COST 526
"Automatic Process Optimization in Materials Technology"
(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **February 28, 2004**

1. Reporting Period	**1.7.2003 – 31.12.2003**
Project title	OPTIMIZATION OF FORGING CHARACTERISTICS OF METAL IN MUSHY STATE
Project leader	Jaroslav Horský
Organization	Brno University of Technology, Czech Republic
Main collaborators involved	University of Ljubljana, University of Krakow

2. Funding Situation

Amount of money received specifically for COST	12 kEuros
Other resources partially used for the project	kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)
Comparison of optimization methods with Krakow University.

Participation in the Working Group Meeting in Krakow + project progress report
YES
YES

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

US Steel Kosice, Vitkovice Ostrava. Measurement of heat boundary conditions and implementation into contcast simulator.

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Short-term scientific mission Petr Kotrbacek	University of Krakow 16.10. – 30.10. 2003

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

Optimization of numerical model

A set of experiments was conducted to investigate the influence of deformation rate on resisting forces. The temperature in all these experiments was held at 1405 °C (corresponding to 70 % of the solid phase), while ram velocities of 0.5 cm/min, 5 cm/min and 10 cm/min were used. The force-displacement curve followed the same pattern in all cases (Fig.1), with a typical softening in the central stage of the upsetting process, followed by final hardening at the end.

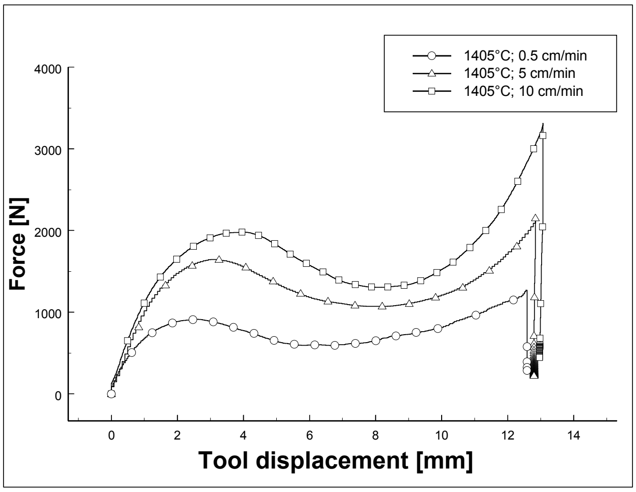

Figure 1. *Resisting force as a function of tool displacement and velocity (0.5; 5 and 10 cm/min) at constant temperature 1405 °C.*

Identification of material parameters

For these experiments, a non linear viscoplastic model developed by Perzyna was used. Here, the flow curve of material is described by

$$\sigma = \left[1 + \left(\frac{\dot{\varepsilon}}{\gamma}\right)^{m}\right]\sigma_0(\varepsilon) \qquad [1]$$

where:

σ = material yield stress,

$\dot{\varepsilon}$ = equivalent plastic strain rate,

m = strain rate hardening parameter,

γ = material viscosity parameter,

$\sigma_0(\varepsilon)$ = static yield stress of material, which is a function of some hardening parameters in general.

The computational simulations were realized by ANSYS as a viscoplastic problem, using the updated Lagrangian approach to cope with large strain and displacements. Due to geometry, axisymmetrical elements could be used (Fig.6), which increased substantially the computational efficiency of the analysis. The friction between tool and specimen was supposed to obey Coulomb's law, with constant friction coefficient value of 0.25.

The evaluation of constitutive parameters was based on minimisation of the objective function

$$s = \sum_{i=1}^{k.n} [E_i - F_i]^{2} \qquad [2]$$

where *n* is the number of check points on the force – displacement curve, *k* is the number of realized and simulated experiments for different ram velocities and E_i , F_i are the compression forces obtained from experiment and from computation, respectively. The minimisation technique used was the subproblem approximation method, which can be described as an advanced zero-order method in that it requires only the values of the dependent variables, and not their derivatives. Key role in this method plays the quadratic approximation of the objective function. Each optimization loop generates a new data point, and the objective function approximation is updated. It is this approximation that is minimized instead of the actual objective function.

