Effect of Hot and Cold Rolling on Grain Size and Texture in Fe-Si Strips with Si-Content Larger than 2 wt%

E. Gomes[1,a], J. Schneider[1,2,b] K. Verbeken[1,3,c], H. Hermann[2] and Y. Houbaert[1]

[1]Ghent University, Department of Materials Science and Engineering, Technologiepark 903,
B-9052 Ghent, Belgium

[2]Institut für Metallformung, Technische Universität Bergakademie Freiberg, Bernhard-von-Cotta-Str.4, D-09596 Freiberg, Germany

[3]Postdoctoral Fellow of the Fund for Scientific Research F.W.O.-Vlaanderen – Belgium

[a]edgar.gomes@UGent.be; [b]schneider.juergen@t-online.de; [c]kim.verbeken@UGent.be

Keywords: Hot rolling, cold rolling, Fe-Si alloys, microstructure and texture.

Abstract. The crystallographic texture and grain size have a strong influence on the magnetic properties of FeSi alloys. These microstructural parameters are determined by the thermo-mechanical processing of the material. Here, some recent results on FeSi-alloys with variable Si-content and without phase transformation are presented. Hot rolling conditions were varied in broad interval of parameters and afterwards, the samples were cold rolled and annealed. After the different processing steps, the samples were characterized by optical microscopy, X-ray diffraction and Electron BackScatter Diffraction (EBSD) in order to evaluate the texture, grain size and the homogeneity of the structure through the thickness. This allowed to study the evolution of the intensity of the favourable magnetic texture components during processing.

Introduction

Fe-Si alloys, with a Si content that is high enough to suppress the ferrite to austenite transformation, are widely used for non-oriented electrical steels because of their low values for the specific magnetic losses. The magnetic properties are influenced by metallurgical factors such as the chemical composition and the processing parameters during reheating, hot rolling, cold rolling and annealing. The relevant structural features: i.e. grain size, distribution of crystallographic orientations as well as the appearance of precipitates are influenced by these thermomechanical properties. The ability to control these features throughout the manufacturing process is self-evidently of great technical importance. The main focus for electrical steels is to evaluate the effect of rolling and annealing on the resulting grain size and on the intensity of the favourable texture components: i.e. the {110}<001> Goss, {100}<001> cube and {100}<110> rotated cube components, and fibres, i.e. the theta ({100}<uvw>) and eta ({hkl}<100>) fibre. Furthermore, a homogeneous structure across the thickness is preferable. Compared to conventional steels, the understanding of the evolution of the microstructure along the processing route for these Fe-Si alloys is far less from complete. The relevant magnetic crystallographic orientations are mostly not regarded in conventional steels, where a large gamma fibre ({111}<uvw>) is of interest. Furthermore, a small grain size is desirable for high strength steels, whereas large grains are beneficial for electrical steels because they lower the losses.

It has been shown that a hot band annealing of Fe-Si alloys improves the magnetic properties [1] [2]. The hot band annealing, especially for Fe-Si alloys with phase transformation, leads to an enhanced intensity of the Goss and cube texture as well as of the eta-fibre. Similar effects may be obtained by choosing higher coiling temperatures after hot rolling [3]. It has also been demonstrated that a coarse grained hot band structure gives a higher intensity of Goss texture [4][5]. A final hot rolling in the two phase region and ferritic region may also result in better magnetization behaviour of the materials[6][7].

Little or no literature data are available on the effect of different hot rolling parameters, as well as the optimum combination of the processing conditions during hot rolling, cold rolling and annealing, on the resulting texture intensities in Fe-Si alloys without phase transformation. The interest in the case of for example ferritic stainless steels, was limited to the α and γ-fibre as well as the Goss component, which appear in shear deformation in the surface region, and their intensities in the hot rolled and annealed state. The aim was to obtain a high intensity of the γ-fibre in the final annealed material. A high intensity of the γ-fibre has to be avoided for the FeSi material. Moreover, there is no model available that correlates the microstructural characteristics and their evolution along the processing route with the magnetic properties of the resulting material.

