THE INFLUENCE OF NIOBIUM CONTENT ON HOT FLOW STRESS OF HSLA STEELS

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Abstract

Uniaxial hot compression tests performed on a HDS-20 Hot Deformation Simulator were utilized to compare the influence of niobium amount on hot flow stresses of these steels. For both steels, the temperature range from 700 °C to 1200 °C in combination with the nominal strain rate range from 0.1 s^{-1} to 100 s^{-1} were investigated. A unique computing method was employed to correct the shape of the experimentally obtained hot flow stress curves influenced by the barrel-like shape of the test samples at high strains. Decrease in temperature led to an increase in hot flow stress. The same influence had an increase in strain rate. The hot flow stress of the steel S355J2H is almost at each temperature higher when compared to the steel P355NH. Nevertheless, different flow stress behavior was observed at small strain rates.

Keywords: HSLA steel, uniaxial hot compression test, flow stress curves, peak stress

1. INTRODUCTION

Z-Group Steel Holding, a.s., Czech Republic [1] is engaged in production of the seamless steel tubes by the Mannesmann way [2, 3]. Microalloyed steel P355NH or EN 10216-3, which is intended for the production of the seamless steel tubes for pressure purposes, and S355J2H or EN 10210-1 vary especially by the amount of the niobium (0.013 % in case of the steel P355NH and 0.037 % as for the S355J2H, respectively). The processing of the steel tubes with thinner wall thickness from these steels is accompanied by the crack creating at the initial part of the rolled tubes. A quick wall cooling at the end parts of the rolled tubes probably causes this phenomenon. This fact then leads to the flow stress increase in these end parts and thus to the increase in crack occurrence in this area. The effect of decreasing temperature on the flow stress increase is obvious. The flow stress increase is also caused by a higher value of the strain rate. In addition, above-mentioned steels vary essentially by the amount of the niobium. This microalloying element has powerful strengthening effect caused by recrystallization deceleration during forming, which leads to a significant flow stress increase [4].The goal of this paper was to determine the influence of the forming temperature and amount of niobium on the maximum hot flow stress of the above-mentioned HSLA steels at high-rate strains. The values of the maximum flow stresses will then be used to evaluate the deformation behavior of the investigated steels. The results of this investigation should be employed to improve the technological process of the seamless steel tubes production in view of the above-mentioned crack occurring. For instance, the hot deformation behavior of the steels intended to produce seamless steel tubes by the Mannesmann way was also studied in [5, 6].

2. EXPERIMENT

The solution of the above-mentioned issue was based on the utilization of the Hot Deformation Simulator HDS-20 at VSB-TU Ostrava whose testing module Hydrawedge II [7] enables to achieve the nominal strain rate up to 100 s^{-1} [8]. The cylindrical compression-test specimens with the diameter of 10 mm and the height of 15 mm were prepared from casts of the above-mentioned steels. The both casts had the similar carbon equivalent (0.41 in both cases) and chemical composition (**Table 1**). However, they vary essentially by the niobium content (**Table 1**). For the uniaxial compression tests of both steels were chosen the deformation temperatures of 1200 °C; 1100 °C; 1000 °C; 900 °C; 800 °C and 700 °C. These temperatures were combined with the nominal strain rates values of 0.1 s^{-1}; 1 s^{-1}; 10 s^{-1} and 100 s^{-1}. Each sample was preheated at the temperature of 1280 °C, cooled down on the deformation temperature, and deformed at this temperature by the uniaxial compression with the maximum height-true strain of 1.0.

Table 1 Chemical composition of the casts of the steel P335NH and S355J2H

	C (%)	Mn (%)	Si (%)	N (%)	V (%)	Nb (%)
P355NH	0.13	1.31	0.25	0.01	0.045	0.013
S355J2H	0.14	1.38	0.29	0.01	0.059	0.037

