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THE INFLUENCE OF SPEED COOLING ON SOME PROPERTIES OF LAMINATED STEEL

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ABSTRACT

This study presents a possibility to predict the connection between the cooling regime and the properties of steel. An important factor to enhance the properties of steel is the speed of the cooling regime. To be in accordance with the experimental results, this study considered a correlation between the speed of cooling for laminated steel with a low carbon content and other properties of steel. It is important to choose the optimal cooling regime because the steel was laminated at high temperature.

KEYWORDS: steel properties; cooling speed, correlation; statistical model

1. Introduction

Carbon is the most important element of steel because this chemical element determines the chemical structure and its properties. In the case of steel with a low content of carbon, its structure has two important components: Ferrite (F) and pearlite (P). Ferrite has a low mechanical strength but has plastic properties. Cementite in steel has high hardness but is fragile. Therefore, an increased content of carbon increases the hardness and the strength of steel and decreases its plasticity.

For example, the literature shows that for steels with 0.11% C, 0.48% Mn, and 0.24% Si the microstructural parameters which determine their mechanical properties are the size and shape of pearlitic and ferritic grains. The microstructure of this type of steels is formed by pearlite (P) and ferrite (F) as constituents. These types of steels are used currently without chemical treatments, for metal construction and machine building, for elements of metal structures subjected to small requests. Because the steel with low carbon content has high plastic properties below 550 °C, the thermal stresses will not lead to the formation of cracks.

Damage of materials means the progressive or sudden deterioration of their mechanical strength due to loading, thermal or chemical effects (*see [4] Vuong Nguyen Van Do 2016*). It is important to know how the properties of steels can be improved. For this case, it is necessary to find a causal relation between a technological parameter (the speed of cooling regime) and the mechanical properties of steel (for example, the resilience – KV - of steel).

After an experimental program, the values obtained were used to determine a correlation between these variables through an empirical study.

2. Experimental results

Three groups of 8 steel samples were considered. The chemical composition of the material is presented in Table 1. Three cooling regimes were applied: (1) cooling regime in normal conditions; (2) cooling in airflow (in jet of air); (3) cooling in the metallic recipient.

Table 1. *Chemical composition of steel*

Steel grade	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Al (%)
Fe510 (Euronorm); S355	0.14	1.51	0.31	0.010	0.010	0.041

The initial temperatures were: 850 °C (for the first batch of samples), 900 °C (for the second batch of samples), 950 °C (for the third batch of samples) and 1000 °C (for the last batch of samples). If the cooling mediums are different, the speeds of the cooling are different, too.

In Figure 1 was represented the evolution of the thinning of the samples (Z or Ψ) during the tensile tests [6]. In Figure 2 was represented the evolution of the resilience (KV+20 ºC) which depends on the initial temperatures, in the first case [6].

In Figures 3 and 4 are presented the variations of the resilience (KV +20 ºC), in the other two different cooling regimes: in metallic box and in jet of air. The best values have been obtained in the cases of higher values of the cooling speed, in jet of air regime.

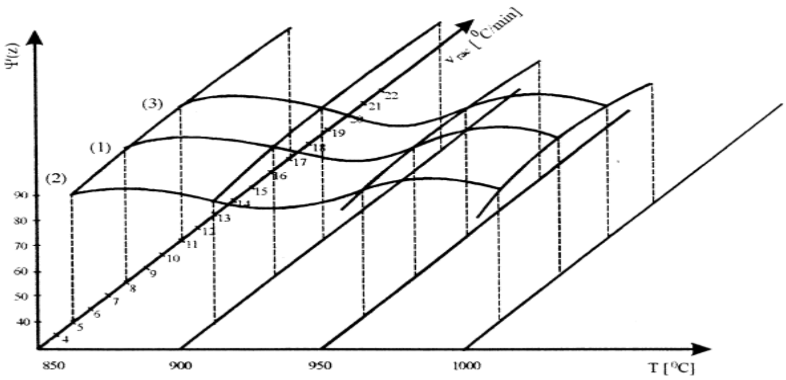

Fig. 1. *Thinning of the samples during the tensile tests depending on cooling regimes (1, 2 or 3) and on initial temperature*

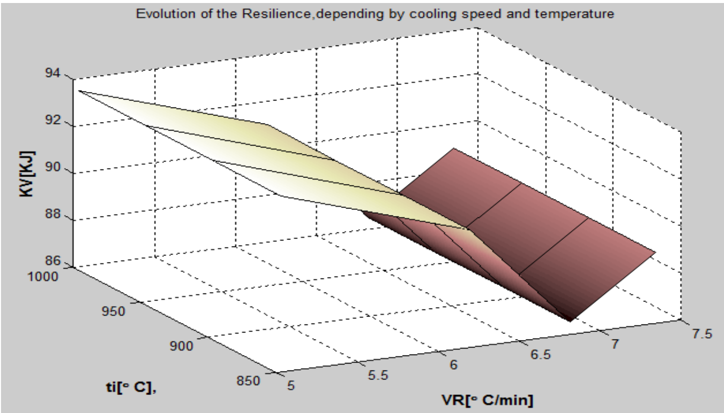

Fig. 2. *Evolution of resilience (KV), depending on cooling speed (VR) and initial temperature, for the cooling regime (1)*

