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MATHEMATICAL MODELING TO PREDICT MECHANICAL PROPERTIES VALUES FOR HOT ROLLED S235 STEEL

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ABSTRACT

The present paper presents the creation of a mathematical model for predicting the values of the mechanical properties of hot-rolled strips. The paper presents the way of developing the mathematical model, based on a statistical development method, namely, the active experiment method.

The equations of the developed mathematical model successfully allow the prediction of the values of the studied mechanical properties, thus saving material, time and money.

KEYWORDS: steel, hot rolling, thermal treatment, mathematical modeling, prediction of property values

1. Introduction

Even today, steel remains the most used material in the car construction industry, the construction of oil and gas pipelines and many others. Many of the semi-finished products from which various benchmarks are obtained, are obtained through the metallurgical processing of hot plastic deformation.

Mathematical modeling of technological processes in general and of metallurgical ones in the present case, is a basic tool that is extremely useful both in the conception phase and in the one in which the operation of metallurgical installations is analysed [1].

Mathematical modeling together with the use of computers, allows obtaining the optimal regimes for metallurgical processes. By performing mathematical modeling through statistical methods, it is possible to approach the optimal decision problem as a problem of great technical and economic effectiveness [2].

Mathematical modeling operates with numerical quantities without conditioning the way of subjective interpretation, in a certain context of the results obtained. It requires the knowledge of all the elements that contribute to the description of the phenomenon, the possibility of quantitative expression and, as far as possible, without any subjective addition, the most thorough knowledge of the conditions in which the phenomenon takes place, the specification of the restrictions imposed on some quantities or functions, as well as the complete definition of the pursued goal [3].

Mircea Malița defines the model as "a mental or written, qualitative or mathematical representation of a part of a reality that constitutes a system (i.e. a whole with interconnected parts). The model selects the most representative components of the system and describes the relationships that select" [4].

Creating a model not only serves knowledge but also has practical purposes, constituting a basis for experimentation.

The large number of mathematical models made over time have shown that for the same model the formulated requirements form a contradictory set. From this it follows that any mathematical model satisfies, as a rule, only a part of the established requirements. Mathematical models can be classified according to several criteria. The most representative, in this sense, are: the information they contain and the mathematical tool used.

The main requirements imposed on a quality model are: coherence, correctness, consistency, efficiency and usability [5].

The use of monofactorial methods for the study of multifactorial processes, in addition to the fact that they require a long period of work, cannot guarantee the determination of the conditions for achieving the optimal values of the performance function. From this point of view, the introduction and development of statistical processing methods and especially those that concern modeling by using experiment programming methods is a useful and highly effective tool [6].

The mathematical models obtained by these methods can be used not only to reveal the extreme

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(optimal) conditions, but also as an important source of information, necessary for the optimal management of metallurgical processes [7].

In the analysis of a system when it is required to find out by calculation the performance indicators of the given system, this requires knowledge of the mathematical model of the system, that is, of the relations between the output quantities and the exogenous quantities [8].

2. Experimental conditions and obtained results

The paper presents the way to create a mathematical model for predicting the values of the mechanical properties of hot-rolled strips.

Experiments were carried out in a trial with hot-rolled S235 steel strip, having thicknesses of: 2 mm, 6 mm, 10 mm, and the carbon concentration being: 0.1101 %C; 0.1261 %C; 0.1421 %C, for steel grade S235.

Table 1 shows the chemical composition according to EN10111:2008(E) for the steel brand S235 studied.

For each tape thickness studied, having the three carbon concentrations, determinations were made in order to find out the values of the mechanical properties: R_m, $Rp_{0.2}$, A_5.

Following the laboratory tests on the samples taken from the rolls caught in the experimental program, the values of the studied mechanical properties were recorded, values which are reproduced in Table 2.

Table 1. *Chemical composition according to EN10111:2008(E) for steel grade S235*

Chemical Composition											
C%	**Mn%**	**Si%**	**P%**	**S%**	**Al%**	**Cu%**	**Cr%**	**Ni%**	**V%**	**Ti%**	**Mo%**
0.04-0.08	0.45-0.55	0.01-0.02	0.013-0.019	0.011-0.016	0.020-0.040	0.050-0.080	0.030-0.040	0.030-0.050	0.002-0.003	0.000-0.001	0.003-0.005

Table 2. *Values of the S235 steel properties*

Thickness [mm]	%C	R_m - measured [MPa]	$Rp_{0,2}$ - measured [MPa]	A_5 measured [%]
2	0.1101	419	344	29
	0.1261	434	371	30
	0.1421	478	397	30
6	0.1101	415	270	32
	0.1261	419	287	31
	0.1421	448	327	30
10	0.1101	378	270	32
	0.1261	416	284	31
	0.1421	427	298	30

We considered the following technological parameters as the main influencing factors (independent variables):

a) Tape thickness - G, [mm];

b) Carbon concentration - C, [%].

