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RESEARCHES CONCERNING THE DEFORMATION BEHAVIOUR OF A LOW CARBON STEEL

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ABSTRACT

The paper shows the results of the researches meant to establish the equation of deformation behavior of low carbon steel. The behavior law is established by the experimental way, using the torsion test method. The composed constitutive law had very good experimental verification.

KEYWORDS: thermo-plastic behavior, torsion test, stress intensity, strain intensity.

1. Introduction

The plastic deformation of a metallic material is described by the equation between the stress, strain, strain rate and temperature [1]:

$$\sigma = \sigma(\varepsilon, \dot{\varepsilon}, T) \quad (1)$$

In this equation σ is the stress intensity in the real deformation conditions, ε - strain intensity, $\dot{\varepsilon}$ - strain rate intensity, T – temperature.

The equation of plastic deformation behavior is necessary for the evaluation, programming, modeling, simulation and optimization of the plastic deformation processes. This paper presents the results of researches effectuated for establishing the equation of plastic deformation behavior for low carbon steel for wires, destined to reinforce concrete.

2. Experimental conditions and results

The constitutive equation is established through experimental way using a torsion testing machine. The researched material has 0.18% carbon, 1.23% manganese, 0.21% chromium, 0.15% nickel. The testing sample is cylindrical and its active zone has the following dimensions $\phi 6 \pm 0.02$ mm in diameter and the length 36 ± 0.1 mm. The testing installation is equipped with: electro-hydraulic system for action of sample with the power of 5kW, the revolution is 1-2000 rpm, data acquisition system type Spider 8, heating system, maximum temperature of 1100^{0}C and precision ±5 ^{0}C [3,4].

The research program covers a temperature area, according to the researched material and a domain of the strain rate values. A test corresponds at a certain strain rate value and certain temperature according to the established research program. For testing we must regulate the revolution of hydraulic system, then this system mounts the sample in the action device and we turn on the function the heating system. Also it is also activated the data acquisition system. The research program consists in: research temperatures of 1023K, 1073K, 1123K, 1173K and the revolution of 25, 107, 400 rpm. As result of the torsion test we obtain the $M(\varepsilon)_{\dot{\varepsilon},T}$ torque diagram. The experimental torsion moment diagrams are rendered in the figure 1, 2, 3.

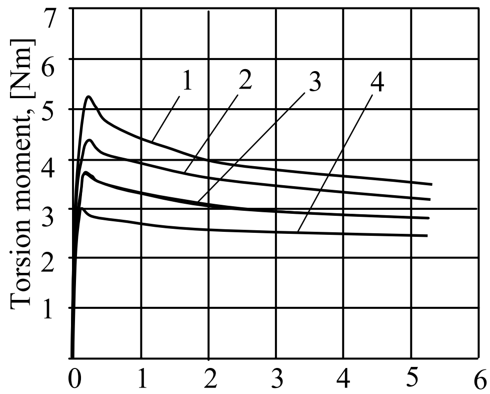

Fig. 1. *The torsion moment diagram – strain for the revolution of 25rpm: 1-1023K, 2-1073K, 3-1123K, 4-1173K*

The analysis of the diagram shows that at the increasing of the strain rate the deformation resistance of material increases and its deformability decreases.

At the increasing of the temperature the deformation resistance decreases and the deformability increases. At the temperature of 1073K it is manifest a trend of decreasing of the plasticity. The function of the torsion moment is depended of the deformation degree (ε), strain rate ($\dot{\varepsilon}$) and the temperature (T). The mathematical expression of the torque is the following:

$$dM = \frac{\partial M}{\partial \varepsilon} \cdot d\varepsilon + \frac{\partial M}{\partial \dot{\varepsilon}} \cdot d\dot{\varepsilon} + \frac{\partial M}{\partial T} \cdot dT \qquad (2)$$

