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Influence of Thickness on Magnetic and Microstructural Properties in Electrical Steels Semi-Processed of Low Efficiency

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Abstract. In this study, a steel for semiprocessed electrical purposes of non-oriented grain with approximately 0.05% carbon content and 0.02% silicon content was evaluated. Lamellas with kind of thicknesses 0.58 mm, 0,66 mm and 0.87 mm were processed on an industrial scale with a strain rate in the hardening lamination between 3 and 5%. The magnetic properties were evaluated after the wet heat treatment. The loss separation method was applied, estimating the hysteretic plot with hysteresis measure in the quasi static condition and the parasitic losses calculated according to Thomson's Equation. By increasing grain size, permeability increases and coercivity decreases. However, in the case of losses, there is an optimum grain size. After the procedure of separation of losses, it was observed that increase of thickness results in increase of the anomalous parcel of magnetic losses.

Introduction

Concern over natural resources and energy performance in countries has led society to reduce electric energy consumption and create measures to reduce energy waste. Thus, it is necessary to increase the energy efficiency of electromagnetic equipment and devices using electric steels with lower magnetic losses. The electric steels are easy magnetizing materials used in the manufacture of electrical equipment cores to increase energy efficiency and their service life, minimizing magnetic losses of the material.

Magnetic losses are the main technical parameter of selection and control of electrical steels and are divided into three components: hysteretic losses, anomalous losses and parasitic losses. The hysteretic losses are generated during the magnetization of ferromagnetic materials and their intensity depends on the microstructural parameters of the material. The parasitic losses are related to the variation of the magnetic flux, which induces the passage of electric current inside the steel sheet, being directly related to the electrical resistivity of the material and the thickness of the steel sheets that make up the magnetic circuit [1]. The anomalous losses are the difference of the experimental measure between the losses hysteretic, in the quasi-static condition, and the parasitic losses. The anomalous losses increase with grain size increase and are proportional to the parasitic losses, because they occur due to the parasitic microcurrents that circulate around the domain walls when they move [2]. The anomalous losses are the difference of the experimental measure between the losses hysteretic, in the quasi-static condition, and the parasitic losses. The anomalous losses increase with grain size increase and are proportional to the parasitic losses, because they occur due to the parasitic microcurrents that circulate around the domain walls when they move. However, there is an optimum grain size for the minimize of losses in the iron, since above 150 µm the anomalous losses increase. This work relates to relate the thickness of a semiprocessed electric steel of non-oriented grain with the behavior of the magnetic losses, also a microstructural analysis of the material will be performed before and after the heat treatment carried out under a controlled atmosphere, aiming at a steel with a satisfactory cost / benefit.

Experimental

The material studied in this work is a low efficiency electric steel with thicknesses of 0.58 mm, 0.59 mm and 0.87 mm. For this material, thermal treatment was performed simulating the annealing in the engine manufacturers that use (GNO) electric steel to optimize the magnetic properties of the material, that is, reducing magnetic losses.

The analyzed material was identified in Table 1. All samples are representative of the same steel, with the same process parameters being only different in the thicknesses. For this reason, we can consider the same chemical composition.

Table 1. Identification of samples provided to CSN (Companhia Siderurgica Nacional)

Identification	Thickness	Chemical Composition (% máx)					
		C	Mn	P	S	Si	Al
Sample 1	0.58 mm	0,05	0,200	0,025	0,01	0,02	0,06
Sample 2	0.59 mm						
Sample 3	0.87 mm						

The analyzed samples were obtained from industrial scale processing after hardening lamination, where a deformation rate of 3 to 4% was observed. Analyzes were performed before and after heat treatment.

In order to promote the improvement of magnetic properties, reduce carbon content, reduce residual stresses, promote grain growth and the formation of a surface layer of oxides capable of promoting electrical insulation, the semiprocessed electric steels pass through by a heat treatment. The treatment used in this case was annealing in decarbonizing atmosphere. This heat treatment was carried out in a LINDBERG 51668 HR oven, with an atmosphere of 90% hydrogen and 10% Nitrogen, heating at 7 ° C / min, at approximately 550 ° C the atmosphere becomes decarbonizing, HN + H2O. The soaking occurs at 770 ° C for two hours. Subsequently the material is cooled at a rate of 2 ° C / min, when the oven reaches 550 ° C the atmosphere becomes nitrogen up to 400 ° C, when the oven is switched off, followed by a slow cooling with the oven closed until at room temperature.

