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DETERMINATION OF A FAMILY OF CREEP CURVES EQUATION FOR 16 Mo 3 STEEL BASED ON EXPERIMENTAL RESEARCH

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Abstract

The experimental researches carried out by the authors, on 16 Mo 3 steel subjected at a 500 °C temperature are detailed. A relationship is introduced which illustrates the phenomenon of plastic deformation accumulation during the development of creep. By extrapolating the results, the equation of the family of creep curves is obtained which represents a surface within the system of coordinates ε_p , σ and t. The advantage of the employed method is outlined namely obtaining the equation of creep curves family after a reduced number of tests.

1. INTRODUCTION

Within chemical, petroleum, metallurgical and energetic industries, several installations are functioning during long time at high pressures and temperatures. In such circumstances thermostable steels are required. These steels are supposed to have a corresponding creep behaviour.

In this paper the results of the experimental researches carried out at 500° C, on 16 Mo 3 steel, are detailed. The obtaining of a variation law of the plastic deformation accumulated within the material is a function of both stress and time.

2. EXPERIMENTAL PROCEDURE

Chemical analysis

Using the spectral analysis method, by means of a spectrometer, type Quantovac, the chemical composition was determined for the alloy under study. The obtained results are listed in Table 1, as compared to the chemical composition prescribed by STAS 8184-87.

Table 1. **Chemical composition, weight %**

	C	Mn	Si	Cr	Mo	P	S	Al	Ni
specimen	0.18	0.70	0.26	0.04	0.32	0.002	0.007	0.006	0.04
standard	0.12- 0.20	0.50- 0.80	0.15- 0.35	max 0.30	0.25- 0.40	max. 0.035	max. 0.040	0.010- 0.030	max. 0.30

Tensile test

In order to determine the mechanical characteristics, tensile tests were performed at the temperatures: 20°C, 300°C, 400°C, and 500°C.

The following characteristics were determined:

- proof stress Rp_{02} ;
- tensile strength Rm ;
- percentage elongation A;
- percentage reduction of area Z.

The tests were performed according to SR EN 10002-1:1994 and SR EN 10002-5:1995 standards.

The tests results are shown in Table 2.

Table 2. **Mechanical characteristics**

Mechanical characteristic	Temperature			
	20 °C	300 °C	400 °C	500 °C
Rp_{02}, MPa	290	195	175	165
Rm, MPa	450	355	340	325
A, %	21.5	24.6	26	27
Z, %	60	69	73	75.5

Creep tests

Both the shape and the dimensions of the specimens, used within creep tests, are shown in Figure 1.

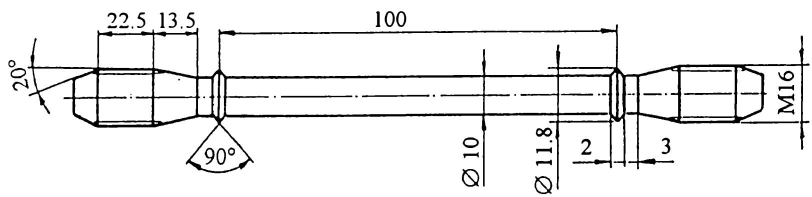

Figure 1. Creep specimen

The tests were performed on a type MF 3000 installation.

Heating is achieved by an electric furnace. For temperature measuring three PtRh-Pt thermocouples are used. Both temperature adjustment and maintaining are accomplished by means of an electronic regulator. Thus, the temperature is maintained at 500±1.5°C, during the entire test.

Strains are measured by means of an mechanical extensometer with levers, which achieves an accuracy of 0.1 μm.

Creep tests have been performed at stresses of 100 MPa, 125 MPa, 135 MPa and 150 MPa, while temperature was maintained at 500°C.

The results of the above tests are illustrated in Figure 2.

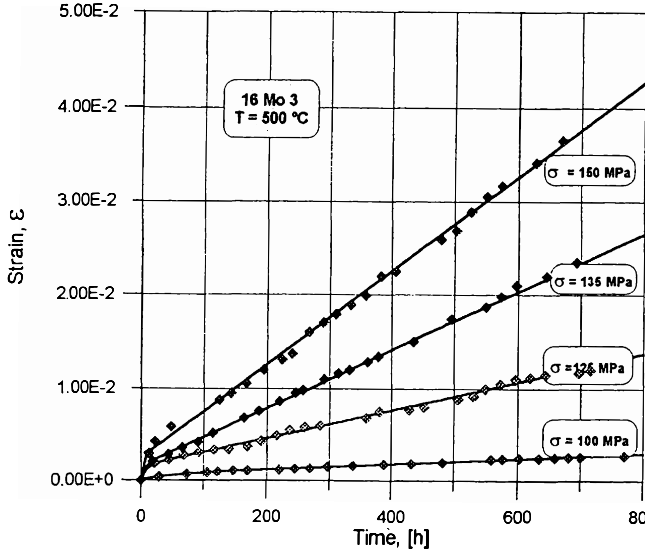

Figure 2. Creep curves of the 16 Mo 3 Steel

In Figure 3 a magnified detail of the above curves is shown which allows to notice that the first creep stage (primary creep) lasts less than 200 hours after which the stabilized secondary creep stage follows (with constant creep rate).

