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Computer Simulation of the Torsion Testing Method with Variable Grip’s Acceleration

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Abstract

Torsion tests, as well as a number of other test methods, allow to study the rheological properties of various materials, including properties in hot state. However, existing specimen-loading methods as well as methods of experimental data post-processing do not provide obtaining reliable data on the strain resistance of materials sensitive to the strain rate, at high temperatures for example. The article proposes to use the specimen-loading mode with variable grip’s acceleration. This loading mode with the proposed experimental data post-processing algorithm allows to determine the rheological properties of materials that are sensitive to strain rate accurately. In order to verify the new testing method the finite element simulation problem was solved. In Deform-3D software, the process simulation of torsion testing specimens of JIS-NCF718 steel with constant temperature value 982°C was carried out. The simulation results show that it is possible to determine the strain resistance of materials with the knowledge only of the values of torque and the angle of twist, which are read during the test. Thus, the finite element simulation confirmed the theoretical consistency of the proposed method for testing materials that are sensitive to strain rate.

Keywords: hardening curves, strain resistance, torsion test, strain rate sensitivity, finite element simulation

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1. Introduction

Strain resistance is the most important characteristic of a material, the knowledge of which is necessary to improve existing and to develop new technological processes of material forming. The knowledge of how strain resistance depends on strain, strain rate and temperature make it possible to formulate the conditions for the material’s transition from elastic to plastic as well as to formulate the boundary conditions for the boundary-value problem of continuum mechanics. The strain resistance of some material can be represented at any time by the expression [1, 2]:

$$\sigma_s = \sigma_s(\epsilon, \xi, \theta), \quad (1)$$

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where ε and ξ – strain and strain rate values, θ – the temperature of material. In some cases, Eq. 1 is also true for cold deformation processes of materials that are sensitive to the strain rate [3].

The constitutive equations of the continuum mechanics can be determined only in experiment. The most widely used methods of testing are tensile, compression, torsion, bending as well as some types of technological tests. Meanwhile torsion tests are usually considered to be the perfect but little studied method for determining the rheological properties of steels and alloys [4]. The advantage of torsion tests in comparison with tensile and compression tests is the possibility of obtaining large values of strain and strain rate, which take place in many real processes of material processing by pressure [3, 5, 6]. However, in torsion tests it can't be defined the actual value of the strain resistance σ_s, so the shear strain resistance $\tau_s = \sigma_s/\sqrt{3}$ is defined.

The present paper is devoted to the new method so study of rheological properties of materials sensitive to the strain rate by torsion testing.

2. The Torsion Testing Method with Variable Grip's Acceleration

In paper [7] it is shown that existing methods of testing specimens by torsion, such as [8-13], do not allow to study the rheological properties of steels and alloys sensitive to the strain rate, in the hot state for example. In order to ensure the reliability of the obtained data on the strain resistance with the use of torsion tests, the new method for testing specimens with variable grip's acceleration is proposed in application No. 2018132149 of 07.09.2018 for the patent of the Russian Federation for the invention. The essence of the proposed method is as follows. Torsion tests are carried out at a constant temperature value θ of the gauge of a specimen. During the test, determine the values of the angle of twist φ, as well as the torque *M*, which provides for the plastic deformation of the gauge of a specimen. During the test, ensure compliance with the condition

$$k = \frac{\xi}{\epsilon} = \text{const.} \qquad (2)$$

In the case of using specimens with a cylindrical gauge of the radius *r* and length *l* the condition presented by Eq. 2 is provided by exponentially changing the value of the angle of twist:

$$\varphi = \sqrt{3}\frac{l}{r}ce^{kt}, \qquad (3)$$

where c and k – parameters with an arbitrary value. The shear strain resistance of the material is determined by the formula

$$\tau_s(\epsilon, \xi, \theta) = \frac{1}{2\pi r^3}\left(3M + \frac{dM}{d\epsilon}\epsilon\right), \quad (4)$$

where $\epsilon = \frac{1}{\sqrt{3}} r \frac{\varphi}{l}$, $\xi = k\epsilon$.

