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INFLUENCE OF NIOBIUM AS MICROALLOYING ELEMENT IN 3%Si STEEL GRADE FOR ELECTRICAL INDUSTRY

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ABSTRACT

The paper presents the results of the laboratory research on the chemical composition and crystallographic texture in 3% Si steels and their influence on the level of magnetic losses in the final sheet.

The magnetic properties have been estimated by means of the core losses observed on samples taken from the three steels after the secondary annealing.

It has been noticed that the microalloyed Nb steel showed the highest percentage of Goss texture in the final sheet and the lowest values of the magnetic losses of the three steels under study.

KEYWORDS: inhibitor phase, Goss texture, core losses

1. Introduction

The particles of the secondary phase are in the silicon steel either as inclusions proceeded from steel making for example: $Si0_2$ AL_20_3; FeO, or as inhibitors of the grains - growth: AlN; TiN; NbN; NbC, MnS and so on.

By their size, shape and distribution, these secondary phases control grain-size growth during secondary recrystallization, which will influence the Goss texture level (110) [100], and therefore the core magnetic losses, the main characteristics of the 3% steel grade. The secondary recrystallization takes place when a certain grain-size is built-up, that exceeds a critical diameter and has a different crystallographic orientation than that of the matrix.

In a layer near the surface of the cold rolled strip, the grains of (110)[100] texture are building up that are including the adjacent grains if these have same or similar orientation to this component. These are forming "the embryo" or "the potential nuclei" for the secondary recrystallization. [1]

2. Experimental materials and procedures

Within this study, three steels of different chemical composition have been investigated, as highlighted in Table 2**.**

Table 1. *Chemical composition of investigated steels*

Steel grade	Chemical composition (%)						
	C	Si	Mn	S	P	Al	Nb
A (MnS)	0.004	3.04	0.08	0.015	0.009	0.002	0.09
B (AlN)	0.004	3.02	0.07	0.020	0.013	0.007	-
C (NbCN)	0.003	3.04	0.07	0.022	0.009	0.01	-

Steel A originated from a commercially produced continuous cast slab, typical for the silicon steel produced in industrial conditions. The inhibitor phase in this steel is MnS. Steels B and C are laboratory melts of about 50 kg produced in a vacuum induction furnace with a pressure of 60 bar, where either AIN or Nb (C,N) have been selected as inhibitor phase in addition to MnS. The bulk chemical composition of the laboratory heats was similar to steel A of industrial production. For the study of the secondary phases and their influence on the Goss texture, the specimens were taken from the hot and cold rolled strips, after primary annealing, and from the finished strip, after annealing of the secondary recrystallization [2].

The texture was determined by a reflection method and the volume fractions of the various texture components by an inverse pole figure method. Furthermore, torque measurements were used to confirm these findings. The core losses of the transformer sheets from the laboratory studies were determined for inductions of 0.5, 1.0 and 1.5 T using single strip samples of 30 mm width and 180 mm length, and were compared with data from industrial production.

3. Results and discussions

3.1. Hot rolled samples

All specimens showed a rather high amount of silicate inclusions, often in the form of stringers. Furthermore, steel A contained also elongated manganese sulphides and the two laboratory heats B and C exhibited complex globular inclusions, identified as (Ca, Al, Mn) oxy-sulfides. Besides these inclusions, which had a size of a few micrometers, fine particles of < 100 nm were also found.

These particles were identified by X-ray diffractometry as MnS in steel A, A1N in steel B and both, NbC and NbN, in steel C.

The severity of the Goss texture in the hot rolled samples also depended on the processing conditions. Figure 1 shows that a finish rolling temperature of 1000^{0}C was most favourable to achieve a high amount of the (110)[100] orientation, especially when the higher cooling rate was applied.

The observed reduction in the volume fraction of the Goss texture with higher finish rolling temperatures than 1000^{0}C is according to expectations.

The lower volume fraction of the Goss texture obtained after finish rolling at 900^{0}C is probably caused by a certain transformation from α into γ-iron at this temperature.

