CORRELATION STUDY OF MAGNETIC PROPERTIES OF COLD ROLLED STEEL STRIPS SILICON NON-ORIENTED ELECTRICAL STEEL

Elena Valentina STOIAN

Valahia University of Targoviste, Faculty of Materials Engineering and Mechanics, Department of Materials Engineering, Mechatronics and Robotics, Str. Aleea Sinaia, No. 13, Targoviste, Romania,

Email: elenastoian22@gmail.com

Abstract: *The paper presents the study of the magnetic properties of cold rolled steel strips silicon non-oriented electrical steel. Are shown correlations between the characteristics silicon steel with non-oriented grains, made using least squares, and using regression equations. The experimental group studied was the siliceous strips with non-oriented grains with a thickness of 0.50 mm and a carbon content of between [0.028 to 0.032]% C. Magnetic Loss were determined before and after aging, producing a mathematical modeling in terms of the relationship between magnetic and carbon content Loss of electrical tape analyzed.*
After determining magnetic losses were obtained regression equations between specific magnetic 1.5T 1.0 T, respectively, before and after aging. For the 0.5 mm laminate strips were obtained very good correlation coefficients. Also they were obtained significant correlation coefficients for magnetic induction values before and after aging.

Keywords: *electrical steel, loss magnetic, microstructures, non-oriented grains, grain size*

1. INTRODUCTION

Silicon steel was developed at the beginning of the 20th century and soon became the preferred core material for large transformers, motors, and generators. Silicon-bearing steels are used as soft magnetic materials in electrical appliances and devices and are rated in terms of power loss when magnetized in an alternating electric field. The total amount of these steels is around 1 % of the world production of steel .[1,2] The production of electrical steel sheet and strip in the last 10 years has almost doubled. Non-oriented electrical steel sheets, commercially also called lamination steel, silicon electrical steel, silicon steel or transformer steel, are special steel sheets tailored to produce certain magnetic properties.

The NO electrotechnical steels belong to group of soft magnetic materials. The typical applications of NO steels are electromotors, generators etc. [3–5]. Constant attempts to improve the quality of electrical steels have quite naturally stimulated a search for corresponding improvements in the physical interpretation of magnetic losses [6, 7]. 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 in terms of grain size and crystallographic texture. [8]

The magnetic behavior of non-oriented electrical steels is controlled by the alloy content and several microstructural parameters, such as texture, grain size, and impurities. Silicon, aluminum, manganese and other microalloying elements such as antimony and tin are the chief elements used to obtain the desired properties.[9,10]

2. EXPERIMENTAL DETAILS

The investigation was carried out using commercially produced steels M400-50A, (according to EN 100027-1). The laminate strips were cold rolled from the hot band thickness of 2.4 mm to the final thickness of 0.5 mm with a grade of 80% reduction, the strip width of 1030 mm.

The final heat treatment was performed on a continuous decarburizing and annealing “dynamo” line using the same processing parameters for all experimental materials.

Decarburization was conducted at a temperature of 830˚C using a wet $H_2 + N_2$ atmosphere with a dew point of 29˚C. The decarburization and grain growth soaking times of 619-510 seconds. Recrystallization treatment was conducted at 940^0C.

During the heat treatment and decarburization annealing treatment line speed was 32 m / min. Following heat treatment, it is found that the grain size is becoming smoother.

The resultant magnetic properties were measured via frame Epstein (according IEC 60404-2) with an exciting current frequency of 50 Hz at 1.5 T and 1.0T, induction after an aging treatment of 225˚C for 24 hours. Hot rolled strip resistivity the whole experimental lot ranged from 0.27 to 0.39 Ωmm.

3. REPRESENTING OBSERVATIONAL DATA THROUGH EQUATIONS BY LEAST SQUARES

Of the numerous applications of least squares, the most important is the ability to determine the best equation for representing a particular type of observational data.

Between two variables x and y, there may be a connection strict form y = f (x) or on the contrary they may be independent of each other.

We define the notion of functional determined Contact: occurs when the value of the independent variable x corresponds to a single well-determined value of the variable y. It is said that between the two variables statistically there is a connection type.
The research statistics of the causal link involves solving two fundamental issues:

- Determine the law of variation of the dependent variable y: y = f (x1, x2, ... xn) known as regression problem;
- Characterization and direction of y = f link between variable (x1, x2, ... xn), which is also called correlation problem.