3. RESULTS AND DISCUSSION

3.1. The flow stress curve correction

The result of each compression test was obtained in the form of the flow stress curve calculated by the internal algorithm of the used simulator. By this way obtained experimental curves exhibits, from the theoretical viewpoint, an inappropriate increase in flow stress beyond the true strain of 0.4 or 0.6 - see the black lines in **Fig. 1** and **Fig. 2**. This phenomenon can be a problem for oncoming flow stress prediction at high strains. The reason why this is occurring can be explained by varying friction on the contact surfaces between sample and anvils. It is obvious that this fact causes the barrel-like shape of the testing samples. The internal calculating algorithm of the HDS-20 is then probably unable to fully reflect this excessive barreling at strains above the value of 0.4 or 0.6, respectively. This issue can be overcome by the complicated mathematical methods that are described for example in [9, 10]. In the event of our research, we derived the simple mathematical function that is able to correct the shape of the flow stress curves in the steady-state area. This function is protected as a valuable know-how [11]. The blue lines in **Fig. 1** and **Fig. 2** represent examples by this way corrected curves. **Fig. 2** also shows that the addition correction (smoothing) of the shape of the previously corrected flow stress curves is necessary at high strain rates values because of higher scatter of the recorded data. This smoothing is suitable for the determination of the basic shape of the flow stress curves and the peak coordinates. Unfortunately, this correction method does not allow to correctly describe the shape of the curves in the ending phase and also does not exhibit the smooth start phase (see the red line in **Fig. 2**).

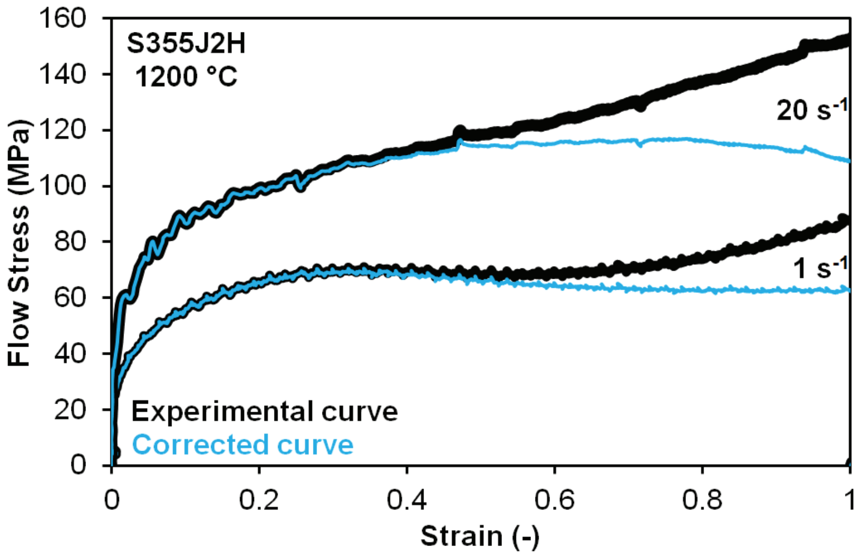

Fig. 1 Flow stress curve correction

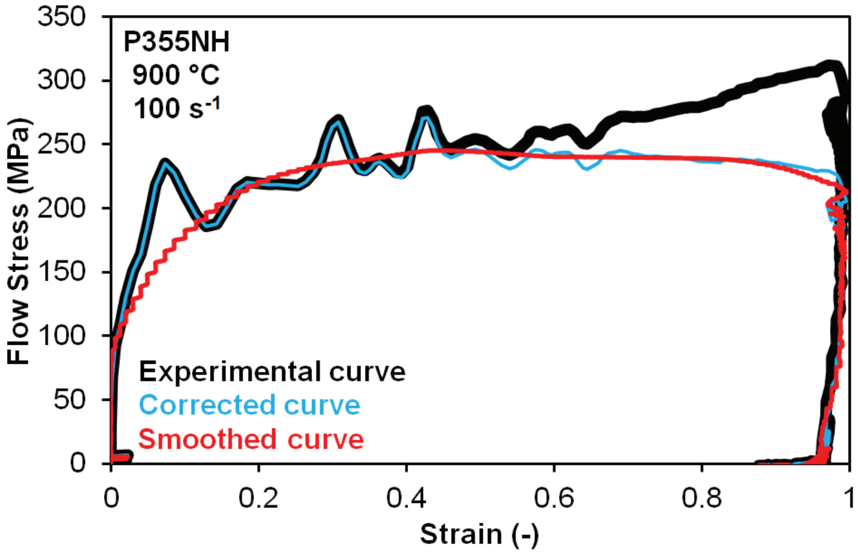

Fig. 2 Flow stress curve smoothing

3.2. Activation energy at hot forming and prediction of the maximum flow stress

Thanks to the above-mentioned corrections was possible to obtain the experimental values of the maximum flow stress. Possible prediction of these values can be done through these inverse hyperbolic-sine equations [12]:

$$\sigma_{max} = \frac{1}{0.0681} \cdot \arg\sinh \sqrt[1.4354]{\frac{Z}{1.35 \cdot 10^{16}}} \tag{1}$$

$$\sigma_{max} = \frac{1}{0.0618} \cdot \arg\sinh \sqrt[1.3599]{\frac{Z}{2.36 \cdot 10^{17}}} \tag{2}$$