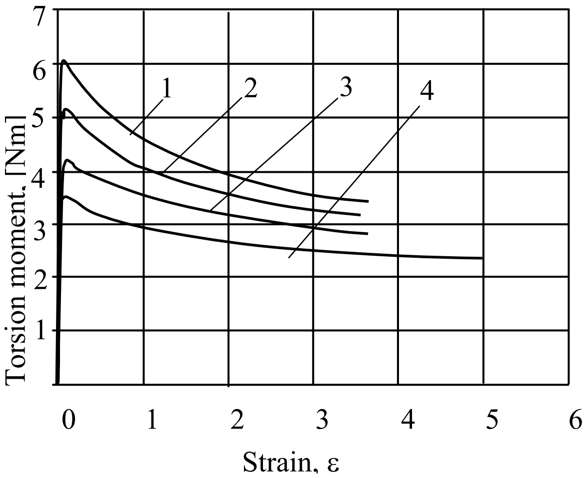

Fig. 2. *The torsion moment diagram – strain for the revolution of 107rpm: 1-1023K, 2-1073K, 3-1123K, 4-1173K*

The methodology of the solving of torsion testing diagrams and results are rendered in the [2].

For the maximum values of the torque the expression (4) becomes:

$$dM_{\max} = \frac{\partial M_{\max}}{\partial \dot{\varepsilon}} \cdot d\dot{\varepsilon} + \frac{\partial M_{\max}}{\partial T} \cdot dT \qquad (3)$$

The deformation strength of the metallic materials varies with the strain ε by a hardening law (power or exponential law), with the strain rate $\dot{\varepsilon}$ by a power law and in function of temperature through an exponential law.

The general mathematical expression of the torsion moment, frequently used for description of the function of the torsion moment has the following expression [2,4,5]:

$$M_{max} = A_1 \cdot \dot{\varepsilon}^m \cdot exp\left(\frac{m \cdot Q}{RT}\right) \qquad (4)$$

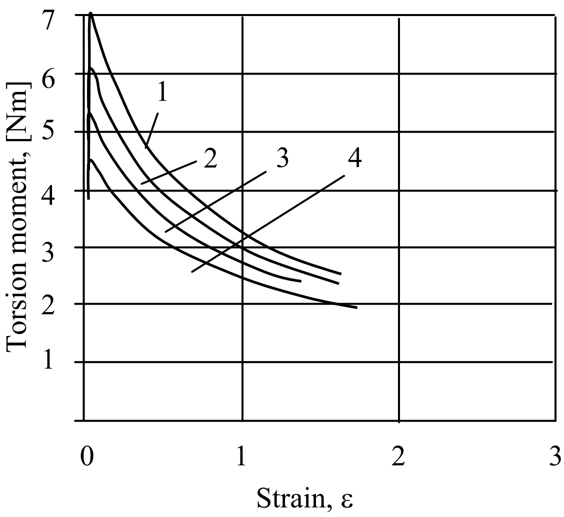

Fig. 3. *The torsion moment diagram – strain for the revolution of 400rpm: 1-1023K, 2-1073K, 3-1123K, 4-1173K*

In (3) *m* is the coefficient of the sensibility of deformation strength at the strain rate, Q is named the activation energy of deformation process, R – the ideal gas constant, T – temperature, in Kelvin, A_1 – experimental constant. We selected the maximum values of the torque, which correspond at the research tests, according to the strain rate and temperature values we obtain the adequate diagrams. We transformed the relation (3) in the linear form (we applied the logarithmic coordinates) and applied a regression calculus program with two independent variables and one dependent variable and we obtained the diagram rendered in figure 4 and the following results for experimental constants:

A_1 = 0.081786 ;
m = 0.115973 ;
Q = 354.808 kJ/mol

The value of the multiple correlation coefficient is 0.9827751. Thus the mathematical expression of the maximum torsion moment is the following:

$$M_{max} = 0{,}081786 \cdot \dot{\varepsilon}^{0{,}115973} \cdot \exp\left(\frac{4949{,}259}{T}\right) \qquad (5)$$

We admit a composed function for the hardening factor. The torsion moment may be defined by equation [2,5]:

$$M(\varepsilon,\dot{\varepsilon},T) = \begin{cases} A_1 \cdot (1-\exp(-n\varepsilon)\cdot\left(\bar{\dot{\varepsilon}}\right)^m \cdot \exp\left(\frac{mQ}{RT}\right) & \text{for } \varepsilon \le \varepsilon_0 \\ A_2 \cdot \exp\left(-p(\varepsilon-\varepsilon_0)\right)\left(\bar{\dot{\varepsilon}}\right)^m \cdot \exp\left(\frac{mQ}{RT}\right) & \text{for } \varepsilon > \varepsilon_0 \end{cases} \qquad (6)$$

