RESEARCHES REGARDING THE STRUCTURE AND MAGNETICAL CHARACTERISTICS OF 3%Si MICROALLOYED STEEL STRIPS

Ana Doniga, Elisabeta Vasilescu, Stela Constantinescu
“Dunarea de Jos” University of Galati, Romania

Abstract
This paper – work shows the experimental results made on the three silicon steel heats, varied microalloyed, to get grain growth inhibitors. Thus, no. 1 heat was Nb microalloyed, heat no. 2 – Al microalloyed, and heat no.3 was considered the comparison material, being made in the industrial conditions. The test specimen were hot and cold rolled and thermal treated in accordance with the strips, manufacturing technology for transformer tolls. Length ways technological flaw the evolution of the structure, Goss texture as well as final magnetic characteristics were pursued.

It was established that Nb microalloyed steel shows higher characteristics because more pronouncedly Goss texture and lower magnetic losses were gotten against to the test specimen of the other two heats.

1. INTRODUCTION

Silicon steel strips belong to the group of the soft magnetical material with the following characteristics: high relative magnetical permeability, with low temperature dependency and frequency, high saturation induction, low remanent induction, low coercitive field, core losses (by hysterezis and by low eddy current) and high electrical resistivity [1].

Research studies made by M.P.Goss [2] and afterwards by M.Littman [3] proved, for the first time, that a tight correlation is between magnetic characteristics of the transformer's sheets and a certain crystallographic orientation, whence the name of steel with oriented grains.

Development of the crystallographic orientation type (110)[100] or "Goss texture" in an about 3% Si steel an important decrease of the core losses is determined, reaching up to 0.6...0.7 W/kg in steel strips.

Goss texture is formed during the hot rolling and developed during the cold rolling and thermal treatment, in the presence of the secondary phase particles of the steel as: MnS, AlN, NbC, type etc; parting as "inhibitors" id est to limitate the grain growth in the first phases of the cold processing [4].

After the inhibitors did their part, during the primary annealing, the particles of the scattered phases should be removed from the matrix, during the secondary annealing, to allow the emphasized growth of the grain. That is why, the selection of a certain inhibitor should be correlated to the secondary recrystalization parameters to assure an advanced dissolution of the dispersion phase-particles and to get a certain size of the grain and of an emphasized Goss texture.

Because Nb, as NbN or NbC, has a good solubility at a high temperature, in comparison to MnS, or AlN, a Nb microalloyed steel was tested, having MnS as inhibitor, comparative to an industrial steel.
2. MATERIALS AND EXPERIMENTS

To make experiments, three charge of silicon steels obtained in the following conditions have used:

- the 1st steel with addition of Nb and the 2nd steel with add of Al, experimental elaborated in vacuum induction furnace and forged in semi-manufactured of 7x30x70mm.
- the 3rd steel elaborated and strip hot rolled in industrial conditions to SIDEX S.A.Galati.

Further on, rolling and heat and cold treatment have been achieved in laboratory conditions. Finally, strips of 0.35x30mm from studied steels ones have been obtained.

The chemical composition of steel strips experimentally obtained is listed in table 1.

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Al</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.004</td>
<td>0.08</td>
<td>3.04</td>
<td>0.015</td>
<td>0.009</td>
<td>0.002</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>0.004</td>
<td>0.07</td>
<td>3.02</td>
<td>0.020</td>
<td>0.013</td>
<td>0.07</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.003</td>
<td>0.07</td>
<td>3.04</td>
<td>0.022</td>
<td>0.009</td>
<td>0.01</td>
<td>-</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The researches made, lengthways time, on the silicon steel plates (strips) pointed out that Goss texture (110)[100] comes out, for the first time, in the hot rolled plate and is conveyed by texture memory up to the finished plate after the whole cycle of hot rolling, cooled rolling and thermal treatment.

In the experiments of this paper-framework the texture evolution of the hot rolled plates was followed to the rolling temperature.[5] The results are shown in fig. 1.

![Figure 1](image-url)  
**Figure.1** Ratio variation of Goss texture to hot rolling temperature

Generally speaking, a ratio increase of Goss texture is established up to 1000°C and, afterwards, a diminution to 1100 - 1200°C. Nb steel shows a little bit higher percent of Goss texture against to those two steel-grades at all rolling temperatures. Lower rolling temperature (800 - 900°C) delays the recrystallization process leading to a delay of Goss texture development, too.

