COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.7.2002 – 31.12.2002**
Project title: **Modelling and Optimisation for Competitive Continuous Casting** Project leader: **Prof. Bozidar Sarler** Organization: **Laboratory for Multiphase Processes** **Nova Gorica Polytechnic** **Vipavska 13, SI-5000 Nova Gorica, Slovenia** Main collaborators involved: **Prof. Bogdan Filipic, SI** **Prof. Jaroslav Horsky, CZ** **Prof. Erkki Laitinen, FI** Industrial partners, steel: **ACRONI, SI** **INEXA-STORE, SI** **NOVA HUT, CZ (through partner CZ)** **RAUTARUUKKI, FI (through partner FI)** Industrial partners, aluminium: **IMPOL, SI**	Project team: Nova Gorica Polytechnic **Dr. Jure Mencinger** **Igor Kovacevic** **Janez Perko** **Robert Vertnik** **Miha Zaloznik** ACRONI **Ales Lagoja** **Jozef Triplat** **Emil Subelj** INEXA-STORE **Gojko Manojlovic** **Janko Cesar** IMPOL **Rajko Safhalter** **Edvard Slacek** **Marina Jelen** **Franci Tomazini**

2. Funding Situation	
Amount of money received specifically for COST	5kEuros
Other resources partially used for the project	45kEuros

3. International Collaboration (mention group and type of work done in collaboration during the reporting period)
Participation in the Working Group Meeting in Budapest + project progress report **YES, project presented by Prof. Bozidar Sarler**
Prof. Bogdan Filipic Joint development of optimisation procedures for continuous casting of steel and aluminium alloys. **Prof. Jaroslav Horsky** Joint industrial measurements of cooling in continuous casting of steel and aluminium alloys. **Prof. Erkki Laitinen** Joint development of object functions for continuous casting of steel and aluminium alloys.

4. Industry participation (mention name of companies and work done in collaboration during the whole project)

COST 526 TASKS:
Precompetitive tasks:
Development of advanced mesh-free solver for coupled heat, mass, momentum and species transfer and verification of the solver for specific conditions in continuous casting of steel and aluminium alloys

ACRONI, SI
Competitive tasks:
Improvement of continuos casting simulation system for steel slabs
Validation of the simulation system for a spectra of steel grades
Development of objective function for competitive casting
Automatic off-line process optimisation
Automatic on-line process optimisation

INEXA-STORE, SI
Competitive tasks:
Improvement of continuos casting simulation system for steel billets
Validation of the simulation system for a spectra of steel grades
Development of objective function for competitive casting
Automatic off-line process optimisation
Automatic on-line process optimisation

IMPOL, SI
Competitive tasks:
Improvement of D.C. casting simulator for aluminum billets and slabs
Validation of the simulation system for a spectra of aluminum alloys
Development of objective function for competitive casting
Automatic off-line process optimisation
Automatic on-line process optimisation

NOVA HUT, CZ (see reports of partner CZ)
RAUTARUUKKI, FI (see reports of partner FI)

5. Meetings, visits, exchange of scientists, short-term scientific missions	Location, date
Regular contacts with project partners.	

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

In the reporting period the following advances regarding simulation based optimization of the continuous casting of steel process has been made:

Continuously cast products are subject to several different types of quality problems. Their quality is determined by the desired composition and cleanliness of the melt, by the expected shape and surface smoothness of the final product, and by as low as possible cracking, macro- and micro-segregation. The experience gained during continuous casting of steel evolved in empirical metallurgical cooling criteria for the process. Present authors have further developed this criteria for several years from the basic set defined and what follows represents their fourth improved and enhanced generation. They are listed in product quality, caster safety, productivity, maintenance, and ecology categories: Quality: (I) maximum depth of the liquid pool, (II) maximum strand surface cooling rate in the spray cooling zone, (III) maximum strand surface re-heating rate in the spray cooling zone, (IV) maximum strand surface temperature in the unbending region, (V) maximum negative strand surface deviation at a given axial position, (VI) maximum positive strand surface deviation at a given axial position; Safety: (VII) minimum safety thickness of the steel crust at the mold outlet, maximum safety depth of the liquid pool; Productivity: (VIII) minimum appropriate casting speed, (IX) maximum appropriate superheat; Maintenance: (X) minimum secondary spray water flow for not damaging the caster, Ecology: (XI) minimum spray water consumption. It is believed that the consideration of the listed criteria leads to the best product quality, caster safety, caster economy, caster service intervals, and caster ecology. Each casted steel group has been metallurgicaly evaluated regarding its sensitivity to optimization parameters. A database of empiric optimization parameters for each steel group has been developed.

