INFLUENCE OF THE PLASTIC DEFORMATION PARAMETERS AND INITIAL GRAIN SIZE ON THE MECHANICAL PROPERTIES DEFINED DURING HOT TORSION TEST OF AUSTENITIC STEELS

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Abstract
The influence of the initial grain size and plastic deformation parameters on the mechanical properties during hot tension test has been analysed. As a material for the research has been chosen a Cr-Mn austenitic steel of 17/17 grade, as well as Cr-Ni austenitic steel (18/9) the chemical composition of which is similar to that of AISI304. The plastic strain has been performed on a torsion plastometer and geometrical characteristics were defined by means of a computer programme NuBiPo32 developed in the Department of Material Science.

1. Introduction
The characteristics of plasticity defined in plastometer tests, i.e. the flow stress and deformation depend either upon the deformation parameters (temperature, deformation speed, time interval between subsequent deformation steps) [1] and on the parameters of microstructure specifications. The temperature and deformation speed are practically expressed by means of Zener-Hollomon parameter [1]. Maximum flow stress $\sigma_{pmax}$ and deformation $\varepsilon_{pmax}$ are the basic ratings defining the deformation ability of steel.

In this work are elaborated the functional relations representing the influence of initial grain size and plastic deformation parameters onto technical properties of austenitic steels. Besides, there is defined by means of statistic tests a rate of influence of individual parameters onto the values $\sigma_{pmax}$ and $\varepsilon_{pmax}$ received from hot torsion test.

2. Research Methodology
The tested material was composed of two austenitic steels – Cr-Mn and Cr-Ni. The Cr-Mn steel characterized by contents of 0.5%C, 17%Cr and 17%Mn was hyperquenched from 1150°C, 1200°C and 1250°C with 60 min. holding time. As comparative material was chosen a Cr-Ni steel, having composition of 0.03%C, 18.5%Cr and 8.9%Ni. Steel Cr-Ni was hyperquenched from the temperature 1150°C and 1200°C with 60 min. soaking time.

The plastometric examinations were performed on a torsion plastometer of SETARAM Co. [2]. Torsion test was executed in the range of 800÷1100°C temperatures and deformation speed 0.02÷2.1 s$^{-1}$. The deformation was defined as a function of sample rotations during torsion [3]:

$$\varepsilon = \frac{2}{\sqrt{3}} \cdot \arcsin \left( \frac{\pi R N}{L} \right)$$

where: $\varepsilon$ = deformation, $R$ = equivalent radius, $L$ = tested length of sample [mm]
$N$ = number of sample rotations (torsions) [rot.]

Flow stress $\sigma_p$ [MPa] defined according to relation (2) accounting for the torque $M'$, sample radius $R$, parameters $m$, $p$ and the axial force $F$:
There is also defined the course of flow stress function, and determined are the characteristic values of \( \sigma_{p_{\text{max}}} \) and \( \varepsilon_{p_{\text{max}}} \) as well as the stress of steady flow state \( \sigma_s \) and corresponding deformation \( \varepsilon_s \).

Grain size was analysed on microsections parallel to sample axis after solution heat treatment. To determined the size of grain was used a software for automatic image analysis „MET-ILON“, taking each time the measurements of 500 grains. As a parameter describing initial grain size was taken the mean area of flat section of grain \( (A_0 [\mu m^2]) \).

### 3. Results

The curves of flow illustrating influence of temperature, deformation speed and initial size of austenitic grain on the course of flow stress variations in function of deformation of tested steels Cr-Mn and Cr-Ni in hot torsion test, are presented on exemplary figures 1÷4. Raising of torsion temperature in the range 800 – 1100°C for samples of both steels is causing an intensive decrease of maximum flow stress \( \sigma_p \) and reduction of corresponding deformation \( \varepsilon_p \) (fig.1, 4, 5). Increase in deformation speed of Cr-Mn steel samples in the scope of 0.02 to 2.1s\(^{-1}\) and steel Cr-Ni from 0.04 to 2.5s\(^{-1}\) results in growth of maximum flow stress \( \sigma_{p_{\text{max}}} \) and rise of deformation \( \varepsilon_{p_{\text{max}}} \) (fig.2). The maximum flow stress and corresponding deformation values for both steels are in proportion to the initial grain size before deformation (fig. 3, 4, 5).

\[
\sigma_p = \left[ \frac{\sqrt{3}M'}{2\pi R^3} \right]^2 \times (3 + p + m)^2 + \left( \frac{F}{\pi R^2} \right)^2 \right]^{0.5}
\] (2)

During torsion of samples of Cr-Mn and Cr-Ni steels in temperature up to 900°C after surpassing the deformation corresponding to maximum flow stress, at the flow curve is observed a gradual reduction of stress leading to destruction of sample (fig.1, 2). In samples of Cr-Mn and Cr-Ni steels subjected to deformation in temperature 1000°C and higher, for the whole analysed range of torsion speeds, after surpassing the deformation \( \varepsilon_{p_{\text{max}}} \) the stress becomes fixed at steady level \( \sigma_s \) (fig.1÷3).
Fig. 2. Influence of deformation temperature on the shape of curves: stress – deformation at a deformation speed \(0.46\text{s}^{-1}\) for Cr-Ni steel. Mean flat section area of initial grain \(A_0=6000\mu\text{m}^2\).

Microstructures of austenitic steel after solution heat treatment with differentiated grain size:

a) \(A_0 = 2300\mu\text{m}^2\). Magn. 100×
b) \(A_0 = 5900\mu\text{m}^2\). Magn.100×
c) \(A_0 = 20300\mu\text{m}^2\). Magn.100×.

