COMPARISON OF THE FLOW STRESS FUNCTIONS DETERMINED IN THE HOT COMPRESSION AND TORSION TESTS

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POROVNANIE NAPÄTOVO – DEFORMAČNÝCH KRIVIEK ZO SKÚŠOK ZA TEPLA V TLAKU A KRUTE

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Abstrakt

V článku sú prezentované vzťahy dosiahnuté zo skúšok za tepla v krute a tlaku medzi priebehom napätia, deformačnej rýchlosti a teploty pre austenitickú oceľ triedy 18-8. Krutová skúška bola vykonaná na torznom plastometri na Ústave tvárnenia kovov TU Bergakadémie Freiberg (Nemecko) a Katedre modelovania procesov a medicínskeho inžinierstva Sliezskej TU (Poľsko). Skúška v tlaku bola realizovaná na servohydraulickom zariadení TU Bergakadémie Freiberg. Sledovaná oblasť teplôt bola: 900, 1000, 1050, 1100, 1150^{0}C, pričom deformačné rýchlosti boli 0,036, 0,36 a 3,6 s^{-1}. Výsledky dosiahnuté z plastometrických testov boli použité za základ pre odvodenie analytickej funkcie priebehu napätia, známej v literatúre ako Hensel – Spittelova funkcia. Konštanty v rovnici popisujúcej napäťovo – deformačnú krivku boli určené pomocou metódy mnohonásobnej lineárnej regresie. Sú demonštrované základné rozdiely medzi krivkami napätie- deformácia a kvantitatívnym definovaním plasticity materiálu pomocou maximálneho napätia, deformácie zodpovedajúcej maximálnemu napätiu a deformácie do lomu. Diversifikácia napäťovo – deformačných kriviek určených experimentálne viedla k určeniu základných diversifikovaných konštant v Hensel – Spittelovej rovnici. Obdržané rozdiely sú spôsobené rozdielnosťou skúšobných metód: tlak a krut, technických postupov na výskumných zariadeniach, zahrňujúcich geometriu vzoriek a metódy pre prenos zaznamenaných signálov do vzťahov medzi napätím a deformáciou, určením termického efektu a diferenciácie deformačných rýchlostí. Uvedené rozdielnosti vedú k rozdielnosti parametrov v Hensel – Spittelovej rovnici.

Abstract

In the article is presented the comparison of relationships obtained in the hot torsion and compression tests between the flow stress, strain rate and temperature for an exemplary austenitic steel 18-8 grade. The torsion test was performed with use of torsion plastometers being the research equipment in Institut fűr Metallformung TU Bergakademie Freiberg

(Germany), the Process Modelling and Medical Engineering Dept. at Silesian Technical University (Poland), while the compression test was made on servo-hydraulic machine in TU Bergakademie Freiberg. Applicable range of temperatures was 900, 1000, 1050, 1100 and 1150°C, while the range of strain rates was 0.036, 0.36 and 3.6 s^{-1}. The results obtained from the torsion and compression tests were taken as basis for determination of analytic function of the flow stress known in the literature as Hensel-Spittel function. The constants in flow stress relation were determined using the method of multiple linear regression. Demonstrated are essential differences both, in the curves of flow stress relations and in the quantities defining the plasticity of material, such as: peak flow stress, deformation corresponding to peak stress and the strain to fracture. Diversification of the flow curves as defined in experiments leads to obtainment of essentially diversified constants in the Hensel-Spittel equation. Obtained differences are due to application of different research methods: compression and torsion; from the technical advance of research equipment, applicable research procedures, including the geometry of samples and the method for conversion of recorded measurement signals into relation between the flow stress and strain, accounting for the thermal effect and differentiation of strain rates. The appearing incompatibilities are leading to diversification of parameters of Hensel-Spittel function.