Any modelling of the evolution of the structural features during hot rolling in such Fe-Si alloys needs beside a detailed study of the flow curves at practical relevant processing parameters [8] a complex characterization of the softening behaviour: dynamic and static recovery and recrystallization behaviour during hot rolling as well as cold rolling and annealing. We will present in this paper results on the evolution of the grain structure and textures along the processing route for two Fe-Si alloys with a Si-content larger than 2wt%. Thereby, special attention is given to the appearance of the cube texture at different hot rolling conditions.

Experimental Procedure

At first, hot rolled samples of Fe-2.4wt%Si and Fe-3.0wt%Si with a width of 80mm and a thickness of 2mm were fabricated using the four stand high speed hot rolling mill at TU Freiberg. Before hot rolling, the materials have been annealed at 1260°C. The final thickness was reached after six passes. The reduction was larger than 40% in the first five passes. The finishing temperature (FT) and the subsequent cooling conditions to 200°C have been varied over a wide range of parameters. On the one hand, FT varied between 700°C and 1100°C and on the other hand, after finishing, the samples were rapidly cooled to temperatures ranging from 400°C to 950°C and followed by a variable holding time and temperature. Finally, the samples were slowly cooled to 200°C at a constant rate of 50K/h. The hot rolling process summary of the studied samples is shown in the Table 1. After hot rolling, the samples were cold rolled to a thickness of 0.50mm. Finally, annealing was realized in a laboratory furnace to simulate the continuous annealing process. The samples were rapidly annealed to about 950°C in 45s and finally cooled to 200°C in 300s. Besides metallographic investigations with optical microscopy, the Electron BackScatter Diffraction (EBSD) technique was used for detailed. Orientation distribution functions (ODFs) were measured using EBSD on a FEI XL30 ESEM equipped with a LaB_6-filament and XRD on a Siemens D5000 diffractometer, using MoK_α radiation (λ= 0.070926nm). The step sizes at EBSD were 0.8, 5 and 10 µm. The texture was analyzed by ODFs in the φ_2 = 0° and 45° sections. The grain size was determined using the linear interception technique. The homogeneity of the grain size and texture across the thickness was also analyzed.

Sample Name	*Si Content*	*Finishing Temperature*	*Rapid Cooling To*	*Holding Temperature (Baking time)*	*Slow Cooling To*
A	2.4%	860°C	800°C	750°C (20min)	200°C
B	2.4%	1010°C	950°C	750°C (2h)	200°C
C	3.0%	820°C	400°C	-	200°C
D	3.0%	860°C	800°C	750°C (2min)	200°C

Table 1: Summary of the hot rolling parameters for the different samples studied.

Results

Microstructure and Texture of Hot Rolled Samples

Figures 1 and 2 show the optical micrographs for quite different hot rolling schedules for both materials. As expected, rapid cooling from the finishing temperature at hot rolling to 400°C results in a deformed structure across the thickness of the strip for both alloys, see Fig. 1 (left). Although high finishing temperatures and a thermal treatment at 750°C causes for both alloys large grains in the sample, the central region still displays a deformed structure, see Fig. 1 (right). At moderate finishing temperatures of 800°C to 860°C recrystallized grains appear in the surface region for both alloys. In the region of about a quarter of the thickness recrystallized grains as well as non-recrystallized zones appear, see Fig. 2. This resulting grain structure may be correlated with the different stress levels after hot rolling as a function of s (distance from the central line; s = 1 – surface). The small grains at the surface are characterized mainly by high intensities on the well-known bcc shear components. It was also found that the crystallographic orientations of the deformed area of the A sample consisted mainly of the rotated cube orientation, which is interesting for magnetic applications, see Fig. 3 (right). For the hot rolled FeSi3.0 samples with TF: 850°C to 950°C the lowest intensities of the α and cube fibres are observed independent of the cooling conditions. For the other samples, the ODF obtained from EBSD measurements on a TD section, displays remarkable intensity on the α fibre, a maximum at the rotated cube component and a weak gamma fibre, see Fig. 3 (right), Fig. 4 (left) and Fig. 4 (right) respectively.