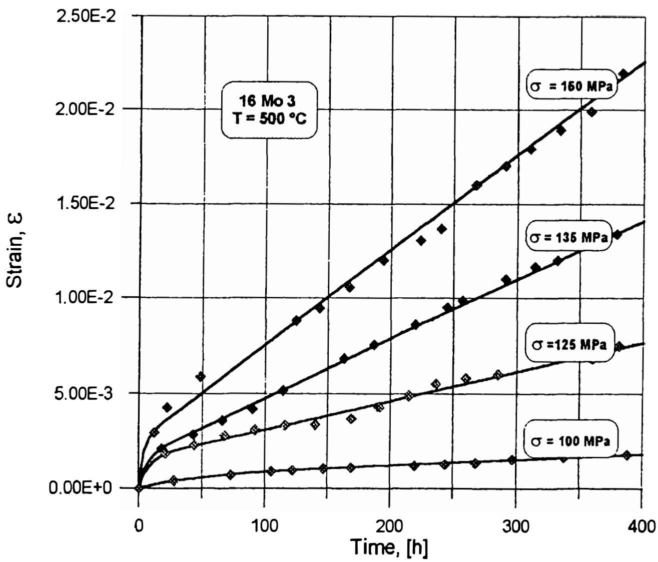

Figure 3. Detail of the creep curves shown in Figure 2

For the evolution with time, of plastic deformation accumulations which occurred at both constant stress and temperature, a function of the following type is assumed:

$$\varepsilon_p(t) = A \cdot t + B\,(1 - e^{-C \cdot t}) \qquad (1)$$

where:

ε_p - plastic strain;

t - time (hours);

A, B, C - coefficients depending upon material, stress and temperature.

Based on the experimental results and applying the method of least squares the coefficients A, B and C have been determined.

The following functions are obtained:

- for σ = 100 MP

$$\varepsilon_p(t) = 2.916962E\text{-}6 * t + 6.462485E\text{-}4 * [1 - \exp(-2.164146E\text{-}2 * t)] \qquad (2)$$

- for σ = 125 MPa

$$\varepsilon_p(t) = 1.51292E\text{-}5 * t + 1.588712E\text{-}3 * [1 - \exp(-0.1266204 * t)] \qquad (3)$$

- for σ = 135 MPa

$$\varepsilon_p(t) = 3.112322E\text{-}5 * t + 1.633766E\text{-}3 * [1 - \exp(-0.1566979 * t)] \qquad (4)$$

for σ = 150 MPa

$$\varepsilon_p(t) = 5.015502.E\text{-}5 * t + 2.52473E\text{-}3 * [1 - \exp(-0.2718363 * t)] \qquad (5)$$

The determined functions are represented, as well, in Figure 2 and 3. A very fair agreement is noticeable between experimental results and the proposed curves.

In the purpose to set a function for the creep curves family, the obtained results for coefficients A, B and C are extrapolated.

An extrapolation function is adopted, under the form of a 4 th degree polynom, of the kind:

$$f(\sigma) = a_4 \cdot \sigma^4 + a_3 \cdot \sigma^3 + a_2 \cdot \sigma^2 + a_1 \cdot \sigma + a_0 \qquad (6)$$

The values of a_i ($i = 0 \div 4$) coefficients are listed in Table 3, for the functions A(σ), B(σ) and C(σ).

Table 3. **Coefficients a_i, for A(σ), B(σ) and C(σ)**

Function	Coefficient				
	a_0	a_1	a_2	a_3	a_4
A(σ)	-1.77E-7	6.53E-8	4.10E-10	-3.87E-11	3.22E-13
B(σ)	-5.48E-6	1.16E-5	-2.31E-7	2.11E-9	-2.33E-8
C(σ)	1.07E-3	7.34E-4	-1.56E-5	5.27E-8	6.65E-10

Finally the equation of a surface is obtained, of the type:

$$\varepsilon_p(\sigma,t) = A(\sigma) \cdot t + B(\sigma) \cdot (1 - e^{-C(\sigma) \cdot t}) \qquad (7)$$

This is represented in Figure 4.

The intersection between the obtained surface and certain σ = constant planes allows to derive the corresponding creep curves. The aspect of these curves is illustrated in Figure 5.