Based on the calculation of the temperature distribution in the strand, the metallurgical cooling criteria can be explicitly evaluated. The technologist has an opportunity to search for the weak points of the process parameter setting. Using the simulator, he is able to properly tailor all process parameters. This is much easier, safer and cost effective than real-word experimentation. Such simulation is of pronounced importance when designing the process parameter settings for the continuous casting of new materials. With the heat transfer model, the design changes on the plant such as change of the rolls, spray nozzle type, etc., can be easily tested. The heat transfer model can straightforwardly answer to some of the important safety questions. For example, can a pressure drop in one of the cooling systems cause a break-out, etc. In addition, it is extremely useful for training of the caster operators.

Several automatic options have been added to help the caster technologist achieve proper metallurgical length or proper temperature in the predetermined points of the strand. A simulation system manipulator has been added to the simulation system for this purpose, which permits the automatic calculation of the casting speed and/or spray flows in order to achieve the desired temperature profile. This option permits a fast and easy adjustment of the caster parameters.

As the number of possible process parameters is high and the criteria are highly conflicting, determining appropriate values is not trivial. A novel approach to process parameter optimisation has been employed in the presented simulation system. The approach relies on the heat transfer model, metallurgical cooling criteria and a genetic algorithm, which is a stochastic optimisation method from the field of evolutionary computation. The system iteratively and automatically improves the parameter settings: the genetic algorithm guides the search through the parameter space and activates the heat transfer model to evaluate the candidate parameter settings. 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 automatic optimisation approach connected to the present system is detailed in an accompanying report by B.Filipic.

The process regulation in continuous casting of steel is based on compensation of the changes in steel grade, casting temperature, mold heat extraction, and cooling water temperature by the changes in casting speed and secondary cooling. Process regulation is based on sensitivity coefficients that are built in the controllers of the casting device. The sensitivity coefficients of how process parameters influence the metallurgical length or strand temperature at different locations can be automatically calculated from the simulation system as a function of the steel grade and format.

The simulation system has been validated with respect to the strand temperature field and with respect to the metallurgical length. The surface temperatures are measured by the on-line two color pyrometer and by the infrared thermography. Both methods give temperature results that are used for calibration of the simulation system. The calibration includes correction of the measured spray heat transfer coefficients, roll transfer coefficients, and radiation coefficients with respect to the steel grade and format. The calculated temperatures at the strand outlet usually fall within +/- 10K with respect to the measured values. The metallurgical length is measured by the Kytonen method. In this method, a wedge is fed between the rolls of the caster. As the wedge moves under the roll, it causes tensile stress, and cracks are formed in the solidification front of the strand. The shell thickness is than determined from the cracks.

7. List of publications

a) Published

B.Sarler, DRBEM for heat transfer and fluid flow problems. Electronic journal of boundary elements, 2002, vol. BETEQ, no. 3, pp. 360-367.

B.Sarler, Towards a mesh-free computation of transport phenomena. Eng. anal. bound. elem. 2002, vol. 26, no. 9, pp. 731-738.

J.Horsky, M.Raudensky, B.Sarler, Secondary cooling in continuous casting, 4th European Continuous Casting Conference, Birmingham, 14-16 October 2002. London: IOM Communications, 2002, vol. 2, pp. 830-838.

b) Submitted for publications

c) In preparation

B.Sarler, R.Vertnik, A.Lagoja, G.Manojlovic, E.Subelj, J.Cesar, J.Triplat, A simulation system for modelling and optimisation of continuos casting of steel, B.Sarler, D.Gobin (eds.), Proceedings of Eurotherm 69 Seminary, Heat and Mass Transfer in Solid-Liquid Phase Change Processes, June 25-27, Ljubljana, Slovenia, 2003.

B.Sarler, J.Mencinger, M.Zaloznik, R.Vertnik, J.Perko, R.Safhalter, E.Slacek, M.Jelen, F.Tomazini, A simulation system for modelling and optimisation of D.C. casting of aluminium alloys, B.Sarler, D.Gobin (eds.), Proceedings of Eurotherm 69 Seminary, Heat and Mass Transfer in Solid-Liquid Phase Change Processes, June 25-27, Ljubljana, Slovenia, 2003.

B.Filipic, B.Sarler, R.Vertnik, Evolutionary Optimisation of Continuos Casting of Steel, Int.J.Manuf.Mater.Process.