperature; FT – hot rolling finishing temperature; A-T – annealing temperature; A-t – annealing time; * additional hot strip annealing before cold rolling

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Light microscopy, SEM and EBSD was used to investigate the microstructure. The IFW Dresden and the Stahlzentrum e.V. Freiberg did the EBSD measurements. Both use the EDAX system. The optical microscopy and EBSD measurements were carried out in the plane perpendicular to the sample transverse direction. Measurement settings were like in [6], the map size depends on the cross section of the sample, which was measured completely. To analyse the texture data the program MTEX was used [5]. The orientation distribution functions ODFs were calculated by the harmonic series expansion method assuming orthorhombic sample symmetry, with a half width of 5° and a resolution of 5°. Results of the texture measurements are presented as constant $\phi_2 = 45^o$ section of the ODF. Of particular interest are the $\theta$-, $\alpha$- and $\gamma$-fibre [7].

3. Results and Discussions

3.1 Hot rolled material

Figure 1 shows the cross section of hot rolled material with a low finishing temperature without any further heat treatment (specimen A and B). The cross section reveals a heterogeneous character of the microstructure. The grains in the mid-thickness region are elongated bands and pancake shaped. Within the bands no grain boundaries appear and the orientation is identical. The region close to the surface has elongated grains but has also small equiaxed grains and many grain boundaries. The reason for the heterogeneity is the gradient of strain during the hot rolling and the temperature schedule after finishing hot rolling. The texture consists of rotated cube $\{100\}<110>$ components and the thinner material has a lower intensity of the $\alpha$-fibre and $\gamma$-fibre than the thicker material.

![Figure 1](image1.png)

*Figure 1: Hot rolled sample A and B; microstructure (BSE); orientations $\{100\}<110>$ (gray shading) deviation of 15° and grain boundaries calculated with misorientation > 10°; texture ODF $\phi_2=45^o$ for total cross section*

Figure 2, sample C and D with strip thickness 1.3 mm, illustrates the resulting texture depending on a thermal treatment immediately after the last pass of hot rolling. At appropriate finishing temperatures at hot rolling and annealing conditions immediately after the last hot rolling pass a higher intensity of the desired $\theta$-fibre texture can be obtained. For different thicknesses of the hot rolled material, in the range of 1.3 mm to 2.3 mm, similar conditions of hot rolling finishing temperature and annealing conditions after the last hot rolling pass lead qualitatively to the same image of the texture.
Hot strip annealing, as an additional processing step before cold rolling, can also cause a higher intensity of preferable magnetic texture, see Figure 3. The microstructure changes from a deformed to an equiaxed structure with few bands in the mid-thickness layer.

3.2 Cold rolling and annealing

The intensity of the rotated cube component remains after cold rolling, see Figure 4. A higher intensity of this component were found for the samples, which had already more pronounced rotated cube components in the hot rolled state. The appearance of the microstructure has not changed much in comparison with the hot rolled state. The surface layer has no equiaxed grains, almost no grains are visible and every part shows a deformed structure. The mid-thickness layer stills shows the elongated bands without grain boundaries and with a homogenous orientation.

Results obtained after final annealing of the cold rolled material are exemplary presented in Figure 5. The texture intensities of the final annealed samples depends sensitively on the annealing conditions. It was possible to keep the θ-fibre but the intensities and the recurrence of the γ-fibre cannot be prevented. It seems that a smaller heating rate is beneficial. Similar results were found for the other samples.
Figure 4: Sample A and B, cold rolled with total reduction of 70%, microstructure (BSE) and ODF section $\phi_2 = 45^\circ$ (total cross section, EBSD-data)

Figure 5: Sample A different final annealing treatments, $hr$ – heating rate, $cr$ – cooling rate, $T$ – annealing temperature, $t$ – holding time at $T$, RT – room temperature; a) $hr = 2.6$ K/s, $T_{\text{max}} = 900^\circ$C, $t = 120$ s, quenching to RT; b) $T_1 = 650^\circ$C, $t_1 = 60$ s, $T_2 = 950^\circ$C, $t_2 = 60$ s; c) $T_1 = 650^\circ$C, $t_1 = 120$ s, $T_2 = 950^\circ$C, $t_2 = 120$ s

4. Conclusions
A high intensity of $\theta$-texture in the hot strip can be obtained by different hot rolling parameters as described. Cold rolling reduces the preferable cube texture intensity. In the cold rolled state the typical rolling textures $\alpha$- and $\gamma$-fibre appear. Nevertheless, the results show a higher intensity of $\theta$-fibre texture after cold rolling for hot strip with higher intensity of this texture fibre component. The final annealing destroys the desired high intensity of $\theta$-fibre, if the process is not controlled in an appropriate way (heating rate, maximum annealing temperature, two step annealing). More studies are necessary to collect experimental data for the interplay of the different steps and to realise a modelling and of the underlying processes.

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