

ANALYSIS OF THE MECHANICAL PROPERTIES OF ELECTRICAL STEEL

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Abstract: This paper presents the microstructural aspects of strips cold rolled laminar and the influence of grain size on the total magnetic loss at 1T respectively 1.5T, for silicon steel strips with non-oriented grains after decarburized and annealed treatment. We find that the hardness at the head of the rolls is higher for all 5 analyzed rolls, on the other hand, for the rolls from batch II the hardness at the ends is higher than the hardness at the head. The hardness values are included in the EN standards 10106. The regression equations drawn for R_c in the raw state, as well as in the aged state, show us significant correlation coefficients very close to the value of 1, that is 0.98 for $R_{c\text{ raw}}$ and 0.97 for $R_{c\text{ aged}}$. The regression equations plotted for R_m in the raw state for the batch of bands analyzed, as well as in the aged state, show us significant correlation coefficients very close to the value of 1, i.e. 0.91 for $R_{m\text{ raw}}$ and 0.98 for $R_{m\text{ aged}}$.

Keywords: electrical steel, hardness, raw state, aged state

1. INTRODUCTION

The electrical steel belong to class of soft magnetic materials. The typical applications of electrical steel used in the core of the electromagnetic device like electric motors, generators, transformers etc. [1–3-5]. High permeability and low iron loss have been particularly required in recent years in order to achieve higher efficiency and hence energy saving. Therefore it is important to control the final microstructure of these steels. The grain size and crystallographic texture, because it is necessary to have a good properties. [6] One simple way to increase magnetic polarization is to decrease the basic alloying element contents, i.e. silicon and aluminum. This approach however, increases the core loss and decreases both the yield and tensile strengths while increasing the polarization of the final product. Another approach is based on the improvement of the crystallographic texture in the final product by optimization of the production practices prior to the final heat treatment. From the physical-metallurgical point of view, the control of hot band structure and texture is necessary. [7-11]

The magnetic properties of non-oriented electrical steels is controlled by the type of alloying. Alloying elements like silicon, aluminum, manganese and other microalloying elements such as antimony and tin content modification the magnetic properties. [12,13, 16]

Of the major alloying elements used for electrical steels, antimony and tin are particularly noted for their effects on texture. [13, 14]

Electrical steel was developed at the beginning of the 20th century. Today is the preferred core material for a lot of transformers, motors, and generators. [15, 16, 17,19]

The production of electrical steel sheet and strip in the last 10 years has almost doubled.

There is a wide range of equipment in which non oriented electrical steel sheets are incorporated, from the simplest domestic appliances to hybrid electric vehicles. [16, 18, 20]

2. EXPERIMENTAL DETAILS

a) The distribution of chemical composition analyzed on the laminate strips non-oriented silicon steel grains

Table 1 shows the chemical composition analyzed rolled steel strips obtained with of the spectrometer Q4 Tasman. Based on the results obtained were made graphics for each alloying element of silicon steel, for all 10 types, laminate strips analyzed.

Table 1. Chemical composition analyzed for rolled steel strips

Rolled strips	C[%]	Mn[%]	Si[%]	S [%]	P [%]	Al[%]
1	0,023	0,188	1,137	0,002	0,068	0,173
2	0,024	0,19	1,147	0,0024	0,07	0,18
3	0,025	0,198	1,162	0,0028	0,071	0,182
4	0,024	0,204	1,174	0,003	0,073	0,185
5	0,026	0,206	1,183	0,0036	0,074	0,189

6	0,027	0,21	1,185	0,004	0,075	0,191
7	0,028	0,216	1,196	0,0045	0,077	0,194
8	0,029	0,218	1,215	0,005	0,079	0,196
9	0,03	0,221	1,224	0,0054	0,08	0,198
10	0,032	0,223	1,227	0,006	0,082	0,206

From table 1, we find that for these 10 types of strips analyzed carbon content is between 0.023 and 0.032% and manganese content varies from 0.188% and 0.223% Mn. The main negative effect of carbon in non-oriented electrical steel, is the appearance of aging magnetic transition, phenomenon caused by carbides precipitation in ferrite grains. Precipitation of carbides can take place at ambient temperature over long periods of time or at higher temperatures in a short period of time. [19]

From table 1, we observe variation of silicon content of 1.137% to 1.227% for the group of strips analyzed. Silicon contributes to increasing resistivity alloy and therefore reduce eddy current losses.