The researches made in this paper work proved that the texture ratio (110)[100] in case of Nb-steel is about 10% higher than MnS (used as inhibitor) -steel, and about 7% higher than Al-steel.
The microstructure evolution are shown in fig 2.

![Figure 2](image)

**Figure 2** Hot rolled steel microstructure (T\text{roll} = 900°C; magnify x 100)
Ab – steel 1; bc – steel 2; c – steel 3

The researches made with up-to-date investigation methods concluded that the texture (110)[100] begins to set up in the hot rolled plate at about 1/10 depth sub-surface and the crystalline grains, having this crystallographic orientation, will constitute the potential grains of Goss component at secondary recrystallization conveyed by the "texture memory" of hot rolled plates [5]. These, 3% Si steel grades with small quantity of Nb, Mo, Ti, At spotlighted this phenomenon more emphasized than the steel -grades that use MnS as inhibitor, without any addition.

After the second rolling, the secondary annealing having in view the obtaining of some structure with large grains, characteristically this type of steel.(fig.3)

Could be noticed that grain size is very much different from a steel grade to another, for same annealing condition. Thus, for steel grade 1 the grain size grows from 1- 2 mm at 1000 °C, to 7 - 8 mm at 1150 °C. At steel grade 2, the grain size is smaller, even at higher temperature (1150°C), not exceeding 4 mm. The steel grade 3 has very big grain-sizes, both at 1000°C and 1150°C too, reaching up to 16 -18 mm. Nevertheless, a very big grain-size doesn't mean a perfection of the texture. Large grain-sizes consist of sub-grains with light disorientation to rolling direction that influences negatively the intensity of a certain texture component.

Thus, as could be seen from figure 4, the highest Goss texture ratio was gotten for steel grade 1, annealed 6 hours at 1150°C. For steel grades 2 and 3 the values closed to Goss texture component were gotten, but lower than steel grade 1.

The present research have demonstrated that in the evolution of structure and the Goss texture, an important factor is also the nature of particles of secondary phases with part of inhibitor from steel.

Therefore, in the two experimental steels, the particles are of type of nitrides and carbides (NbN, NbC, in the steel with Nb and AlN in the steel with Al), and in the industrial steel 3, the particles are sulphides (MnS).

As a result of experiments, the evolution curves of the Goss texture are similiary in all the three steels but in different proportion depending on the type of particles of inhibitory phases from each steel (fig 4)
Figure 3. Microstructure after the secondary annealing
a – steel 1, Ta = 1150°C; b – steel 1, Ta = 1000°C; c – steel 2, Ta = 1150°C; d – steel 2, Ta = 1000°C; e – steel 3, Ta = 1150°C; f – steel 3, Ta = 1000°C

Figure 4. Goss texture variations to secondary recrystallization parameters

The most increased percent of the Goss texture has been recorded at the steel 1 with Nb, after which follows the steel 2 and then the steel 3.
The magnetic losses were measured on the some specimen on which Goss texture was analyzed, after the secondary annealing. It was established that at once with increase of temperature and time of secondary annealing, the magnetic losses decrease. At temperature of 1150°C and 6 h maintenance time. The lowest values of the magnetic losses were gotten for all steel grades (fig.5).

![Figure 5 Core losses of the experimental steels](image)

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. These, 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.

4. CONCLUSION
The gotten results led to the following conclusions:
- Goss texture is formed in the hot rolled plate the most favorable temperature being 1000°C to get a high ratio of the component (110)[100];
- Goss texture is stressed developed at once with the recrystallization temperature increase, after cold rolling;
- At temperature of 1150°C the highest Goss texture ratio was gotten for those studied three steel grades;
- Core magnetic losses decrease at once with Goss texture ratio increase;
- Nb microalloyed steel had the best behavior where the highest ratio of Goss texture and lowest values of the magnetic losses were gotten.

5. BIBLIOGRAPHY
[1] * * * - Studiu documentar privind fundamentarea unei noi tehnologii de fabricatie a benzilor electrotehnice. Studiu ICEM, 1980.