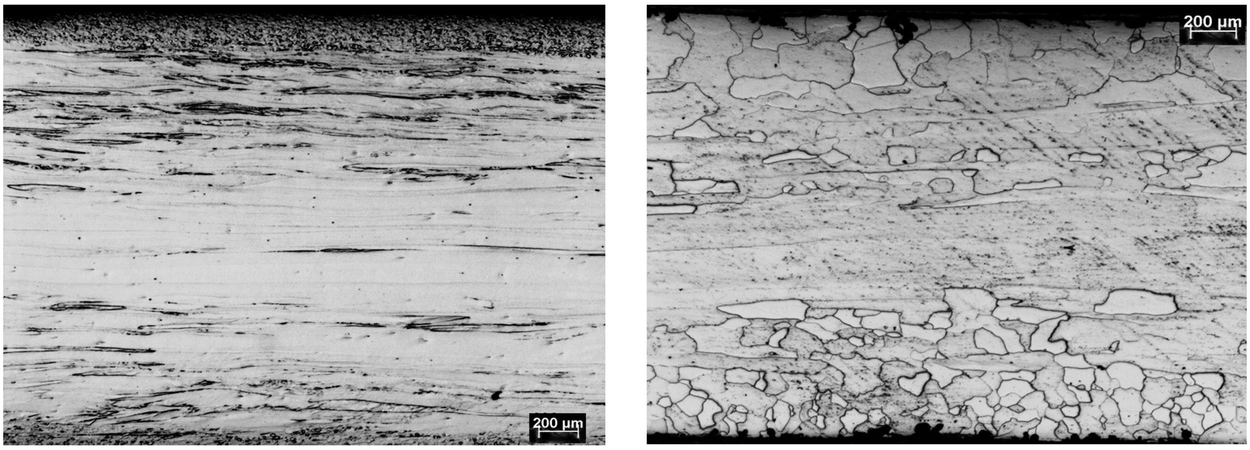

Fig. 1: Optical micrographs for sample C (left) and optical micrographs for sample B (right).

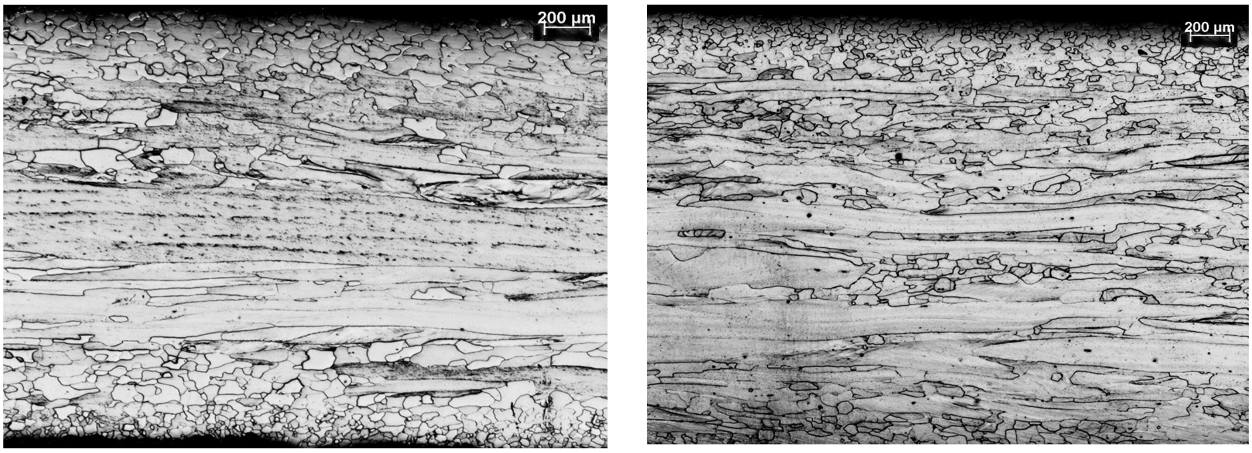

Fig. 2: Optical micrographs for sample A (left) and for sample D (right).

The texture analysis by XRD at different depths s (s = 0 central line; s= 1 surface) indicate high cube texture at s = 0 for the sample A, while for the sample D the intensity of the cube fibre is very low, see Fig. 5. Even at s = ¼ the intensity of cube texture of sample A is relatively large and becomes finally low in the surface region. Although it must also be mentioned that the very large grain size probably influences the obtained texture, even when the XRD is used.