The equation (1) is valid for the steel P355NH and equation (2) for the steel S355J2H, respectively. In both equations, σ_{max} (MPa) represents the maximum flow stress and Z (s^{-1}) is the Zener-Hollomon parameter [13]:

$$Z = \acute{e} \cdot \exp\left(\frac{Q}{R \cdot T}\right) \tag{3}$$

In the equation (3), $\acute{e}$ (s^{-1}) represents the strain rate, R (8.314 $J \cdot K^{-1} \cdot mol^{-1}$) is the universal gas constant, T (K) represents the deformation temperature and Q ($J \cdot mol^{-1}$) is the activation energy at hot forming. The value of the Q is 534.9 $kJ \cdot mol^{-1}$ in the event of the steel P355NH and 554.3 $kJ \cdot mol^{-1}$ as for the S355J2H, respectively. These values of Q were calculated by the traditional hyperbolic-sine equation [14]. For the all above-mentioned calculations was used the special interactive software ENERGY 4.0, working on the principle of partial linear regressions [15].

3.3. Comparison of the maximum flow stress

In order to compare effectively the influence of the deformation temperature and the content of the niobium amount on the hot flow stress of the investigated steels, the 3D-graph of both examined steels was assembled; see **Fig. 3** represents the steel P355NH and **Fig. 4** for the S355J2H, respectively. It is clear that flow stress of both steels increase with the decreasing deformation temperature and the growing strain rate. Nevertheless, the influence of the declining temperature on the flow stress increase is greater in case of the steel S355J2H.

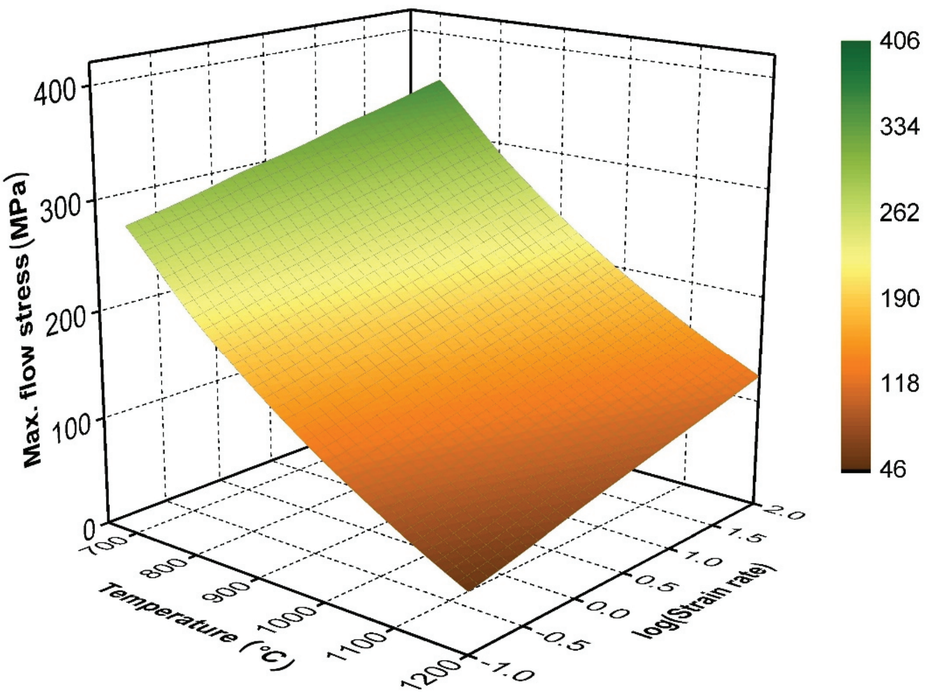

Fig. 3 3D-graph of maximum flow stress of the steel P355NH depending on temperature and strain rate

