THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 1 – 2009, ISSN 1453 – 083X

RESEARCHES ON THE VISCOPLASTIC BEHAVIOR OF A CrMo ALLOYED STEEL

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ABSTRACT

The paper shows the results of the researches concerning the deformation behavior of alloyed steel with chromium and molybdenum. The plastic deformation behavior is researched in the experimental way, using the torsion test method. The result of the research program including the various temperatures and strain rates is systematized.

KEYWORDS: constitutive equation, torsion test, stress, strain, temperature.

1. Introduction

The knowledge of constitutive equation is necessary for the evaluation, modeling, simulation and optimization of the plastic deformation processes. For this aim, in the calculus program, it is applied the three-dimensional constitutive equation [1, 2]:

$$\dot{\varepsilon}_{ij} = \frac{2}{3} \cdot \frac{\dot{\varepsilon}_0}{\sigma_0} \cdot S_{ij} \qquad (1)$$

In this equation $\dot{\varepsilon}_{ij}$ - is the component of the strain rate tensor, $\dot{\varepsilon}_0$ - is the strain rate intensity, σ_0 - stress intensity, in real deformation conditions, S_{ij} - component of the deviator tensor of stress state. This component is defined by:

$$S_{ij} = \sigma_{ij} - \delta_{ij} \cdot \sigma_m \qquad (2)$$

σ_{ij} is the component of the stress tensor, δ_{ij} – Kronecker's symbol, σ_m – mean normal stress of the stress tensor.

This equation is defined if the mono-dimensional constitutive equation is known. In this paper are presented the results of researches for establishing of the constitutive equation for steel alloyed with chromium and molybdenum.

2. Experimental conditions

The deformation behavior is established through experimental way using a torsion testing machine.

The chemical composition of the researched material is rendered in table 1.

***Table 1.** Chemical composition of steel, [%]*

C	Mn	Si	P	S	Cr	Mo
0,43	0,55	0,45	0,037	0,035	1,01	0,35

The form of active zone of the sample is cylindrical and has the dimensions $(\phi 6 \pm 0.02) \times (36 \pm 0.1)$ mm.

The torsion testing installation is equipped with: electro-hydraulic system for action of sample with the power of 5kW, the revolution is 1-2000 rpm, Spider 8 data acquisition system, heating system, temperature max 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 to a certain strain rate value and a certain temperature according to the established research program. As a result of the torsion test we obtain the torque diagram $M(t)_{\dot{\varepsilon},T}$ where t is the time, which may be transformed in strain. Thus, we obtain the $M(\varepsilon)_{\dot{\varepsilon},T}$ diagram.

3. Experimental data

The research program consists in: research temperatures of 20, 400, 600, 750, 850, 900, 950, 1000 ^{0}C and the revolution of 0.319; 0.943; 2.962; 10.01 rev/s.

The influence of the temperature on the torsion moment, at the 0.319 rev/s, is rendered in figure 1.

The maximum torque connected with the temperature is shown in figure 2.

The maximum strain connected with the temperature is shown in figure 3.

Up to a temperature of 600 ^{0}C, the maximum torque has great values and the maximum strain has small values.

The plastic deformation is difficult.

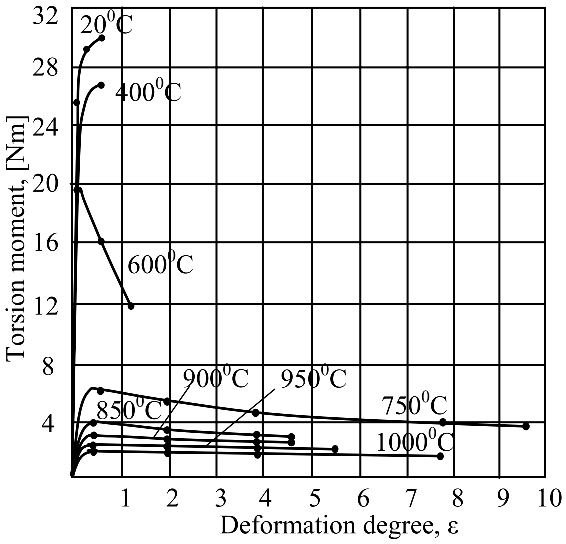

Fig. 1. *Influence of temperature on the torque diagrams, at 0.319 rev/s*

At the temperature of 600 ⁰C the torsion moment increases until the maximum value. The increasing of the strain leads to the decreasing of the value of torque because the effective temperature increases as a result of the caloric effect of the plastic deformation.