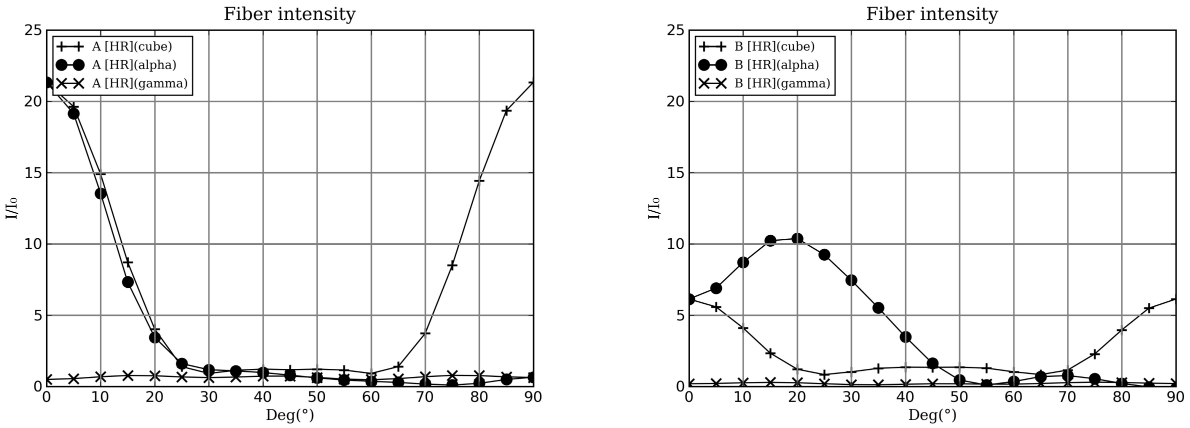

Fig. 3: Texture intensities for α, γ and cube fibres in the $\varphi_2 = 45°$ section of hot rolled sample A (left) and texture intensities of hot rolled sample B (right) obtained by EBSD.

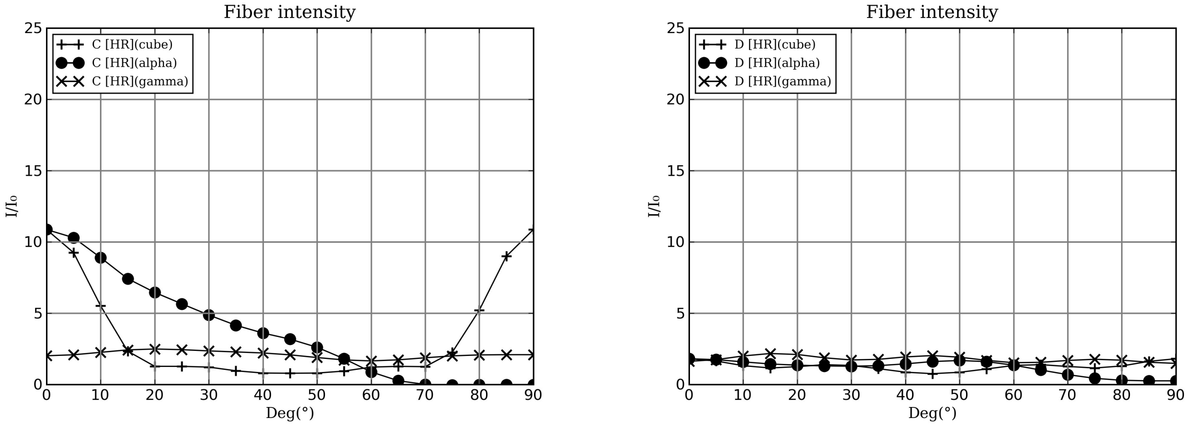

Fig. 4: Texture intensities for α, γ and cube fibres in the $\varphi_2 = 45°$ of hot rolled sample C (left) and texture intensities of hot rolled sample D (right) obtained by EBSD .

Microstructure and Texture of Cold Rolled and Annealed Samples

After cold rolling, the ODFs obtained from EBSD measurements reveal for both samples intensities on the alpha fibre and on the gamma fibre. Similar results were obtained by XRD.With respect to the relevant magnetic textures it is interesting to remark that increased intensity on the rotated cube component remains visible after cold rolling and that a higher intensity for this component is found for the sample which also already had a more pronounced rotated cube component in the central region after cold rolling. The realized annealing with a rapid increase to the maximum annealing temperature of about 950°C results in a remarkable drop of the intensity on the magnetically desired intensity of the cube fibre compared to the hot rolled state, see Fig. 6 Still there is a certain intensity of the magnetically favourable eta and theta fibres. In general the intensity of the γ fibre increases, as was also shown before [9].