Design variables of the minimisation were the constitutive parameters m, γ and a table of discrete values of $\sigma_0(\varepsilon)$, from which the static yield stress can be reconstructed as a continuous, piecewise linear curve. To increase efficiency and stability of the minimisation procedure, it is good to start with realistic values of design variables. This is why they were first estimated by hand-calculation as mean values of m,γ, supposing for a moment that there is a simple uniaxial stress state in the specimen with no friction and no bulging. Then the following relation can be written

$$\frac{\sigma_{\max}}{\sigma_{stat}} = 1 + \left(\frac{\dot{\varepsilon}_{\max}}{\gamma} \right)^m \quad , \qquad [3]$$

where $\sigma_{\max}$, σ_{stat} are the maximal and relaxed mean stress obtained from the loading force measurement) and $\dot{\varepsilon}_{\max}$ is the maximal mean strain rate. Using [3] for the loading rates 0.5 cm/min and 10 cm/min, starting values for the first loop of the following rigorous minimisation were estimated as m = 0.4, $\gamma = 7.10^{-4}$ and were used together with constant starting value of static yield stress $\sigma_0 = 1$MPa.

Minimisation of [2] by repeated computational simulation described above then yielded the following material parameters of [1]:

– strain rate hardening parameter $m = 0.35$
– viscosity parameter $\gamma = 3.3 \times 10^{-4}$

To quantify the correlation between the measured and computed compression force, a weighted relative deviation D was evaluated for each of the three experiments,

$$D = \sqrt{\frac{1}{u_{\max}} \sum_{i=1}^{n} \left(\frac{E_i - F_i}{E_i} \right)^2 \Delta u_i} \quad , \qquad [4]$$

where Δu_i, $u_{\max}$ are the incremental and total tool displacement, other symbols see eq.[2]. The deviation for various tool velocities reached the following values:

0.5 cm/min … D = 0.12
5cm/min … D = 0.13
10 cm/min … D = 0.10

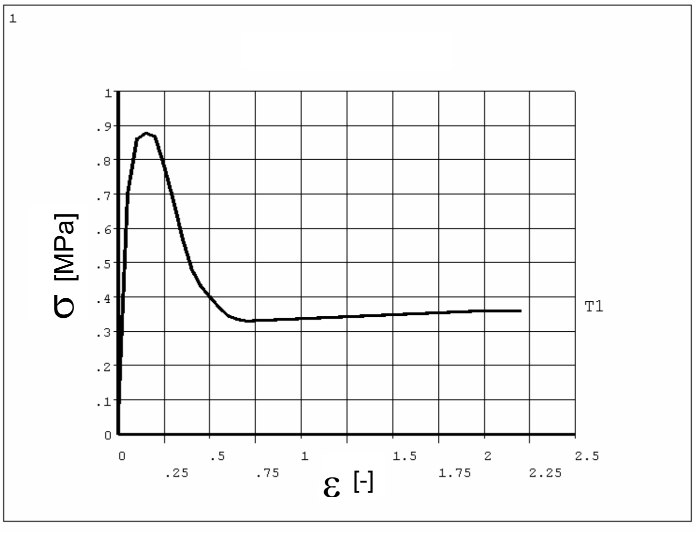

Figure 2. *Static yield stress $\sigma_0(\varepsilon)$ for tested steel at temperature 1405 °C.*

Back extrusion test

Experimental work continued with back extrusion tests. The aim of this work was verification of practical usage of steel forming in the mushy state. Principal scheme of the test arrangement is plotted in Figure 3.