The values of low sulfur content between 0.002 and 0.006%, as shown in table 1. Sulfur is especially damaging because of the formation of fine particles of manganese sulphide, MnS, which prevents grain growth and therefore it is ideal that the presence of sulfur in the strips analyzed to be in low concentrations.

According to table 1, it is found that strips analyzed shows a phosphorus content of between 0.068 and 0.082. In carbon steel for electrical uses, phosphorus content must not exceed the value of 0.15, which in this case is carried out.

b) Determination of mechanical properties

Unoriented grain steel is not as sensitive to deformation as oriented grain steel. The shearing stresses from the stamping operation of electrical equipment sheets constitute the only source of deformation that could affect the magnetic properties. However, these tensions are tolerated.

The steels with oriented grain are subjected to thermal treatments in order to obtain a yield limit as low as possible, obtaining magnetic properties in one direction (rolling direction) that are much different from the properties measured in other directions.

The mechanical characteristics, the yield strength R_c , and the breaking strength R_m , determined on the hot-rolled strip, are between: $R_c = 23.9 - 44.5$ [daN/mm²], and $R_m = 38.9 - 53.4$ [daN/mm²].

After the strip is cold rolled, the thermal annealing treatment follows, during which the yield strength (raw R_c) and the breaking strength (aged R_m) are determined, having values between: $R_{c \text{ raw}} = 23.9 - 44.3$ [daN/mm²] and raw $R_m = 31.7 - 52.7$ [daN/mm²], according to tables 2 and 3.

After annealing, the thermal aging treatment is performed, resulting in the following values for the mechanical characteristics: $R_{c \text{ aged}} = 25.5 - 35.7$ [daN/mm²] and $R_{m \text{ aged}} = 39.4 - 46.9$ [daN/mm²], according to the tables 2 and 3.

Table 2. Raw and aged R_c yield strength for the lot of strips analyzed

$R_{c \text{ raw}}$	$R_{c \text{ aged}}$
23,9	31,7
25,4	32,3
26	33,7
26,6	34,8
27,3	35,5
27,8	36,7
28,4	38
29,1	39,8
30,4	40,4
31,2	42
35,5	44,7
37,5	47,4
38,7	48,7
40,5	50,7
44,3	52,7

Table 3. The breaking strength R_m in the raw state and in the aged state for the lot of tapes analyzed

$R_{m \text{ raw}}$	$R_{m \text{ aged}}$
25,5	39,4
26,7	40,3
27,3	41,4
28	41,8
29,1	42
29,9	42,3
30,8	42,9
31,5	43,2
32	43,9
33,3	44,2
34,4	44,9
35,9	45
36	45,5
38,1	46
39,4	46,9

The notion of raw refers to characteristics determined before aging, i.e. immediately after the heat treatment of annealing, and aged refers to characteristics determined after the heat treatment of aging.

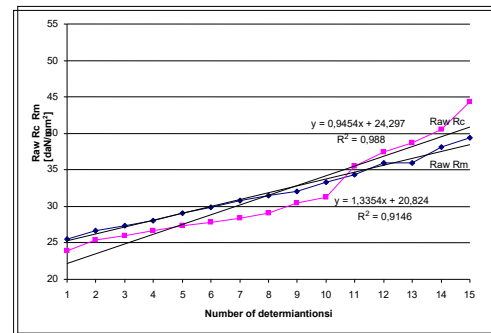


Figure 1. Raw and aged R_c yield strength for the batch of strips analyzed

The regression equations plotted for R_c in the raw state, as well as in the aged state, show us significant correlation

coefficients very close to the value of 1, i.e. 0.98 for raw R_c and 0.97 for aged R_c .