It is assumed that the equation takes the form:

y = a + bx (1)

where b is the constant that interests us most. [11]
For example consider the dependence of specific magnetic loss 1.0 T C depending on the content of the experimental group made up of M 400-50A electrical strips with thicknesses of 0.50 mm and the content of C is between [0.028 to 0.032]% C. The data examined are shown in Table 1.

Tabel 1. The magnetic losses before aging on [0.028-0.032]% C at 1.0T

P 1,0 [W/kg]	C [%]
2,11	0,032
2,04	0,03
2,08	0,031
2,01	0,03
2,01	0,031
2,03	0,032
2,08	0,032
2,05	0,032
1,98	0,029
2,07	0,032
1,87	0,029
2,07	0,03
2,06	0,03
1,89	0,03
1,99	0,03
2,11	0,031
2,02	0,031
1,9	0,029
2,05	0,031

If y represent the values defined by the equation obtained by the method of small squares:

y = a + bx (2),

and y_0 the observed values, we will seek, when it came to compensation conditional observations, consider a and b so that the sum $\Sigma(y_0-y)^2$ or what is the same $\Sigma(y_0-a-bx)^2$ to be minimal. If n is the number of points (measurements) results observed:

$$\frac{\partial}{\partial a}\left[\sum_{i=1}^{n}(y_0-a-bx)^2\right]=0, \qquad (3)$$

$$\frac{\partial}{\partial b}\left[\sum_{i=1}^{n}(y_0-a-bx)^2\right]=0, \qquad (4)$$

From that we get:

$$na+b\Sigma x=\Sigma y_0 \qquad (5)$$

$$a\Sigma x+b\Sigma x^2=\Sigma xy_0 \qquad (6).$$

From these equations we get:

$$a=\frac{\sum_{i=1}^{n}x^2\sum_{i=1}^{n}y_0-\sum_{i=1}^{n}x\sum_{i=1}^{n}xy_0}{n\sum_{i=1}^{n}xy_0-\left(\sum_{i=1}^{n}x\right)^2} \qquad (7)$$

$$b=\frac{n\sum_{i=1}^{n}xy_0-\sum_{i=1}^{n}x\sum_{i=1}^{n}y_0}{n\sum_{i=1}^{n}x^2-\left(\sum_{i=1}^{n}x\right)^2} \qquad (8)$$

For determining intensity of correlation between the two variables are calculated correlation coefficients r:

$$\sum_{1}^{19}x=38.42\Rightarrow\sum_{1}^{19}x^2=77.778 \qquad (9)$$

$$\sum_{1}^{19}y=0.582\Rightarrow\sum_{1}^{19}y^2=0.582 \qquad (10)$$

$$\sum_{1}^{19}xy=1.1778 \qquad (11)$$

$$\bar{x}=2.022, \qquad \bar{y}=0.0306 \qquad (12)$$

$$\left(\bar{x}\right)^2=4.089, \qquad \left(\bar{y}\right)^2=0.000938 \qquad (13)$$

$$r=\frac{\sum_{i=1}^{n}xy-n\,\overline{xy}}{(n-1)S_xS_y}=\frac{\sum XY-n\overline{XY}}{\sqrt{(\sum X^2-n\overline{X}^2)(\sum Y^2-n\overline{Y^2})}} \qquad (14)$$

$$S_x=\sqrt{\frac{1}{n-1}\left(\sum x^2-n\overline{x}^2\right)} \qquad (15)$$

$$S_y=\sqrt{\frac{1}{n-1}\left(\sum y^2-n\overline{y}^2\right)} \qquad (16)$$

S_y, is called the standard error of the estimate. From the calculations we obtain r = 0.69.
After determination of the coefficient r is calculated:

$$b = r\frac{S_y}{S_x}, b = 45{,}773 \quad (17)$$

$$a = \overline{y} - b\overline{x} = 0{,}62 \quad (18)$$

Resulting equation :
Y=45,773 X + 0,62 ,

therefore P1,0=45,773 C + 0,62. (19)

Testing verify correlation coefficient comparing the absolute value of the correlation coefficient multiplied by the empirical with a critical value of PT given confidence level. [11,12] Breakpoints product for different values of the level of trust and different values of n number of measurements are given in Table 2.

