Study of strain resistance of steel applied for manufacture of large-sized shaped sections

Iaroslav Frolov

Prof., Doctor of Science (tech.)
Chair of Metal forming
National Metallurgical Academy of Ukraine

Henryk Dyja

Prof. Dr. hab. inz.
Director of the Institute of Forming and Safety Engineering
Czestochowa University of Technology, Poland

Gennadii V. Berheman

Candidate of Technical Science
CEO PJSC EVRAZ DMZ
Dnipropetrovsk, Ukraine

Vitalii V. Andreiev

Candidate of Technical Science, Associate Professor
National Metallurgical Academy of Ukraine
Dnipropetrovsk, Ukraine
E-mail: vitalii.andreiev@metal-forming.org

Andriy A. Samsonenko

Candidate of Technical Science, Associate Professor
National Metallurgical Academy of Ukraine
Dnipropetrovsk, Ukraine
E-mail: samsonenko@metal-forming.org

Abstract
The strain resistance is an important physical value, which characterizes metal flows. It is used for evaluation of energy-efficiency of metal forming processes, particularly for determination of energy-power parameter. At present time, many experimental researches for determination of given value were conducted; however, the problem of determination of reliable data of the metals and alloys strain resistance value under the conditions of the hot-forming method is relevant.
The experimental researches and theoretical analysis of strain resistance value of steel 5ps, 09G2D and 63 at a temperature comprised between 800…1200 °C and strain rate in the range of 0,1; 1 and 10 s^{-1} are conducted in the paper. Hensel-Spittel regression equation coefficients are determined; they are necessary for quantitative assessment of metal stress resulting from the process of the computer modeling. Moreover, regarding the energy-efficiency of the strain resistance, the correct temperature velocity parameters for considered values of strain degrees are determined with the use of methods of hardening and softening.
Key words: STEEL, RHEOLOGY, EXPERIMENT, DEFORMATION, DEPENDENCE, HARDENING, SOFTENING, STRAIN RESISTANCE, METHOD, ENERGY-EFFICIENCY

At present day, new steel and alloy stamps are commonly being introduced in the perspective of increase of the strength-weight ratio of final product. However, the use of these steels under the conditions of traditional rolling plants is problematic because of the complex technical process, which involves adherence to the temperature velocity parameters and high level of energy power parameters (EPP) of the strain resistance. According to it, the most relevant problems are development of advanced and improvement of current strain technological mode of traditionally used grades of steel such as Steel 5 (used for production of the angle sections and roll-formed channels) [1], 09G2D (used for production of the section of car post) [2] and Steel 63 (used for production of the crane rails) [3], with the chemical composition presented in Tables 1-3.

Table 1. The Chemical Composition of Steel 5ps

Melting No	C, %	Mn, %	Si, %	S, %	P, %	Cr, %	Ni, %	Cu, %
6968	0.37	0.71	0.06	0.023	0.021	0.08	0.02	0.03

Table 2. The Chemical Composition of Steel 09G2D

Melting No	C, %	Mn, %	Si, %	S, %	P, %	Cr, %	Ni, %	Cu, %	Al, %	Ti, %
13471	0.1	1.67	0.34	0.14	0.17	0.01	0.01	0.27	0.06	0.01

Table 3. The Chemical Composition of Steel 63

Melting No	C, %	Mn, %	Si, %	Max					
5592	0.62	0.81	0.23	S, %	P, %	Cr, %	Ni, %	Cu, %	As, %
				0.028	0.036	0.04	0.01	0.02	0.008

The rheological characteristics of the strain materials, which are changed in a high range according to the thermomechanical conditions of metal forming, are one of the potential factors in solving of this problem. Much attention is paid to the issue of obtaining of solid data on rheology of metals and alloys under the conditions of hot strain [4-6]. It is also proved, by the fact, that nowadays the mathematical simulation of the strain (rolling, forging, pressing, etc.) with the use of the finite element method (FEM) [7-8] is widely practiced. Moreover, the finite element method (FEM) requires solid data on the strain resistance of metals in the context of calculation of emerged stresses (qualitative data) and the following calculation of energy power parameters, which determine energy efficiency.

