COST 526

Automatic Process Optimization in Materials Technology

Final Report

edited by **Dr. Fredy Hediger** (Chairman)
Piotr Swiatek (Scientific Officer)

Contents

Foreword from the Chairman

The main objective of the COST 526 action „**A**utomatic **P**rocess **O**ptimization in **Ma**terial **T**echnologies" (APOMAT) was to develop and to apply numerical optimization methodologies to automatic process design in material technologies*,* i.e. casting, injection moulding, forging, sheet metal forming, heat treatment, welding, coating, and chemical processes*.* The approach is based on quantified product qualities and related to process targets and constraints, including economic aspects.

In response to the market-driven pressure for reducing time-to-manufacture, numerical analysis has become state-of-the-art in materials science and processing. Over the past two decades, a large range of different virtual processing models have been developed world-wide and software codes partially commercialized. The common platform is the integration of material laws, including appropriate numerical schemes, e.g. the finite element method, for solving generic equations for heat transfer, fluid flow, and concentration or stress/strain evolution on both macroscopic and microscopic length scales. For a large number of process steps (and also complete manufacturing procedures), these numerical tools have proven to be successful in terms of quality improvement and process design. The main feature of virtual process models (simulation models or simulators) is the numerical analysis of a process step, providing insight into the status quo of a process at each stage. At the same time, such models enable the execution of virtual experiments, and therefore facilitate systematic process optimization by trial-and-error methods ("manual optimization"). Oriented accordingly, the concerted R&D activities of the COST 512 action remained ongoing from 1993 until 1998, successfully chaired by Prof. Michel Rappaz, EPFL-Lausanne (Switzerland).

A substantial upgrade of this procedure is to combine virtual models with numerical optimization techniques. The logical connection is the so-called quality, cost or objective function, including its constraints, which allows for automatic quantitative quality assessment of the simulation results. Typically, the quality function relates a set of process parameters to a number of quantitative material laws describing the specific material properties emerging from a specific process step. Achieving this task requires high-level interdisciplinary development work among material scientists, process engineers and computer scientists. It has been the intention of COST 526 to promote this topic at a European level and the action, which got underway 29 March 2000 will end 28 September 2005. Eleven countries signed up to the action and approximately thirty proposals were evaluated (24 being approved by the Management Committee). Finally, 22 projects took up their work, each assigned to one of the three working groups "Thin-Walled Product Processing", "Liquid/Solid Processing" or "Bulk Product Processing". The forth working group "Optimization Methodologies" was created as a discussion forum (Fig. 1). During the course of the action, due to severe funding problems four projects have been withdrawn.

For presentation and coordination of project activities seven joint working group meetings each followed by an MC meeting have been arranged and a final joint meeting is planned for November 2005 in Besancon, France. A comprehensive website, www.cost526.de, was designed and maintained for communication and information. One of the key outcomes of the action is the close cooperation established between some of the material scientists, simulation engineers and computer scientists involved in this action for

- formulating quantitative material qualities based on appropriate material laws for quality function design, taking account of inherent constraints

- providing accurate and high-performance process simulation software
- dealing with high-dimensional, nonlinear optimization problems.

In May 2005, the “First Invited COST 526 Conference” was held in Morschach, Switzerland, organized by the Institute of Informatics, University of Applied Sciences Aargau, Switzerland. The objective was to give a comprehensive demonstration of the COST 526 topic, including presentations of all participating COST projects and contributions from industry and academia. The conference provided an open platform both for strengthening ongoing collaborative work and for initiating new relationships, while also disseminating state-of-the-art automatic process optimization techniques. The conference proceedings are available at the COST 526 website.

<table>
<tr><td colspan="3">Cost 526 (APOMAT)
Chairman: F. Hediger
Scientific secretary: P. Swiatek</td></tr>
<tr>
<td>WG 1
Thin Walled Product Processing
WG leader: J.-P. Ponthot
deputy: J.-L. Batoz
participating projects:
B 1, CH 1,D 1, F 1, F 3, F 4</td>
<td>WG 2
Liquid-Solid Processing
WG leader: J.-C. Gelin
deputy: N. Hofmann
participating projects:
CH 2, CH 4, CZ 1, CZ 5, D 4, F 2, FIN 1, SL 1, SL 4</td>
<td>WG 3
Bulk Product Processing
WG leader: L. Fourment
deputy: T. Rodic
participating projects:
CH 3, CZ 2, CZ 4, F 5, PL 1, SL 2, SL 3</td>
</tr>
<tr><td colspan="3">WG 4
Optimization Methodologies
WG leader: B. Filipic
deputy: C. Knopf-Lenoir</td></tr>
</table>

Figure 1: Working group structure

One important criterion for project evaluation was that each project was to start from a well-defined technical process, including an appropriate numerical simulation model. The intention was to draw maximum effort to the design of the quality function, including a dedicated optimization scheme and – last but not least - to the overall checking process (calibration, verification and validation). However, in the course of this action in a number of projects the performance of the simulator used for numerical process optimization proved to be insufficient: either the underlying physical models were too simple for the calculation of relevant process quantities or the software was not accurate enough and often too slow with respect to computing time.
Resolving these challenges could be the goal of a follow-up action aimed at a more product-driven approach for automatic process optimization.