At the 750 ⁰C the value of the maximum torque is small and the maximum strain is very high. Consequently, the plastic deformation behavior of the researched material, at this temperature, is very good.

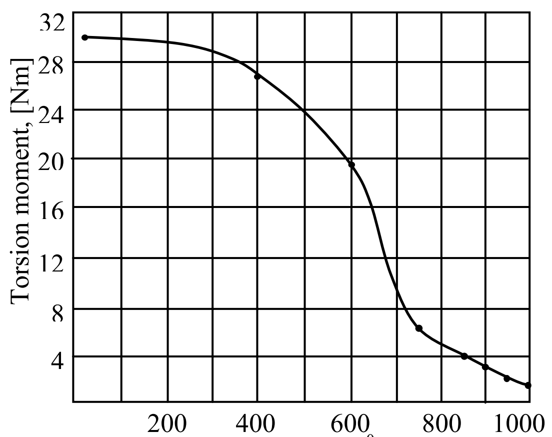

***Fig. 2**. Influence of temperature on the maximum torque, at 0.319rev/s*

At the temperatures greater than the 800⁰C we have the hot plastic deformation regime. The deformation stress is small and the deformation capacity is high.

The explanation of this behavior consists in the structural transformation of the material in function of the temperature. Thus at the 700 – 750 ⁰C we have a favorable structural state as result of the perlite-austenite transformation and the very good deformation behavior of the ferrite at these temperatures.

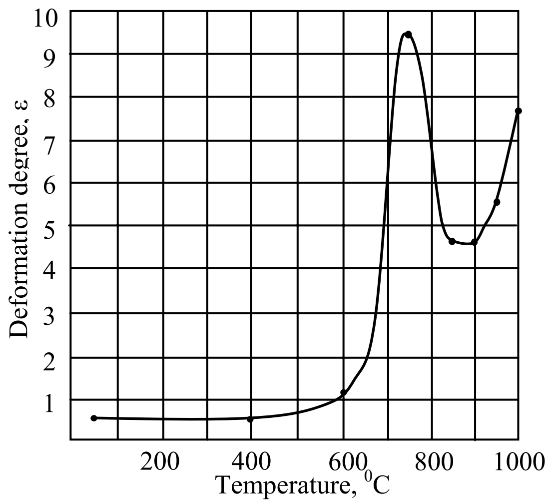

Fig. 3. *Influence of temperature on the maximum strain, at 0.319rev/s*

The explanation of this behavior consists in the structural transformation of the material in function of the temperature. Thus at 700 – 750 ⁰C we have a favorable structural state as a result of the perlite-austenite transformation and the very good deformation behavior of the ferrite at these temperatures.

For temperatures greater than 750 ⁰C the steel has a viscoplastic behavior specific for hot deformation.

The diagrams of the torsion moment, at the hot deformation area, are shown in figures 4, 5, 6 and 7.

