THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 2 – 2008, ISSN 1453 – 083X

ON THE CONSTITUTIVE EQUATION OF A LOW CARBON STEEL

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ABSTRACT

The paper shows the results of the researches concerning the equation of deformation behavior of low carbon steel. The behavior law is established starting from the experimental torsion moment. The composed constitutive law had very good experimental verification.

KEYWORDS: constitutive equation, torsion test, stress intensity, strain intensity

1. Introduction

The establishing of the equation of plastic deformation behavior is a process of transformation of the torsion moment function in the stress intensity function, respectively, the equation between the stress intensity, strain, strain rate and temperature [1]:

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

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

This paper it presents the results of researches effectuated for transformation of the torsion moment diagrams, in the aim of establishing the equation of plastic deformation behavior for low carbon steel.

The influence of the strain rate and temperature is defined by the equation [1]:

$$M_{max} = 0{,}081786 \cdot \dot{\varepsilon}^{0{,}115973} \cdot \exp\left(\frac{4949{,}259}{T}\right) \qquad (2)$$

The function of the stress intensity is defined by the equation (3):

$$M(\varepsilon, \dot{\varepsilon}, T) = \begin{cases} A_1 \cdot (1 - exp(-n\varepsilon)) \cdot (\dot{\varepsilon})^m \cdot exp\left(\frac{mQ}{RT}\right) & \text{for } \varepsilon \le \varepsilon_0 \\ A_2 \cdot exp\left(-p\left(\varepsilon - \varepsilon_0\right)\right) \cdot (\dot{\varepsilon})^m \cdot exp\left(\frac{mQ}{RT}\right) & \text{for } \varepsilon > \varepsilon_0 \end{cases} \qquad (3)$$

In this equation A_1 and A_2 are function of the strain rate and temperature, ε is the strain intensity, $\dot{\varepsilon}$ - strain rate intensity, T – temperature, *m* – exponent of the strain rate, *Q* – activation energy, *R* – perfect gas constant.

2. Experimental results

The first expression is valuable for the small values of the strain and the second for the great values of strain.

The calculus demonstrated that the good value of the factor *n* for the description is of 0.82.

Using this value for *n* and the experimental values from the torsion moment diagrams we obtained the values of A_1 factor which are rendered in figure 6.

The factor A_1 increases at the increasing of the temperature. The variation of this factor with the strain rate is a function with minimum.

Using the statistic calculation program and adopting a polynomial function we obtained the following expression:

$$A_1 = a + b \cdot \dot{\varepsilon} + c \cdot \dot{\varepsilon}^2 + d \cdot T + e \cdot T^2 \qquad (4)$$

The constants have the values:

a = -25.8439
b = - 0.67378
c = 0.323974
d = 0.064487
e = -3.33E-05

The coefficient of multiple determination (R^2) = 0.8933896392.

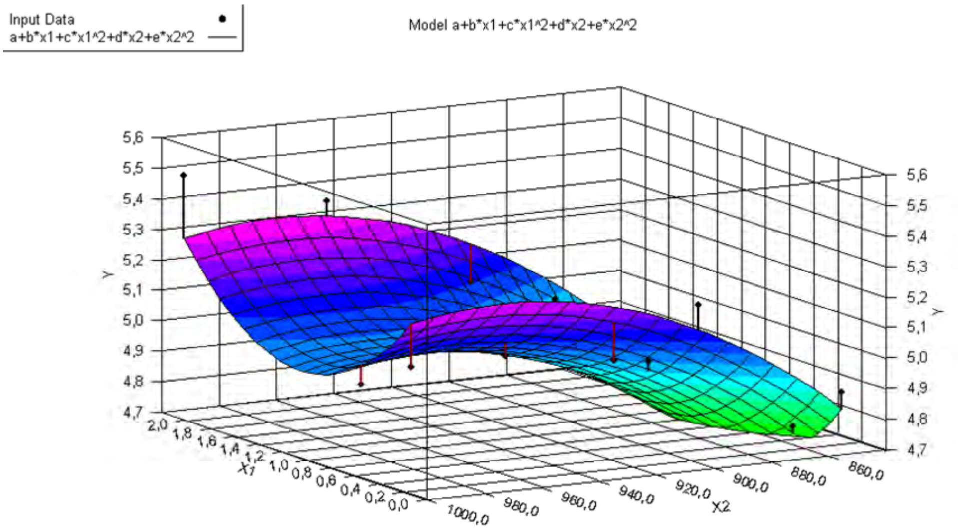

***Fig. 6.** The variation of the factor A_1 with the $\dot{\varepsilon}$ and T*

At the great strains we must use the second expression for calculus of the stress intensity. This expression shows that the values of the stress decrease exponentially with the strain because of thermal deformation effect. The thermal effect is greater at the great values of the strain rate.

