COST 526

"Automatic Process Optimization in Materials Technology"
(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.7.2004 – 31.12.2004**
Project title	Numerical Optimization of the Bridgman Casting Process for Stationary Gas Turbine Blades
Project leader Organization	**Dr. J. Jakumeit** ACCESS e.V. Intzestrasse 5, D-52072 Aachen, Germany
Main collaborators involved	Dipl.-Inf. M. Emmerich, ICD, Dortmund, Germany Dr. G. Laschet, ACCESS e.V.

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

3. International Collaboration
(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Brunov
X YES

4. 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

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.

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**

COST 526

“Automatic Process Optimization in Materials Technology”

(APOMAT)

Half-Yearly Report

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

1. Introduction

The highest gas turbine efficiency is achieved today with single-crystal (SX) or directionally solidified (DS) blading material, commonly produced in a Bridgman furnace. The Bridgman process is controlled by time dependent parameters (withdrawal speed, heater temperatures), which are ideal for the application of numerical optimization [1]. In addition the blade casting is the most expensive process during the manufacturing of a turbine making a reduction of the fabrication costs by optimization very interesting for the industry.

In the first year a preliminary optimization loop has been developed based on the validated casting simulation tool CASTS [2]. Goal of the optimization was an improved withdrawal profile for the Bridgman process of a cluster of 3 SX blades. The simulation results were evaluated by 4 criteria:

- the probability of local freckle formation;
- the degree of curvature of the solidification front;
- the ratio G/v (temperature gradient over solidification speed) must be greater than a critical value (~600 K/s), describing the transition from columnar dendritic growth to an equiaxed grain structure;
- the process time.

A test of different optimization strategies showed that the MAES (see below) is an effective optimization strategy in terms of convergence speed and robustness. It was successfully applied to the optimization of industrial turbine blades. In this periode, the influence of the input parameter on the simulation results were investigated in detail.

2. Metamodel-assisted optimization strategy

A problem with Evolution Strategies for the optimization of process parameter is the high number of solutions needed to find an optimum. A derandomization was used to reduce this number to a practical size below 100. For a further reduction a metamodel-assisted optimization strategy was developed in the first half of 2003. The metamodel based strategies are compared with the standard downhill simplex algorithm [3] and the derandomised evolution strategy (DES) used so far [4]. For this comparison a simplified blade was used, which can be simulated with in one hour. The results showed that the metamodel-assisted evolution strategy MA-DES outperforms classical methods with respect to the results obtained with the same number of precise evaluations.

3. Application of the MA-DES to an industrial turbine blade

In the last period the MA-DES was successfully applied to the optimization of an industrial turbine blade, the cluster of 3 SX blades mentioned above. The withdrawal profile was discretized using 6 velocity values at the withdrawal positions: 6 cm, 20 cm, 28 cm, 36 cm, 44 cm and 60 cm. For comparison the turbine blade was also optimized by a downhill simplex (DS) algorithm. The DS starts with a rather good solution but finds no further improvements. But the MA-DES could find a significantly improved solution with a higher withdrawal velocity around 20 cm and a low velocity at 40 cm. Compared to a withdrawal profile designed by a casting engineer the numerical optimized withdrawal profile leads to a higher quality of the blade within a shorter process time. A new optimization using 11 velocities to describe the withdrawal profile could not show an additional benefit.

4. Integration into the Optimization tool box of the FH-Aargau

In this period CASTS was integrated into the Optimization tool box of the FH-Aargau. The tool box comes with a JAVA based graphical user interface (GUI) (see figure 2), which simplifies the combination of optimization algorithm, protocol unit, simulation distributor and application.

