



COST 526

**“Automatic Process Optimization in Materials Technology”
(APOMAT)**

Half-Yearly Report

To be sent to V.Tesch@access.rwth-aachen.de until **August 31, 2002**

1. Reporting Period	1.1.2002 – 30.6.2002
Project title	OPTIMIZATION OF FORGING CHARACTERISTICS OF METAL IN MUSHY STATE
Project leader Organization	Jaroslav Horský Brno University of Technology, Czech Republic
Main collaborators involved	University of Ljubljana

2. Funding Situation

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

11.5 kEuros
kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Saint-Dié des Vosges + project progress report
 YES

4. Industry participation

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

Nová Hut' Ostrava. Measurement of heat boundary conditions and implementation into contcast simulator.

5. Meetings, visits, exchange of scientists, short-term scientific missions	Location, date



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6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

1. Introduction

Processing metals in semi-solid or mushy state has emerged as a vital commercial process to produce metal and metal-matrix composite components. Among other benefits, it reduces the force requirement in forging processes because of the lower flow stresses involved, or increases die life in die casting operations due to the lower temperature associated. Great amount of work has been done at the Massachusetts Institute of Technology and the University of Tokyo in studying the semi-solid structure and its rheological properties as well as the forming methodology. This process has been broadly termed as the semi-solid metal forming process and refers to the forming of metal that has been partially solidified under vigorous agitation, so that the dendritic structure is fully broken up; its viscosity can be varied over a wide range, depending on the processing conditions.

2. Experiment

Aim of the experiment

Constitutive model and parameters used for the simulation of mushy state steel forming need to be determined or specified. Therefore, an experimental program was prepared verifying the influence of the following factors:

- contents of solid and liquid phase
- loading rate
- cumulated strain

The result of all types of realized experiments is the resisting force F , expressed as a function of the forming tool position x , under constant temperature T and tool velocity v :

$$F = f(x); \quad v, T = \text{constant}$$

Two series of measurements were realized, first with constant velocity, but different temperature of experiments and vice versa.

Experimental material

Tool carbon steel was tested. It has a low content of additions (Table 1) which enables to study its parameters using the equilibrium metastable binary diagram Fe-C.

Table 1: Chemical composition of steel.

Element	Quantity [%]
C	1.03
Cr	0.02
Mn	0.22
Ni	0.05
Si	0.19
Cu	0.089
P	0.014

Mo	0.025
S	0.027
V	0.038
Al	0.018

Description of the experimental apparatus

The basic part of the stand is formed by load frame INSTRON, equipped with a position measuring device and a dynamometer. Signal of position sensor and signal of dynamometer are converted by the data acquisition system. This allows synchronic data transmission into a computer.

Furnace is placed in the frame. The furnace has a design allowing to reach the mushy state of steels (max. temperature is 1 600 °C) and to access the sample-area both from the top and the bottom side. The heated elements are made from SUPERKANTHAL (MoSi₂). The temperature is measured by means of two thermocouples. The type of thermocouple is PtRh-Pt13 and it is placed close to the material sample.

Description of the experimental method

The experimental apparatus enables to provide the “hot upsetting test” of a steel cylinder at very high temperatures corresponding to the melting point of the specimen. The first approach - the indentation of a thin tool into steel in semi-solid state (“indentation test”), can be used at higher temperatures, i.e. also for a larger liquid phase in the specimen. The stress of the thin tool increases quickly with the increasing content of the solid phase, which may result in its failure. On the contrary, the temperature, at which the liquid content reaches a value where the tested cylinder cannot keep its original shape and gets destroyed due to the gravity, limits the second test. These two methods enable to study the steel behaviour within the whole temperature range between the liquidus and solidus curves.

After the evaluation of the “needle test” and the “hot upsetting test” we decided to model first the relation “force – deformation“ at the “hot upsetting test”. The decision was accepted because of a simpler mode of deformation of the compressed specimen and better ability to model frictional conditions in compression. At the needle test, the surface of the contact between the tool and metal is increasing and it is difficult to estimate its friction in semi-liquid state.

Hot upsetting test

Steel sample is cylindrical. The ratio of sample height to diameter is $H_0/D_0 = 1,6$. The sample diameter is then 12 mm and its height 19.2 mm. The tested steel sample is placed on a corundum fine-grained ceramic disc with a ground surface. The massive support under the specimen is made of refractory concrete. Protective atmosphere is led through the refractory concrete directly to the steel sample. The tool is made of refractory concrete. The steel sample is loaded through a second corundum disc by the tool (Fig. 2).