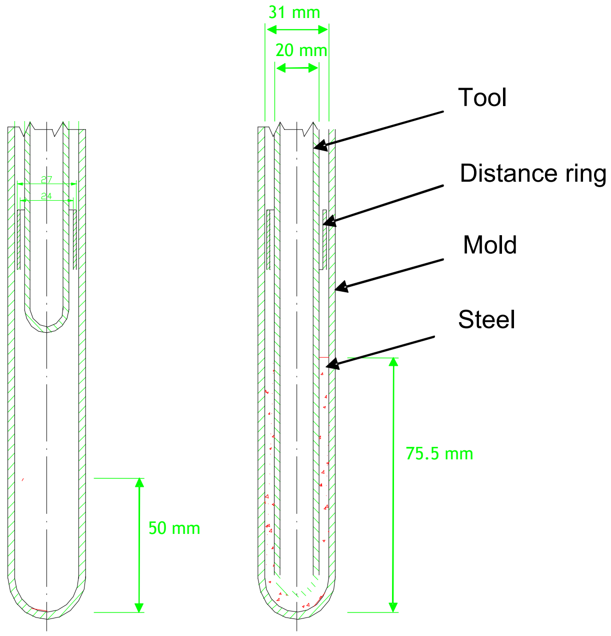

Figure 3 Principal scheme of back extrusion test

Steel sample was placed into the mold, construct of ceramic U-tube. At the beginning steel is melted and than temperature is decrease to prescribe working temperature. Tool, made of ceramic is connected to dynamometer. Force and tool position is monitored by a data acquisition system. A results of force record for different contents of solid/liquid phase are summarized in Figure 4. Photo 1 shows cross section of split sample.

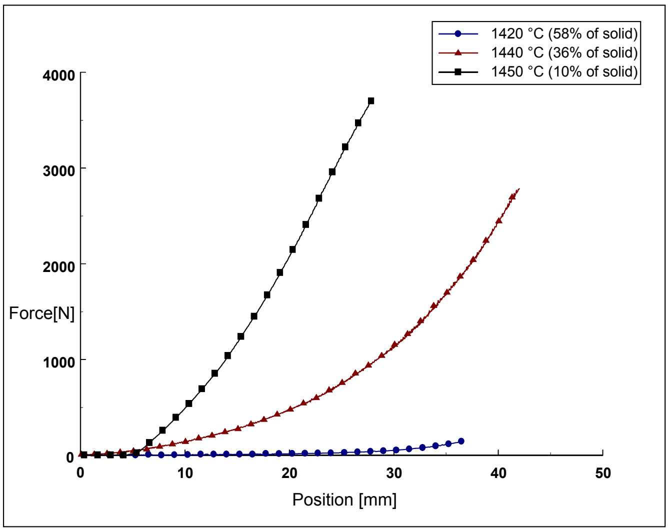

Figure 4. Force-position record

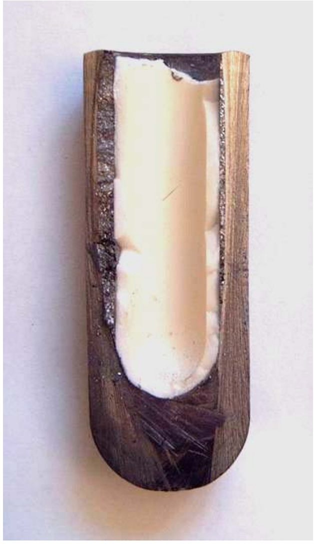

Photo 1 Split sample

7. List of publications

a) Published

Řídký, R. – Petruška, J. – Horský, J. – Kotrbáček, P.: Experimental Study of Semi-solid Steel Deformation, Engineering Mechanics 2003, May 12-15, Svratka, Czech Republic, ISBN:80-86246-18-3.

Petruška, J. – Řídký, R. – Horský, J. – Kotrbáček, P.: Identification of Semisolid Steel Behaviour, 20 th Danubia- Adria symposium on Experimental Methods in Solid Mechanics, September 24-27, Gyor, Hungary, ISBN: 963-9058-20-3.

b) Submitted for publications

Horský, J.- Kotrbáček, P. - Petruška, J. - Řídký, R.: Experimental Study of Semi-solid steel deformation, International Journal of Forming Processes.

c) In preparation

Paper for Metal Forming 2004 conference, Krakow