Key words: Flow stress, strain to fracture, hot torsion test, hot compression test, material plasticity, austenitic steel, Hensel-Spittel function

1. Introduction

The torsion and compression tests are generally approved tests for determination of plasticity characteristics of material [1 – 3]. They have both, the advantages and disadvantages. In compression test there appear a friction between the tool and sample, what has unfavourable effect at determination of plasticity characteristics and must be accounted for in calculations of the flow stress [4]. On the other hand, the torsion test is characterized by non-uniform distribution of deformation over the length and cross-section of sample, what obstructs a calculation of relation between a torque moment and number of twists onto relation of flow stress and strain [5]. It can be stated [5-8] that diversification in modernity of testing equipment, free choice in execution of test, difficulties in accounting for thermal effect and heterogeneity of deformation can lead to essential differentiation of results obtained in different research centres.

In present work is made a comparison of the results from the hot torsion and compression tests of austenitic steel 18-8 grade. The tests were executed at Silesian Technical University and TU Bergakademie Freiberg.

2. Test procedure

2.1Tested material

For plastometric examinations was taken an austenitic steel 0H18N9 (X2CrNi18.9) grade in form of rolled rods of 15 mm dia. Chemical composition of tested steel is presented in Table 1.

Table 1. Chemical composition of tested steel 18-9.

Steel	C	Cr	Mn	Ni	Si	P	S	B
	%							
0H18N9 X2CrNi18 9	0,028	18,40	0,187	8,90	-	0,036	0,012	-

Prior to execution of plastometric samples the rods were solution treated from temperature 1150°C with holding time 60 min.

2.2Determination of plasticity characteristics

Examinations adopted for determination of the flow characteristics of material were executed in two research centres. The torsion test No.1 was performed at torsional plastometer in Department of Process Modelling and Medical Engineering of Silesian Technical University in Katowice (Poland), while test No.2 in the Institute of Plastic Working TU Bergakademie Freiberg (Germany). In Bergakademie Freiberg was additionally executed a compression test. It can be assumed that all tests made in German Institute were executed in the same deformation conditions as those in Polish University. For tests were taken five temperatures within the range 900°C – 1150°C and three strain rates 0.036 [s^{-1}], 0.36 [s^{-1}] and 3.6 [s^{-1}]. Tested material was heated up to temperature 1200°C and held in this temperature through 5 minutes, then subjected to deformation. All recorded data were used for determination of the flow stress and strain. To define these parameters were taken the following relations:

- flow stress

$$\sigma_P = \sqrt{3} \cdot \tau \tag{1}$$

$$\tau = \frac{3M}{2\pi R^3} \tag{2}$$

- strain

$$\varphi = \frac{\overset{*}{\gamma}_N}{\sqrt{3}} \tag{3}$$

while

$$\overset{*}{\gamma}_N = 2\ln\left(\frac{\overset{*}{\gamma}}{2} + \sqrt{\frac{\overset{*}{\gamma}{}^2}{4} + 1}\right) = ar\sinh\frac{\overset{*}{\gamma}}{2} \tag{4}$$

In Nadai-Mises' formula there is additionally considered the representative radius being in relation to external radius R*/R = 0.75. A formula for non-dilatational strain has then the following form:

$$\overset{*}{\gamma} = 0{,}75\frac{2\pi RN}{L} \tag{5}$$

where: R – external radius of sample,
L – measured length of sample,
N – number of twists

Such approach to this problem allows to avoid additional divergencies, which can be provoked by application of different relations for calculation of deformation, what can be noticed in Fig.1. The calculations made for test No.1 are showing that for identical deformation conditions, the obtained flow curves are achieving different values of the strain limit, and simultaneously various courses of the flow curves. Application of the

