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

COST 526
Automatic Process Optimization in Materials Technology
(APOMAT)

Title:

Advanced Parameter Optimization Methods Preliminary Used for Casting Processes

Keywords:
model-based optimization, process parameters, evolutionary computation, gradient-based methods, hybrid algorithms, empirical metallurgical criteria, continuous casting, high pressure die casting

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1. Duration / run time of the project
1 September 2001 – 31 August 2004

2. Overall cost
150 kEURO

3. Funding situation
Most of the funding is already assured through the ongoing research programme „Intelligent Systems“ conducted at the Jozef Stefan Institute and supported by the Slovenian Ministry of Education, Science and Sport. Additional funding will be provided by industrial partners.

4. Project partners indicated to participate
National partners:
- Nova Gorica Polytechnic, Slovenia (Prof. Bozidar Sarler)
- Acroni Steelworks, Jesenice, Slovenia (Mr. Emil Subelj)

European level partners:
- VTT Manufacturing Technology, Espoo, Finland (Dr. Eero Pellikka, Dr. Joachim Wendt)
- Faculty of Mechanical Engineering, Brno University of Technology, Czech republic (Prof. Miroslav Raudensky)

Automated parameter optimization methods based on material process simulation will be developed and preliminarly applied to continuous casting of steel and high pressure die casting of aluminium castings. This proposal specifically focuses on development and evaluation of the optimization methodology and is related to the work previously done at the University of Oulu by Erkki Laitinen, and at the University of Ljubljana (now continuing a the Nova Gorica Polytechnic) by Bozidar Sarler, both also participating in the COST 526 Action. The concept of empirical metallurgical cooling criteria by Laitinen will be considered as a basis for process parameter optimization. It will be extended by introducing additional criteria and the possibility of tuning the relative importance of individual criteria against each other. The continuous casting simulator developed by Sarler will be used as a source of initial information on the search space exploited during the optimization algorithm design. At a later stage, the optimization calculations for the Slovenian industrial partner will be done using this simulator as well.

The participating partners will contribute to the collaborative approach as follows:

- Jozef Stefan Institute: design of objective functions, development of optimization algorithms, their integration with process simulators, numerical experimentation
- Nova Gorica Polytechnic: design of steel continuous casting simulator, formulation of optimization criteria, identification of relevant process parameters
- Faculty of Mechanical Engineering, Brno University of Technology: measurements of process variables to verify numerical results

- Acroni Steelworks: providing specifications and data needed for process simulation and optimization, evaluation of results, exploitation of the developed methodology
- VTT Manufacturing Technology: development of parameter optimization methodology for high pressure die casting of aluminium castings in collaboration with Jozef Stefan Institute and Nova Gorica Polytechnic

Expected mutual benefits of this collaboration are improvements of process simulators, efficient optimization methodology and improvements of industrial material processes with respect to safety, quality and productivity.

5. Project partners to be found

None

6. Short description of the material process to be optimized

The proposed project deals with development and evaluation of parameter optimization methods for casting processes. The focus is on:

- design of objective functions for optimization,
- employment of advanced stochastic algorithms,
- their hybridization with traditional optimization techniques,
- integration of optimization methods with process computational models,
- evaluation on industrial casting processes.

The methodology will primarily be developed for and applied to the industrial process of continuous casting of steel. The process is used at steel making plants worldwide to produce steel semi-manufactures, such as slabs, billets and blooms. It is a complex metallurgical process in which molten steel is cooled and shaped into semi-manufactures of desired dimensions. The heart of a casting system is the mould where primary cooling of the liquid steel is performed. As a result, formation of a solid shell on the slab emerging from the mould is initiated. The solidification continues as the slab led by support rolls passes through the caster. It is additionally cooled by water sprays positioned along the strand. Finally, the solidified slab is cut into pieces of predefined length.

The economical relevance arises from the fact that continuously cast steel represents the major part of the total steel production. World annual production of continuously cast steel is increasing and currently exceeds 750 million tons. It is estimated that demands for steel products will continue to grow, in particular in the areas of stainless and special-purpose steels.

As the proposed optimization methodology imposes no limitations on the process to be optimized, it will be applicable to other casting processes as well. It will also be evaluated on high pressure die casting which is used for manufacturing large series of aluminium castings in automotive, electronic and consumer goods industry.

7. Material(s) involved:

Steel and aluminium alloys of various grades.

