COST 526 - 'Automatic Process Optimization in Materials Technology' – (APOMAT)

Final Report – 31 July 2005

Summary sheet

Project Code	D4
Title	Numerical Optimization of the Bridgman Casting Process for Stationary Gas Turbine Blades
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Main collaborators involved	Dipl.-Inf M. Emmerich, ICD, Dortmund, Germany Prof. Dr. N. Hofmann, FH-Aargau, Switzerland

Funding Situation (for the whole project)

Amount of money received specifically for COST	80 kEuros
Other resources partially used for the project	40 kEuros

International Collaboration (mention group and type of work done in collaboration during the whole project)

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

Alstom Power Ltd, Segelhof 1, CH-5405 Baden-Dättwil, Schwitzerland

ALD Vacuum Technologies GmbH, Hanau, Germany

Together with our industrial partners we defined one real gas turbine blade and one simplified blade for the application of the optimization strategies. We have the permission to publish results obtained with these test cases.

Meetings, visits, exchange of scientists, short term scientific missions (mention main events during the whole project)	Location, date
ERUOTHERM Seminar 69	Ljubljana, Slovenia, July 2002
EUROGEN 2003	Barcelona, Spain, Sept. 2003
Short scientific mission to Dr. L. Fourment, CEMEF (F5) by M. Emmerich	Nice, France, Nov 2003
Bioinspired Optimization Methods and their Applications	Ljubljana, Slovenia, Oct. 2004

(BIOMA'04) First Invited Cost 526 Conference	 Morschach, Schwitzerland, May 2005

Main Outcome of the project (mention only the major points)

- **Optimization of complex manufacturing processes**
  Even complex processes like Bridgman casting, which can only be simulated using computational expensive programs, can be successfully optimised by numerical methods. The number of optimisation parameters should not exceed the range of 10-20 and parallel computation must be used to get a significant improvement within a week.

- **Optimization strategy**
  The Metamodel Assisted Derandomized Evolution Strategy (MA-DES) was found to be a stable optimization algorithm for optimising the Bridgman casting process. It was used for calibration of material and process parameters as well as different quality functions and showed a stable and fast convergence in all applications. Here, fast convergence means the identification of a good solution or a significant improvement within a small number of necessary function evaluations.

- **Objective function definition**
  While single goals like a defined quality measure or a best fit to experimental results can easily be transformed into a numerical objective function, it was found to be difficult to combine contradictionary goals like a good quality and a low process time into one objective function. Here a multiobjective optimisation strategy may be the better approach. The investigation of multiobjective strategies will be the contents of following research projects.

- **Parameter calibration**
  The MA-DES was successfully used to calibrate different material and process parameters for an industrial Bridgman process for gas turbine blade production. One main outcome of the calibration was that the simulation model underestimated the heat capacity of the Bridgman furnace, because several parts of the furnace were neglected in the model, since they should not directly influence the heat distribution. But the calibration showed that they, nevertheless, have a significant influence on the heat capacity.
  In addition, this application revealed that a calibration is mandatory for a quantitative simulation of complex processes. A numerical optimization can be used very efficiently.

- **Quality optimisation**
  The likelihood of casting defects in a directionally solidified gas turbine blade could be reduced to almost zero by optimising the time dependent temperatures of the heaters in the Bridgman furnace. A reduction of the heater temperature shortly after the start of the withdrawal leads to a significantly improved temperature distribution on the blade during solidification. The results of the optimisation are currently applied by our industrial partners to the real casting process.

- **Quality and process time optimisation**
  Great effort was invested to achieve an appropriate definition of the objective function. While the 3 quality criteria could be successfully integrated into one objective by a newly developed approach (see above) the combination of short process time and good blade quality into one objective was found to be difficult. By dividing the objective function into three parts, a useful approach could be developed which could be used to improve the withdrawal profile of the Bridgman process towards a better quality produced in a shorter process time. But the results indicate that the use of a multi-objective strategy may be more promising when contradictory objectives should be optimised simultaneously.

Publications, related to this project

Published

R. Laqua, T. Ivas, J. Scheele, J. Jakumeit, M. Braun and M. Pelzer, *Mold Filling and Solidification Simulations of Investment Casting Processes using CASTS-FLUENT,* Proceedings of ERUOTHERM Seminar 69, Ljubljana, 2003

M. Emmerich,ICD and J. Jakumeit, *Metamodel-Assisted optimisation with constraints: A case study in material process design,* Procceedings of EUROGEN 2003, Barcelona

Jürgen Jakumeit, Michael Emmerich *Optimization of a gas turbine blade casting using evolution strategies and kriging*, B. Filipic, J. Silc, Proc. Int'l Conf. Bioinspired Optimization Methods and their Applications (BIOMA'04), 95-104, Jozef Stefan Institute, Ljubljana, Slovenia, 2004

J. Jakumeit, M. Herdy and M. Nitsche, *Parameter optimization of the sheet metal forming process using an iterative parallel Kriging algorithm,* Struc Multidisc Optim 28, 2004, pp 1-10

Jürgen Jakumeit, *Numerical Optimization of the Bridgman Casting Process for Stationary Gas Turbine Blades,* Proccedings of the First Invited Cost 526 Workshop, Morschach, 2005

Submitted for publication

In preparation

Jürgen Jakumeit, Michael Emmerich, *Numerical Optimisation of Gas Turbine Blade Casting*

Will you continue the actual cooperation with your partners after the end of the action?

X Yes	❑ No

Would you participate in a possible “spin-off” action continuing the present one?

X Yes	❑ No

Will you continue your present work/collaboration with another European action?

❑ Yes	❑ No