Table 2. Minimum admissible values (n = number of measurements, PT = confidence level)

n \ P	0,90	0,95	0,99	0,999
10	1,65	1,90	2,29	2,62
11	1,65	1,90	2,32	2,68
12	1,65	1,91	2,35	2,73
13	1,65	1,92	2,37	2,77
14	1,65	1,92	2,39	2,81
15	1,65	1,92	2,40	2,85
16	1,65	1,93	2,41	2,87
17	1,65	1,93	2,42	2,90
18	1,65	1,93	2,43	2,92
19	1,65	1,93	2,44	2,94
20	1,65	1,94	2,45	2,96
21	1,65	1,94	2,45	2,98
22	1,65	1,94	2,46	2,99
23	1,65	1,94	2,47	3,00
24	1,65	1,94	2,47	3,02
25		1,941	2,475	3,026
26		1,941	2,479	3,037
27		1,942	2,483	3,047
28		1,943	2,487	3,056
29		1,943	2,490	3,064
30		1,944	2,492	3,071
35		1,947	2,505	3,102
40		1,949	2,514	3,126
45		1,950	2,521	3,145
50		1,951	2,527	3,161
60		1,953	2,535	3,183
70		1,954	2,541	3,198
80		1,955	2,546	3,209
90		1,956	2,550	3,219
100		1,956	2,553	3,226

Testing correlation coefficient is as follows:

$$0.69 \cdot \sqrt{19-1} = 2.92$$

Note that 2.92 is greater than 2.44 and less than 2.94. So the correlation coefficient is significantly exceeds the critical value for the confidence level of 0.99.
In conclusion loss increases with increasing the concentration of carbon, C.

4. ANALYSIS OF REGRESSION EQUATIONS FOR ELECTROTECHNICAL STRIPS

On the coils where the concentration of C is between [0028-0032%] C, in accordance with Table 1, were highlighted these correlations wich are presented in Table 3:

Table 3

The magnetic properties of cold rolled steel strips

B 25 raw [T]	B 25 aging [T]	P 1,0 raw [W/kg]	P 1,0 aging [W/kg]	P 1,5 raw [W/kg]	P 1,5 aging [W/kg]	C[%]
1,605	1,605	1,85	1,85	4,2	4,2	0,0285
1,61	1,61	1,9	1,9	4,3	4,3	0,029
1,6115	1,615	1,95	1,95	4,35	4,35	0,0295
1,62	1,62	2	2	4,4	4,4	0,03
1,625	1,625	2,15	2,15	4,45	4,45	0,0305
1,63	1,63	2,1	2,1	4,5	4,5	0,031
1,635	1,635	2	2	4,6	4,6	0,0315
1,634	1,64	1,95	1,95	4,65	4,65	0,032
1,645	1,64	2	2	4,7	4,7	0,031

Regression equations analysis was carried on the same lot cold rolled strip steel Electrotechnical silicon non-oriented electrical steel. The study carried out on a total of 10 coils, which were obtained magnetic characteristics shown in Table 3.

5. RESULTS AND DISCUSSIONS

Based on experimental results obtained and presented in table 3 have been some correlation between the magnetic properties of rolled strip before and after aging.

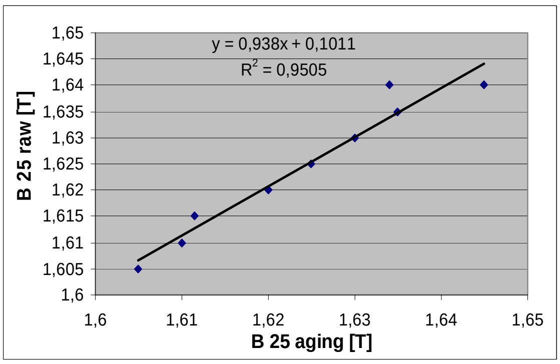

Fig. 1 Correlation diagram for magnetic flux density

According to figure 1, we see that between magnetic induction values before and after aging obtain a correlation coefficient R = 0.95, significant coefficient for a confidence level of 0.999.

