fproject

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, 2005**

1. Reporting Period	**1 July 2004 – 31 December 2004**
Project title	**Advanced Parameter Optimization Methods Preliminarily Used for Casting Processes** (SI1)
Project leader Organization	Dr. Bogdan Filipič Jožef Stefan Institute, Ljubljana, Slovenia
Main collaborators involved	• Tea Robič Jožef Stefan Institute, Ljubljana, Slovenia • Prof. Božidar Šarler, Robert Vertnik Nova Gorica Polytechnic, Slovenia • Emil Šubelj Acroni Steelworks, Jesenice, Slovenia • Prof. Erkki Laitinen Department of Mathematical Sciences, University of Oulu, Finland

2. Funding Situation

Amount of money received specifically for COST	1 kEuros
Other resources partially used for the project	5 kEuros

3. International Collaboration

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

Participation in the Working Group Meeting in Brno + project progress report

■ YES

□ NO

Project leader Bogdan Filipič participated in the 6th Joint Working Group Meeting in Brno, Czech Republic, held 18–19 November 2004. He coorganized the session of WG4 on optimization methodologies and reported on the progress of the project SI1 in WG2.

In addition, two research visits were exchanged with the COST 526 partner FIN1 Prof. Erkki Laitinen from Department of Mathematical Sciences, University of Oulu, Finland. These were part of the Slovenian-Finnish project *Numerical Optimization of Continuous Casting of Steel*, 2004–2006. During these contacts, joint research on optimizing process parameters for continuous casting of steel was initiated (see description in *Progress within the reporting period*).

4. Industry participation

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

Rautaruukki Steel provided data for a test example of coolant flow optimization in continuous casting of steel described in this report.

5. Meetings, visits, exchange of scientists, short-term scientific missions	Location, date
Visit of Bogdan Filipič at the Department of Mathematical Sciences of the University of Oulu	Oulu, Finland, 8–15 September 2004
Visit of Prof. Erkki Laitinen at the Department of Intelligent Systems of the Jožef Stefan Institute	Ljubljana, Slovenia, 9–15 October 2004

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

In applied research performed previously in this project, the numerical simulator of continuous casting of steel developed at the Nova Gorica Polytechnic (COST 526 project SI4) was integrated with the optimization toolbox implemented at the Jožef Stefan Institute and tested for possible improvements of process parameter settings at the Acroni steel plant. In the reporting six-month period, closer research collaboration was initiated with the Department of Mathematical Sciences of the University of Oulu, Finland. Its objective is to enhance the methodology of numerical modeling and optimization of continuous casting of steel and verify it in industrial continuous casting. The following activities were carried out over the reporting period:

- integration of the numerical simulator of the continuous casting process developed at the University of Oulu with the optimization toolbox implemented at the Jožef Stefan Institute into a prototype software environment,
- numerical optimization of the secondary coolant flows for continuous casting of a selected steel grade at the Rautaruukki Steel,
- comparative analysis of the obtained results based on previous results for the Acroni steel plant.

The principal task of the applied simulator is to dynamically track the temperature field in the slab as a function of process parameters. A 3D model of the slab is considered and only a quarter of its domain taken into account in calculations due to the assumed symmetry. The simulator uses the finite element numerical approximation. Because of its computational efficiency it is capable of on-line process control. It has already been verified in industrial continuous casting.

A steady-state variant of the simulator was integrated into the optimization environment and tested in off-line parameter optimization in the way practiced in the past in the project SI1 for the Acroni steel plant. The test problem selected for the joint study was optimization of coolant flows in the secondary cooling zone of a Rautaruukki continuous caster. The goal was to tune the flows in such a way that the target temperatures in nine centerline zones and nine cornerline zones of the slab (see Table 1) would be approached as closely as possible.

Table 1: Target temperatures along the centerline and cornerline of the slab

Centerline		Cornerline	
Zone	Target temp. [ºC]	Zone	Target temp. [ºC]
1	1050	10	880
2	1040	11	870
3	980	12	810
4	970	13	800
5	960	14	790
6	950	15	780
7	940	16	770
8	930	17	760
9	920	18	750

The cost function to be minimized was defined as

$$J = \frac{1}{2}\left(\int_{L_M}^{L_Z} (T - T_1)^2 \, dz + \int_{L_M}^{L_Z} (T - T_2)^2 \, dz\right)$$

where z denotes the longitudinal dimension of the slab, T_1 and T_2 are the target centerline and cornerline temperatures, respectively, T is the actual temperature, L_M the length of the mold and L_Z the length of the slab. Preliminary numerical experiments were performed with next descent local optimization technique. The resulting process performance was visualized (see Figure 1), the results were analyzed from the point of view of the coolant flow values and their cost, and certain problem characteristics were identified. The findings were as follows:

- the tuned coolant flow vales and the obtained costs match, within the applied calculation precision, with the results of previous calculations performed in project FIN1;
- according to the optimization algorithm performance, the fitness landscape searched in this optimization task seems to be rather smooth, probably unimodal;
- there is not much interaction among the considered parameters (coolant flows) as each one mainly affects the temperature field in its own slab zone and at most in the adjacent one, hence one could obtain good starting solutions by assuming the cost function separable.