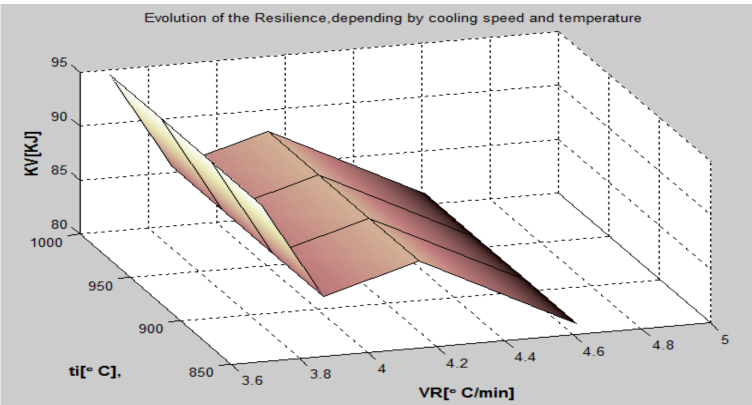

Fig. 3. *Evolution of resilience (KV), depending on cooling speed (VR) and initial temperature, for the cooling regime (3)*

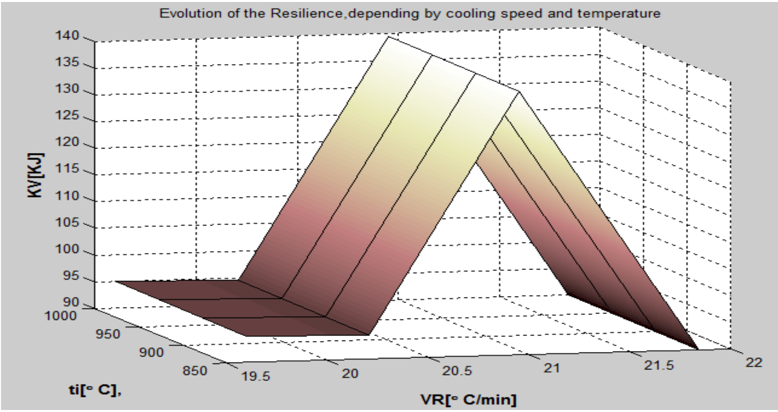

Fig. 4. *Evolution of resilience (KV), depending on cooling speed (VR) and initial temperature, for the cooling regime (2)*

The thinning of the samples (Z or Ψ) during the tensile tests is higher in the case of the initial temperature T = 1000 °C and the speed of cooling VR = 21.84 °C/s (cooling in jet of air). In the case of cooling in jet of air, the speed of the cooling will be the highest and the mechanical properties have the best results.

In Table 2 are presented some of the experimental results obtained [6].

Table 2. *Obtained experimental results*

Speed of cooling Vrac [°C/S]	HB	A5[%]	KV [KJ]	Cooling regime	Code samples
4.61 (cooling in metallic recipient)	162.5	31.05	89	(2)	2.8
7.35 (cooling in normal conditions)	181.5	32.5	81	(1)	2.4
21.84 (cooling in jet of air)	184	33.2	90	(3)	2.13

3. Statistical model

To determine the model parameters, this operation can be performed using the method of least squares. It starts from the regression equation of a simple linear model. For example, to prove the causation between the cooling speed (VR.) and the resilience (KV-20 °C) in the case of the initial temperature Ti = 850 °C, statistical methods were used to check the next assumption: we assume that there is a causal relationship between the independent variable "VR" and a dependent variable "KV". Between these variables there is a direct connection. In Figure 3 was represented the evolution of the resilience of steel at 850 °C, which depends on the type of the cooling regime.

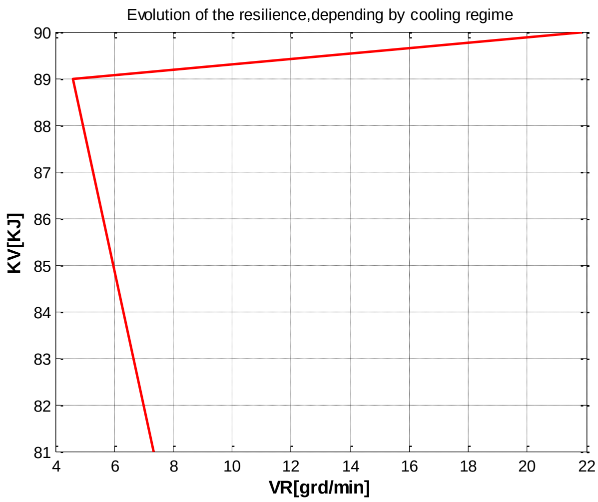

Fig. 5. *Resilience (KV) depending on cooling speed corresponding to different regimes*