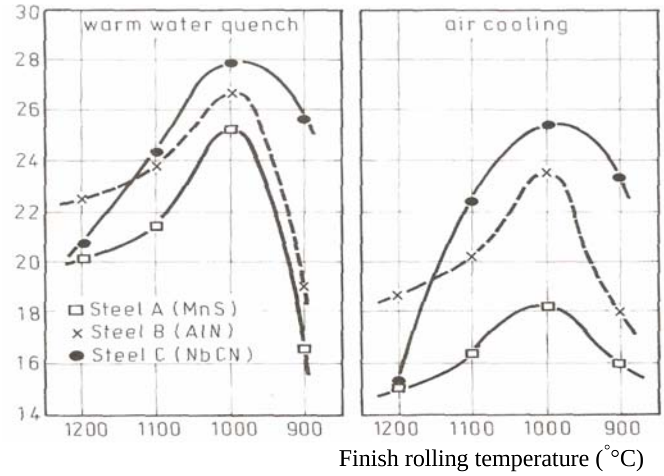

Fig. 1. *Influence of hot rolling conditions on the volume fraction of Goss texture*

3.2. Cold rolled sheet

In all three cold rolled and annealed steels the volume fraction of the Goss texture was higher than in the hot strip material. It also increased with longer annealing time and in most cases was higher with a higher annealing temperature. However, for the longest annealing time and the highest annealing temperature tested in this study, not necessarily the highest volume fraction of the Goss texture was obtained, Figure 2 [3].

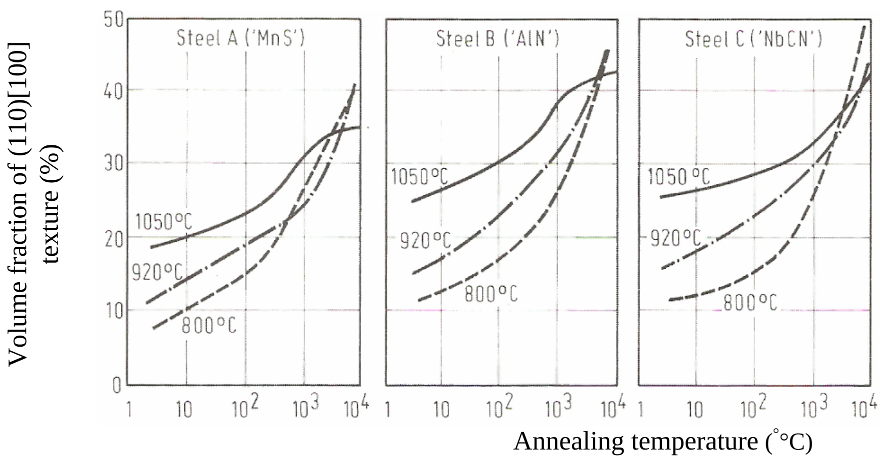

Fig. 2. *Volume fraction of the Goss texture after 1st recrystallisation annealing*

Samples, annealed by recrystallisation at 920^0C for 5 min were further cold rolled by 50 %. Then the second primary recrystallisation plus decarburisation heat treatment and finally the secondary recrystallisation annealing were carried out. Figure 3 shows that the absolute value of the Goss texture exhibited more than double the volume fraction compared to the observation after the first recrystallisation treatment. Furthermore, the Goss orientation increased with higher annealing temperature and longer annealing time and the ranking of the three steels became more pronounced.