The set of mechanical properties is considered as a parameter to be optimized: R_m, $Rp_{0.2}$, A_5.

We established the following experimental conditions:

- for the tape thickness, G, the values for the upper level, the base level, the lower level and the range of value variations were set:

base level: $x_1(0) = 6$ mm;
variation range: $\Delta x_1 = 4$ mm;
upper level: $x_1(+1) = 10$ mm;
lower level: $x_1(-1) = 2$ mm.

For carbon concentration:
base level: $x_2(0) = 0.1261$ %;
variation range: $\Delta x_2 = 0.016$ %;
upper level: $x_2(+1) = 0.1421$ %;
lower level: $x_2(-1) = 0.1101$ %.

For the coded representation of the experiment, the following notations and symbols were used:

Independent variables:
x_1 - tape thickness, G [mm];
x_2 - carbon concentration, C [%].
Dependent variables (parameters to optimize)
Y1 - breaking strength, R_m [MPa];
Y2 - yield strength, Rp_{02} [MPa];
Y3 - specific elongation at break, A_5 [%];
Yi values are expressed in natural units.

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Since the influence of two factors on the performance of the process (Y) is being studied, we carried out a complete factorial experiment of type 22 [2].

The calculated values for the coefficients: for the three equations of the mathematical model of S235 steel are shown in table 4.

***Table 3.** Matrix of full 22 factorial experiment for S235 steel*

Nr. exp.	X_0	X_1	X_2	$X_1 \cdot X_2$	Y_1	Y_2	Y_3
1	1	1	1	1	427	298	30
2	1	-1	1	-1	478	397	30
3	1	1	-1	-1	378	270	32
4	1	-1	-1	1	419	344	29

***Table 4.** Values of coefficients C_0, C_1, C_2, C_{12} for S235 steel*

The coefficients / Y_i	C_0	C_1	C_2	C_{12}
Y_1	425.5	-23	27	-2.5
Y_2	327.25	-43.25	-20.25	-6.25
Y_3	30.25	0.75	-0.25	-0.75

After calculating the coefficients, the equations of the mathematical model in the form of equation 1, in coded quantities, respectively equations 2, 3 and 4 [2] resulted:

$$Y_n = C_0 + C_1X_1 + C_2X_2 + C_{12}X_1X_2 \quad (1)$$
$$Y_1 = 425.5 - 23 \cdot X_1 + 27 \cdot X_2 - 2.5 \cdot X_1 \cdot X_2 \quad (2)$$
$$Y_2 = 327.25 - 43.25 \cdot X_1 + 20.25 \cdot X_2 - 6.25 \cdot X_1 \cdot X_2 \quad (3)$$
$$Y_3 = 30.25 + 0.75 \cdot X_1 - 0.25 \cdot X_2 - 0.75 \cdot X_1 \cdot X_2 \quad (4)$$

After replacing the coded sizes (X_1, X_2) with the natural sizes (G - band thickness, C - carbon percentage) the equations of the mathematical model expressed in natural sizes will be obtained.

$$Y_1 = 435.81 - 5.25 \cdot G + 192.15 \cdot C - 3.90 \cdot C \cdot G \quad (5)$$

Y_1 - equation of the mathematical model in natural sizes for Rm of S235 steel.

$$Y_2 = 368.82 - 9.58 \cdot G + 185.12 \cdot C - 9.76 \cdot C \cdot G \quad (6)$$

Y_2 - equation of the mathematical model in natural sizes for Rp0.2 of S235 steel.

$$Y_3 = 28.443 + 0.3345 \cdot G + 5.46 \cdot C - 1.17 \cdot C \cdot G \quad (7)$$

In the Figures from 1 to 9, the values of the mechanical properties studied, obtained experimentally, are shown in a comparative way with those obtained by calculation with the help of the developed mathematical model.