To study the correlation between the variables we used unifactorial regression. Unifactorial regression can describe with success the relationship between two analyzed indicators. In the case of unifactorial regression, only the variable factor (x) has an action on the result feature (y) [3]. Other possibly factors have a constant action negligible (y-f(x)). The estimation function is given by the following expression:

$$\hat{y} = a + b \cdot x \quad (1)$$

We have the following expressions *(see [1-3] or Scradeanu 2015)*:

$$n\hat{a} + \hat{b}\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \quad (2)$$

$$\hat{a}\sum_{i=1}^{n} x_i + \hat{b}\sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} x_i y_i \quad (3)$$

It is estimated that the bond between these two variables (VR and KV) is represented by the equation of straight line. The mathematical model must continue with the characterization of the connection intensity between the two variables using the correlation coefficient "$r_{x,\ y}$" and the correlation report (*see Scradeanu, 2015 and Simofi, 2013*).

In this case, n = 3 and the system of the equations (4) will be:

$$3a + 33.79b = 260$$
$$33.79a + 552.259b = 2971.24$$

Solving the system and applying the substitution method, results:

$$b = 0.249 > 0$$
$$a = 83.860$$

The estimation function will be:

$$y = 83.860 + 0.249x \quad (5)$$

Comparing the real values of **y** with the adjusted values for the *resulting feature* ŷ, there are some differences, presented in Table 3.

Table 2

x	ŷ
4.61	85
7.35	85.69
21.84	89.29

Table 3

ŷ	ŷ - y
85	85-81= 4
85.69	85.69-89= -3. 31
89.29	89.29-90 = -0.71

Using Matlab Program, the correlation graphic corresponding to the equation (5) was obtained for the values corresponding to the adjusted values for resulting feature **ŷ** (see Tables 2 and 3 and Figure 6).

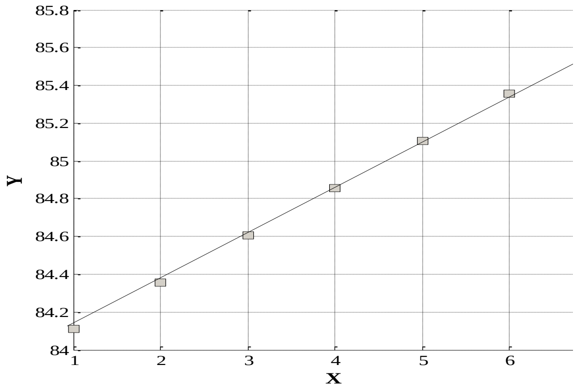

Fig. 6. *Graphic representation for adjusted values of resulting feature ŷ, calculated with relation: ŷ = 0.249 x + 83.860*

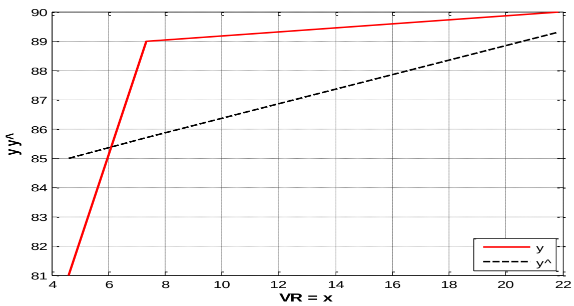

Fig. 7. *Graphic of correlation*

It is estimated that the bond between these two variables (VR and KV) is represented by the equation of straight line. The mathematical model must continue with the characterization of the connection intensity between these two variables using the correlation coefficient ($r_{x,y}$) and the correlation report (*see [1] Scradeanu, 2015*).

$$n\hat{y} = \sum_{i=1}^{n} x_i\, y_i \quad (6)$$

The above relation, for *covariance coefficient*, can be written (*see [1-3] or Breaz N., Craciun M. Gaspar P.2011, Curs)*:

$$M(x \cdot y) = n^{-1} \sum_{i=1}^{n} x_i y_i \quad (7)$$

For n =3, ȳ = M(x y) = 2971.24/3 = 990.41

The simple correlation coefficient "r" will be:

$$r = \frac{n\sum^{n} x_i y_i - \left(\sum^{n} x_i\right)\left(\sum^{n} y_i\right)}{\sqrt{n\sum^{n} x_i^{2} - \left(\sum x_i\right)^2} * \sqrt{n\sum^{n} y_i^{2} - \left(\sum^{n} y_i\right)^2}} \quad (8)$$

In this case, r = 0.5.

The simple correlation coefficient is positive: $r_{x,y} > 0$ shown that a direct connection between the variables (VR and KV) exists. This result indicates the correlation, a direct connection between these two variables.

4. Conclusions

This work wants to demonstrate that the model of linear unifactorial regression- commonly used in economics - has applications in steel engineering. This study determined a correlation between the variables. Because r = 0.5 < 0.95, we cannot talk about a relative deterministic connection but it was statistically proved that a direct and strong connection between the variables exists.

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