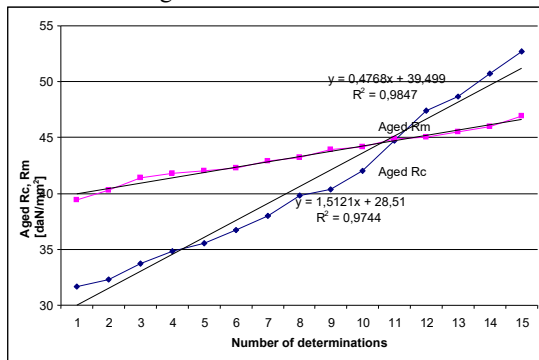


Figure 2. The breaking strength R_m in the raw state and in the aged state for the lot of tapes analyzed

The regression equations drawn for R_c in the raw state, as well as in the aged state, show us significant correlation coefficients very close to the value of 1, i.e. 0.98 for raw R_c and 0.97 for aged R_c , for the first batch and 0.91 and 0.98 respectively for the second batch. After determining the yield strength and breaking strength, hardness measurements were also made on the 10 rolls, measurements which are presented in table 6. Hardnesses were measured both at the head and at the end of the roll.

Table 4. The hardness values measured

No. of roll	End hardness [HV]	Head hardness [HV]	Hardness [HV]
1	174.7	170.0	179.1
2	181.0	181.4	185.2
3	180.0	178.6	179.6
4	181.0	179.6	179.3
5	185.3	178.4	178.9
6	177.6	181.1	174.0
7	176.9	173.7	185.4
8	177.0	180.1	178.6
9	180.8	177.8	179.6
10	184.1	187.0	178.4

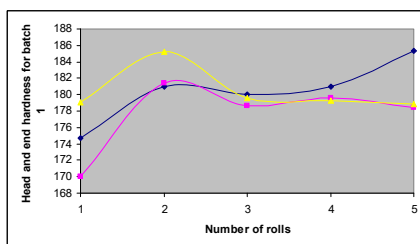


Figure 3. Variation of hardness for batch I of strips

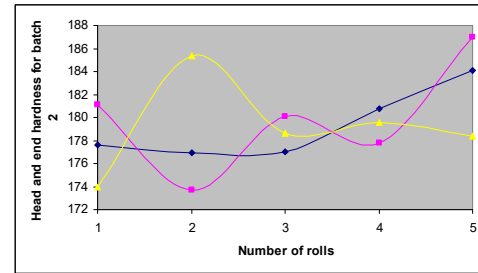


Figure 4. Variation of hardness for batch II of strips

The blue curve represents the hardness determined at the ends of the rolls and the red curve is the hardness measured at the head of the roll. The yellow curve represents the final hardness measured.

We find that the hardness at the head of the rolls is higher for all 5 analyzed rolls, according to figure 3, on the other hand, for the rolls from batch I the hardness at the ends is higher than the hardness at the head, according to figure 4. The hardness values are included in the EN standards 10106.

3. RESULTS AND DISCUSSION

According to chemical analysis strips analyzed shows that the carbon content is between 0.023 and 0.032% C, which is very good because the main characteristic of the strips is low carbon content for to obtain good magnetic properties. The main negative effect of carbon in non-oriented electrical steel is the appearance of aging magnetic transition caused by carbide precipitation inside the ferrite grains.

After the first cold deformation the structure is a structure with crystalline grains undeformed polyhedra, uniform.

As the degree of deformation increases, crystalline grains elongate in the direction of principal strain more than the degree of cold deformation is higher.

The regression equations drawn for R_m and R_c in the raw state, as well as in the aged state, show us significant correlation coefficients very close to the value of 1, this means that the values of experimental data are very good.

4. CONCLUSIONS

After cold rolling, in both cases analyzed structure is completely cold working, the grains are completely deformed. Cold working is characterized by increased resistance to deformation of the material, more so the degree of deformation applied is higher. The crystalline grains are elongated.

In the fine structure the cold working occurs by increasing the density of dislocations. The processes that cause changes in the structure and properties of metal are cold working and the recrystallization.

The introduction of high-permeability products and particularly the development of hybrid electric vehicles will be a major source of the expansion of non-oriented electrical steel sheets in the future.

According to Colton's empirical rules, we can state that there is a very good correlation between all the mechanical characteristics determined and the chemical composition,

since the values of the correlation coefficients had values above 0.75, which indicates a very good correlation between the percentage of carbon and the losses magnetic before and after aging, for the bands analyzed as well as between the mechanical characteristics measured in the raw state and in the aged state.

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