EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH - COST

COST 526

Automatic Process Optimization in Materials Technology

(APOMAT)

Title:

Optimization of Forging Characteristics of Metal in Mushy State

Keywords: Forging, mushy state, metal

Organization/Company:

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1. Duration / run time of the project

1.1.2000 – 28.03. 2004

2. Overall cost

2 670 000 CZK / **77 kEURO**

3. Funding situation

Funding is being assured partially (45% of the total costs) by the Czech Ministry of Education (per each year extra). The rest of overall costs has to be supported from the university resources.

4. Project partners indicated to participate

National partner:

1. Brno Academy of Science, Department of Material Structure, RNDr. Ji í Svoboda, CSc. (contact person), Žižkova 22, Brno, Czech Republic

International partner:

1. University of Ljubljana, Faculty of Mechanical Engineering, Laboratory of Fluid Dynamics and Thermodynamics, Ass.Prof.Dr. Božidar Šarler (contact person), Ašker eva 6, 61000 Ljubljana, Slovenia
2. CEMEF, Ecole Nationale des Mines de Paris, Dr. Elisabeth Massoni (contact person), B.P. 207, 06904 Sophia Antipolis

   Cedex, France

Industrial partner:

1. Steelworks Nová Hu , a.s., Dr. Ladislav Válek (contact person), Vratimovská 689, Ostrava 70702, Czech Republic
2. ITA, Ltd., Dr. Pavel Šime ek (contact person), Martinská 6, 709 00 Ostrava, Czech Republic
3. Steelworks T inec, Dr. Jaroslav Pindor (contact person) , Pr myslová 1000,739 70 T inec,

Czech Republic

The collaboration with the Slovenian group was established primarily for measurements in industrial and laboratory environments. Experimental work in the area of continuous casting will be coordinated at BUT by Dr. Miroslav Raudenský. The simulators subsequently use plant-specific heat transfer correlation. The object functions have been developed together with industrial partners who will continue to deliver all necessary process information, assist in model adaptation and finally use the automatic optimization software. The collaboration between involved national and international partners is already well established and will be continued in this project.

The industrial partner ITA Ltd. is cooperating in the field of result evaluation and material law specifying.

The collaboration with Cemef (Fr) is based on the long-time bilateral contract between both institutes in the area of simulation process of mushy state forging.

Collaboration with industrial partner is oriented to application of the experimental results.

5. Project partners to be found

Proposals of other institutions and industrial companies, concentrating on the topic aims - forging in mushy state and continuous casting, are welcome to be involved in the project.

6. Short description of the material process to be optimized

The aim of the project is to determine material characteristics of material forming in mushy state and, consequently, their application in mathematical models describing the process concerned. The forming of materials in the mushy state, i.e. in the range between the solidus and liquidus, is a quite new method. Regular searches of the COMPENDEX, INSPEC and ISMEC databases confirm the increasing interest in new technologies regarding material forming in mushy state. These enable to produce wires, rods, tubes and plates from ferrous alloys, non-ferrous alloys, pure metals and metal-ceramic materials. Also composite materials which cannot be formed in any previous procedure can now be produced by these technologies. The main advantage of forming in mushy state is a very low deformation resistance during forming in comparison with traditional methods. Final mechanical properties depend on forming conditions. There are two main aspects. The first one is the percentage of solid/liquid phase and the second one is the speed of deformation. These two parameters can be optimized.

The second area of interest - continuous casting is a well known technology. The computational modelling of the process is becoming an increasingly powerful tool to help with basic machine design calculations, identifying and quantifying the mechanisms of various types of defects, troubleshooting the origin of particular defects, and optimizing the various process conditions to increase the productivity or minimize the defect.

7. Material(s) involved:

Carbon and austenitic steel, metal-ceramic composite

8. Optimization potential of the process or process step

Motivation

COST 526 is initiating large-scale inter-disciplinary cooperation aimed at:

1. *defining material properties via constitutive material models and designing process-specific objective functions*
2. *making available accurate and high-performance simulation software to defined quality standards*

3. *solving multi-dimensional, non-linear optimization tasks.*

All the above goals of COST 526 directly fit to proposed project. (1) Constitutive material models describing steel in mushy state have not been known yet. The models are necessary for (2) making accurate simulations in continuous casting and in the new technology of forming in mushy state. Using the accurate models and development of multi-dimensional inverse task for specification of constants in material models demand international co-operation of research laboratories (SI, Fr, CZ).

The main aim of this proposal in the continuous casting aspect is to develop a computational framework for automatic prediction of optimum process parameters setting, particularly the cooling conditions. Most of previous advances have been based entirely on the empirical knowledge gained from experimentation with the process. Present approach combines empirical knowledge which results in the definition of optimization criteria (3), computational heat transport model of the process, and optimisation procedure. The continuous casting process has a substantial optimisation potential because the process involves many input parameters which are almost impossible to set optimally through experimentation only. The potential in forging in mushy state can not be specified as a precise one for continuous casting because this is a completely new technology and no tools (simulation and material parameters) are not available. The project should make the first steps in optimisation of the process.