The last two characteristics of the coolant flow optimization problem are also known from calculations performed for the Acroni continuous caster and will be used in the future to further increase the efficiency of the optimization procedure.

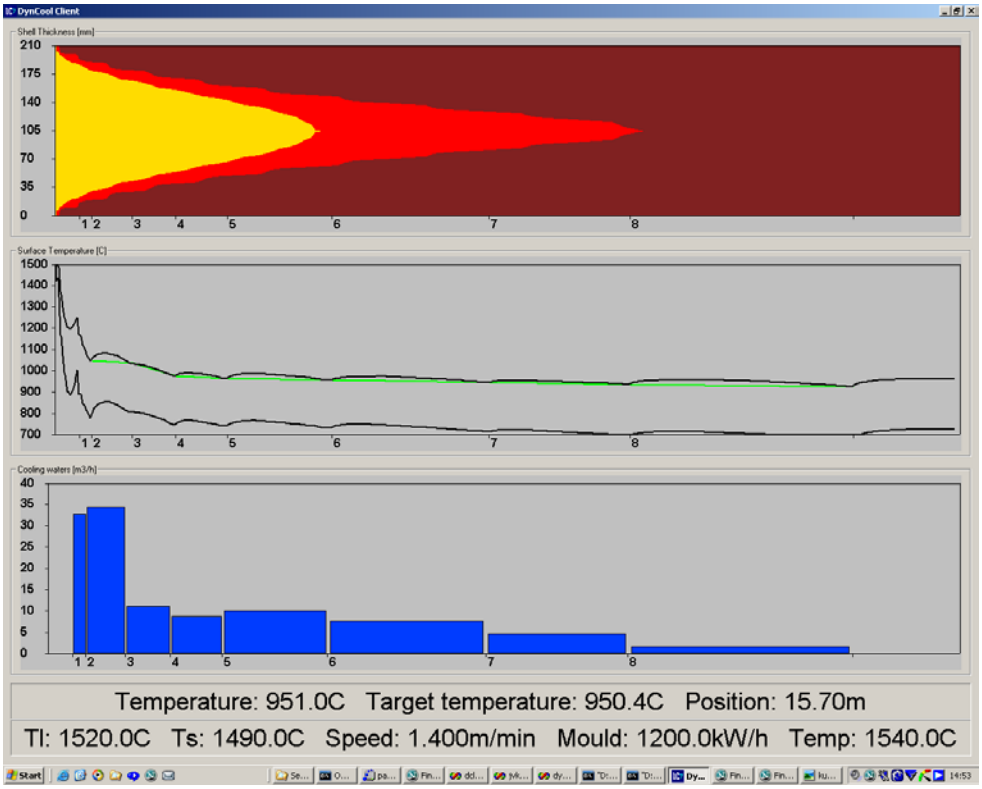

Figure 1: Continuous casting of a selected steel grade at the Rautaruukki Steel as visualized by the numerical simulator developed in COST 525 project FIN1, and tuned with optimization software implemented in the project SI1. The diagrams show (from top to bottom): phase distribution in the slab, surface temperatures and coolant flows in the secondary cooling zone.

Finally, in addition to the work described, part of research in the project SI1 was devoted to the optimization of another material process of interest to COST 526. For deep drawing, a response surface model of the process stability as a function of the process parameters was constructed and used for process optimization. The results are reported in a submitted publication.

7. List of publications

a) Published

T. Robič, B. Filipič: In search for an efficient parameter tuning method for steel casting. In B. Filipič, J. Šilc (Eds.), Bioinspired Optimization Methods and their Applications, Proceedings of the International Conference BIOMA 2004. Jožef Stefan Institute, Ljubljana, 2004, pp. 83–94.

B. Šarler, R. Vertnik, B. Filipič: Automatic process parameter optimisation in continuous casting of steel, *Fourth International Conference on Solidification and Gravity,* Miskolc-Lillafüred, Hungary, 2004, pp. 121–122.

b) Submitted for publication

G. Gantar, K. Kuzman, B. Filipič: Increasing the stability of the deep drawing process by simulation-based optimization. Submitted for publication to *Journal of Materials Processing Technology.*

c) In preparation

B. Filipič: Efficient simulation-based optimization of process parameters in continuous casting of steel. In preparation for the First Invited Cost 526 Conference, Morschach, Switzerland, 2005.