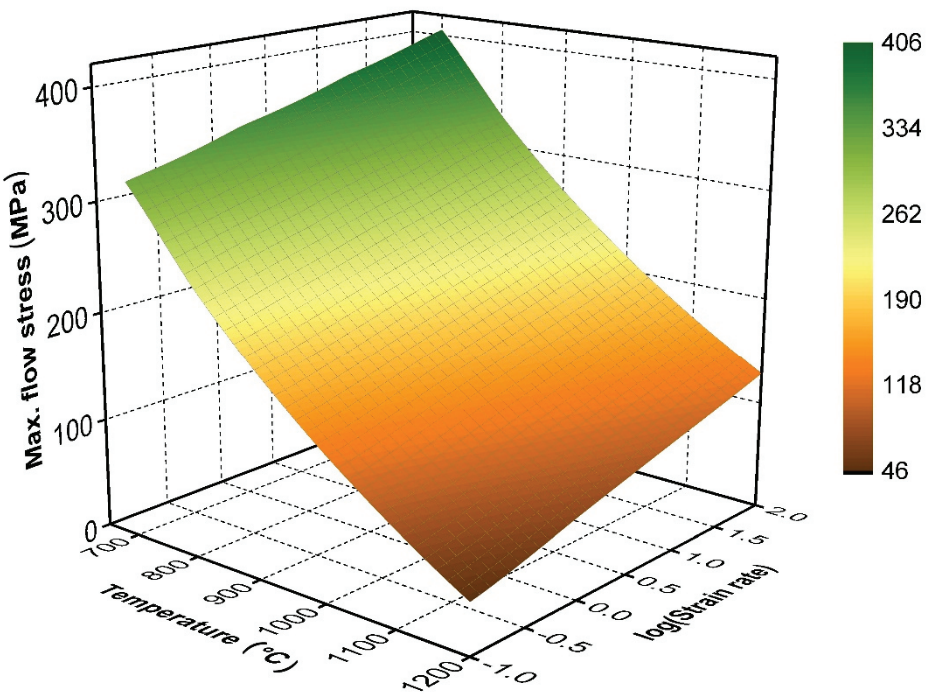

Fig. 4 3D-graph of maximum flow stress of the steel S355J2H depending on temperature and strain rate

This fact is distinct mainly at lower deformation temperatures (approximately below 900 °C). The reason of this phenomenon can be probably attributed to the stronger precipitation strengthening in case of the steel S355J2H. The maximum flow stress differences between both steels at the highest deformation temperature (1200 °C) are essentially negligible. The exception, however, occurs at lowest strain rate (0.1 s^{-1}). In this case, the maximum flow stress of the steel P355NH exhibits even higher values against the steel S355J2H alloyed by the higher amount of the niobium. It seems that the influence of the niobium on the flow stress increase is insignificant with respect to the higher deformation temperatures and lower strain rates. A similar trend can be observed also at the strain rate of 1 s^{-1}. The decrease in deformation temperature leads in the event of both steels to the gradual reduction of the influence of the growing strain rate on the maximum flow stress increase. This phenomenon was observed when nominal strain rate was increased from 20 s^{-1} to 100 s^{-1}. However, this fact is nearly negligible and at lower strain rates is essentially imperceptible.

4. CONCLUSIONS

On the basic of the hot compression tests performed by the Hot Deformation Simulator HDS-20 was possible to obtain the experimental flow stress curves of two microalloyed steels (P355NH and S355J2H) in the temperature range from 700 °C to 1200 °C and the strain rate range from 0.1 s^{-1} to 100 s^{-1}. The values of the maximum flow stresses were obtained and the equations for their prediction in case of both investigated steels were derived. The flow stress of the steel S355J2H was higher because of the higher content of niobium. The influence of the decreasing deformation temperature on the flow stress increase has higher sense in case of the steel S355J2H. This can be explained by the stronger precipitation strengthening caused by the higher content of niobium. The influence of the higher amount of the niobium on the flow stress increase is essentially negligible when low strain rate and high deformation temperature take place. The values of the maximum flow stress should be used to improve the technological process of the seamless steel tubes production by the Mannesmann method to prevent crack occurring in the initial part of the rolled tubes.

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