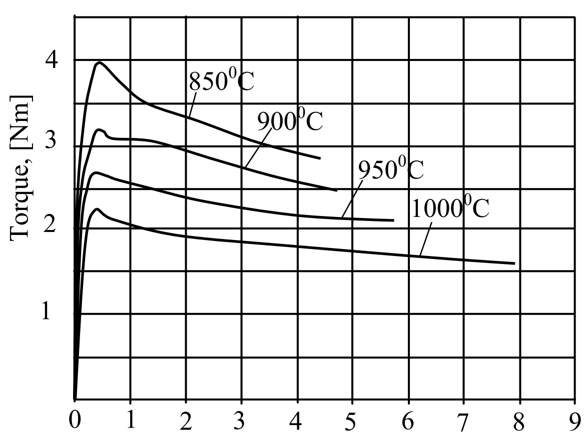

Fig. 4. *The torque diagrams at the 0.319 rev/s*

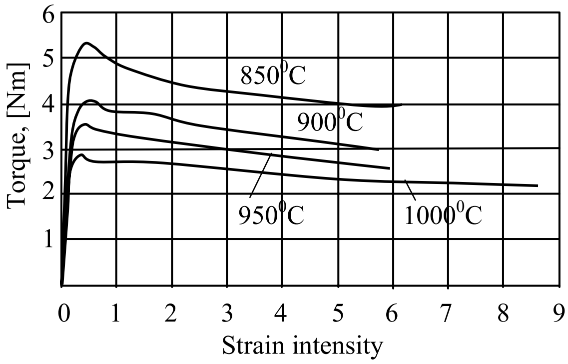

Fig. 5. *The torque diagrams at the 0.94 rev/s*

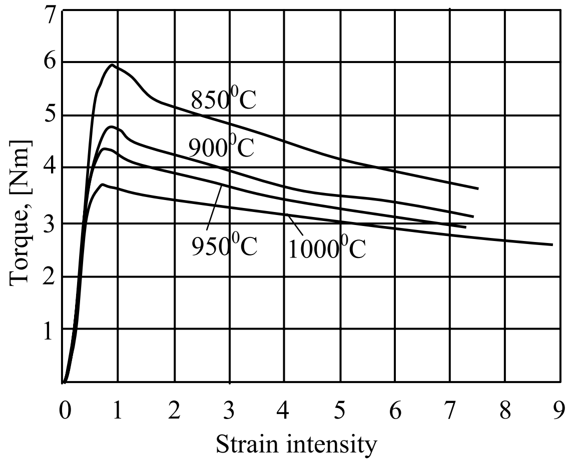

Fig. 6. *The torque diagrams at the 2,962 rev/s*

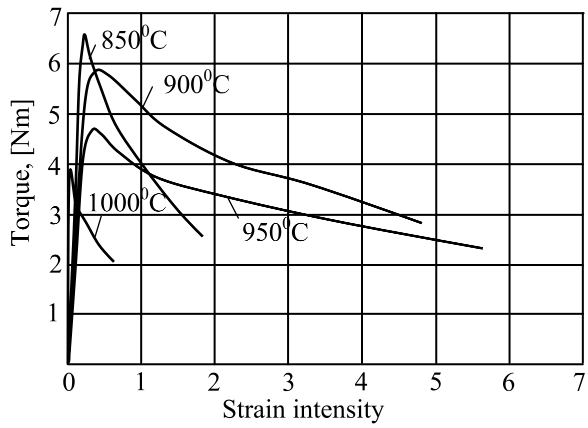

Fig. 7. *The torque diagrams at the 10.01 rev/s*

The influence of the strain rate and temperature on the deformation resistance of the researched steel may be described by the variation of the maximum torsion moment with these deformation factors.

In figures 8 and 9 are shown the graphics of the dependence $M_{max}(\dot{\varepsilon}, T)$.

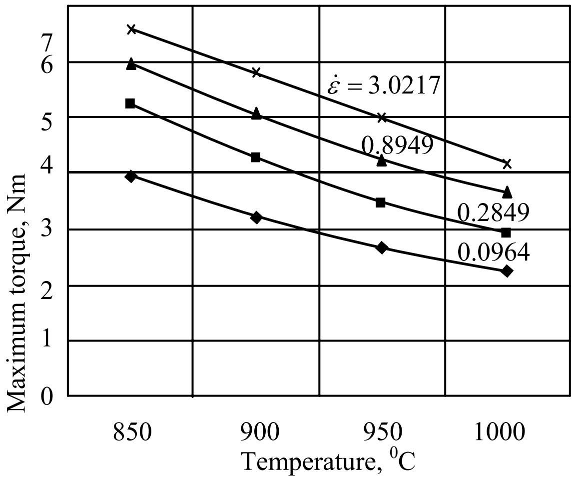

Fig. 8. *Variation of the maximum torque with temperature and strain rate*

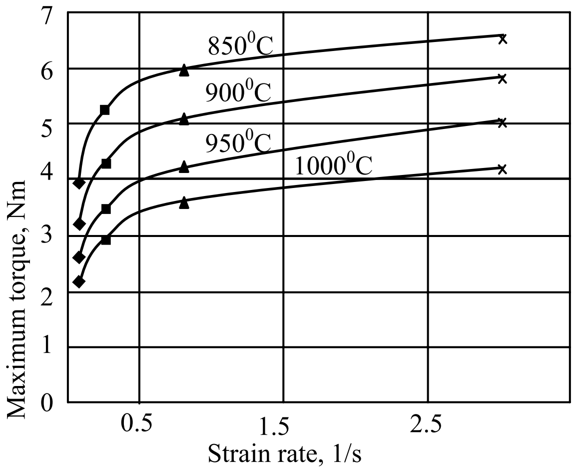

Fig. 8. *Variation of the maximum torque with strain rate and temperature*

The increasing of the temperature leads to the decreasing of the maximum torsion moment. This variation is determined by the increasing of the dislocations mobility when the temperature increases and, consequently, the activation stress decreases.