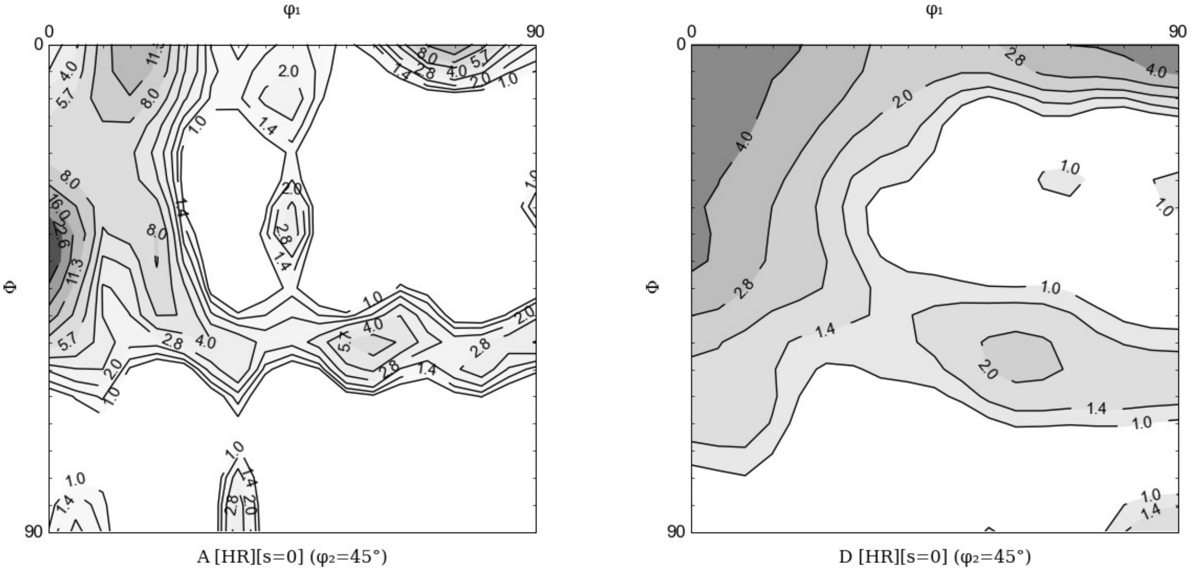

Fig. 5: φ2 = 45° section of ODF obtained by XRD of hot rolled samples of FeSi2.4 and FeSi3.0 (same samples as in Fig. 2) at the central line of the sample.