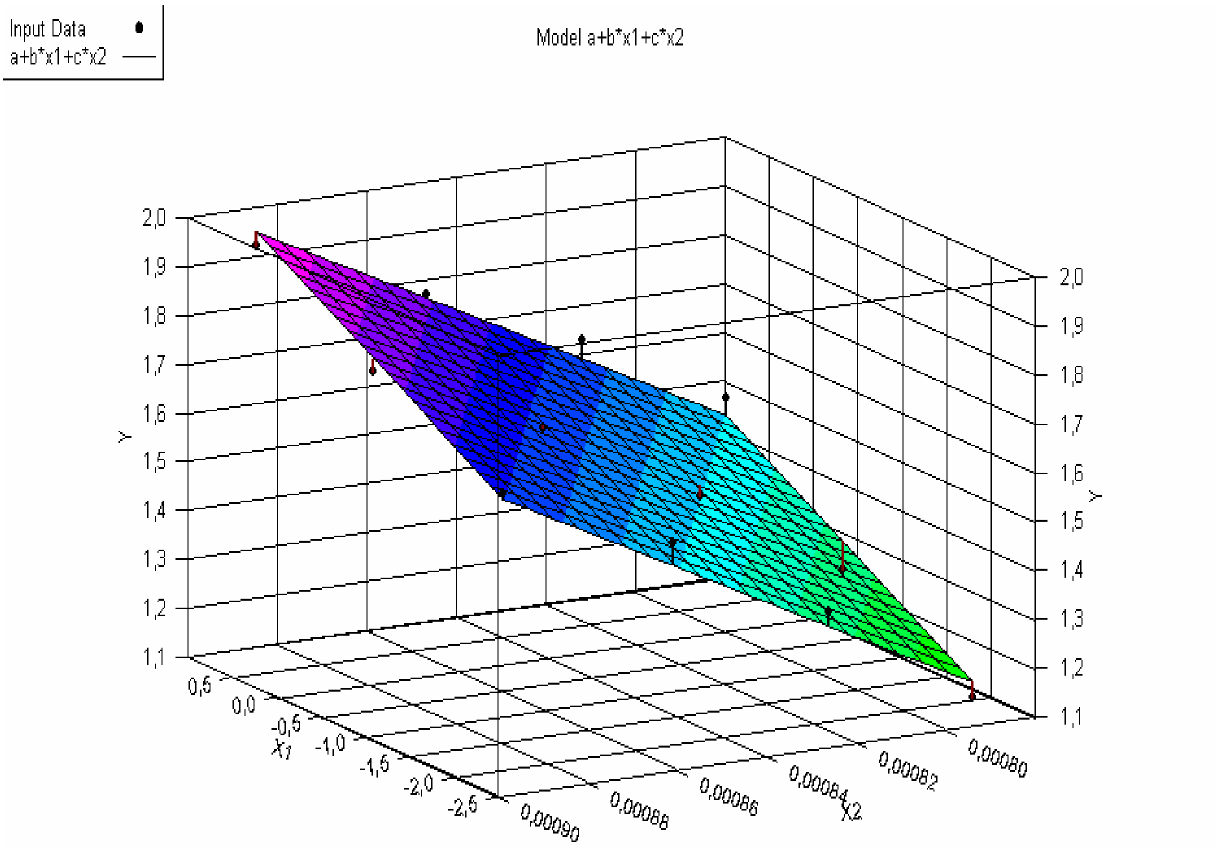

***Fig.4.** Torsion moment diagram in logarithmic coordinates: 1-25rpm, 2-107rpm, 3-400rpm*

In this expression ε_0 is the value of the strain which corresponds at the maximum value of the torsion moment.

This factor is, also, a function of the strain rate and temperature. The experimental data for the strain ε_0 that corresponds at the maximum torque are rendered graphically in figure 5.

The function of the ε_0 has the expression:

$$\varepsilon_0 = a_\varepsilon \cdot b_\varepsilon{}^T \cdot \dot{\varepsilon}^{c_\varepsilon} \qquad (7)$$

The constants from this equation have the values:
a_ε =0.86267066
b_ε =0.99736158
c_ε =-0.549919768

Coefficient of Multiple Determination (R^2) = 0.9583618773.

This shows that the use of the expression (8) leads to the good values for the factor ε_0.