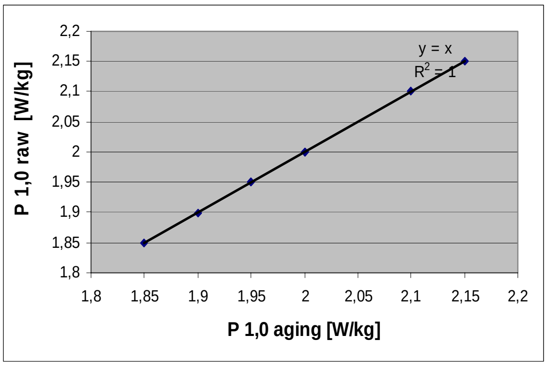

Fig. 2 Correlation diagram for specific the magnetic losses 1.0T

Between specific magnetic loss amounts to 1.0 T before and after aging is obtained correlation coefficient R = 1, significantly for a confidence level of 0.999. This can be seen in figure 2. The same thing can be observed at specific magnetic loss 1,5T, according to figure 3.

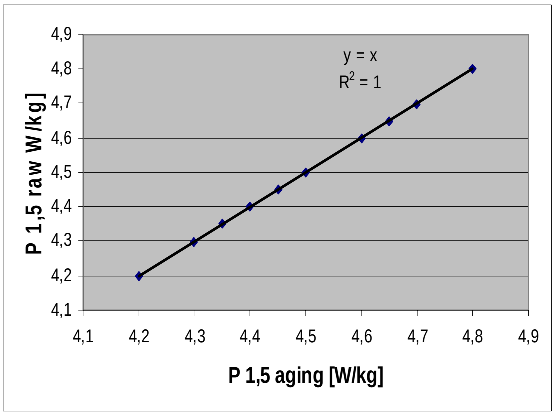

Fig. 3 Correlation diagram for specific the magnetic losses 1.5T

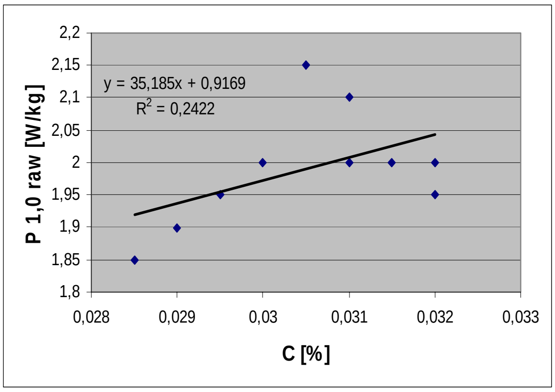

Fig.4 Correlation diagram of specific the magnetic losses depending on the carbon content 1.0T

Figure 4 presents the analysis of possible correlations between the experimental group throughout loss specific magnetic and carbon content and notes that there is a correlation coefficient determined satisfactorily. The correlation coefficient is R = 0.242.

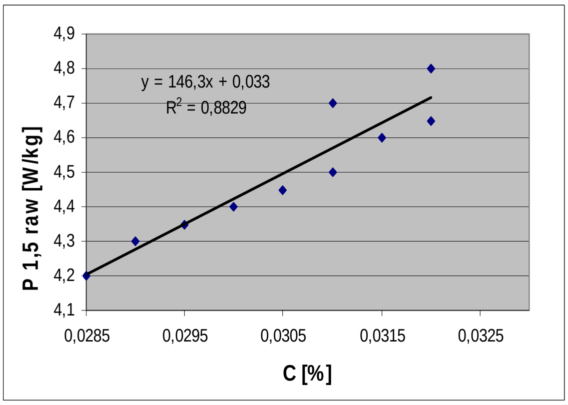

Fig. 5 Correlation diagram of specific the magnetic losses depending on the carbon content 1.5T

Between specific magnetic losses at 1.0 T before aging and the concentration of C, to obtain a correlation coefficient R = 0.24, significant for a confidence level of 0.90.

Between 1,5T specific magnetic noticeable loss before aging and the concentration of C, to obtain a correlation coefficient R = 0.88, significant for a confidence level of 0.99.

6. CONCLUSIONS

From the data obtained is remarkable specific magnetic losses increased to 1.0 T and 1.5 T, before aging, with the percentage of increase carbon, as shown in the table 3.
In conclusion noticeable loss 1,0T specific magnetic and 1,5T increase with increasing concentration of carbon, such as mathematical modeling observational data representation made by the equations by least squares is true in the case studied, ie, in the case electrical strips with non-oriented grains studied in this paper.

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