The proposed method of testing allows to take into account strain rate effects in changing the properties of materials, while the existing methods are suitable only for studying the rheological properties of materials insensitive to the strain rate. However, the Eq. 3 is not feasible at the beginning of the test, because the twist angle at the initial time is zero. The solution of this problem is as follows. The moment of time t^* is determined, to which monotonous increase of the angle of twist is carried out to a value equal to $\varphi = \sqrt{3}\frac{l}{r} c e^{kt*}$. Starting from the moment of time t^* and after it the change of the angle of twist of a specimen is carried out in strong accordance with the Eq. 3. The moment of time t^* can be determined from the condition:

$$\begin{cases} \int_0^{t^*} \frac{\xi^*}{t^*} t dt = \epsilon^*; \\ \xi^* = k\epsilon^*. \end{cases} \quad (5)$$

As a result of solving the Eq. 5 we find:

$$t^* = \frac{2}{k}. \quad (6)$$

Parameter k values are selecting at the planning stage of the experiment, while ensuring the study of the properties of the material in the variation range of strain and strain rate of interest (Fig. 1). The researcher determines the maximum values of the strain and strain rate, and the minimum values of the strain and strain rate, corresponding to the time t^*, can be calculated by formulas

$$\begin{cases} \epsilon^* = ce^2; \\ \xi^* = cke^2. \end{cases} \quad (7)$$

The Eq. 7 shows that it is possible to vary the lower limit of the variation range of strain and strain rate, in which the rheological properties of the material are studied. Selecting the appropriate value of the parameter c allows doing it.

When the maximum strain and strain rate values are assigned, the duration of the test can be determined using one of the formulas

$$t_{\text{end}} = \frac{1}{k}\ln\left(\frac{\epsilon^{\max}}{c}\right) \quad (8)$$

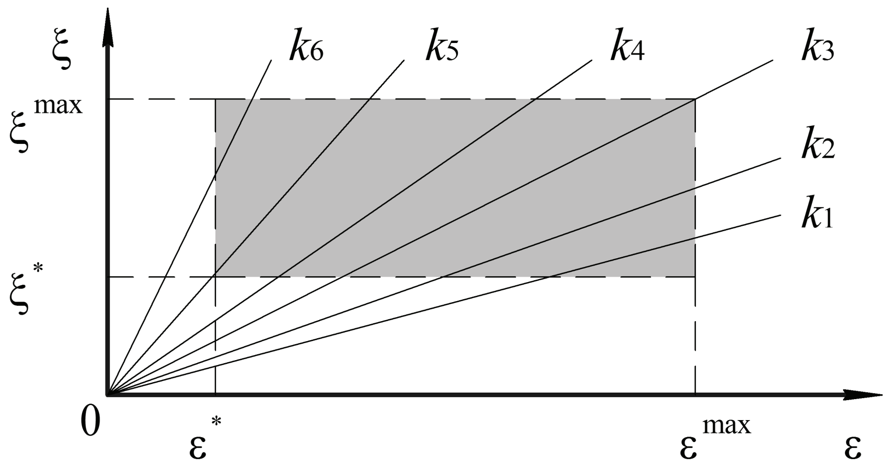

Figure 1: Selection of the parameter *k* values at the planning stage of the experiment.

or

$$t_{\text{end}} = \frac{1}{k} \ln \left(\frac{\xi^{\max}}{ck} \right) . \tag{9}$$

When the moment of time t^* is determined with the use of Eq. 6, assign the time low to the value of the angle of twist can be defined:

$$\begin{cases} \varphi = \dfrac{\sqrt{3}}{4} \dfrac{l}{r} ck^2 e^2 t^2, & t \le t^*; \\ \varphi = \sqrt{3} \dfrac{l}{r} c e^{kt}, & t \ge t^*. \end{cases} \tag{10}$$

3. Research Method

This paper proposes to use the finite element simulation in Deform-3D software in order to verify the possibility to obtain exact values of the strain resistance of materials sensitive to strain rate with the knowledge only of the torque and angle of twist values in accordance to the proposed torsion testing method. Papers [14, 15] describe approaches to the determination of unknown properties of materials by solving the so-called inverse problem. The inverse modelling is the iterative minimization of discrepancies between the results of an experiment and computer simulation. During this minimization, the desired properties of material are varying. Nevertheless, the proposed approaches do not guarantee the desired result in a short time and are of a stochastic nature.

