



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	Advanced Parameter Optimization Methods Preliminarily Used for Casting Processes
Project leader Organization	Dr. Bogdan Filipic Jozef Stefan Institute, Ljubljana, Slovenia
Main collaborators involved	<ul style="list-style-type: none"> • Nova Gorica Polytechnic, Slovenia (Prof. Bozidar Sarler, Robert Vertnik) • Acroni Steelworks, Jesenice, Slovenia (Emil Subelj) • VTT Industrial Systems, Espoo, Finland (Dr. Joachim Wendt) • Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic (Prof. Miroslav Raudensky)

2. Funding Situation

Amount of money received specifically for COST	2 kEuros
Other resources partially used for the project	8 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
 NO

Project leader Bogdan Filipic participated in the 1st Joint Working Group Meeting in Saint-Dié des Vosges and presented the progress of his project at the meeting of WG2. As the leader of WG4, he organized a session on optimization methodologies with five speakers and he gave the introductory presentation “Optimization, Material Processes and the Role of WG4 in COST 526”.

In Saint-Dié des Vosges, discussions were held with Dr. Joachim Wendt from VTT Industrial Systems, Espoo, Finland, an international partner of the Jozef Stefan Institute in COST 526. It was agreed that the optimization approach developed at the Jozef Stefan Institute for continuous casting of steel would be adjusted for high pressure die casting of aluminium castings, given that VTT Industrial Systems get financial support from their industrial partner. The initial steps in this collaboration would be to install an efficient process simulator, select relevant parameters and define the quality function.

Prof. Miroslav Raudensky from Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic, visited Ljubljana and presented recent research and applied projects of his laboratory to the Slovenian COST partners Nova Gorica Polytechnic and Jozef Stefan Institute. Our further collaboration will include experimental verification of our numerical results in Brno and visits of their postgraduate students interested in model-based optimization of material processes at our institutions.

4. Industry participation

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

Preliminary optimization of process parameters for continuous casting of a selected steel grade was performed for the Acroni Steelworks, Jesenice, the largest Slovenian steel plant. The results were evaluated and some modifications suggested for our optimization system consisting of a process simulator and an evolutionary algorithm. Additional steel grades were selected to be optimized in the next project period.



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5. Meetings, visits, exchange of scientists, short-term scientific missions	Location, date
Visit of Prof. Miroslav Raudensky from Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic	Ljubljana, Slovenia, 22.1.2002
Meeting with Dr. Joachim Wendt from VTT Industrial Systems, Espoo, Finland	Saint-Dié des Vosges, France, 20.5.2002

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

Introduction

The focus of this project is on the design of model-based optimization methodology for casting process. At present stage we work on process parameter optimization for continuous casting of steel. To date we have implemented an experimental version of the optimization environment, consisting of a numerical simulator of the casting process, developed by B. Sarler at the Nova Gorica Polytechnic, and a simple evolutionary algorithm for numerical optimization. The environment has been initially developed for and tested at the Acroni Steelworks, Jesenice, Slovenia. In this report we describe the optimization objectives, the optimization environment, preliminary results obtained and evaluated recently, and plans for future work.

Optimization objectives

Continuous casting of steel is subject to various requirements regarding the quality of the product, and the safety and economy of the process. However, the product quality is among the primary concerns of competing steel producers. The quality of continuously cast steel is determined with respect to the desired composition and cleanliness of the melt, the required shape and surface smoothness of the product, and the degree of cracking and segregation. The experience gained in continuous casting of steel over the last decades has evolved into empirical metallurgical cooling criteria. They restrict variations in the strand temperature field to assure desired product characteristics. Examples of the criteria include:

- maximum depth of the liquid pool,
- maximum strand surface cooling rate in the spray cooling zone,
- maximum strand surface reheating rate in the spray cooling zone,
- minimum strand surface temperature in unbending point,
- maximum negative strand surface temperature deviation in the spray cooling zone, and
- maximum positive strand surface temperature deviation in the spray cooling zone.

They were originally proposed by E. Laitinen and are being gradually accepted into metallurgical practice. The empirical cooling criteria can be fulfilled by properly setting the parameters of the continuous casting process, such as the casting temperature, casting speed, coolant temperatures and flows, etc. However, tuning the process parameters is a demanding task, since the number parameters is high (usually between 20 and 30), and the criteria pose conflicting requirements for their values. In addition, parameter tuning based on real-world experimentation is infeasible because of the costs and safety risks. Alternatively, the process can be assessed and checked for possible improvements through a computational procedure.

The optimization environment

The integrated optimization environment operates automatically: the evolutionary algorithm navigates the search through the parameter space and invokes the simulator to evaluate the parameter settings, while, given the parameter values, the simulator computes the temperature field in the strand and assesses the metallurgical cooling criteria. In this respect it complies with the general framework of automatic material process optimization promoted and studied in COST 526 (Figure 1).