In order to verify the level of decarburization of the material as a function of the treatment, measurements of the carbon content were obtained, using Leco type equipment, model CS 444 and TC 436. Magnetic loss and permeability were measured by an Epstein Board, supplied by Brockhaus Messtechnik, model MPG100D, using 1T inductions at 50, 60 and 100 Hz frequencies and induction of 1.5 T at a frequency of 50, 60 and 100 Hz. All samples were analyzed in a Zeizz Axiotho optical microscope, previously polished and attacked with Nital 3%, where grain size (ASTM E112 standard), microscopy and metallography were obtained. Determination of texture (macrotexture) by X-ray diffraction in a Rigaku diffractometer model DMAX-2100, in which is coupled a goniometer of horizontal texture "muhipurpose".

Results and Discussion

Chemical Analysis

From the analysis of Figure 1 it is possible to observe that there was a reduction of 70% of the carbon content before and after the heat treatment. The final annealing has as one of the objectives to promote decarbonation, since carbon in solid solution, as well as other impurities such as sulfur, oxygen and nitrogen causes the anchoring of the walls of the domain, which causes the reduction of the magnetic losses from the plot Hysteretic, in addition to restricting grain growth. Therefore, decarburization is important for the optimization of the magnetic properties directly because it causes the reduction of C in solid solution and the volumetric fraction of carbides in the metal matrix, and indirectly, to allow grain growth and decrease residual stresses.

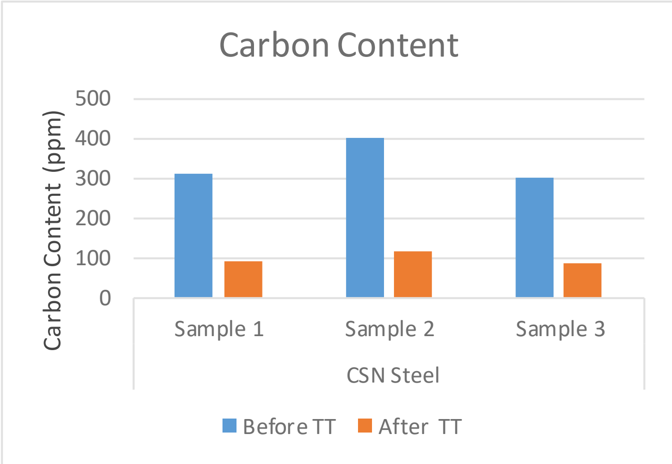

Fig. 1. Comparative graph of the variation of the carbon content of the samples analyzed before and after the heat treatment

Semi-processed steels may be susceptible to magnetic aging if, after decarburizing, the steel has a final carbon content between 30 ppm to 200 ppm [3]. The material analyzed is a low carbon steel, with 300 to 400 ppm of carbon before the heat treatment, but after the annealing in decarbonizing atmosphere there was a visible reduction of the level of carbon in solid solution, however the contents found are within the range suggested by the Literature where there is a possibility of magnetic aging.

Grain size and texture

The grain size has a very strong effect on magnetic losses and is therefore considered an important selection variable the electric steels. The final carbon content also influences the grain size, since they restrict the growth of the same, the lower the carbon content the larger the grain size [1].

Before the heat treatment, as can be seen in the Figure 2, the sample 2 is the one with the highest carbon content, 400 ppm C, and consequently, a smaller grain size of 23 µm. After the heat treatment, these characteristics reflect, also presenting a smaller grain size, 180 µm and higher carbon content (97 ppm C). Despite the values, this sample was the one that came closest to the optimal grain size, 150 µm [4], in this way we can observe that we obtained a lower value of anomalous losses in counterpart a higher value of hysteretic losses. With a smaller grain size, the contour density becomes larger, because it is more difficult to move the domain walls since these contours as well as the carbon in solid solution function as a partial blockage of the magnetization of the ferromagnetic materials, leading to an increase coercivity and, consequently, to greater hysteretic losses.

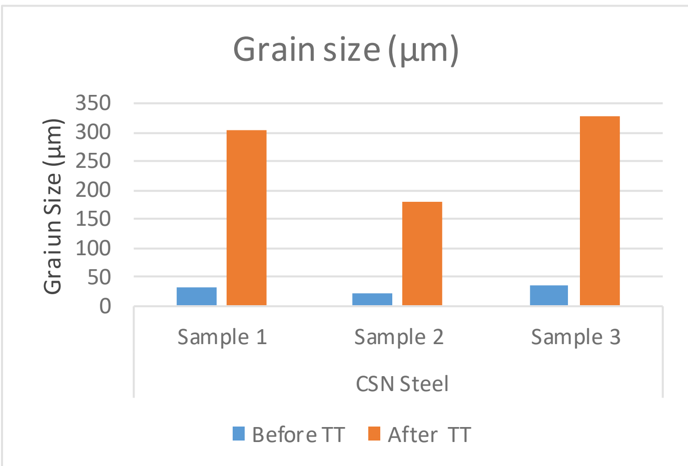

Fig. 2. Comparative graph showing the grain size of the samples before and after the heat treatment

Texture analysis was also performed from ODFs obtained by X-ray diffraction. Before the heat treatment as expected, the preferred plane is the fibers (111) but after the heat treatment, with the increase of the grain size and the occurrence of the second recrystallization, fibers of easy magnetization were observed, as can be seen in Table 2, and the ODF´s can be seen in the Figure 3.

