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Analysis and modelling of complex rheologic mediums in conditions of thermomechanical loading

Chigirinsky V.V.

D.Sc. in engineering, professor,
Head of ZNTU Metal Forming Department
Zaporizhzhya National Technical University,
Zaporozhye, Ukraine
E-mail: valerij@zntu.edu.ua

Putnoki A.Yu.

PhD in Technical Sciences, postdoctoral student
of ZNTU Metal Forming Department
Zaporozhye National Technical University,
Zaporozhye, Ukraine
E-mail: al.putnoki@gmail.com

Abstract
The study represents analysis and modeling of mechanical, physical properties of the medium under conditions of complex rheological loading. It contains experimental design data of yield stress depending on the strain ratio and speed, as well as the temperature and chemistry of two steel grades. The article demonstrates that under different thermomechanical factors the scheme of force impact is changed with gradual decrease after the maximum value is reached.
Key words: MATHEMATICAL MODEL, YIELD STRESS, STRAIN RATIO AND SPEED, MEDIUM RHEOLOGY, STRAIN LOADING

Introduction

There known a lot of words devoted to the study of plastic medium properties and, particularly, the dependence of plastic resistance on the thermomechanical process variables (degree, speed of deformation and temperature). Elementary mathematical models allow to determine power factors of plastic flow depending on the deformation parameters only according to increasing scheme. Zyuzin-Browman dependencies may be an example [1].

$$\sigma_T = \sigma_1 \cdot (\varepsilon)^{T_1} \cdot (и)^{T_2} \cdot exp(\tau_3 T) \qquad (1)$$

where σ_1 - is yield point, determined by the steel grade; σ_1 - is basic yield point; ε - is degree of vertical deformation; $\dot{o}_i$ - is deformation rate; T – is metal temperature; $\dot{o}_i$ - is the constant, determined by steel grade.

The similar loading scheme takes place in the Andreyuk-Tyulenev's scheme [2].

$$\sigma_T = \sigma_0 \cdot (\varepsilon)^{T_1} \cdot (и)^{T_2} \cdot (T)^{m_3} \qquad (2)$$

There is experimental data, which shows more complex influence of deformation parameters on the power characteristics of plastic forming [3]. Together with the increase of yield load, there is its reduction when deformation increases, fig.1.

Fig. 1 shows that descending rate of curves is also determined by deformation rate.

Problem statement

Plastic medium in the process of deformational

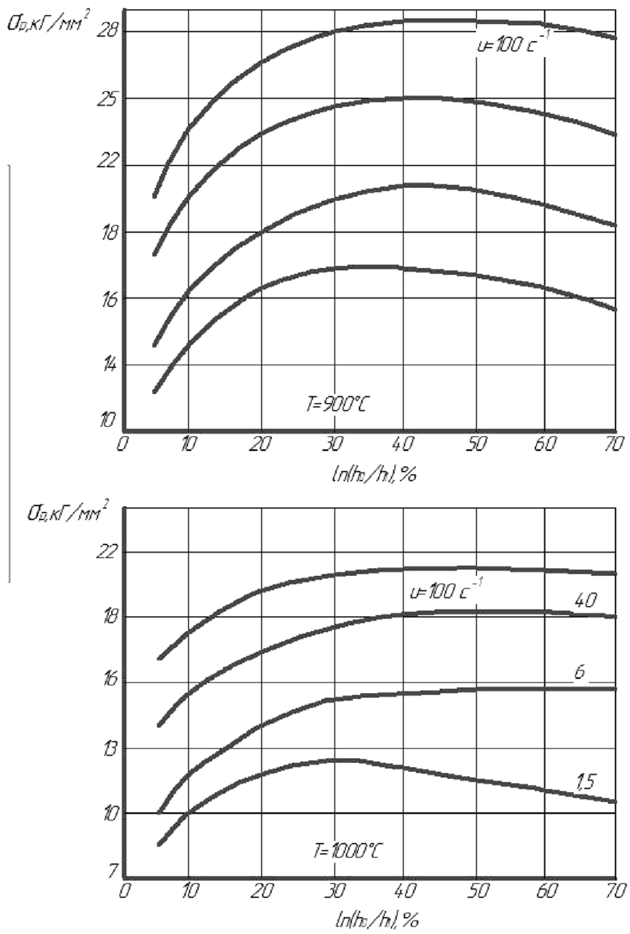


Figure 1. Yield point of medium carbon steel at different strain rates

influence at various stages of loading has different rheology, which is determined by thermomechanical characteristics and chemical composition of steel. There is a necessity to analyze and model sufficiently mechanical, physical properties of medium in conditions of complex rheological loading.