Taking the values for the maximum torsion moment and what corresponds to the strain equal to 1, we obtained the values of the factor *p* rendered in the graphic in figure 7.

This factor increases with the strain rate and temperature.

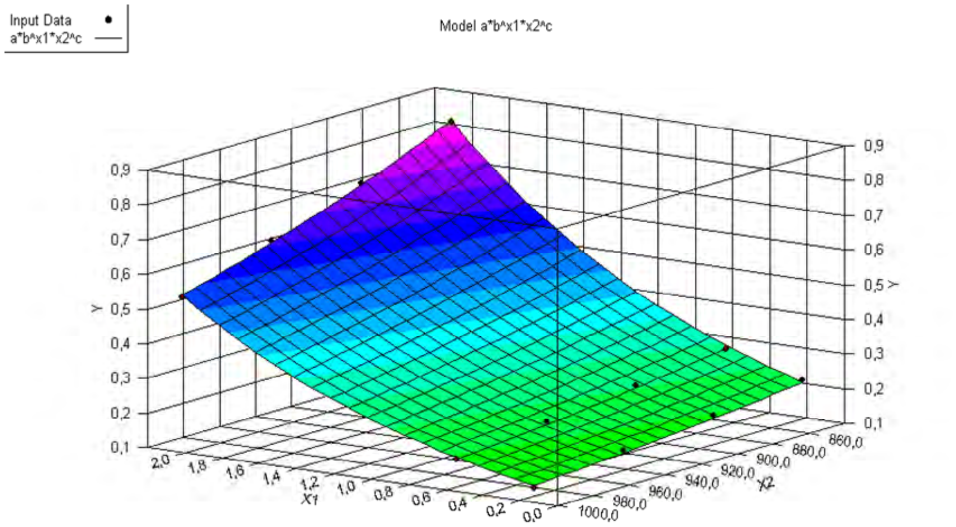

***Fig. 7.** The variation of the factor p with the strain rate and temperature*

The function of the *p* has the expression:

$$p = a \cdot b^{\dot{\varepsilon}} \cdot T^c \qquad (5)$$

The constants from this equation have the values:

a = 5182737
b = 2.006384
c = -2.52708

The coefficient of Multiple Determination (R^2) = 0.9992338986

The factor A_2 is defined in function of the maximum values of the torsion moment. We obtained the values of this factor which are remade and rendered in figure 8.

The function of the factor A_2 has the expression:

$$A_2 = a + b \cdot \dot{\varepsilon} + c \cdot \dot{\varepsilon}^2 + d \cdot T + e \cdot T^2 + f \cdot \dot{\varepsilon} \cdot T \quad (6)$$

The constants from this equation have the values:

