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MAGNETICAL PROPERTIES OF SILICON STEELS USED FOR ELECTROTECHNICAL INDUSTRIES

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ABSTRACT

This paper-work shows the laboratory experiments achieved on more silicon steel plates, where the magnetic ranges were spot- lighted by particular technical requirements. On the same plates the texture analyses were made considering Goss characteristics, shape and orientation of the crystalline grains, too. Finally, a correlation between texture, structure and magnetic characteristics was gotten.

KEYWORDS: silicon steel plates, texture analyses, magnetic characteristics

1. Introduction

In silicon steels, the shape and grain-size have a particular importance, in great extent influencing the magnetically characteristics of the plates.

According to Weiss magnetic field hypothesis, [1] a ferro-magnetic material is made of great number of small regions characterized by a spontaneous parallel orientation of the electronical spins. In the absence of an external magnetic field, Ms magnetization vectors, of various zones, are so oriented that they cancel mutually and the body comes out as a nonmagnetized macroscopical one. These small regions are named spontaneous magnetization range or magnetic range [2].

In the absence of the magnetic field, Ms vector is oriented, in each range, alongside the gentle magnetization axis. It results that if we could see the magnetic range orientation, in a certain way, we should have an information of the crystallographic orientation of the respective plate.

For silicon steel the gentle magnetization axis is [100] and melts the rolling direction, and heavy magnetization axis [111] is at 55° to the axis [100] - fig. 1. This is Goss texture or "cube-on edge". A plate with such texture introduced in a magnetic field of which direction coincides to rolling direction (it means: to gentle magnetization direction) is easily magnetized getting very small magnetic losses ex: for B = 1.0 T, p< 0.6W/kg.

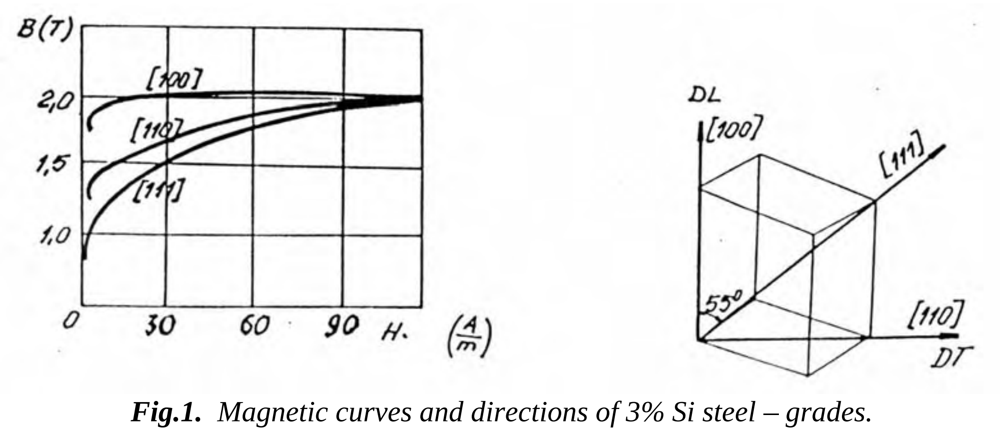


Fig.1. *Magnetic curves and directions of 3% Si steel – grades.*

2. Materials and experiments

In the paper framework, three silicon steel heats were studied and the chemical composition is written in table 1.

The samples were taken from the first cold rolled strips: rolling and black annealing.

***Table 1** Chemical composition of the tested steels*

Steel	C	Mn	Si	S	P	Al	Nb
	[%]						
1	0.004	0.08	3.04	0.015	0.009	0.002	0.09
2	0.004	0.07	3.02	0.020	0.013	0.070	-
3	0.003	0.07	3.04	0.022	0.009	0.010	-

The laboratory experiments were made on the two samples series [3]:

a) 1st series: different reduction ratio of the cold rolling, then secondary annealing for 6 hours at 1150°C. The influence of the reduction range on the texture and core losses in the finished strips was studied.

b) 2nd series: the samples were cold rolled to final thickness 0.35 mm, then secondary annealing at 900°C, 1000°C, 1150°C and hold in hydrogen atmosphere for 2, 4 and 6 hours. The parameters of the secondary annealing influence on the texture and core losses of the finished strips were studied.