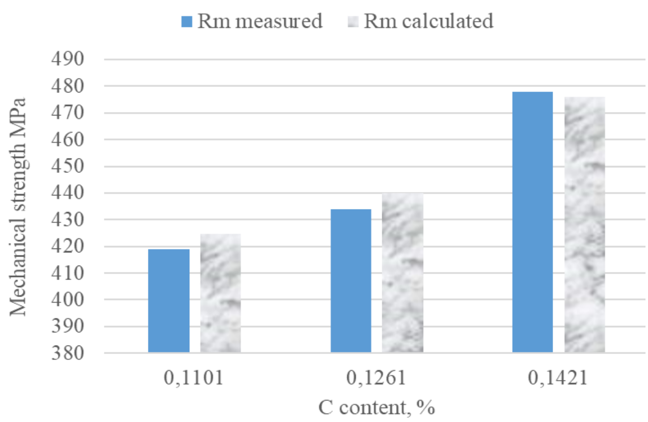

***Fig. 1.** Variation of R_m as a function of %C for 2 mm tape thickness*

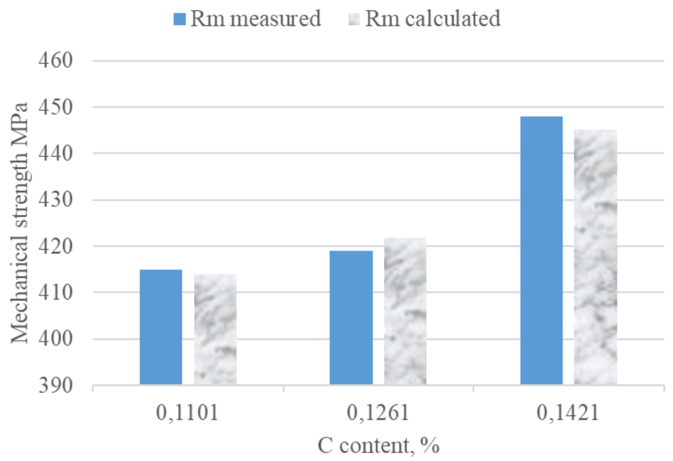

Fig. 2. *Variation of R_m as a function of %C for 6 mm tape thickness*

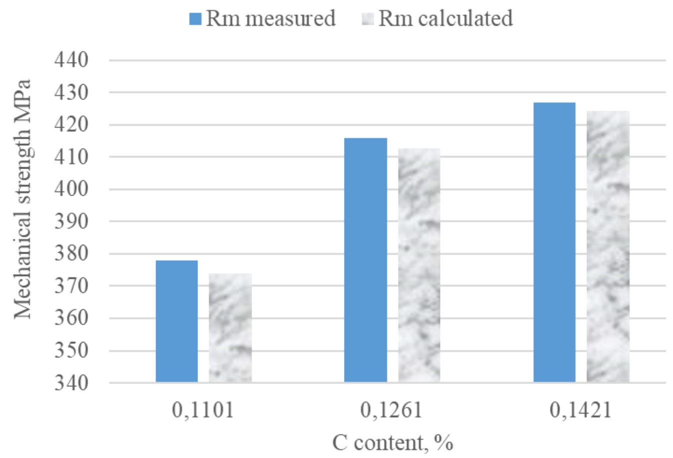

Fig. 3. *Variation of R_m as a function of %C for tape thickness of 10 mm*

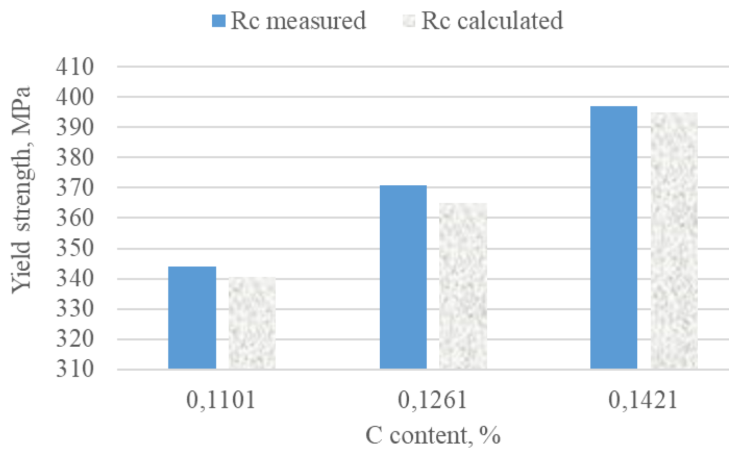

Fig. 4. *Variation of $Rp_{0.2}$ as a function of %C for tape thickness of 2 mm*