Hot upsetting test procedure

- The tested cylinder is placed in the furnace and is heated up to the required temperature in an inert atmosphere.
- The ram is set into the starting position (10 mm above the specimen) (Fig. 2a).
- The temperature in the furnace is homogenised (the homogenisation time is 30 min.).
- The movement of the ram is started with constant velocity of 0.5, 5 or 10 cm/min.
- The tested cylinder is upset using the preset rate and data of the instantaneous position of the tool and the resisting force acting on the tool are recorded (Fig. 2b). The mentioned system of force and position scanning enables a simultaneous transmission of data into the computer.
- The specimen is deformed to a 1/3 of its original height and after stopping the motion of the ram, the relaxation of the tested cylinder is measured (Fig. 2c).
- The motion is reversed and the ram is moved back to the initial position.
- The measurement is repeated for a new specimen and a different upsetting velocity (eventually for different upsetting temperature).

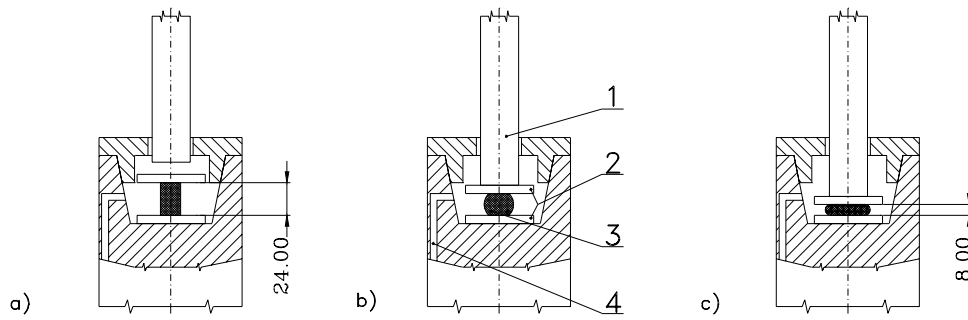


Figure 2 Hot upsetting test

Results of experiments

A set of experiments was conducted to investigate the influence of deformation velocity on resisting forces. The temperature in all these experiments was held at 1405 °C, while the ram velocities of 0.5 cm/min, 5 cm/min and 10 cm/min were used. The curve of resisting force had the same character in all cases. It reached local maximum at about 1/3 of the height reduction, followed by strain softening and then final hardening at the last stage of the compression process (Fig. 3). Maximum values of the force depend on the velocity, with the lowest values reached for velocities of 0.5 cm/min, the highest ones for velocities of 10 cm/min (Fig 3). After stopping the motion of the tool, the relaxation of the resisting force was observed to converge approximately to the same value in all cases.

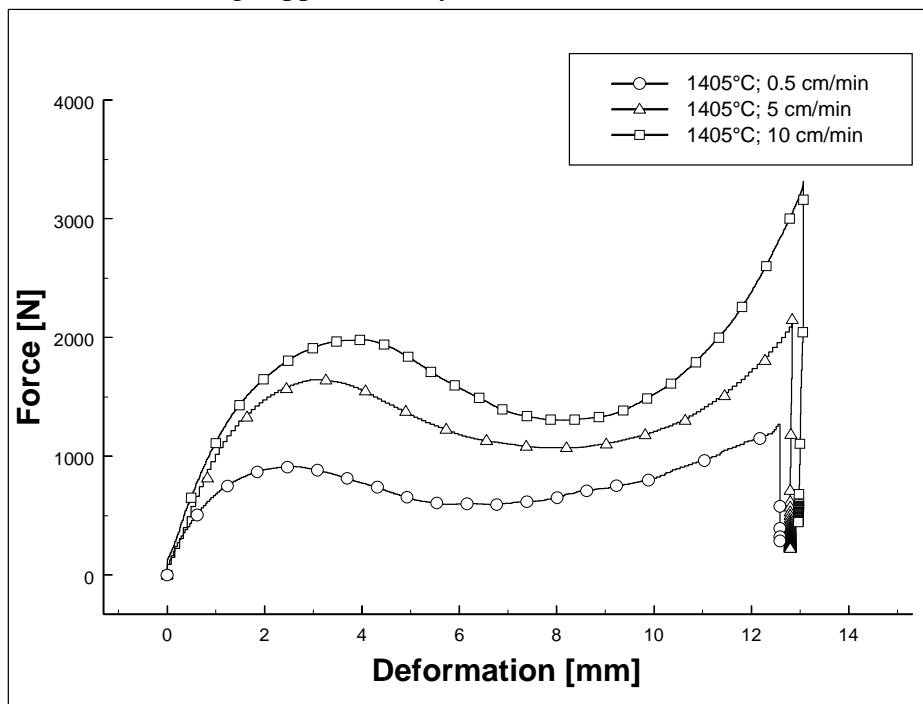


Figure 3: Relationship between force and deformation, constant temperature 1405 °C, velocities of deformation 0.5; 5; 10; and 20 cm/min.

7. List of publications

a) Published

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