The purpose of this paper is experimental investigation of the steels strain resistance (St5ps, 09G2D, St. 63) in the uniaxial compression process as well as evaluation parameters of hardening and softening by hot-forming method.

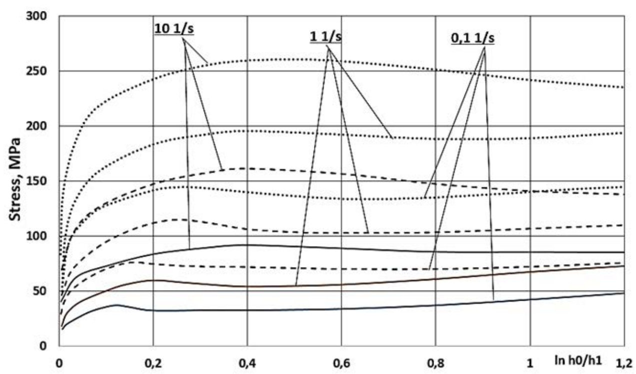
For achievement of the specified purpose, the investigations of rheological properties of the selected grades of steel by the physical simulation process Greeble 3800 [9] of the Czestochowa University of Technology (Poland) were conducted. According to the designed plan, the investigation has been conducted for three temperatures T= 800 °C, 1000 °C and 1200 °C, and for three strain rates $\dot{\varepsilon}$= 0,1; 1 and 10 s^{-1} which are typical almost for the full range of conditions of the traditional process of plastic strain, particularly for the rolling operation. As a result of investigation, the curves (stress-strain curves) of the true strain impact ($ln\ {}^{h_o}/_{h_1}$) on strain resistance (σ_s) for the selected alloy have been obtained (Figures 1-3).

One of the most widespread yield stress calculation models, which is used in the theoretical researches (computer modeling), is Hensel-Spittel equation [10]:

$$\sigma_{yi} = Ae^{a_1 T} T^{a_9} \varepsilon^{a_2} e^{a_4/\varepsilon} (1+\varepsilon)^{a_5 T} e^{a_7 \varepsilon} \dot{\varepsilon}^{a_3} \dot{\varepsilon}^{a_8 T} \quad (1)$$

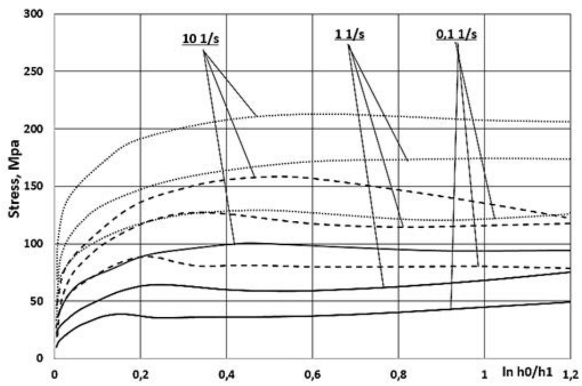
where: σ_{yi} – yield stress; ε – strain intensity; $\dot{\varepsilon}$ – strain rate intensity; T – temperature, A, a_1, a_2, a_3, a_4, a_5, a_7, a_8, a_9 – coefficients of regression.

The steel stress-strain curves obtained (Figure 1-3) with the use of statistical analyses, regression coefficients (Table 4) of equation (1) have been approximated and determined. They are necessary for the further computer modeling of the process of section rolling.