The above task is solved in this paper as follows. The problem of computer simulation of testing specimens with a cylindrical gauge by torsion with variable grip's acceleration is formulated. It is important that the simulation is carrying out for a randomly selected material. To do this, it is convenient to use the existing software's database of materials. At the end of the simulation, the values of the twist angle and the corresponding torque values are determined. These data are used to solve the inverse problem, namely the calculation of shear strain resistance with the use of Eq. 4. The possibility to obtain exact values of the strain resistance in accordance to the proposed torsion testing method is estimated by comparing the initial data on the rheological properties of the material from software's database with the values of strain resistance calculated by Eq. 4. Such approach was used in [7], where it was shown that existing methods of testing specimens by torsion are not suitable for studying the rheological properties of materials in the hot state.

In accordance with the above JIS-NCF718 steel was selected from the material database supplied with the software. The choice of this material is caused by the most detailed description of the rheological properties in some range of strain and strain rate values. The test temperature was assumed to be constant and equal to θ = 982°C. The rheological properties of assigned material at this temperature are described in software and shown in Table 1.

Table 1: Rheological properties of JIS-NCF718 steel at a temperature of θ = 982°C.

		Strain rate ξ, [s^{-1}]							
		0.001	0.0031	0.01	0.0316	0.1	0.3162	1	3.162
Strain ε	0	109.4	120.8	154.4	262.7	238.7	340.8	358.3	400.6
	0.05	112.3	126.6	159.6	263.6	242.1	342.3	368.6	418.7
	0.1	115.2	132.4	164.8	264.5	245.5	343.8	378.9	436.8
	0.15	118	134.7	169	264.5	246.1	342	379	441.9
	0.2	119.5	135.8	171.5	264.4	246.2	339	374.1	444.1
	0.25	120.7	135.8	172.8	264	245.5	333.6	367.6	442
	0.3	121.6	137.1	172.3	264	244.2	330.3	359.1	439.3
	0.35	120.6	134.8	170.8	261.6	242.3	325.6	349.4	434.6
	0.4	119.1	132.9	169.1	259.2	238.5	318.4	340.1	429.3
	0.45	115.3	130.1	166.4	257.6	235.6	312.9	330.4	423.6
	0.5	111.5	129.4	163.7	255	232.4	306.3	322.3	418.2
	0.55	108.3	127.7	161.2	252.9	230.4	300.1	315.5	412.6

The choice of parameter k value was made taking into account tabular data in such a way that the maximum strain and strain rate at the end of the test are equal to $\epsilon^{\max} = 0,5$ and $\xi^{\max} = 3\text{s}^{-1}$ respectively. The parameter k value is

$$k = \frac{\xi^{\max}}{\epsilon^{\max}} = 6\text{s}^{-1}. \tag{11}$$

This value of parameter k allows to cover the most of range of strain and strain rate values presented in Table 1.

The minimum strain value corresponding to the time t^* was assumed to be equal to $\epsilon^* = 0,05$. In this case, the value of parameter c is

$$c = \frac{\epsilon^*}{e^2} = 0,002887. \tag{12}$$

The test time was determined equal to

$$t_{\text{end}} = \frac{1}{k}\ln\left(\frac{\epsilon^{\max}}{c}\right) = 0,86\text{s}. \tag{13}$$

A rod with a diameter of 20 mm and a length of 40 mm with a cylindrical gauge in the middle with a diameter of 10 mm and a length of 20 mm was used as a specimen. To test the specimen with the specified dimensions of the gauge, the angular velocity of grips was determined based on the calculation of the twist angle according to the Eq. 10. Fig. 2 shows how the angular velocity of grips changes. Fig. 3 shows a computer model of the test setup.