Table 2. Sample texture after heat treatment

Identification		Orientacion ($\phi 2$= 45°)	Intensity
CSN Steel	Sample 1	(110)[1-20]	7,1
		(1-10)[001]	8,3
		(111)[1-21]	4,7
	Sample 2	(110)[1-20]	7,5
		(1-10)[001]	7,5
		(111)[-210]	4,28
	Sample 3	(110)[1-20]	7,5
		(1-10)[001]	5,35
		(111)[-210]	2,14

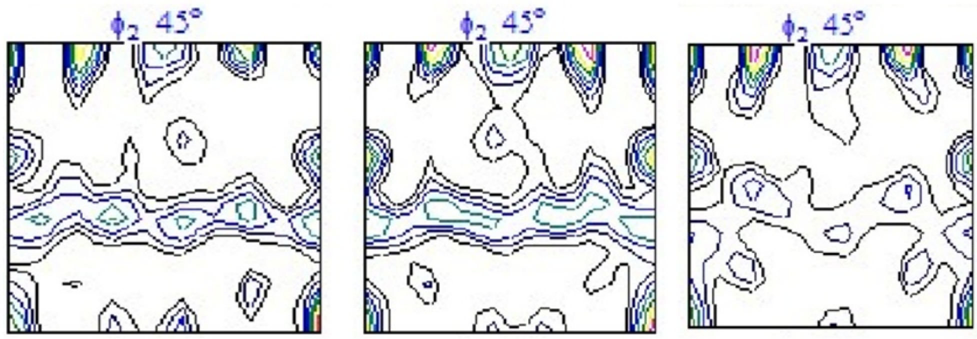

Fig. 3. ODF section $\phi 1$= 0 and $\phi 2$=45° of samples 1, 2 and 3 respectively after the heat treatment

Magnetic properties

From the Epstein test, the measurements of total losses before and after the heat treatment were performed for frequencies of 50, 60 and 100 Hz at inductions of 1.0 and 1.5 T. The hysteretic losses were obtained from the area of the quasi-static hysteresis curve at a frequency of 0.005 Hz.

The parasitic losses were calculated from the Thomson, Pp= $(\pi * f * Bmáx * e)^2 / (6\rho d)$, where Bmáx is the maximum induction, e is the thickness of the sheet, f the frequency, and ρ the resistivity. The anomalous losses were obtained from the difference between the total loss and the sum of the parasitic and hydropathic losses.

One of the reasons for the increase of parasitic losses with the thickness of the plates is related to the film effect. Current tends to focus on the surface of the plate, so the thicker the plate the greater the path the current must make and the central region will not contribute to field amplification, thus reducing the efficiency of the material, will soon have an increase in losses. As can be seen in Figure 4, the PPs in sample 1 and sample 2 have close values, this is since they have nominal manufacturing thicknesses of 0.58 and 0.59 mm respectively. However, sample 2 still has higher parasitic loss values than sample 1. Sample 3, material with 0.87 mm thickness, is the one with the highest Pp value.

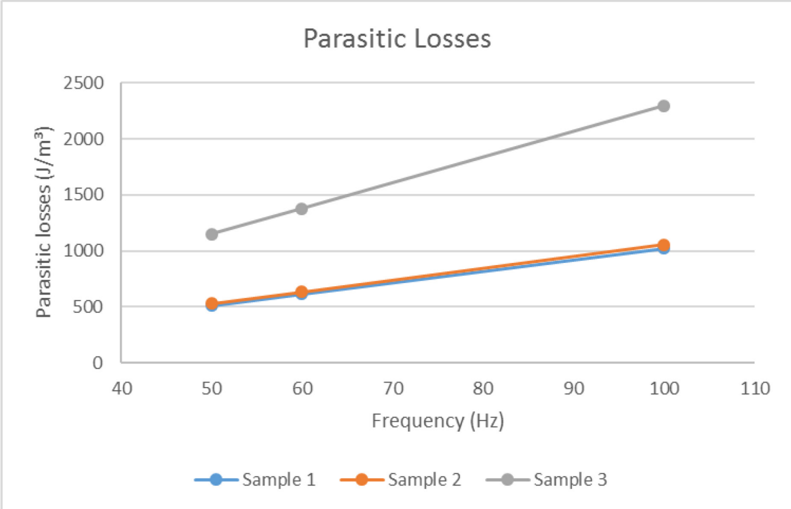

Fig. 4. Evolution of parasitic losses with increasing frequency for the three samples with different thicknesses. Data obtained from the Epstein test with induction of 1.5 T

The hysteretic losses can be seen in Figure 5, the sample 2 presented the highest value of hysteretic losses both before and after the heat treatment, this fact can be explained based on the grain size of the material that in both situations presented the smallest grain size. These losses occur due to the movement of the walls of the magnetic domain and thus the smaller the grain size, the greater the density of contours and the greater the barriers to prevent the movement of these walls, thus increasing hysteretic losses.