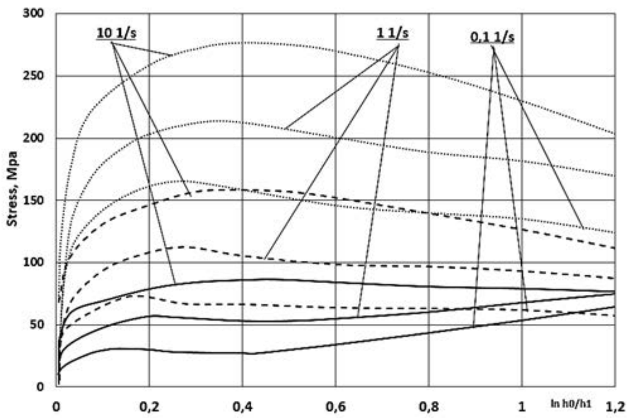
.... - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 1. Stress-strain curves for steel 5ps



.... - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 2. Stress-strain curves for steel 09G2D



.... - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 3. Stress-strain curves for steel 63

Table 4. Coefficients of regression of the equation (1) for the alloys under study

Alloy	A_1	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
St. 5	0.017	-0.005	0.165	0.014	-0.002	5.53	0	-0.28	0.0001	2.03
09G2D	2.07	-0.01	0.22	-0.05	-0.002	0	0	-0.46	0	5.07
St. 63	21702.2	-0.003	0.103	0.065	-0.01	0	0	-0.52	7.96	-0.34

Due to the use of plastic layer materials by the authors of papers [11, 12], it is established that the rheological curves of the metals cannot be shown in the form of monotonic increasing functions which is confirmed by the Figures 1-3. The listed curves have peak of maximum hardening and so-called area of dynamic softening. However, until to present time, the property of the softening has not been used for designing or improving the strain process, which has significant impact on EPP.

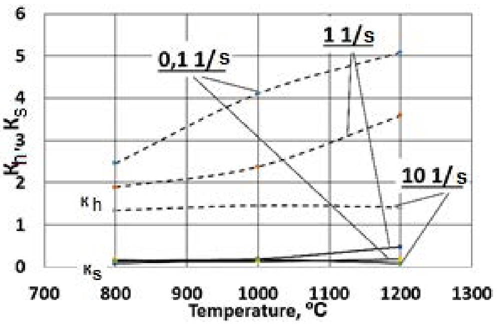
In order to determine the correct strain temperature range of the investigated grades of steel in the context of EPP process, let us use the method of hardening and softening [13]. According to this method, hardening and softening evaluation of different rheology metals is carried out by coefficients (2) and (3) respectively.

$$K_h = \frac{\sigma_{max}-\sigma_0}{\sigma_{max}} / (\varepsilon_{x1} - \varepsilon_0); \quad (1)$$

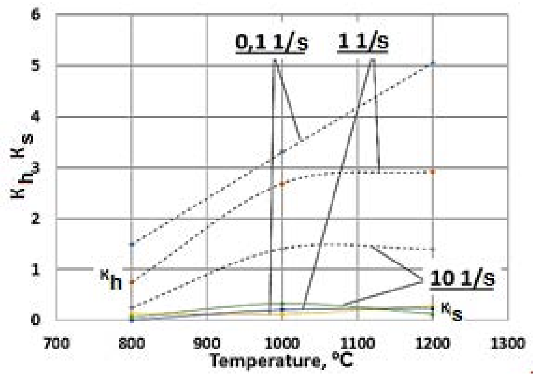
$$K_s = \frac{\sigma_{max}-\sigma_2}{\sigma_{max}} / (\varepsilon_{x2} - \varepsilon_{x1}); \quad (2)$$

where: σ_0 – strain resistance at low strains; σ_{max} and σ_2 – strain resistance for $\varepsilon = \varepsilon_{x1}$ and $\varepsilon = \varepsilon_{x2}$ respectively.