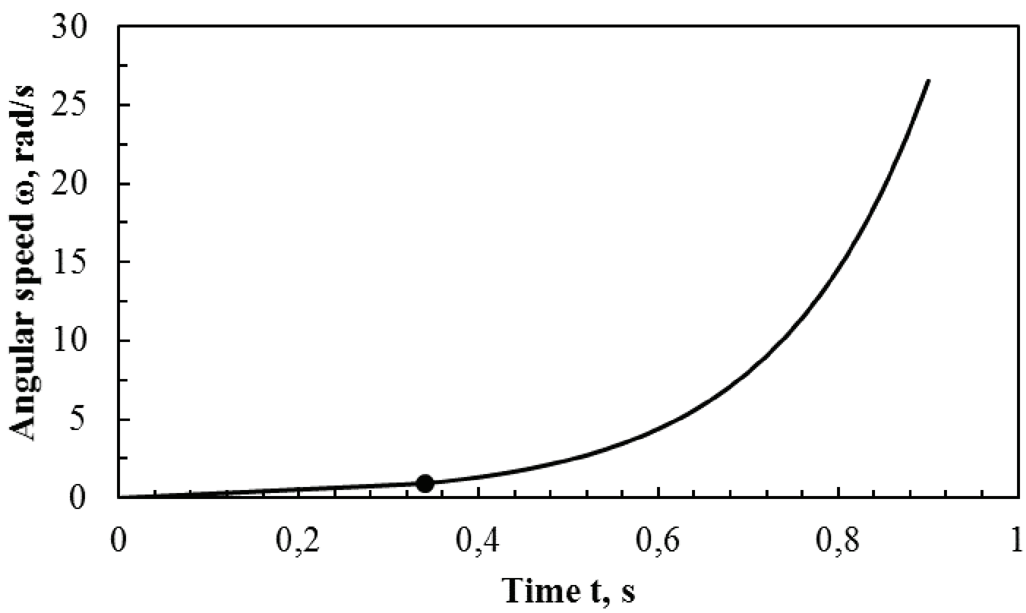

Figure 2: Time low to the value of angular velocity ω, rad/s.

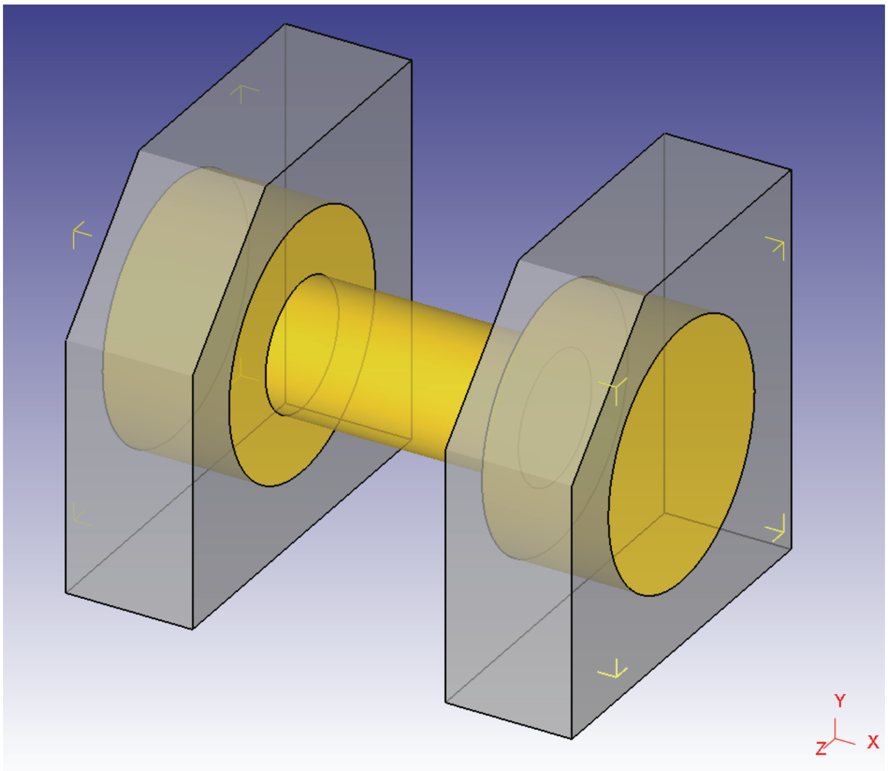

Figure 3: Computer model of the test setup.