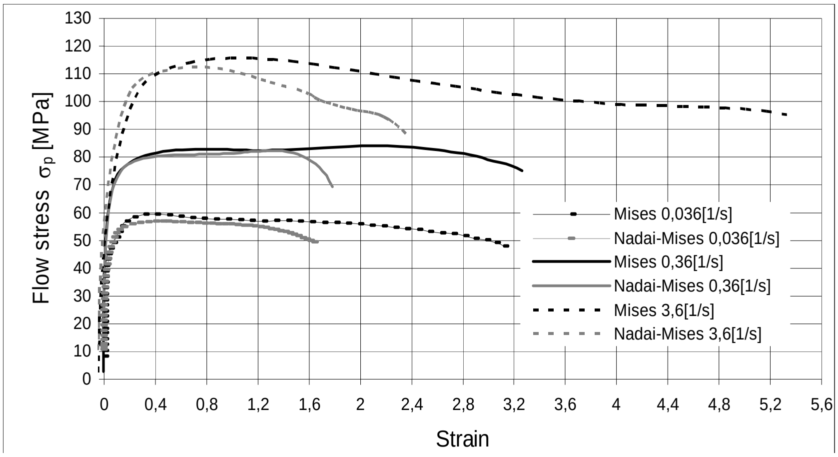


Fig.1 Relationship between flow stress and strain with application of different relations for calculation of strain (T=1000°C)

Misses' relation allows for calculation of the equivalent strain:

$$\varphi = \frac{\gamma}{\sqrt{3}} \tag{6}$$

while:

$$\gamma = \frac{2\pi RN}{L} \tag{7}$$

allows to obtain larger deformations. Therefore, it is very important that at comparison of curves obtained from two research centres, thus generated at different torsional elastometers, to choose one method for calculation of the flow stress and strain.

In the compression test of cylindrical samples the flow stress was calculated according to relationship, which accounts for effect of friction between a tool and sample:

$$\sigma_P = \frac{\sigma_{\acute{s}}}{1 + \frac{\mu}{3} \cdot \frac{d_x}{h_x}} \tag{8}$$

In the formula μ represents the friction coefficient, which in hot working processes is adopted as 0.175, while $\sigma_{\acute{s}}$ being a forming resistance (average unit pressure) is expressed by means of formula:

$$\sigma_{\acute{s}} = \frac{F \cdot h_x}{h_0 \cdot A_0} = \frac{F}{A} \tag{9}$$

The strain is calculated from relation:

$$\varphi = \ln\left(\frac{h_0}{h_x}\right) \tag{10}$$

All calculations were executed in AUK programme (Auswertung Umformtechnischer Kenwerten) in the Institute of Plastic Working at TU Bergakademie Freiberg. The obtained flow curves were additionally corrected accounting for differentiation of temperature.

3. Test results and discussion

3.1 Comparison between torsion tests

In Fig.2 are presented the flow curves obtained from torsion tests executed at Silesian Technical University (sample No.1) and at TU Bergakademie (sample No.2) at the strain rate 0.36 [s^{-1}] for three selected temperatures.

A characteristic feature of all flow curve courses is their mutual resemblance, in spite that the flow curves for austenitic steel 0H18N9 in torsion test No.1 are achieving lower values of flow stress in all performed tests.