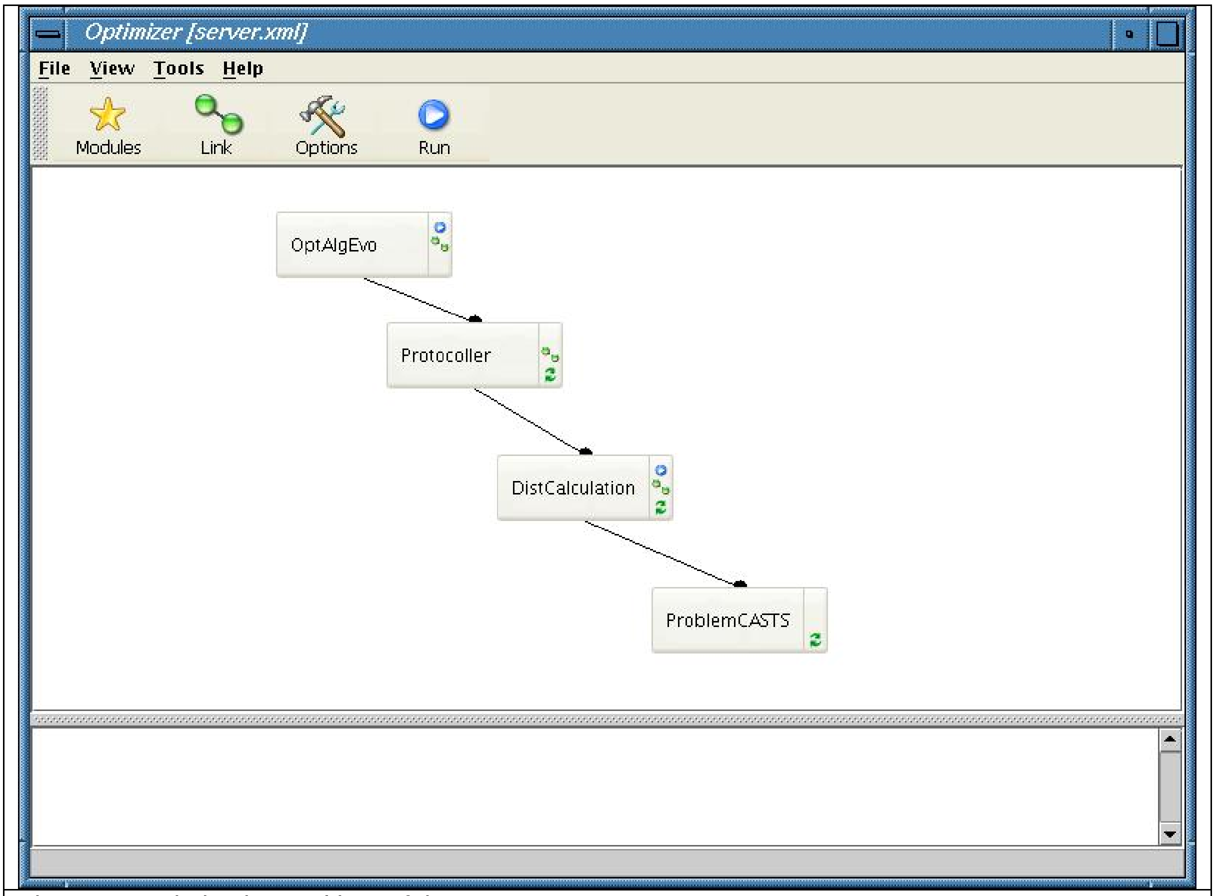

Figure 2: Optimization tool box of the FH-Aargau

At the top of the chain is the optimization algorithm, a evolutionary strategy developed by FH-Aargau (EAA). The different options of this strategy can be selected using the OPTION button. The *n* parameter set, selected for simulation by the EAA, are given to the protocol unit, which writes to information into a file and hands it over to the distribution unit. This unit distributes the *n* parameter sets on the available computers for parallel simulation. Several CASTS simulations are then started on the available network of workstations. The results collected into a POSTGRES data base. This integration of a public domain data base program is one of the new features of the FH-Aargau tool box. It simplifies the handling of the great amount of simulation data, acquired during optimization. The optimization values of the parallel simulations are colleted by the distribution unit and passed to the protocol unit, which memorizes the information and passes it on to the optimizer. Based on the results, the optimization algorithm chooses the next generation of parameters for simulation.

5. Calibration of model parameter for heat transfer coefficients during gap formation

During solidification gaps can form between cast and mold due to the different thermal expansion coefficients of the casts and mold material. For the simulation of this effect a thermomechanical model was integrated into CASTS in the last years [5]. An important part of this model is the influence of the gap formation on the heat transfer between cast and mold. For small gaps the heat transfer coefficient decreases exponentially due to the reduced contact of the rough surfaces. For larger gaps heat transfer is only possible by the gas between the two surfaces and by radiation. The exponential decay of the transfer coefficient, the mean free path of the gas and the temperature, when the gap formation starts, are model parameters, which have to be calibrated by experiments.

For our investigation we used the Svensson test case, an aluminum casting of a cylinder in a steel mold, which is experimentally well documented [6]. The objective function was the least square difference between the experimental findings and the simulation results.

Figure 3 shows that the MA-DES converges rather fast for this application. Four points are marked in the convergence plot, for which the temperature dependence of the heat transfer coefficient (left) and temperature at mold and cast surface are shown in figure 4. Obviously the MA-DES can nicely be applied to such calibration problems.