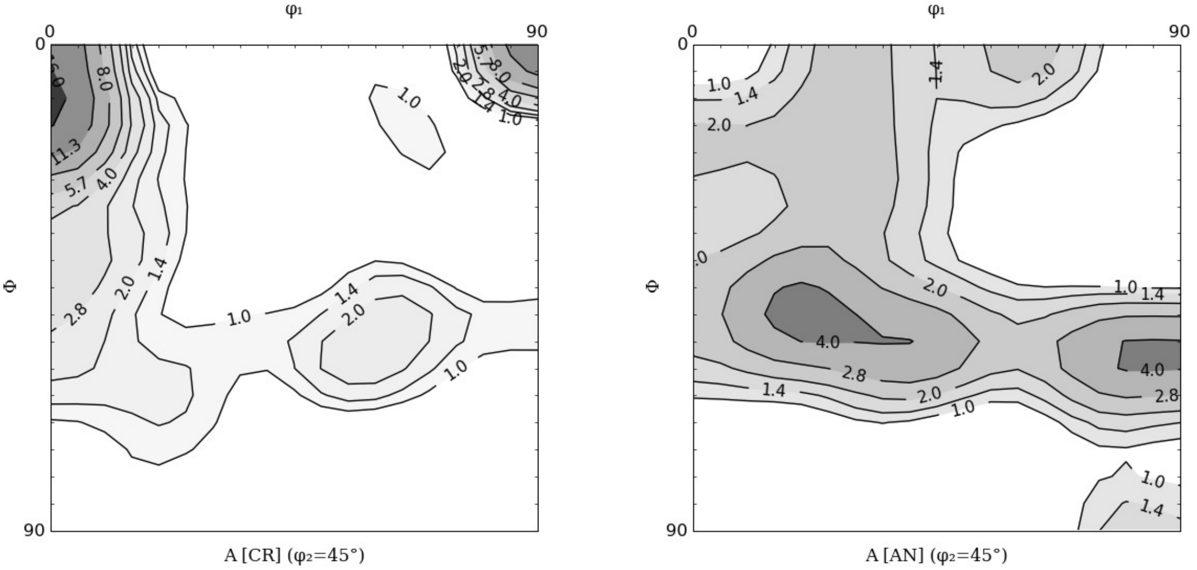

Fig. 6: φ2 = 45° section of ODF obtained from EBSD measurements for sample A after cold rolling (left) and after annealing (right).

Discussion

The observed microstructure and texture across the thickness in the hot rolled samples are for all, quite different, hot rolling conditions rather inhomogeneous. This observation is in agreement with the observations for hot band annealed FeSi based materials with high Si-content (no phase transformation).The resulting texture differs for the FeSi 2.4 and FeSi3.0 materials. The intensities of the α fibre and the cube fibre in the central region of the hot rolled materials depend sensitively on the chemical composition and the hot rolling conditions. In general, the observed textures in the central region resembles those observed for Cr containing stainless steels [10]. For the FeSi2.4 sample which is rapidly cooled to 800°C after hot rolling with TF = 860°C and then slowly cooled to 200°C, the gamma fibre intensities are practically lacking and the texture intensity is concentrated near the rotated cube component. Because of the slow cooling in the temperature interval between 800°C and 400°C, this sample had the opportunity to recrystallize and the rotated cube components appeared to be among the last to recrystallize. Similar results have been reported during recrystallization of cold rolled low carbon steels [11]. After annealing, as for the low carbon steels, we observe an increase of the intensities near the gamma fibre and a lowering of the intensities of the α fibre. The observed texture data are in agreement with the statements made in literature [5][12] that the effect of deformation at cold rolling depends on the starting grain size and that a rapid heating during annealing did not reduce the differences in residual stored energy among various texture components before recrystallization started.

A deeper understanding of the underlying mechanism for the appearance of high intensities of the preferred magnetic textures needs further investigations, especially of the effect of the hot rolling conditions (shear stress or planar stress) as well as of the rate of deformation at cold rolling and the heating rate at annealing.

References

[1] H. Yashiki and A. Okamoto: IEEE T. Magn. Vol. 23 (1987) p. 3086-3088

[2] H. Huneus, K. Gunther, T. Kochmann, V. Plutniok and A. Schoppa: J. Mater. Eng. Perform. Vol. 2 (1993) p. 199-203

[3] R. Kawalla, J. Schneider and A.Hensel: Proc. Workshop Metallurgy and Magnetism, TUBAF-Institut für Metallformung (2004)

[4] M. Kohno, M. Muraki, M. Kawano and M. Komatsubara: Mater. Sci. Forum Vol. 408-4 (2002) p. 785-790

[5] JT. Park, JA. Szpunar, and SY. Cha: ISIJ Int. Vol. 43 (2003) p. 1611-1614

[6] O. Fischer and J. Schneider, J: J. Magn. Magn. Mater. Vol. 254 (2003) p. 302-306

[7] R.Kawalla and J. Schneider: Proc. 16th Intern. Confernece Sin the φ_2 = 45°MM, Verlag Stahleisen GmbH Düsseldorf (2004)

[8] W. Müller et al, to be published

[9] K. Verbeken, J. Schneider, J. Verstraete, H. Hermann, and Y. Houbaert: IEEE T. Magn. Vol. 44 (2008) p. 3820-3823

[10] MY. Huh and O. Engler: Mater. Sci. Eng., A Vol. 308 (2001) p. 74-87

[11] K. Verbeken, L. Kestens and JJ. Jonas: Scr. Mater. Vol. 48 (2003) p. 1457-1462

[12] H. Inagaki: Z. Metallkd. Vol. 82 (1991) p. 265-274