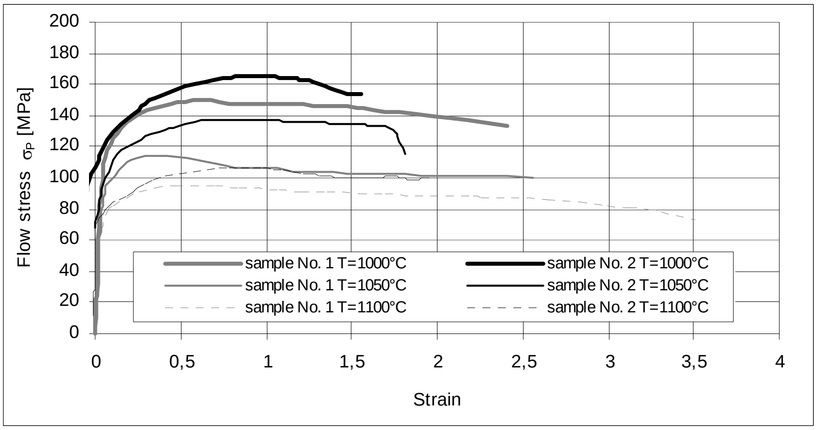


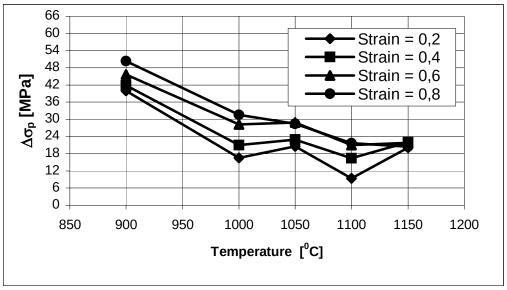
Fig.2 Flow curve courses in torsion tests determined in two different research centres.

In Fig.3 are presented diversified values of flow stress obtained in both torsion tests in function of temperature, for four different strain values. As demonstrated, a diversification of the flow stress is appearing both, for the low and high strain values. Diversification is higher, the higher is a strain rate and lower the deformation temperature.

The presented diversification does not result from adopted methodology of calculations, because calculations were conducted using the same relationships. It can be assumed that this diversification results from different technical mode of test execution, heating condition (resistance or induction type) and various geometry of sample. In tests executed at Silesian Technical University the sample had a measured length 50 mm, while that at TU Bergakademie Freiberg had 15 mm.

3.2 Comparison between the torsion and compression tests

In **Fig.4** are presented the flow curves for austenitic steel 0H18N9 determined in the hot torsion and compression tests. The curve from test No.1, independently from adopted conditions of deformation is situated below a curve defined in the compression and torsion test No.2. Diversification of flow curves depends on the temperature and strain rate, however, one cannot ascertain such evident dependency on the parameters of deformation. This is due to a large scatter of results. It should be noted that in torsion tests was used one sample only to one strain condition, while in compression tests there were two samples. It is probable, that execution of larger number of repetitions would bring a better explanation to the diversification existing between tests executed at Silesian Technical University and TU Bergakademie Freiberg.



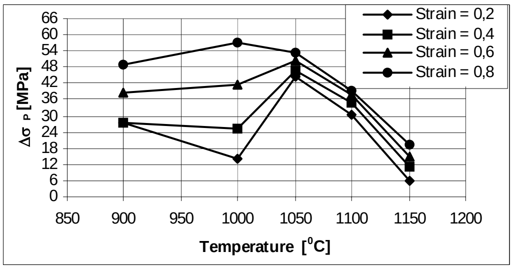


Fig.3 Differences between flow stresses in function of temperature and strain for torsion test No.1 and No.2 at various strain rates.

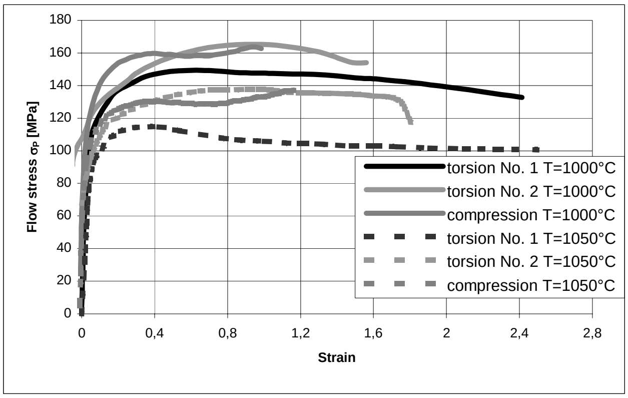


Fig.4 Flow curves from the compression and torsion tests for T=1000^{0}C and 1050^{0}C at strain rate 0.36 [s^{-1}].