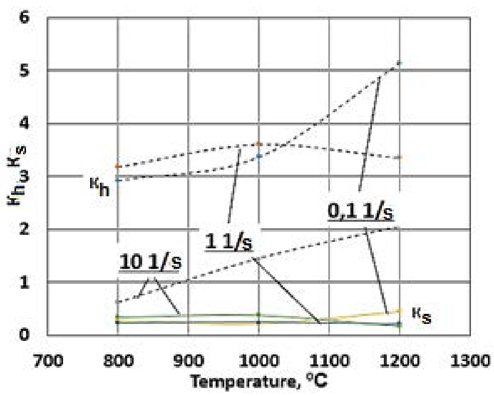
The graphical analysis of specified hardening and softening parameters is provided in Figure 4. From the analyzes of present data, it is evident that steel hardening effects dominate significantly over the steel softening effects during the strain process. According to this, the qualitative picture of change of curves of strain-hardening coefficient (K_h) for the conditions under consideration is different that is due to different chemical compositions. The determined circumstance is also confirmed with the data in paper [14].



a)



b)



c)

Figure 4. The dependence of hardening intensity (K_h) and softening intensity (K_s) for: (a) Steel 5ps; (b) – 09G2D; (c) – Steel 63

The qualitative data range of temperature 900…1100 ºC, which is traditional for the process of section rolling, demonstrates that K_h falls within the limits of 1.4…4.5 irrespective of steel grade.

When comparing the terms of the metal hardening relative coefficient ($\delta K_h = K_h / K_s$), it is established (Fig. 4, a) that the most adverse conditions, according to the energy performance of the rolling operation, are strain at a temperature of T<900 ºC ($\acute{\varepsilon} \leq 1s^{-1}$) and T>1100 ºC ($\acute{\varepsilon} \leq 10s^{-1}$) in the whole range of the considered degrees of strain. The temperature velocity parameters at the level of T=900…1100 ºC ($\acute{\varepsilon} \leq 1...10s^{-1}$) in the range of strain degrees $ln\ h_0/h_1 =$ = 0,25...0,8 are the most favorable conditions.

In the same way as for Steel 5, the data analysis (Fig. 4, b) shows that the temperature velocity parameters are T=900…1100 ºC and ($\acute{\varepsilon} = 1...10s^{-1}$) in the range of strain degrees $ln\ h_0/h_1$= 0.35...0.6.Upon that, when using higher singular degree of strain $ln\ h_0/h_1 \geq 0,45$, it is necessary to apply the average temperature in the metal from the required range (for example, T=1000 °C) and $\acute{\varepsilon} \geq 5^{s-1}$.

The Steel 63 is exception from the considered materials (Fig. 4, c). The conducted analysis of its hardening and softening effects showed that the use of the strain rates $\acute{\varepsilon} \leq 5^{s-1}$ at T=800…1200 °C leads to significant predominance of hardening effects and may have undesirable effect on the power performance of strain process. The most favorable conditions concerning considered situation are the use of higher rates $\acute{\varepsilon}$ = 5...10s^{-1} within the limits of temperature T=800…1100 °C (at $ln\ h_0/h_1 \geq 0,4$). So, for example, the range of the strain relative coefficient of the metal is equal to ($\acute{\varepsilon}$ = 10s^{-1}): δK_h^{800}=1,84; δK_h^{1000}= =3.9; δK_h^{1200}= 13.2 .

Conclusions

1. The obtained results during the experimental investigations and theoretical analysis have allowed establishing the interconnection between stress and strain states of the carbon constructional steel and making an assessment of strain resistance value regarding the stress-strain curves.

2. The value coefficient analysis of hardening and softening showed that the most favorable conditions according to the energy performance of operation are strain conditions, which fall within the range of:

- Steel 5: T=900…1100 °C; ($\acute{\varepsilon}$ = 1...10s^{-1}) ; $ln\ h_0/h_1$= = 0.25...0.8;
- Steel 09G2D: T=900…1100 °C; ($\acute{\varepsilon}$ = 1…10s^{-1}); $ln\ h_0/h_1$= 0.35...0.6.;
- Steel 63: T=800…1100 °C; $\acute{\varepsilon}$ = 5...10s^{-1}; $ln\ h_0/h_1 \geq 0,4$.

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