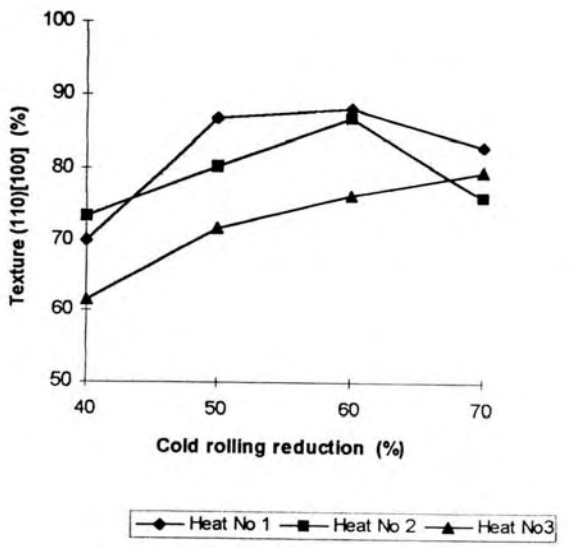


***Fig. 2**. The influence of the cold rolling reduction ratio on texture (110)[100].*

The samples were taken from those three cold finished rolled heats with different reduction degree: 40%; 50%; 60%, 70%. Secondary annealing was used in the same range for all samples. On the finished strips the texture level (110)[100] and core losses were determined. The results are in figure 2 and 3.

From figure 2, it could be seen an increase of reduction from 40% to 60% determining a markable increase of Goss texture level for all three steel grades. The highest Goss texture was gotten for first heat samples (with Nb addition).

The different reduction degree influences the magnetic characteristics (core losses) – fig3.

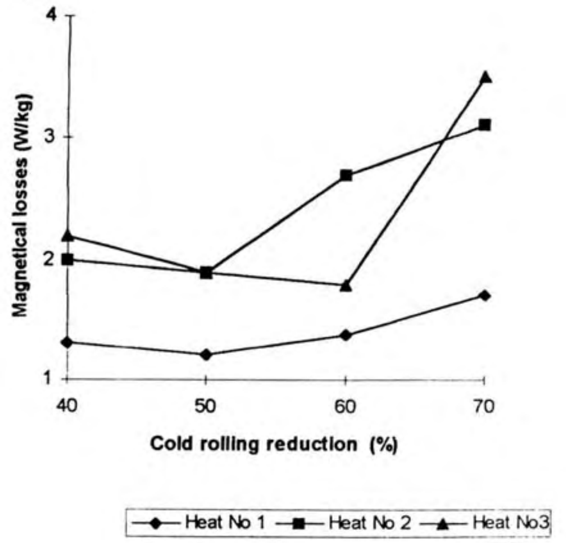


***Fig.3**. Influence of the cold rolling reduction ratio on magnetically losses.*

For steel grade 1 and 2 the lowest value of the core losses is gotten at $\varepsilon = 50\%$, i.e. there where Goss texture level was the highest. For steel grade 3 the lowest values of the core losses are recorded at $\varepsilon = 60$ %, but they are higher than for steel grades 1 and 2. The gotten results are conforming to the data of specialised literature [4] that explains Goss texture formation in the secondary recristallization strip by the orientation change of the main texture components during cold deformation and secondary recristallization. The (110)[100] component, developed during primary recristallization, undergoes rotations during final rolling in two opposed directions round axle [110]//DT.

The most approached slipping system (112)[111] and (112)[111] could be considered the most suitable for solving the tension condition of the initial orientation and, as result, the most movable.

The movability of these slipping systems brings about the marginal displacement that extends on the direction [110]//DT.

The rotation angle increases to deformation increase, attaining about 35° for one degree of 70 % deformation.

These rotations tend to form the two complementary texture components: (111)[112] and (111) [112] that, during the advanced rolling stage (ε > 70 %) could rotate round axle [111] ND. Taking into account that (111)[112] type orientation is rotating with small angles (up to 30°) and it recrystallizes in (110)[100] component during secondary annealing, it is necessary that, during cold rolling, the optimum deformation degree should be established (i.e. original and final thickness of strip) to get the best combination of the crystalographical orientation that will generate the final Goss texture.

After the second rolling, the secondary annealing has in view the obtaining of some structure with large grains, characteristical this type of steel.

In the experiments, the grain size was determined after the secondary annealing at 1150°C, for 6 hours (fig.4).

For Nb steel (steel 1), a grain size with diameter for 6...8 mm resulted, for Al steel (2) the grain-size is of 2 ...4 mm and for MnS (inhibitor) steel 3 a grain size of 10…20mm was gotten, proving that an emphasized influence of the micro-alloying elements is on the finished plate structure.