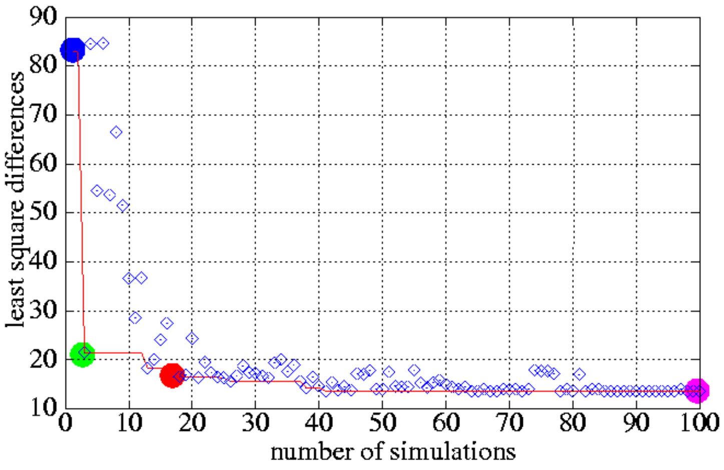

Figure 3: Convergence of the MAES for the model parameter calibration

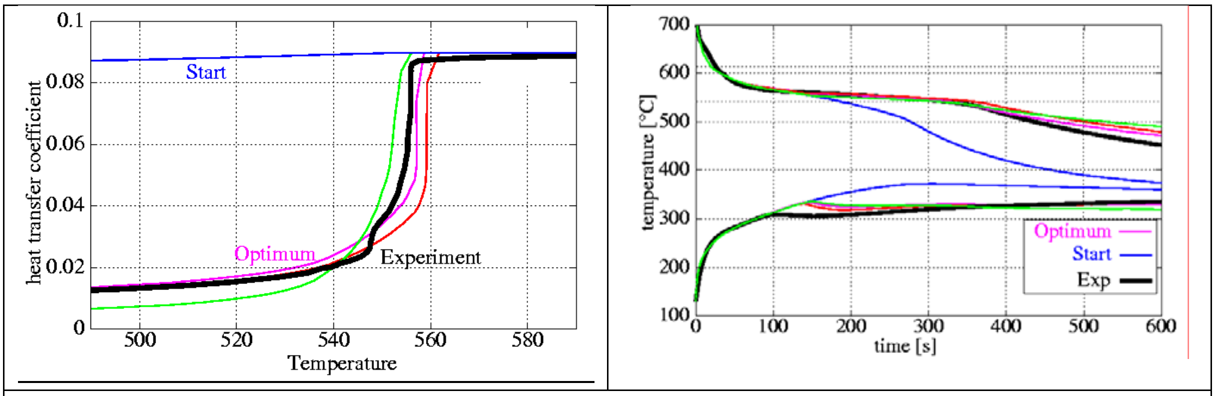

Figure 4: Temperature dependence of the heat transfer coefficient (left) and temperature at mold and cast surface (right) for the for optimization points marked in figure 3

6. Conclusion

First, CASTS was integrated into the optimization tool box one partner in the COST 526 program, the Fh-Aargau, which simplifies the handling greatly. Second, the MA-DES was successfully used to calibrate parameter of a new physical model in CASTS, which describes the heat transfer between cast and mold, when gaps are created due to the different thermal expansion of cast and mold. For the next period, the FH-Aargau tool box and the parameter calibration will be applied to the optimization of an industrial gas turbine blade.

7.References

[1] G. Laschet, M. Schallmo & N. Hofmann: “Optimization tools for Bridgman casting process”, Proc. 7th Conf, on Casting, Welding and advanced Solidification, Ed. B. Thomas & C. Beckermann, TMS editions, San Diego, pp 1095-1102, 1998.

[2] G. Laschet, J. Neises and I. Steinbach: « Micro- Macrosimulation of casting processes”, 4ième école d’été de “Modélisation numérique en thermique”, C8 1-42, Porquerolles, 1998.

[3] H.-P. Schwefel, *Evolution and Optimum Seeking*, Wiley, NY, 1995

[4] T. Bäck. *An overview of parameter control methods by self-adaptation in evolutionary algorithms*, Fundamenta informaticae 35 (1998), pp. 51-66, IOS Press

[5] G. Laschet, J. Jakumeit and S. Benke, *Thermo-mechanical analysis of cast/mould interaction in casting processes,* Zeitschrift fuer Metallkunde

[6] J. Kron, M. Bellet, A. Ludwig, B. Pustal, A. Wendt and H. Fredriksson: “A comparison of numerical simulation models for predicting temperature in solidification analysis with reference to air gap formation”, submitted to Jnl. of Cast Metals Research, (2003).

7. List of publications a) 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* Structural and Multidisciplinary Optimization 28, 1-10 , 2004
b) Submitted for publications
c) In preparation