a = -0.33971
b = -0.04087
c = 0.000952
d = 0.005274
e = -5.31E-07
f = 3.20E-05

The coefficient of multiple determination (R^2) = 0.9473061163

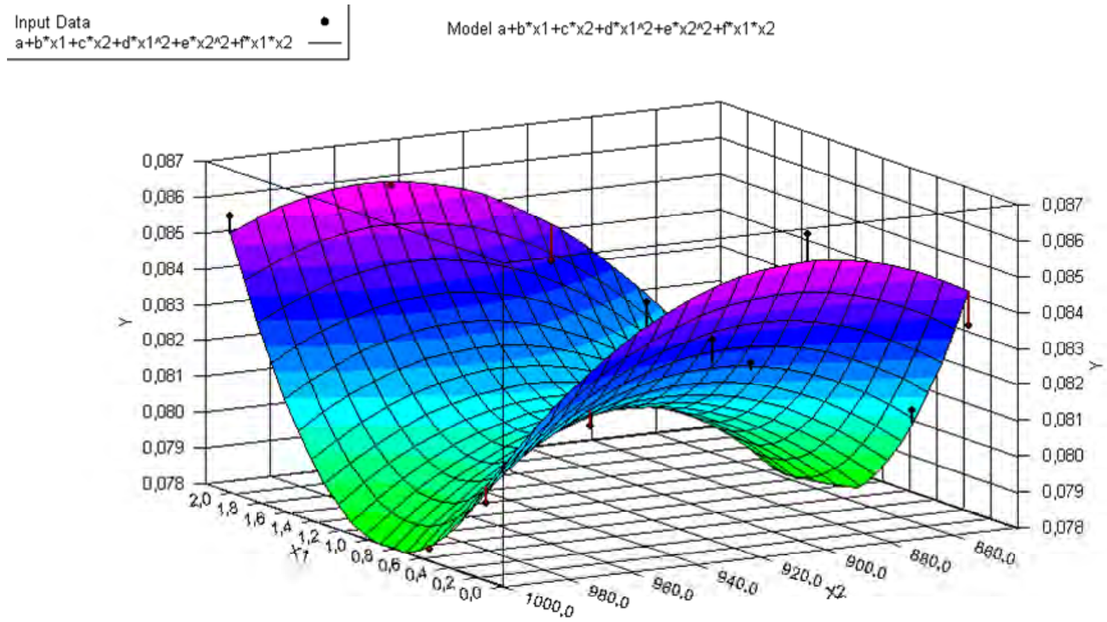

Fig. 7. *The variation of the factor A_2 with the strain rate and temperature*

It may be observed that the mathematical model defined based on experimental data has a good verification, the coefficients of multiple correlation have great values.

For the practical calculus is necessary the constitutive equation of the material defined as the function of the stress intensity in correlation with the plastic deformation factors: strain intensity, strain rate intensity and temperature.

Therefore the transforming of the equation of the torsion moment is necessary.

The stress intensity is defined in function of the torsion moment using the general transforming equation of:

$$\sigma = \frac{\sqrt{3}}{2\pi R^3}\left(3M + \dot{\varepsilon}\frac{\partial M}{\partial \dot{\varepsilon}} + \varepsilon\frac{\partial M}{\partial \varepsilon}\right) \quad (7)$$

It is evident that the stress intensity is defined identically with the torsion moment.

Taking the expression of the dependence of the torsion moment in function of the strain rate, the second factor from parentheses has the value equal to *m*.

Respectively, we have:

$$\dot{\varepsilon}\frac{\partial M}{\partial \dot{\varepsilon}} = m$$

Thus the expression for the calculus of stress intensity, starting of the equation (3) becomes:

$$\sigma(\varepsilon,\dot{\varepsilon},T)=\begin{cases}\dfrac{\sqrt{3}}{2\pi R^3}\cdot(1+m)\cdot A_1\cdot(1-exp(-n\varepsilon)\cdot\left(\dot{\varepsilon}\right)^m\cdot exp\left(\dfrac{mQ}{RT}\right) & \text{for } \varepsilon\le\varepsilon_0\\ \dfrac{\sqrt{3}}{2\pi R^3}\cdot(1+m)\cdot A_2\cdot exp\left(-p\left(\varepsilon-\varepsilon_0\right)\right)\cdot\left(\dot{\varepsilon}\right)^m\cdot exp\left(\dfrac{mQ}{RT}\right) & \text{for } \varepsilon>\varepsilon_0\end{cases} \quad (8)$$

In this relation *R* is the radius of the sample used at the experimental researches, the torsion testing.

Finally, the expression (8) will be used at the modeling of the deformation process.

4. Conclusions

The knowledge of the constitutive equation of the material is necessary for the modeling, simulation and optimization of the plastic deformation process. The best method for establishing the constitutive equation is the torsion testing.

Applying 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 was it established the constitutive equation of a low carbon steel with great mechanical characteristics. The constitutive equation shows that the influence of strain rate is described by the power mathematical relation, the influence of the temperature is described by an exponential function.

The strain has a complex influence described by a compose function.

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