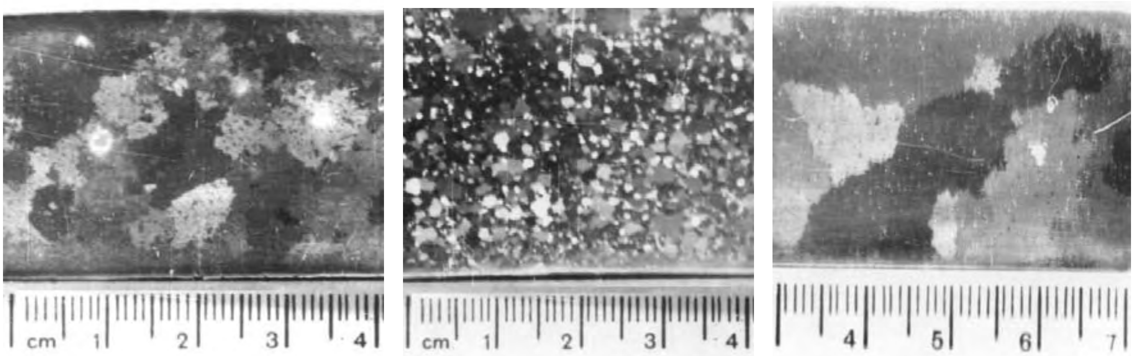


Fig.4. *The macrostructure of sheets after secondary annealing*
a- steel 1; b -steel 2; c –steel 3; t_{ann}*= 1150°C*

The component of the Goss texture increases together with the increase of temperature for all steels, the greatest value being recorded for the steel with Nb, at 1150°C. At the steel 3, although the grains are very large, the Goss texture is lower than at the steel 1 (fig.5). The magnetic losses here measured on some specimen on which Goss texture was analyzed, after the secondary annealing.

It was established that together with the increase of temperature and time of secondary annealing, the magnetic losses decrease [5] at temperature of 1150°C and 6h maintenance time.

The lowest values of magnetic losses were gotten for all steel grades (fig.6).

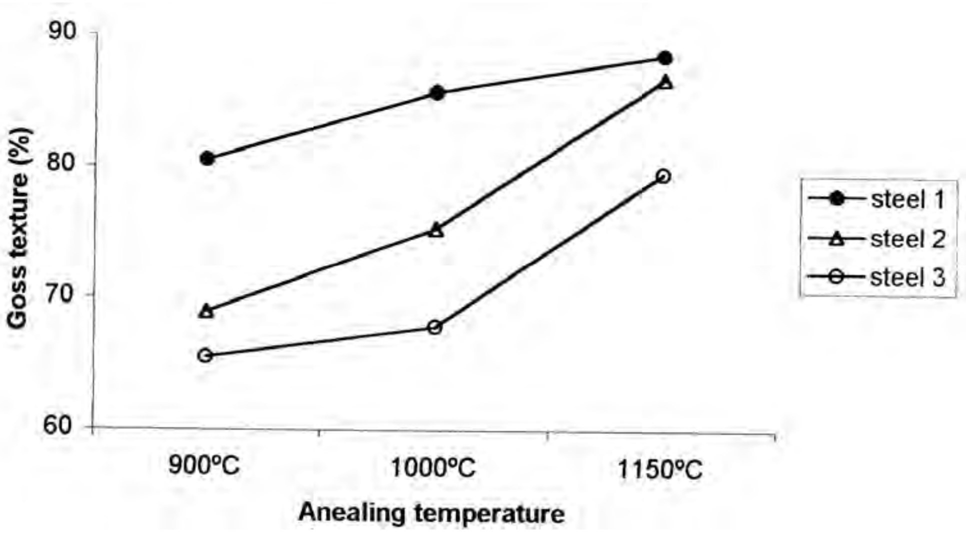


Fig.5*. Variation of the Goss texture to the annealing temperature*

At temperature of 1150°C and 6 h maintaining time the lower magnetic losses are noticed for Nb steel than for the other two steel grades (for B = 1,5 T). These results are very well correlated to grain size and to texture values. Steel grade no.1, with 6…8 mm grain size diameter, shows the highest Goss texture ratio and the lowest value of the magnetic loss.

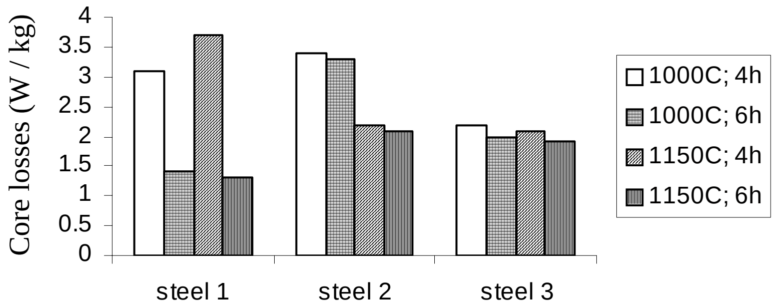
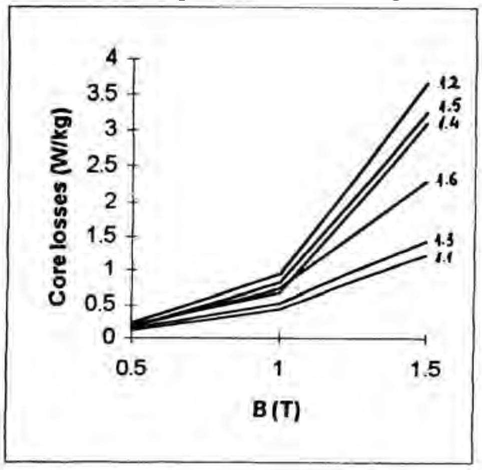