Solution of the problem

Modern mathematical models differ with more complex analytical dependencies, allowing to describe complex rheological properties of materials [3…5].

Functionality of strain factors broadens. These factors along with the temperature, deformation rate effect differently on the power parameters of mechanical medium.

In the work [3] such dependence is used together with velocity ratio

$$\sigma_T = \alpha_1 \cdot \varepsilon^{(\alpha_2 + \alpha_3 T + \alpha_4 \cdot и)} \cdot exp(\alpha_5 \cdot \varepsilon) \cdot u^{(\alpha_6 + \alpha_7 \cdot T)} \cdot exp(\alpha_8 \cdot T), \qquad (3)$$

Galkin's formula [5] is analogous to Zyuzin-Browman's expression, but it differs with decreasing exponential function:

$$\sigma_T = \sigma_0 \cdot и^T \cdot \varepsilon^n \cdot exp(-q\varepsilon) \cdot exp(-pT) \qquad (4)$$

More complex models (3), (4) are explained by more complex rheology of plastic environment, which are revealed by research modern complexes.

Recently Henzel-Shpittel's model gains acceptance [6].

$$\sigma_T = \alpha_1 \varepsilon^{\alpha_2} \cdot exp\left(\frac{\alpha_3}{\varepsilon}\right) \cdot exp(\alpha_4 \varepsilon)(1+\varepsilon)^{\alpha_s \cdot T} \cdot и^{\alpha_6} \cdot и^{\alpha_7 \cdot T} \cdot T^{\alpha_8} \cdot exp(\alpha_9 \cdot T) \qquad (5)$$

where α_i -are coefficients.

Expression (5) is characterized by the product of 9 different functions, which can both increase and decrease the compound action of certain thermomechanical parameters. Complex action of strain degree is defined by four functions.

$$\alpha_1 \varepsilon^{\alpha_2} \cdot exp\left(\frac{\alpha_3}{\varepsilon}\right) \cdot exp(\alpha_4 \varepsilon)(1+\varepsilon)^{\alpha_s \cdot T} \qquad (6)$$

Meaningfulness of each function is determined by $\alpha_5 \dots \alpha_5$ coefficients and the character of change of the function itself. The last multiplier shows particular effect of temperature though deformation degree. Strain rate functionally is in accordance with deformation degree (2). There takes place the dependence of degree and rate of deformation on the temperature factor.

$$\varepsilon^{\alpha_2} \cdot (1+\varepsilon)^{\alpha_s \cdot T} \to и^{\alpha_6} \cdot и^{\alpha_7 \cdot T}$$

Temperature factor in the expression (5) is determined by combined dependency of Zyuzin-Browman and Andreyuk-Tyulenev.

$$T^{\alpha_8} \cdot exp(\alpha_9 \cdot T) \qquad (7)$$

Complex temperature effect is determined by coefficients α_9 and α_9, their indexes and different action of functions (7).

If we take in the expression (5) $\alpha_3 = \alpha_4 = \alpha_5 = \alpha_7 = \alpha_8 = 0$, we will obtain Andreyuk-Tyulenev's expression (2).

$$\sigma_T = \alpha_1 \cdot \varepsilon^{\alpha_2} \cdot u^{\alpha_6} \cdot T^{\alpha_8}$$

It is possible to obtain other combinations. Henzel-Shpittel's model has more general character, thus such combinations of coefficients, at which yield load has more difficult schemes of loading, are possible.

On the Gleeble 3800 plastometer two steel grades with maximum degree of strain ε = 1.2 are experimentally investigated at various temperatures and speeds of deformation. Chemical composition of investigated steels is given in tab. 1.

Table 1. Chemical composition of investigated steels

Steel	C, %	Si, %	Mn, %	S, %	P, %	Cr, %	Ni, %	Cu, %	As, %
Low carbon steel (l.c.)	0.20	0.24	0.48	0.009	0.004	0.04	0.02	0.03	0.08
Medium carbon steel (m.c.)	0.46	0.29	0.6	0.009	0.018	0.25	0.15	0.15	0.09

Table 2. Coefficients α_1- α_9 for investigated steels

Steel	Coefficients								
	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9
Low carbon steel (l.c.)	82.811	0.2133	0.001	-0.0003	-0.3630	-0.0323	0.0002	0.6448	-0.0039
Medium carbon steel (m.c.)	1266.5	0.2997	-0.0005	-0.0004	-0.2028	-0.2282	0.0003	0.3392	-0.0036

According to the program of experiment, coefficients of expression (5) are defined. Results of recalculation are presented in the tab. 2.