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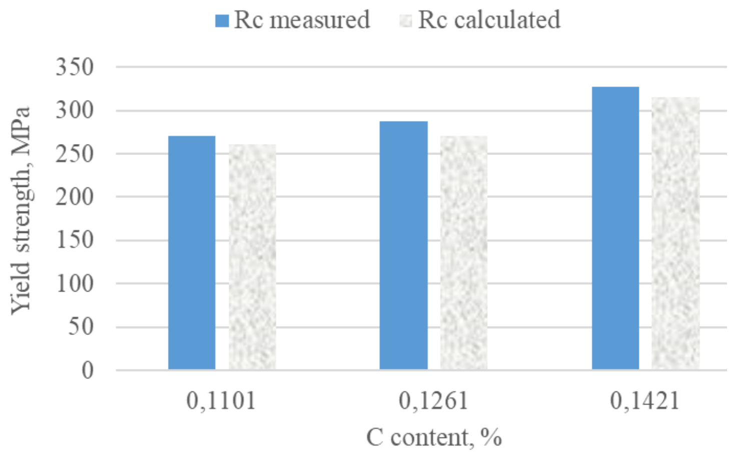

Fig. 5. *Variation of $Rp_{0.2}$ as a function of %C for tape thickness of 6 mm*

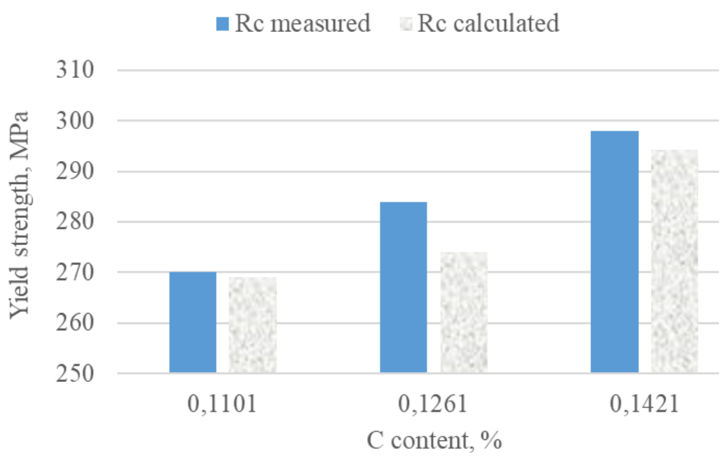

Fig. 6. *Variation of $Rp_{0.2}$ as a function of %C for 10 mm tape thickness*

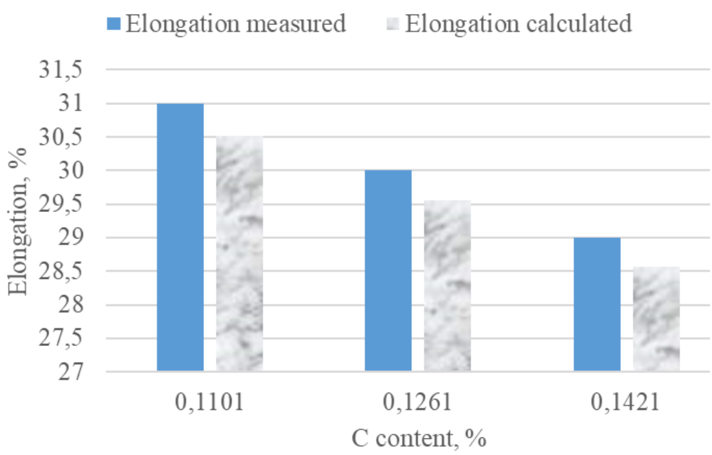

Fig. 7. *Variation of A_5 as a function of %C for 2 mm tape thickness*

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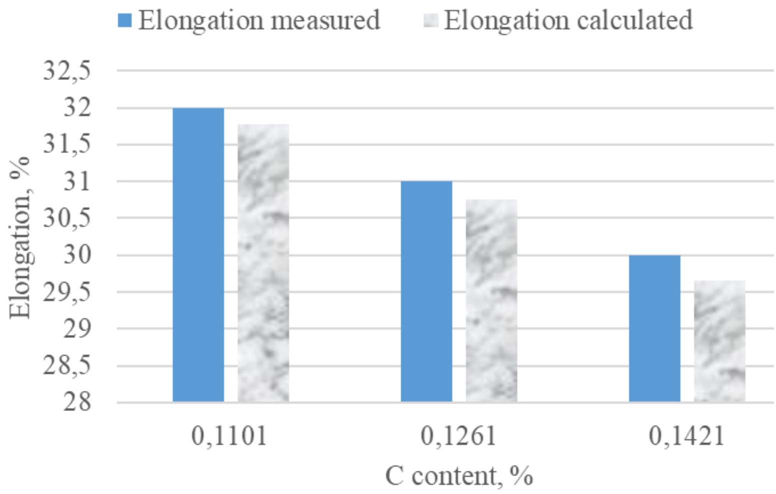