4. Results of the Study

After solving the problem of computer simulation in the Deform-3D software with the use of the hardening curves for steel JIS-NCF718, the values of angle of twist φ and torque *M* were determined starting from the time $t^* = \frac{2}{k} = 0.33$s. According to the Eq. 4, the shear strain resistance of the material was calculated depending on the current values of strain and strain rate at a fixed temperature of θ = 982°C. The obtained data were recalculated to the values of the strain resistance by multiplying by a factor equal to $\sqrt{3}$ and compared with the relevant strain resistance values specified in Table 1 for steel JIS-NCF718. Fig. 4 shows the calculated hardening curve as line, and Table 1 data as surface.

Fig. 4 confirms the match of the calculated hardening curve and the known rheological properties of steel JIS-NCF718. This theoretically proves that the proposed torsion testing method with variable grip's acceleration is consistent. Since the hardening curve is determined only on the basis of the torque and twist angle dependence on time, the proposed testing method can be used to study the rheological properties of materials sensitive to strain rate on real test setup.

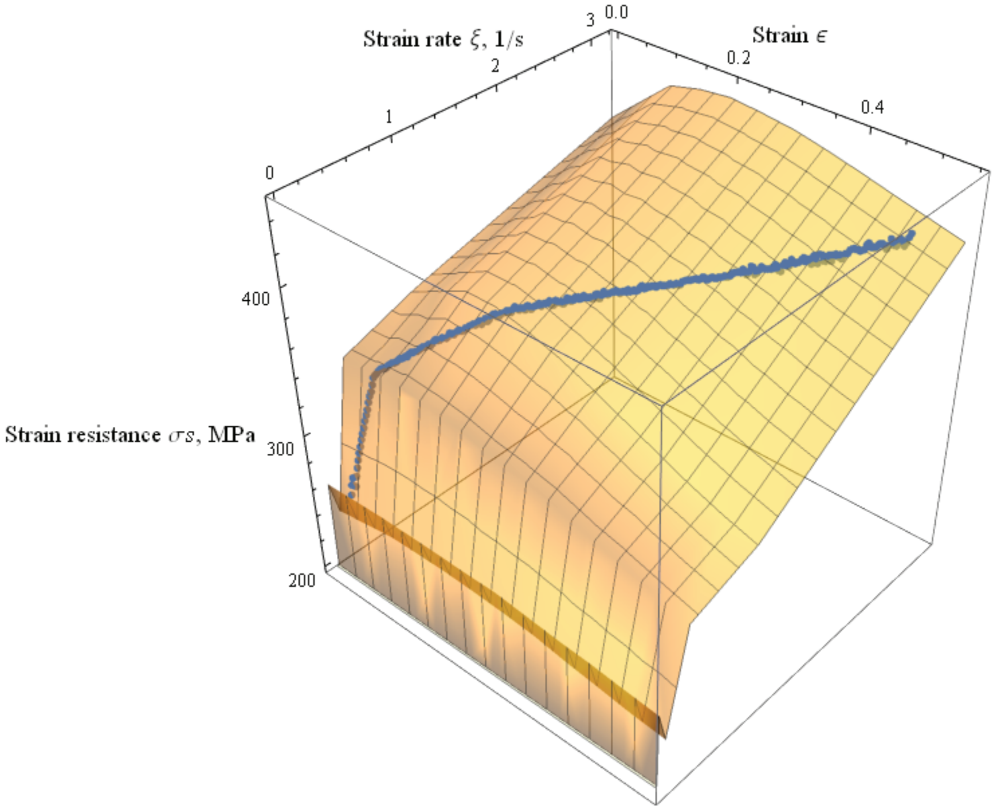

Figure 4: The simulation results of testing specimen of JIS-NCF718 steel by torsion with variable grip's acceleration at temperature value of a θ = 982°C.