In the figure 5 the dependent variable y is defined by the strain ε_0 which corresponds at the maximum torsion moment.

The first independent variable x_1 is defined by the temperature t, in ^{0}C and the second independent variable x_2 is defined by the strain rate $\dot{\varepsilon}$. The values of the strain ε_0 are defined by the temperature through a exponential function and by the strain rate through a power function.

Using this expression we can apply the composed equation (7) at the calculation of the values of the deformation moment at the small deformations, relatively at the $\varepsilon \le \varepsilon_0$, with the first relation of the equation (7), and at the great deformation, using the second relation of the equation (7). For the practical calculus we must use a constitutive equation defined by a relation between the real stress intensity, strain, strain rate and temperature. The establishing of the constitutive equation, relation (1), is described in the next paper.

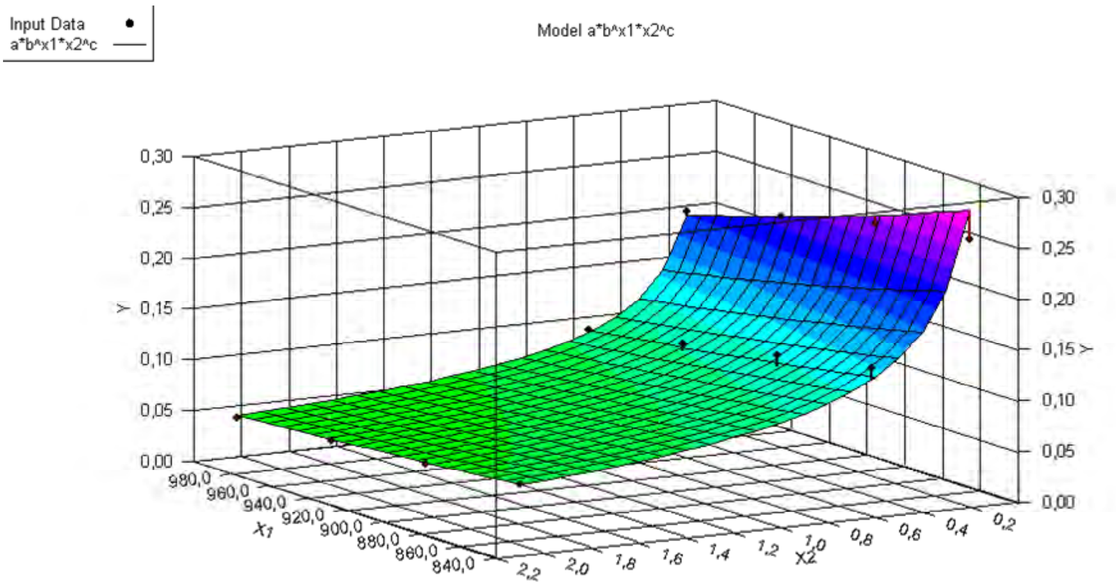

Fig.5. *The variation of the ε_0 with the strain rate and temperature*

4. Conclusions

The best method for establishing the thermo-plastic behavior is the torsion testing.

It was applied a research program at the torsion testing machine in the Plastic deformation laboratory at the Faculty of Metallurgy and Materials Science from *Dunarea de Jos* University of Galati on the samples of the low carbon steel low alloyed with manganese.

They were obtained the torsion moment diagrams necessary for establishing of constitutive equation of this steel.

References

[1]. Cănănău N., 1994, *Teoria deformării plastice,* Universitatea Dunarea de Jos din Galati

[2]. Dumitrescu A.T., 1986, *Contribuţii la modelarea laminarii in calibre.* Teza de doctorat, Institutul Politehnic Bucureşti

[3]. Corobete, G. 2006, *Contribuţii la cercetarea procesului de laminare a sârmelor din otel cu caracteristici mecanice superioare. Teza de doctorat,* Universitatea Dunărea de Jos din Galaţi

[4]. Moussy F., Franciosi P., 1990, *Physique et mecanique de la mise en forme des meteaux.* Presses du CNRS, Paris, ISBN 2-87682-023-4

[5]. Cananau N., Petrea I, Corobete G., 2005, *Modelling of the flow and deformation fields at the profiles rolling by field lines method* , The Annals of "Dunarea de Jos" University of Galati, Fascicle IX.