9. Specified material properties to be achieved

The project is not oriented to get new materials. New or improvement technology should be the project result. The most important factors of technology are as follows:

- low forging force (1/4 - 1/5 of the normal forging force),
- high reduction of the cross section,
- possibility to influence the final metal graphic structure of material,
- avoiding the creation of cracks during the forging of fragile materials.

Plans for the second part of the projects, where composite (metal-ceramic) materials should be formed, are preparing. These material can not be formed by standard technologies. The formed material should achieve homogeneous distribution of ceramic particles and, with using Al-Li alloys, it will be very light and resistant composite.

10. Process parameters to be optimized

Two parameters will be optimized in process of laboratory experiments. The hot upsetting test and needle test enable relatively easy investigate influence of deformation speed on deformation energy. Parameter percentage of solid/liquid phase will be investigated in whole possible range. For the area of continuous casting the thermal history during cooling can strongly influenced final mechanical properties. It is important to find optimal cooling strategy. It is supposed that this information will be used in a design strategy of secondary cooling system of continuous casting process.

11. Material laws including material dependent coefficients

Results of experiments will be used for the identification of parameters in constitutive equation. The Johnson and Cook plasticity model is used and is characterised by the following relation:

where

$$\sigma_y = (A + B\varepsilon_p^n)[1 + c\ln(d\varepsilon_p / d\varepsilon_0)][1 - [(T - T_0)/(T_m - T_0)]^m]$$

A, B, C, n, m … material constants,

ε_p … effective plastic strain,

$d\varepsilon_p$ … effective plastic strain rate for $d\varepsilon_0 = 1\ s^{-1}$,

T … temperature of the material,

T_0 … initial temperature of the material,

T_m … melting temperature of the material.

The above constitutive equation was chosen to include both thermal and deformation aspects for deformation of partially molten steel. Program system LS-DYNA and ANSYS are being used for inverse calculations.

12.Simulator

Simulator is being developed at the partner organisation in Slovenia (see part 4). Two versions of simulator are available: two-dimensional time dependent version for on-line optimization and three-dimensional steady-state for off-line optimization. Date exchange and experiments for improvement of simulator will be conducted at BUT. Numerical code FORGE is being developed for simulations of forging by CEMEF (partner in project, Fr). The simulator will be improved by implementation of developed material model (see part 11).

13.Optimizer

The primary task of this project represents further development of material laws for steel and light alloys in mushy state. The partners in SL and Fr proceed with implementation to the simulators and with optimisation of the processes. An optimizer, based on hybrid evolutionary computation approach is being developed by the partner in Slovenia. A standard interface simulator-optimizer will be developed, allowing to couple different caster simulators with different optimizers. The process of optimisation requires both laboratory study of boundary conditions and investigation of criterion for cost function for optimisation. Practical knowledge of industrial partners (NH Ostrava, CZ) will be used here.

14.Competence / activities of proposer:

The Heat Transfer and Fluid Flow Laboratory (only Laboratory hereafter) is the department of the Faculty of Mechanical Engineering (FME), one of seven faculties at the Brno University of Technology (BUT). The head of the laboratory is Ass. Prof. Miroslav Raudenský. The projects of the laboratory are partially academic and partially industrial. In recent years, the Laboratory research has concentrated on heat transfer, and especially on cooling. The research is oriented, firstly, towards experimental measurements (where special apparatuses were developed), secondly, towards numerical description of the processes and lastly towards a computational simulation of real processes. For the numerical models of material and heat transfer behaviour, thermal inverse tasks have been developed. Next to industrial projects aimed especially to steel industry, the staff entered joint research projects in the framework of international research organizations and programs (Copernicus - Computer Aided Process Simulation of Iron Mushy State Forging, COST 512 - Inverse Problems in Mathematical Modelling and Cost P3 -Modelling and Experimental Study of Solid-Liquid Phase Changes in Binary System, AiF project – German-Czech focused on Hydraulic Descaling, Czech-American Co-operative Program, KONTAKT, Czech–Slovenian project - Modelling and Optimization for Competitive Continuous

Casting).

15.International state of the art and references

The description of the level of the state of the art concerning continuous casting is mentioned in the project of Dr. Šarler.

The forming of materials in the mushy state, i.e. in the range between the solidus and liquidus, is a quite new method. In 1970s first works were published by Prof. Fleming and his colleagues from the Massachusetts Institute of Technology and by Prof. Kiuchi from the University of Tokio. They focused, in their works, on determining of the material characteristics of aluminium, magnesium, tin, lead and their composites, which are materials that have the melting temperature of 600^{o} C at maximum. Experimental temperature of steel makes the test very difficult. It is probably the major reason, that the constitutive equations for steel in mushy state are not available in world's literature.

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