Considering the exponential variation of the atomic and dislocations mobility with temperature (Arrhenius law), the variation of the deformation resistance is, also, an exponential function.

With the increasing of the strain rate the strength of the researched steel increases. The mathematical expression of the variation of the maximum torsion moment with the strain rate is defined by a power law (Norton law). The plasticity of material may be defined by the maximum value of the strain. In the table 2 are rendered the values of the maximum strain connected with the temperature and strain rate.

Table 2. *Values of maximum strain*

	Strain rate, 1/s			
Temperature ^{0}C	0.0964	0.2849	0.8949	3.0217
850	4.305	6.152	7.501	1.882
900	4.751	5.749	7.401	4.849
950	5.802	5.951	7.249	5.701
1000	7.898	8.651	8.902	0.655

The values of the maximum strain are represented in the graphic form in the figure 9.

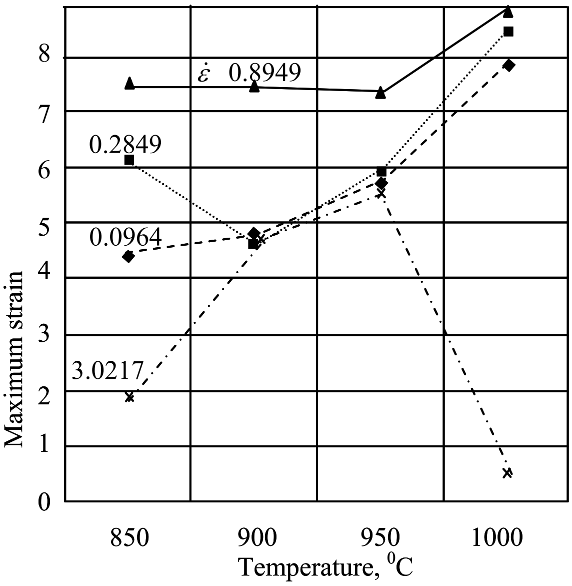

Fig. 9. *Variation of the maximum strain with temperature and strain rate*

For the temperature of 850 ^{0}C, the maximum strain has an important dispersion connected to the strain rate. For a greater temperature, 900 and 950 ^{0}C, the maximum strain increases and the dispersion of values is smaller. For a temperature of 1000 ^{0}C and not great values of the strain rate the values of the maximum strain are the greatest. If the strain rate is great, for this temperature, the maximum strain is smallest.

Figure 10 shows the variation of the maximum strain with the strain rate and temperature. It is evident the maximum values of the strain correspond to the favorable strain rate (0.8949s^{-1}).

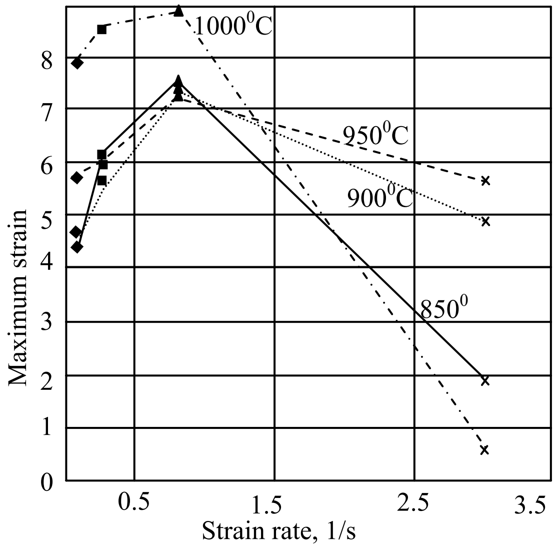

Fig. 10. *Variation of the maximum strain with strain rate and temperature*

4. Conclusions

The knowledge of the constitutive equation of the material is necessary for the modelling, simulation and optimization of the plastic deformation process.

The best method for establishing the constitutive equation is the torsion testing.

Experimental researches showed, that the strength of the researched steel decreases with the temperature and increases with the strain rate. The variation of the plasticity has a complex character connected to the temperature and strain rate.

This is the justification of the necessity of the experimental research establishing the deformation behavior of the metallic material.

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