In fig. 2-4 experimental and calculation data of yield load σ_t, depending on degree, rate of deformation, temperature and a chemical composition is shown. Medium-carbon steel ranks over in almost all elements of chemical composition the low-carbon steel, that found reflection in characteristics of power loading. For all thermomechanical parameters of two steel grades there not revealed constantly increasing scheme of power influence. Starting from ε = 0.3 … 0.5, there formed either maximum of function with its gradual decrease, or change of function happens within insignificant limits. Experimental data for two steel grades stays well within Henzel-Shpittel's model both in deformation, high-speed, temperature parameters, and on a chemical composition, fig. 2-4. Henzel-Shpittel's expression expands possibilities of analytical modeling of the difficult rheological environment, which is in possession by the majority of carbonaceous and alloyed steel grades. It allows to consider and calculate correctly a factor of strain hardening on power, deformation, high-speed and temperature parameters of process, to reveal the defining gears of plastic deformation.

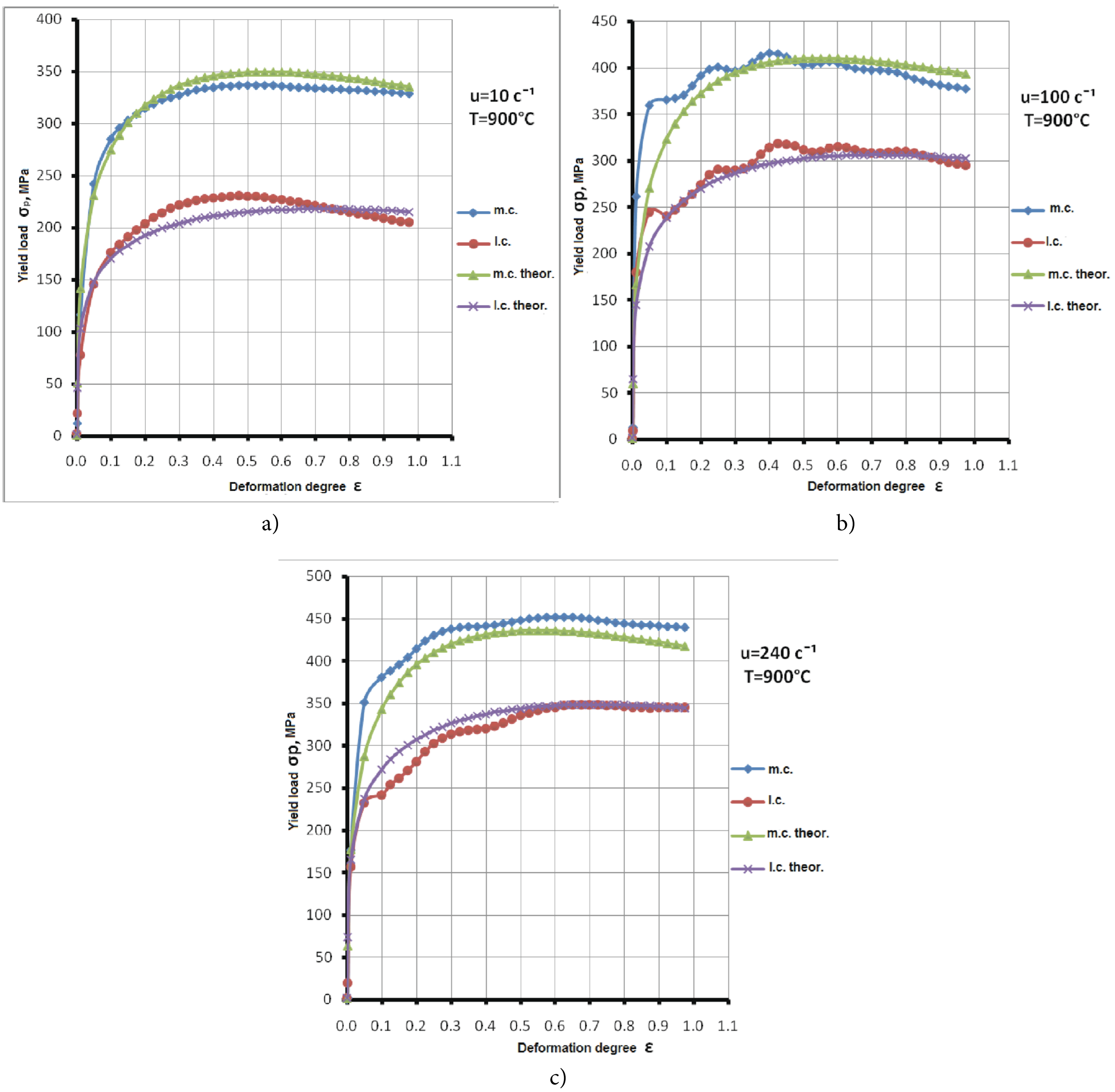
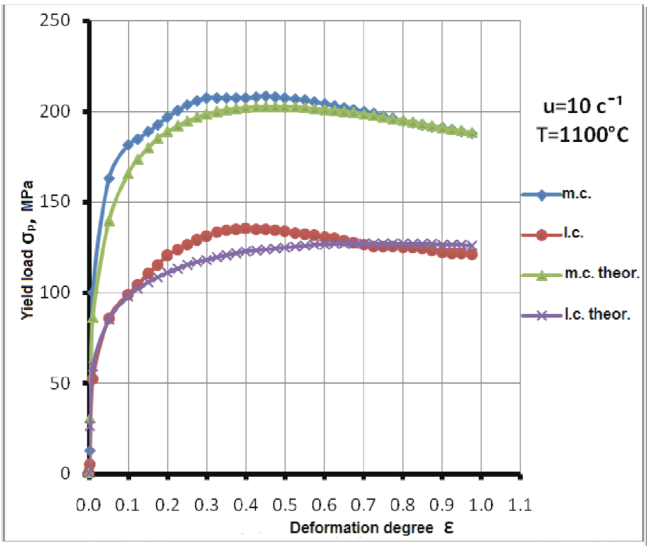