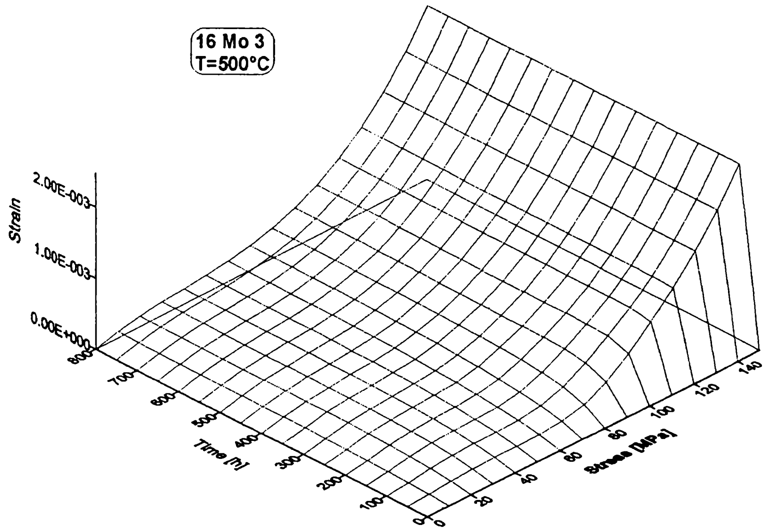

Figure 4. Plastic deformation as a function of both stress and time, for 16 Mo 3 steel at T = 500 °C

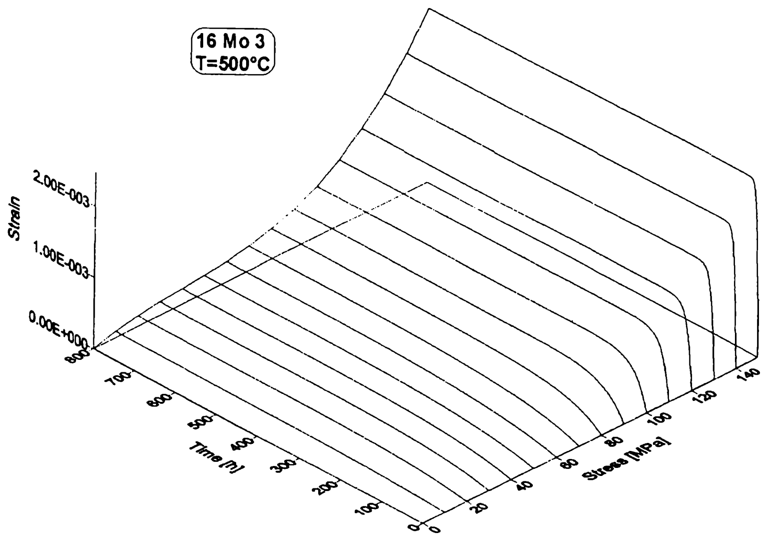

Figure 5. The family of creep curves $\varepsilon_p(\sigma,t)$

Total strain $\varepsilon(\sigma,t)$ is obtained by adding the initial elastic strain, $\varepsilon_0(\sigma)$ to the plastic strain accumulated by creep, $\varepsilon_P(\sigma,t)$:

$$\varepsilon(\sigma,t) = \varepsilon_0(\sigma) + \varepsilon_p(\sigma,t) \tag{8}$$

The intersection of this surface with planes with ε = constant allows to obtain the stress relaxation curves. Such curves are shown in Figure 6.

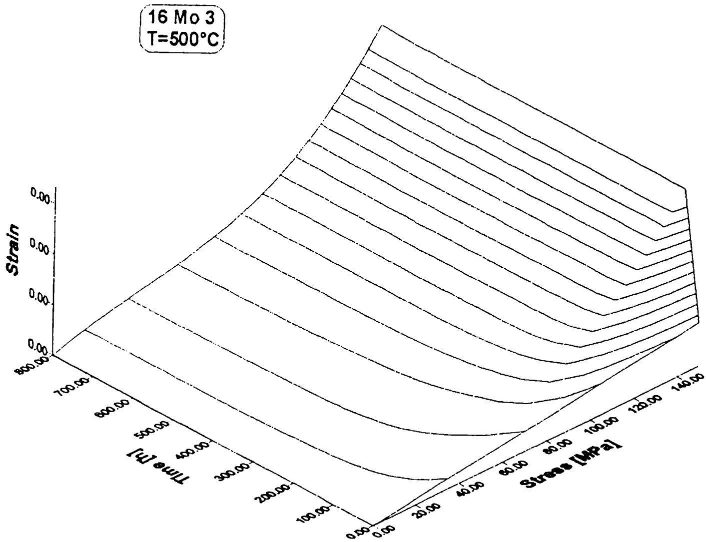

Figure 6. The family of relaxation curves $\sigma(\varepsilon,t)$

3. CONCLUSIONS

It has been certified that the proposed type of function approximates with a fair accuracy the creep curves experimentally-determined.

The extrapolation method, introduced in the paper, has the advantage of a reduced number of tests, required to obtain the equation of a creep curves family.

Based on the processing of the experimentally-determined creep curves, by means the presented method the stress relaxation curves may be obtained.

For a global characterization of steel behaviour, the presented method must be applied at other temperatures, as well.

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