Fig. 3. Influence of initial size of austenitic grain on the shape of curves: stress – deformation of Cr-Mn steels after deformation in temperature 1000°C with a speed \(0.23\text{s}^{-1}\).
Fig. 4. Influence of deformation temperature and initial grain size \( A_0 \) on maximum flow stress \( \sigma_{\text{pmax}} \) of Cr-Mn steel twisted at the rate of \( 0.02 \text{s}^{-1} \).

Fig. 5. Influence of initial grain size \( A_0 \) and deformation temperature on the deformation \( \varepsilon_{\text{pmax}} \) of Cr-Mn steel torsioned at the rate of \( 0.02 \text{s}^{-1} \).

The stress of steady flow state at comparable parameters of torsion is higher for Cr-Mn steels than that for Cr-Ni steels, while the influence of initial grain size on the stress \( \sigma_s \) is insignificant (fig.6).

Relations between parameters of deformation process (Zener-Hollomon value) and mechanical properties defined in torsion test are presented on fig. 7, 8. They show that the influence of Zener-Hollomon parameter onto maximum flow stress \( \sigma_{\text{pmax}} \) for both steels can be presented in form of a power function (fig.7). A relation between the deformation \( \varepsilon_{\text{pmax}} \) and Zener-Hollomon parameter in semi-logarithmic system \( \varepsilon = f(\ln Z) \) is presented instead, by a linear dependence (fig.8). At comparable conditions of torsion process, the Cr-Ni steel shows a larger deformation \( \varepsilon_{\text{pmax}} \) than that for Cr-Mn steel (fig.8). The austenitic steel Cr-Ni is thus a material much more deformable in comparison to Cr-Mn steel, which characterises a high speed of consolidation. It explains the displacement mechanism of dislocation described in work [4].
Fig. 6. Influence of deformation speed and initial grain size $A_0$ on a stress of steady flow state $\sigma_s$ for Cr-Mn and Cr-Ni steels twisted at temperature 1100°C.

Fig. 7. Influence of Zener-Hollomon parameter and initial grain size $A_0$ on maximum flow stress $\sigma_{\text{p max}}$ at flow curve of tested steels.

Fig. 8. Influence of Zener-Hollomon parameter and initial grain size $A_0$ on deformation $\varepsilon_{\text{p max}}$ of tested steels.
Dependence comprising the influence of initial grain size and Zener-Hollomon parameter onto the maximum flow stress $\sigma_{p_{\text{max}}}$ and deformation $\varepsilon_{p_{\text{max}}}$ is being presented in Table 1. These data indicate a strong influence on deformation $\varepsilon_{p_{\text{max}}}$ by both the Zener-Hollomon parameter as by a mean area of initial grain flat section $A_o$ (relations 3, 4), what is proved by the values of the test of significance for multiple regression coefficients $p$. Besides, there was proved an essential influence of the mean area of initial grain flat section $A_o$ and $Z$ parameter onto the maximum flow stress $\sigma_p$ (relation 5).

Table 1. Dependencies between the maximum flow stress $\sigma_{p_{\text{max}}}$, deformation $\varepsilon_{p_{\text{max}}}$ and the initial grain size and Zener-Hollomon parameter [4].

<table>
<thead>
<tr>
<th>Dependence</th>
<th>Steel grade</th>
<th>Appropriate equation</th>
<th>Correlation factor $R^2$</th>
<th>Results of the test of significance for multiple regression coefficients ($pcr=0.05$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_{p_{\text{max}}}$ = f($A_o, Z$)</td>
<td>Cr-Mn (3)</td>
<td>$\varepsilon_{p_{\text{max}}} = B_A \times A_o^{0.14} \times Z^{0.05}$ B_A = 0.008 \times[(10^{-6} \text{mm}^{-2})^{0.14} \times s^{0.05}]</td>
<td>0.93</td>
<td>$A_o - 1.1 \times 10^{-6}$ Z - 7.5 \times 10^{-12}</td>
</tr>
<tr>
<td></td>
<td>Cr-Ni (4)</td>
<td>$\varepsilon_{p_{\text{max}}} = B \times A_o^{0.14} \times Z^{0.05}$ B = 0.018 \times[(10^{-6} \text{mm}^{-2})^{0.14} \times s^{0.05}]</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{p_{\text{max}}}$ = f($A_o, Z$)</td>
<td>Cr-Mn, Cr-Ni  (5)</td>
<td>$\sigma_{p_{\text{max}}} = 348 + 5 \times 10^{-4} \cdot A_o + 1.7 \times 10^{-17} \cdot Z$</td>
<td>0.80</td>
<td>$A_o - 0.01$ Z - 1.6 \times 10^{-4}</td>
</tr>
</tbody>
</table>

*/B_A, B – constants depending on steel grade

Conclusions
1. Demonstrated an essential influence of initial grain size determined by a mean area of flat grain section ($A_o$) and deformation parameters ($\varepsilon$, $Z$) onto flow characteristics defined in hot torsion test of inspected steels.
2. Performed statistical test indicates, that the reaction force of initial grain size and deformation parameters on flow characteristics in hot torsion test is similar for both steels.
3. Values of significance test for multiple regression coefficients indicate, that the strongest effect on deformation $\varepsilon_{p_{\text{max}}}$ is exerted by a Zener-Hollomon parameter, while a smaller one has the initial grain size. Similarly, with respect to reaction force on $\sigma_{p_{\text{max}}}$ stress, the independent variables can be ranked in the following order: Zener-Hollomon parameter, initial grain size.

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Literature