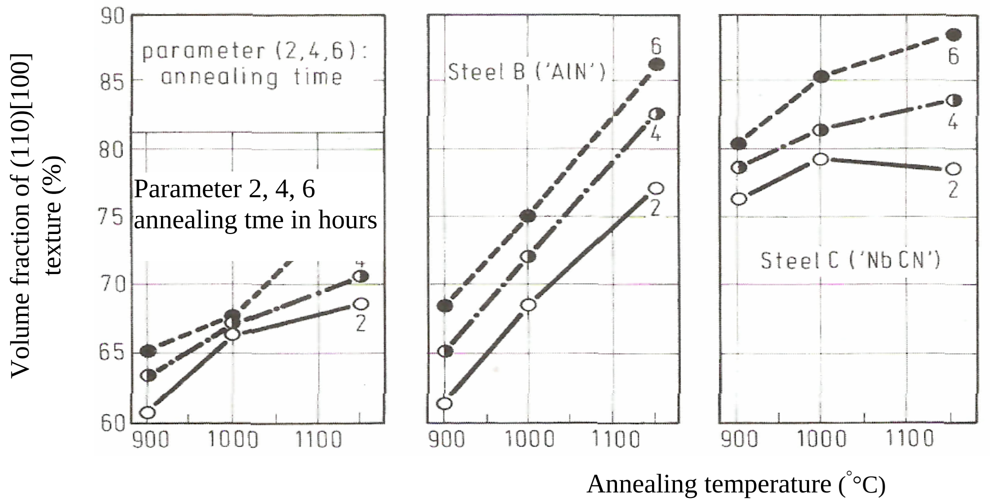

Fig. 3. *Goss texture development during secondary recrystallisation*

Steel C, based on Nb(C,N) as inhibitor phase showed a (110)[100] volume fraction of more than 75% already at the lowest annealing condition tested, i.e. at 900^0C for 2 h, and also exhibited the highest value with 88.5%. On the other hand the second best steel B, based on the A1N technology required an annealing temperature of 1150^0C to obtain a volume fraction of more than 75% of the Goss texture. This is a clear indication of the effective role of Nb(CN) in controlling the grain size which has been drastically reduced after decarburisation, during the first recrystallisation allowing the Goss texture to grow easily. On the other hand the dissolution of A1N particles obviously needs higher temperatures than necessary for Nb(CN) and thus is in agreement with the solubility products.

These results confirm that the both the Goss and the cube texture, which are present already in the hot rolled material, are stable orientations and were not reduced during cold rolling and primary recrystallisation and the (111)[112] orientation rotates during the secondary recrystallisation to the desired (110)[001] texture component […].

3.3. Core losses

The measurements results obtained with transformer sheets of laboratory trials were compared with industrial production data in Figure 4 [4].

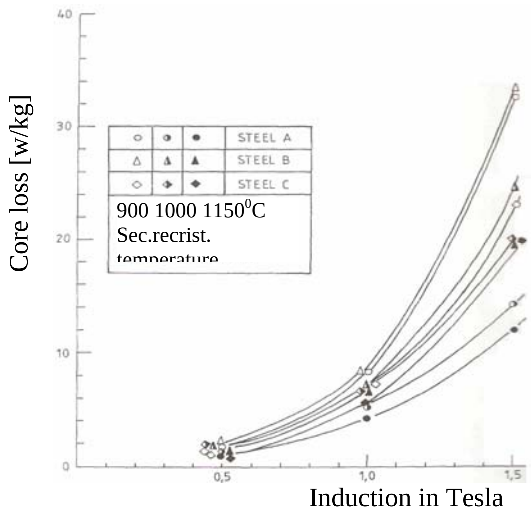

Fig. 4. *Core loss of steels A, B, C as a function of secondary recristallization temperature and induction*

An inspection of Fig. 4 revealed first that Niobium microalloyed silicon transformer steel in which the niobium carbo-nitrides are the inhibiting second phase has also the lowest core losses, followed by the silicon steel in which the inhibiting second phases are AlN and MnS. This is in good agreement with the higher volume fraction of the (110)[001] Goss texture of the niobium bearing steel developed during the secondary recrystallization high temperature anneal.

4. Conclusions

From solubility product considerations, Nb(C.N) could be a suitable inhibitor phase. The characteristic features of an inhibitor phase are the control of the grain size during the first and second primary recrystallization and permitting the formation of a high volume fraction of the Goss texture during the secondary recrystallisation annealing.

Since niobium also forms carbides, this element might add to ageing stability of the final product, which is not possible by other elements that are typically applied. A two stage cold rolling schedule with an intermediary recrystallisation treatment was necessary to obtain a sharp the Goss texture. In this case a higher annealing temperature and longer holding time during the secondary recrystallisation were favourable for the Goss texture maximisation and the Nb(C,N) variant again gave the best results. Furthermore, the dissolution kinetics of this inhibitor phase opened the possibility to obtain the desired texture already at lower annealing temperatures.

Consistent with the highest volume fraction of Goss texture, the core losses were lowest with the Nb(C,N) inhibitor phase compared to variants with A1N or MnS.

Silicon steel processed via a single stage rolling schedule and total deformation being not higher than 80% will also exhibit relatively low core losses when using niobium microalloying, as a result of the already high level of Goss texture component obtained after the hot rolling operation. This is a technology that can be applied to electrical industry steel sheets manufacturing.

The relatively high volume fraction of Goss texture already existing in the hot rolled material and the effective behaviour as inhibitor phase makes niobium an interesting alloying element for optimising grain oriented electrical sheet. Confirmation of these laboratory results in industrial production is foreseen.

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