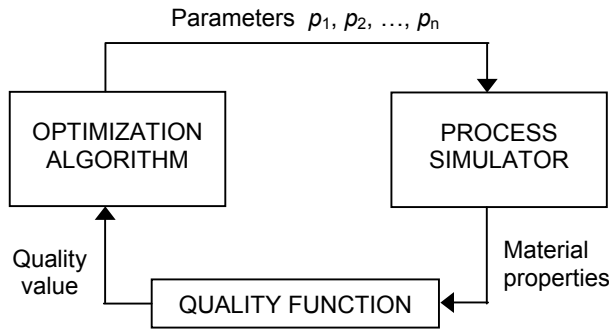


Figure 1: Simulation-based optimization of a material process

The quality function used to evaluate process parameter values is defined as a weighted sum of normalized metallurgical criteria c_j , $j = 1, \dots, N_c$:

$$f = \sum_{j=1}^{N_c} K_j \frac{c_j - c_j^{\min}}{c_j^{\max} - c_j^{\min}}$$

that needs to be minimized. Here K_j are empirically determined weights denoting the importance of the criteria, and c_j^{\min} and c_j^{\max} the lower and upper bounds for the j -th criterion that are obtained in an initial series of simulator runs. The optimization procedure is iterative. Once it converges, the resulting parameter values can be passed to the caster control system that generates appropriate control signals for the casting device.

Preliminary results

The evolutionary approach to process parameter setting was experimentally applied in continuous casting of stainless steel AISI-304. The computation was performed for a slab with the cross-section of 1.06 m x 0.20 m. Out of more than 20 influential process parameters, 14 most significant were subject to optimization. The considered parameters were the casting temperature and speed, and water flow rates of 12 sprays in the secondary cooling subsystem. The optimization objective was to improve the quality of the cast steel and the fundamental metallurgical cooling criteria listed in this report were considered.

The automatic optimization procedure was able to gradually reduce the cost of the process evaluated with respect to the predefined quality function. The parameter values found in optimization suggest to reduce the casting speed from 1.0 m/min to 0.95 m/min and slightly decrease coolant flows at the end of the spray cooling zone. However, as the reduced casting speed would imply lower productivity, which is not desired, a new optimization was carried out with the casting speed fixed at 1.0 m/min. The result in this case indicated that an improvement over the manual parameter setting is possible without decreasing the productivity. The necessary change of parameter values is to increase the coolant flows in the first half of the spray cooling zone. Finally, a calculation was performed to minimize the cost at higher casting speed of 1.05 m/s. The cost obtained under this constraint was only slightly worse than the cost of the manual parameter setting. As expected, the resulting parameter setting suggests higher coolant flows than the setting for casting at 1.0 m/s. The performance traces of the optimization runs are shown and compared with the cost of manual setting in Figure 2.

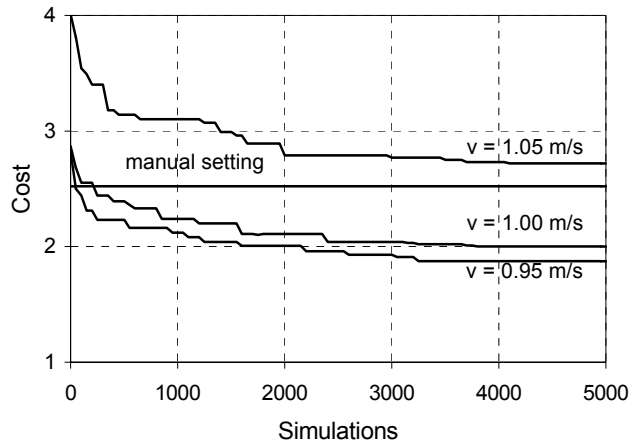


Figure 2: Optimization of continuous casting of steel at various casting speeds

These results have been tested for possible additional impacts on product quality, productivity and process safety. They were however found more appropriate than previous manual values and hence adopted for regular use in production of the considered steel grade.

Future work

Future work will be devoted to the improvement of the optimization methodology as well as to its practical application. It will include:

- a study of the parameter space properties to be exploited in reducing the number of simulations needed in the optimization process,
- optimization with respect to new metallurgical criteria covering additional aspects of steel production, such as economy and ecology, and
- optimization of cooling plans (spray coolant flows) for a set of steel grades of primary interest to our industrial partner.

7. List of publications

a) Published

B. Sarler, R. Vertnik, G. Manojlovic, J. Cesar, M. Sabolic, I. Justinek, B. Marcic, B. Filipic, M. Raudensky, J. Horsky, E. Laitinen: Informatisation upgrades of the Inexa-Store billet caster, phase I. Proceedings of the 4th International Metallurgical Conference on Continuous Casting of Billets, Trinec, Czech Republic, 2001, pp. 17–26.

b) Submitted for publications

B. Filipic: Simulation-based optimization of material properties. Submitted to the 4th International Multi-conference Information Society 2002, Ljubljana, Slovenia.

c) In preparation

B. Filipic, B. Sarler: Model-based evolutionary optimization of process parameters in continuous casting of steel.