Figure 2. Diagrams of experimental and theoretical dependences of yield flow on the degree of deformation at T=900°C and a - u=10 c^{-1}, b - u=100 c^{-1},c - u=240 c^{-1} for investigated steels.



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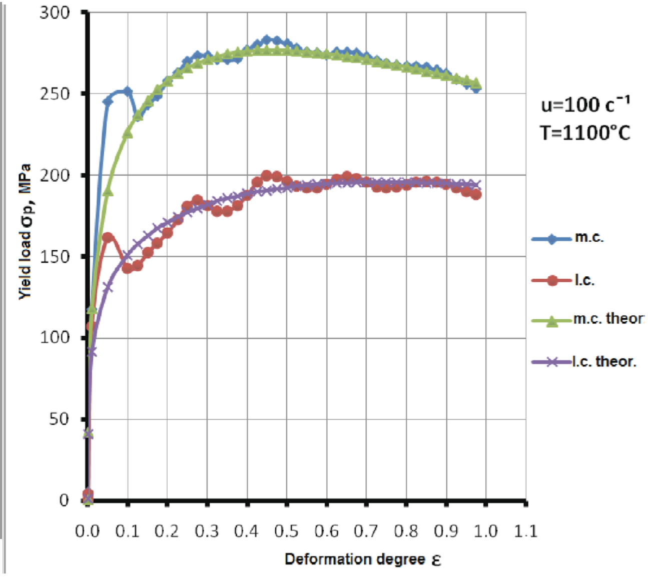

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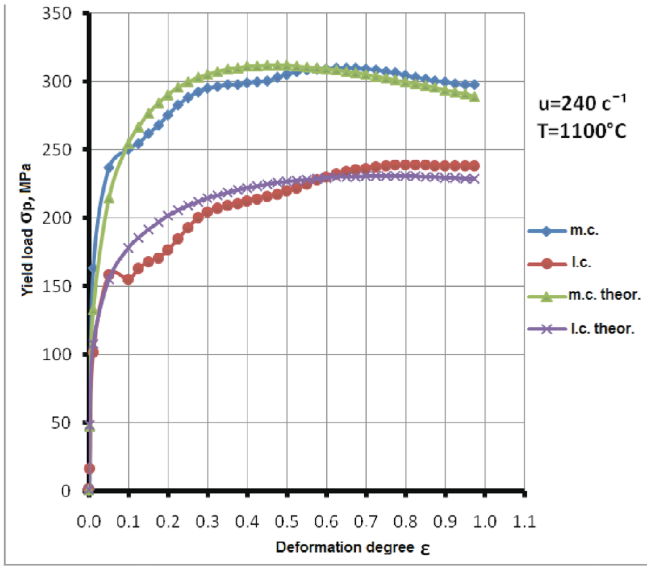