8. Optimization potential of the process or process step

In modern metallurgical practice, the so-called empirical cooling criteria have been introduced to conduct the casting process according to product quality standards. In improving the product quality, safety and productivity of the process have to be considered as well. To satisfy these requirements, numerous process parameters need to be set properly. Optimizing their values is not trivial as the requirements are often contradicting, and the number of possible parameter settings grows exponentially with the number of parameters involved. Moreover, parameter tuning based on real-world experimentation is not feasible due to the cost and safety risks. Thus a feasible approach to process parameter tuning is numerical optimisation based on a computational model of the casting process.

9. Specified material properties to be achieved

Process parameter values affect product quality, productivity, safety and production costs in casting processes. Implemented through empirical metallurgical criteria, these aspects will be incorporated into an objective function that will be used with the optimization procedure. To balance among contradicting requirements, weights will be determined for individual criteria.

In continuous casting of steel, the fundamental concern is to ensure proper internal structure of the cast steel and to prevent crack formation. The automated parameter optimisation will reduce macro-

and micro- segregation, and the internal and surface cracking.

In high pressure die casting of aluminium castings, material properties to be respected and/or improved are electric conductivity, thermal stress distribution and thermal strain distribution, while defects to be avoided are distortions, residual stresses and porosity.

10. Process parameters to be optimized

Optimizing continuous casting of steel, we will consider parameters that affect metal flow and heat transfer during the casting process that are vital to product quality. Parameters to be optimized include casting temperature, casting speed, mould settings, and flow rates in the secondary cooling system.

In high pressure die casting of aluminium castings, the most influencing of the following process parameters will be involved in the optimization procedure: melt temperature, temperature gradients, cooling rates, heating and cooling energy, maximum turbulence and maximum velocity of melt, entry velocity of melt and ejection time.

Restraints for the parameter values (minimum and maximum, discretization) depend on the considered material grade and the specificities of a casting system. They will be derived separately for each optimization task, taking into account empirical parameter setting used before optimization, and constraints that apply in practice.

11. Material laws including material dependent coefficients

Steady state heat transport model of the strand will be used for continuous casting of steel, based on the mixture continuum model of the solid-liquid phase change system. Given the process parameter values, the heat transport model will produce the strand temperature distribution. From the temperature distribution the values of the metallurgical cooling criteria will be extracted and the overall performance of the casting process assessed.

For the aluminium casting process, Navier-Stokes and heat equation will be solved for modelling solidification. Criteria for defect and property estimation will be applied (e.g. Niyama-like criteria). For thermal stress modeling, elasto-plastic and elasto-viscoplastic models will be used.

12. Simulator

A numerical simulator of continuous casting of steel designed by our national partner will be used. The simulator implements the heat transport model using a finite volume method with Crank-Nicolson time discretization and Voller-Swaminathan iteration strategy. The system includes a material properties database and the capability of presenting the results of temperature distribution calculation via a graphic interface. The simulator will interact with optimization procedures via a predefined data exchange protocol.

ProCAST basic module and ProCAST stress module will be applied to simulate the process of high-pressure die casting.

Both simulators are operational so that major code developments are not needed. They will however be tuned to account for the specificities of the simulated processes and devices.

13. Optimizer

The evolutionary computation approach will be used as a basic search strategy to optimize casting process parameters. In particular, an evolutionary algorithm integrated with the process simulator will be employed. The integrated system will operate autonomously: the evolutionary algorithm will iteratively improve a set of parameter settings and activate the simulator to evaluate each setting. A prototype implementation of the optimization environment has already been tested on a real-world problem with success. Further extensions of the code will include hybridization of the algorithm with gradient-based local optimization techniques and incorporation of search operators based on empirical knowledge about parameter interrelations.

The proposed project aims to contribute not only to the improvement of the considered casting processes but also to the advancement of the optimization methodology itself. Challenging issues to be explored in this context include how to distribute the power of the optimization algorithm between stochastic and deterministic steps, and how to tune the algorithm parameters to achieve the best optimization result with minimum computational effort.

14. Competence / activities of proposer:

The project proposer already participates in design and application of evolutionary optimization

procedures for parameter tuning in continuous casting. The developed software has been applied to optimize an industrial continuous casting process for a selected steel grade. Based on promising initial results, the present proposal aims to further enhance the flexibility and efficiency of the methodology and promote its practical application in industrial environment.

15. International state of the art and references

Not much systematic research has been devoted to parameter optimization in casting processes. Rare attempts reported in the literature include application of techniques such as conjugate gradient, quadratic programming and Quasi-Newton methods. Recently, stochastic search algorithms are more and more frequently applied with success in engineering design and production process optimization. Initial work by the project proposer and coauthors demonstrates that, in connection with computational modelling, this approach provides means for further improvements of industrial casting processes.

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