3.3 Function of flow stress

The flow curves determined in different research centres and in different tests were used as initial data for determination of the function of flow stress. For the calculations was selected a function based on thermodynamic parameters, which was elaborated in the German institute [9]:

$$\sigma_F = Ae^{m_1 \vartheta} \varphi^{m_2} e^{\left(\frac{m_4}{\varphi}\right)} (1+\varphi)^{(m_5 \vartheta)} e^{(m_7 \varphi)} \dot{\varphi}^{m_8 * \vartheta} \tag{11}$$

The determined constants (A, m_l, ...) in equation (11) by the linear regression method are collected in Table 2. The constants refer to the data from torsion test No.1, torsion test No.2, the compression test and the common data from torsion test No.1 and No.2.

Table 2 Constants defined in equation (11)

Constants	Torsion test No.1	Torsion test No.2	Torsion test No.1 and No.2	Compression test
A	19077,8	20774	20518,1	5786,27
m_1	-0,00408	-0,00449	-0,0045	-0,00262
m_2	0,337209	0,215451	0,212194	0,403876
m_4	0,001025	-0,00047	-4,4E-05	-0,00026
m_5	-0,00133	6,18E-05	-0,00035	-0,00263
m_7	0,311025	-0,14797	0,101659	0,952045
m_8	0,00012	0,000104	0,000118	0,000125
R^2	0,9782	0,9812	0,9639	0,9881

The differences defined between the constants in equation (11) are inevitable, since as presented in Fig.2 and 3 there exists essential diversification of flow curves for steel 0H18N9. However, it can be stated that the parameter m_l characterizing the influence of temperature is showing similar values in torsion test No.1 and No.2, while another value in compression tests. Parameter m_6 characterizing the effect of strain rate is showing similar values for the torsion and compression tests.

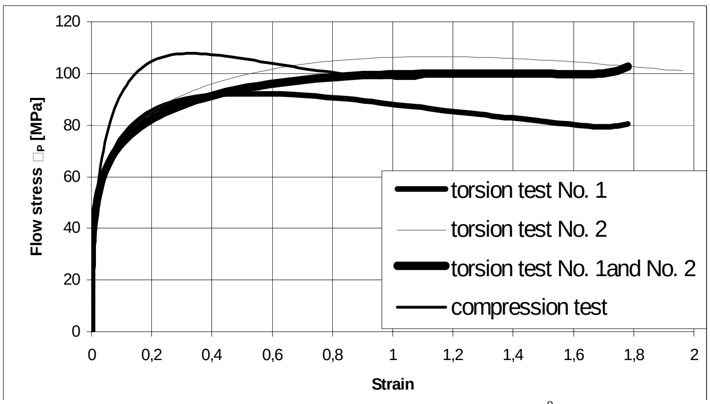


Fig.5 Comparison of flow curves defined by equation (11) for T=1100^{0}C and strain rate 0.36 [s^{-1}].

It is difficult to evaluate the influence of deformation upon flow stress, as it is characterized by four parameters m_2, m_4, m_5, m_7 having much diversified values for the torsion and compression tests. In Fig.5 are showed exemplary courses of curves obtained by means of equation (11). A similar character is showing the curve courses from compression test made at TU Bergakademie Freiberg and the torsion test executed at Silesian Technical University. Though the differences in values of the flow stress are achieving up to 20 [Mpa], yet still both courses are are showing a distinct maximum the exceeding of which results in drop of stress untill coming to a steady state.

4. Summary

Execution of plastometric tests in different research centres, aimed at determination of material plasticity characteristics in hot forming processes, leads to significant diversification of the courses of flow curves and defined values of flow stress and strain to fracture. This diversification results from adopted test (compression, torsion), applied testing equipment, possibilities to maintain required conditions of deformation, as well as adopted methodology for execution of tests and computing of recorded values. Any incompatibilities can lead to diversification of defined parameters in function of the flow stress, although it is proven that the influence of temperature and strain rate on the flow stress is defined in similar way in the torsion and compression tests.

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