Fig. 8. *Variation of A_5 as a function of %C for 6 mm tape thickness*

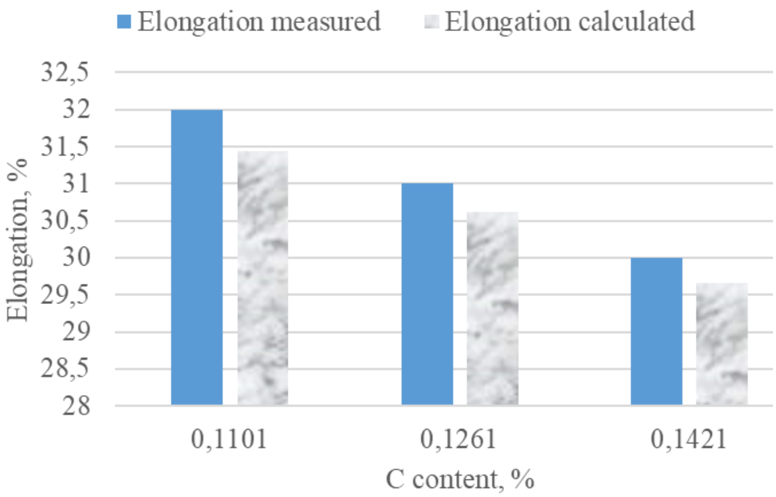

Fig. 9. *Variation of A_5 as a function of %C for 10 mm tape thickness*

By analysing the graphs above, it can be seen that between the values of the mechanical properties calculated, using the equations of the mathematical model, and the measured values, there are very small differences that can be neglected.

For this reason, it can be said that the obtained mathematical model can be successfully used to express the values of the mechanical properties without the need to measure them by specific methods.

3. Conclusion

Following the development of the mathematical model, three equations were obtained that express the dependence of each studied mechanical property on the two factors taken into account (independent variables = input variables), namely: strip thickness and carbon percentage.

From the analysis of the coefficients of the mathematical model equation for Rm it follows that as the carbon content increases there is also an increase in the value of R_m and as the strip thickness decreases there is also an increase in the value of R_m.

The mathematical model equation for $Rp_{0.2}$ shows that the value of $Rp_{0.2}$ increases with decreasing carbon content and strip thickness.

It is observed that the elongation decreases as the carbon content increases.

The calculation of the values of the studied mechanical properties, with the help of the equations of the mathematical model compared to the measured values, highlights small differences between the values of the measured and calculated properties.

Thus, it can be said that the developed mathematical model can be successfully used to predict the values of the mechanical properties without the need to measure them by specific

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methods and in this way, there is an economy of materials, time and labour.

References

[1]. Ciucă I., Dumitriu S., *Modelarea şi Optimizarea Proceselor Metalurgice de Deformare Plastică şi Tratamente Termice*, Editura Didactică şi Pedagogică, Bucureşti, 1998.

[2]. Taloi D., *Optimizarea proceselor tehnologice – aplicaţii în metalurgie*, Editura Academiei, Bucureşti, 1987.

[3]. ***, https://www.academia.edu/39946148/.

[4]. Mircea Maliţa, *Zece mii de culturi o singură civilizaţie*, Editura Nemira, Bucureşti, 2002.

[5]. Cătălin Zisu, Alexandru Mihalcea, *Securitatea sistemelor informaţional-decizionale*, Editura Tritonic, Bucureşti, 2007.

[6]. Șerban R., Dumitrescu T., *Metode de optimizare*, Editura Matrix Rom, Bucureşti, 1998.

[7]. Popescu D., Ionescu F., Dobrescu R., Ștefanoiu D., *Modelare în ingineria proceselor industriale*, Editura AGIR, Bucuresti, 2011.

[8]. Mureşan S. Anton, *Modelare matematică*, Editura Mega – Cluj Napoca, România, ISBN 978-606-543-139-3, 2011.