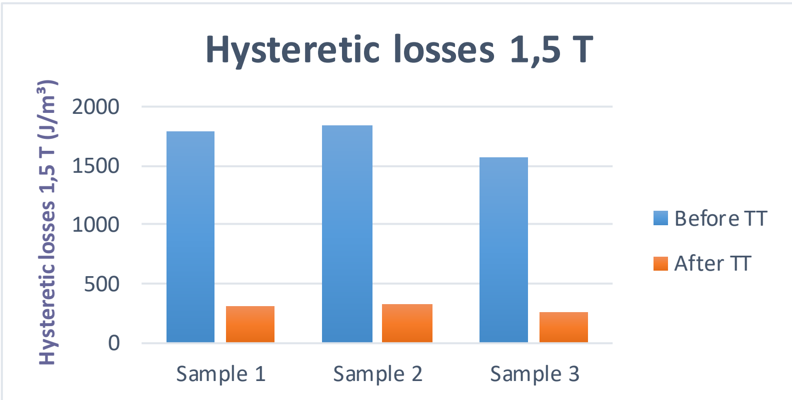

Fig. 5. Hysteretic losses before and after heat treatment of samples

The figure 6 shows the relationship between the anomalous losses and the test frequency for inductions of 1.5 T in the condition after the heat treatment. As can be analyzed, the losses were larger the higher the test frequency. Based on the figure, it can be concluded that sample 3 presented the highest anomalous losses due to the larger grain size, thus showing the effect of grain size on this loss plot. Anomalous losses are proportional to parasitic losses and increase with increasing grain size [2]. For this reason, there is the ideal grain size for the optimization of losses, because the larger the grain size, the smaller the hysteretic losses, but the anomalous losses increase. This grain size can be seen in sample 2, presenting the lowest anomalous losses. There is an increase of the anomalous losses before and after the heat treatment, this difference occurs due to the microcurrent parasites present in the grains after the heat treatment.

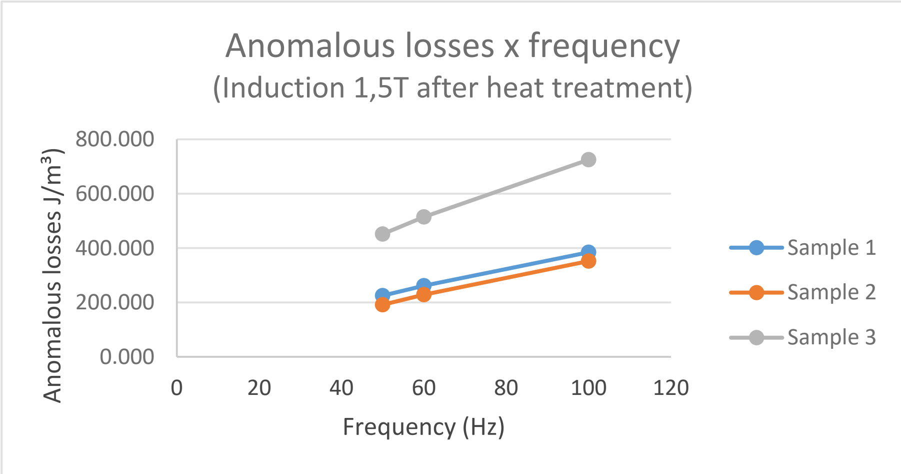

Fig.6. Relation of the anomalous losses after the heat treatment with the test frequency

Conclusions

Based on the results obtained, in the present study of the characterization of steel samples for electrical purposes with different thickness, it can be concluded that: The decarburizing that occurred after the heat treatment considerably reduced the carbon content but not enough so that it does not occur Magnetic aging; The best texture condition was observed in the sample 3 after thermal treatment. It was possible to find textures of easy magnetization, the microstructural characteristics of this condition confirm the result of hysteretic losses, being smaller for sample 3 that presented larger grain size; The thickness exerts an effect on the parasitic losses, being smaller the smaller the thickness and with respect to the anomalous losses it was possible to observe that these losses are smaller the closer to the optimal grain size, in contrast these losses are larger the greater the thickness, the larger Losses obtained for sample 3 before and after the heat treatment.

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