5. Summary

The method of testing to study the rheological properties of materials, which takes into account the effects of strain rate hardening, is proposed. The proposed method involves twisting cylindrical specimens with variable grip's acceleration. The accuracy of strain resistance determining is provided by the fact that the acceleration of the grips is carried out exponentially. The method provides for the stage of preliminary deformation of a specimen until the time t^*. This stage is necessary to enter the exponential loading mode. The new testing method is flexible in terms of assigning the range of strain and strain rate values within which the rheological properties of the material are studied. Computer simulation with the use of finite element method theoretically confirms the match of the calculated hardening curve and the real rheological properties of material sensitive to strain rate. The proposed method expands the possibilities for studying the rheological properties of different materials.

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References

[1] V.L. Kolmogorov, Mekhanika obrabotki metallov davleniem, UPI, Sverdlovsk, 1981.

[2] V.I. Zyuzin, M.Ya. Brovman, A.F. Melnikov, Soprotivlenie deformacii stalej pri goryachej prokatke, Metallurgy, Moscow, 1964.

[3] Yu.N. Loginov, S.L. Demakov, A.G. Illarionov, and A.A. Popov, Effect of the Strain Rate on the Properties of Electrical Copper, Russian Metallurgy (Metally). 2011-3 (2011) 194-201.

[4] P.I. Polukhin, G.Ya. Gun, A.M. Galkin, Soprotivlenie plasticheskoj deformacii metallov i splavov, Metallurgy, Moscow, 1976.

[5] A.V. Konovalov, Constitutive relations for metals under high-temperature plastic strains, Mechanics of Solids. 44-1 (2009) 98-104.

[6] S.V. Gladkovskii, A.I. Potapov, D.R. Salikhyanov, Rheological Properties and Substantiation of Hot Rolling Regimes of Low- and Medium Carbon Structural Steels, Solid State Phenomena. 284 (2018) 653-661.

[7] M.V. Erpalov, E.A. Kungurov, Examination of Hardening Curves Definition Methods in Torsion Test, Solid State Phenomena. 284 (2018) 598-604.

[8] A. Nadai, Theory of flow and fracture of solids, Volume II, McGraw-Hill Bool Company, Inc., New York, 1963.

[9] D.F. Fields, W.A. Backofen, Determination of strain-hardening characteristics by torsion testing, in: Proceedings of the 6th annual meeting of the society, ASTM Proceeding, 1957, pp. 1259-1272.

[10] S. Khoddam, P.D. Hodgson, Post processing of the hot torsion test results using a multi-dimensional modelling approach, Materials & design. 31-5 (2010) 2578-2584.

[11] J.J. Jonas, F. Montheillet, L.S. Toth, C. Ghoh, Effects of varying twist and twist rate sensitivities on the interpretation of torsion testing data, Materials Science & Engineering. 591 (2014) 9-17.

[12] T. Sheppard, D.S. Wright, Determination of flow stress: Part 1. Constitutive equation for aluminum alloys at elevated temperatures, Metals Technology. 6 (1979) 215-223.

[13] K. Laber, A. Kawalek, S. Sawicki, H. Dyja et.al., Application of torsion test for determination of rheological properties of 5019 aluminium alloy, Key Engineering Materials. 682 (2016) 356-361.

[14] S. Cooreman, D. Lecompte, H. Sol, J. Vantomme„ Identification of Mechanical Material Behavior Through Inverse Modelling and DIC, Experimental Mechanics. 48-4 (2008) 421-433.

[15] W. Menke, Geophysical Data Analysis: Dicrete Inverse Theory, Palisades, New York, 2012.