Fig.6. *Core losses of the experimental steels*

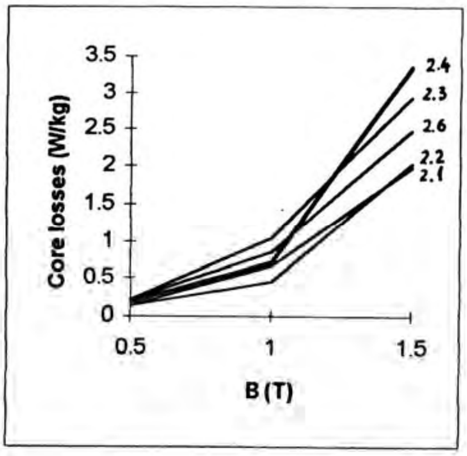
The core losses were comparatively estimated for three values of the magnetic induction: B1= 0.5 T; B2 = 1.0 T; B3 = 15 T and for all heat treatment ranges. The results are recorded in the tables and diagrams from figure 7. Core losses decrease once with increase of the temperature and holding time because an equiaxle or light elongated grain is formated increasing, in the same time, perfection degree of Goss texture.

For steel grade 1(with Nb), generally, lower losses are gotten than for other two steel grades in all heat treatment conditions.



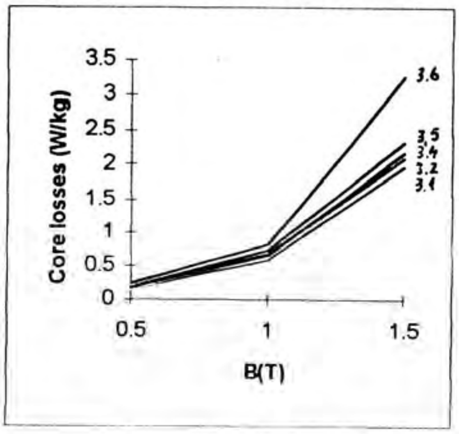
Sample	Recristallization parameters		Core losses (W/kg)		
	Temp (°C)	Time (h)	B_1 = 0.5 T	B_2 = 1.0 T	B_3 = 1.5 T
1.1	1150	6	0.103	0.430	1.217
1.2	1150	4	0.222	0.948	3.668
1.3	1000	6	0.139	0.523	1.427
1.4	1000	4	0.213	0.669	3.111
1.5	900	4	0.187	0.829	3.271
1.6	900	6	0.185	0.731	2.314

(a)



Sample	Recristallization parameters		Core losses (W/kg)		
	Temp (°C)	Time (h)	B_1 = 0.5 T	B_2 = 1.0 T	B_3 = 1.5 T
2.1	1150	6	0.143	0.664	1.974
2.2	1150	4	0.145	0.447	2.041
2.3	1000	6	0.181	0.705	3.338
2.4	1000	4	0.179	0.729	3.367
2.5	900	6	0.202	0.845	2.475
2.6	900	4	0.221	1.044	2.937

(b)



Sample	Recristallization parameters		Core losses (W/kg)		
	Temp (°C)	Time (h)	B_1 = 0.5 T	B_2 = 1.0 T	B_3 = 1.5 T
3.1	1150	6	0.140	0.547	1.982
3.2	1150	4	0.144	0.628	2.112
3.3	1000	6	0.182	0.673	2.105
3.4	1000	4	0.175	0.651	2.181
3.5	900	6	0.180	0.729	2.334
3.6	900	4	0.220	0.826	3.272

(c)

Fig.7. *Core losses for steel 1 (a), steel 2 (b), steel 3 (c).*

3. Conclusions

The gotten results led to the following conclusions:

- Second cold rolling reduction ratio influences the perfection degree of texture. An optimum reduction degree could be established to steel grade, for which the highest level of texture (110)[100] and lowest core losses could be gotten.

- Secondary recristallization is determining the forming of the equiaxed grain structures or light elongated grains, the size of which is influenced by the heat treatment: temperature and holding time.

- Grain size influences the perfection degree of Goss texture and, consequently, the value of the core losses.

-Nb microalloyed steel had the best behavior where the highest ratio of Goss texture and lowest values of the magnetic losses were gotten.

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