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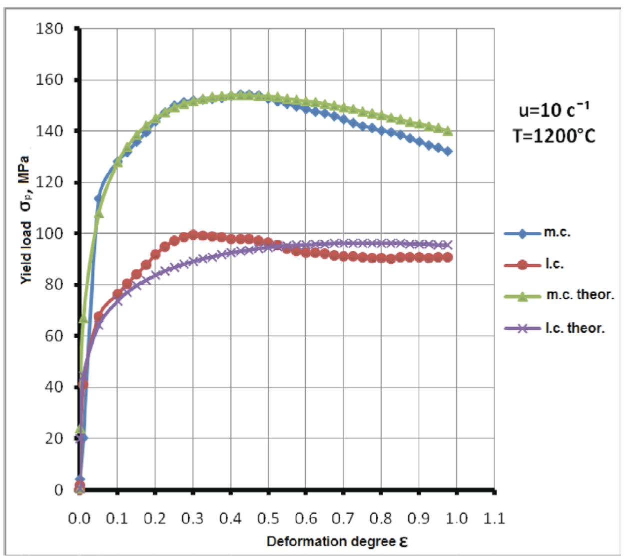
Figure 3. Diagrams of experimental and theoretical dependences of yield flow on the degree of deformation at T=1100°C and a - u=10 c^{-1}, b - u=100 c^{-1},c - u=240 c^{-1} for investigated steels.



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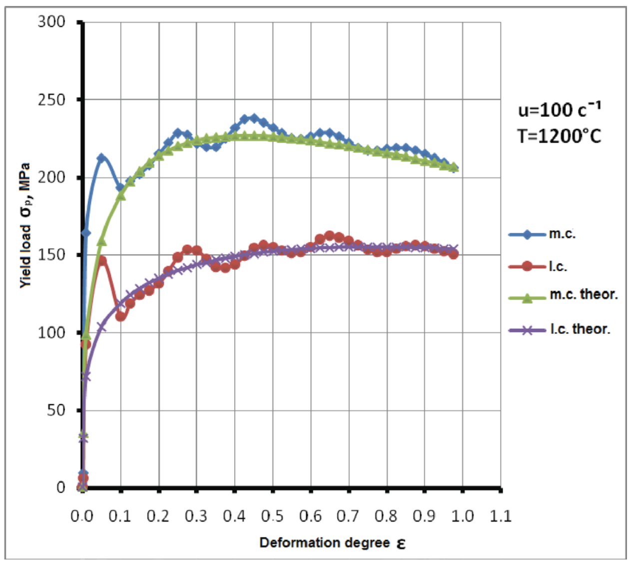

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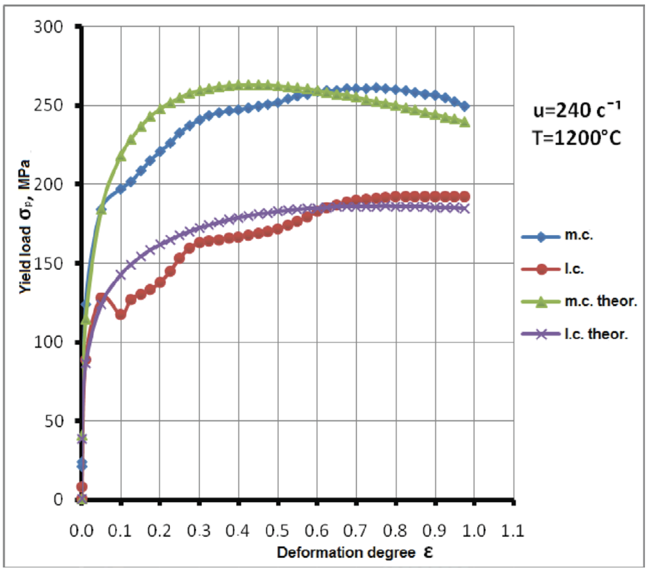

c)

Figure 4. Diagrams of experimental and theoretical dependences of yield flow on the degree of deformation at T=1200°C and a - u=10 c^{-1}, b - u=100 c^{-1},c - u=240 c^{-1} for investigated steels.

Conclusions

1. Elementary mathematical models of mechanical properties of steel in conditions of hot processing characterize the influence of strain and speed parameters according to increasing loading scheme.
2. Real properties of steel and alloys are characterized by complex rheology and power loading scheme.
3. Modern steel grades with complex rheology of the medium are determined by the combined character of influence of thermomechanical parameters on the plastic resistance.
4. Complex analytical model of Henzel-Shpittel allows correctly to determine, both qualitatively and quantitatively, the influence of thermomechanical factors on the yield load during deformation loading.

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