Dr. Fredy Hediger
Chairman of the Management Committee Cost 526

Working Group 1 – Summary Report: Thin walled product processing

Working group leader: Dr. Jean-Philippe Ponthot, Belgium
Deputy: Prof. Jean-Louis Batoz, France

Participating projects:

- **Optimization of sheet-metal blanking and bending processes, Prof. A. POTIRON, France (F4)**
- **Tube and Blank Hydroforming Processes Optimization, Dr. J.M. FAURE, France (F1)**
- **Optimization of Properties and Dimensional Stability of Composites by Controlled Fibre Placement, N. JANSSON, P.O. HAGSTRAND and JA MANSON, Switzerland (CH1)**
- **Optimization of Process Parameters in Sheet Metal Forming, Dr. C. KNOPF-LENOIR, Prof. J.L. BATOZ, Dr. H. NACEUR, Dr. A. DELAMEZIERE, France (F3)**
- **Distributed Simulation –based Optimization in Sheet Metal Forming, Prof. M. GRAUER, Dr. T. BARTH, Germany (G1)**
- **Optimization of sheet and tube metal forming processes, Dr. L. STAINIER, Belgium (B1)**

Summary of working activities

Though all projects are concerned with thin walled products, the basic process in the different project can be different as deep-drawing (G1,B1,F3), hydroforming (F1,B1), blanking and bending (F4).

The materials dealt with were mainly metals (all but CH1), but composite materials were also involved (CH1).

As far as the direct simulations were concerned, many different codes were used. Nevertheless, they were all based on the finite element methods. The codes used were either commercial codes, ABAQUS (CH1,F3,F4), RADIOSS (F1), INDEED (G1) or homemade codes (F3,B1).

So, one can say that for the direct problem simulation quite different approaches were proposed. Therefore, there was a danger that some of the participants, through their discussion, did not meet a common agreement on how to improve their optimization procedures. Actually, the main topics of discussion were the definition of sound optimization variables, objective or cost functions, model parametrization and, of course optimization algorithms. In spit of this diversity the many discussions we had were fruitful and we all agreed on a way to better apprehend the optimization procedures and how to actually implement it. As an example of the results, we will hereafter briefly present and comment a typical example based on the work of project F3.

This problem is concerned with the optimization of the deep drawing of the dashpot cup of a European car (see figure 1)°. The design variables are the initial dimensions of the blank.(figure 1).

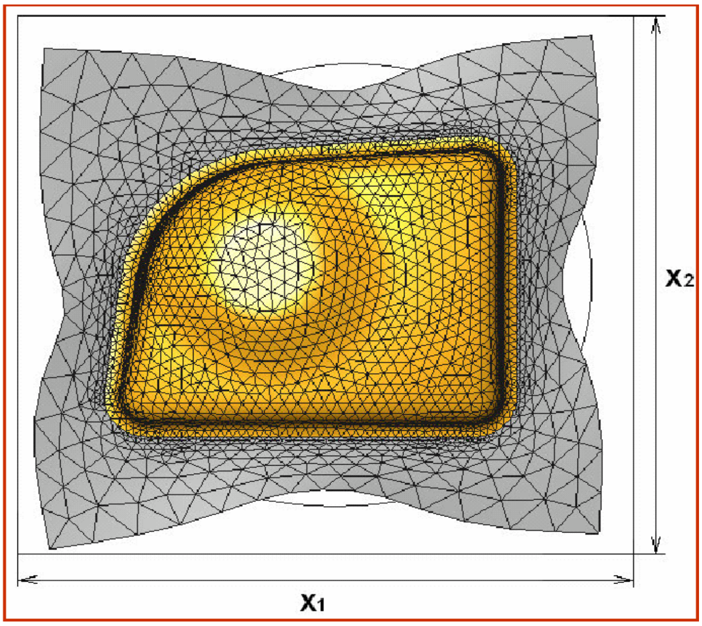

Figure 1: Twingo dashpot cup: optimization variables and final configuration

The process is also constrained in the sense that the strains induced by the deep drawing operations have to be located under the FLC curve (forming limit curve) and above the wrinkling tendency curve (see figure 2).

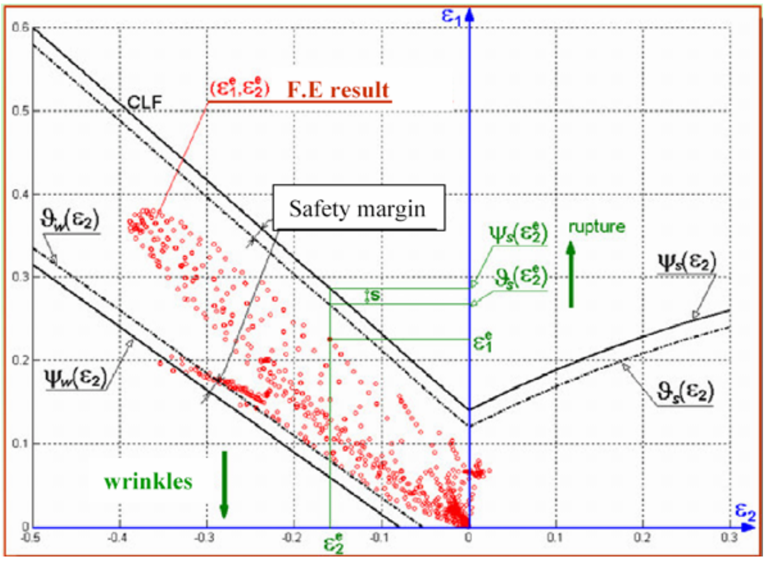

Figure 2. Forming Limit and Wrinkles Curves

The optimization algorithm used is based on **the response surface method,** an algorithm that is now widespread amongst the participants of this working group.

This type of approximation is based on the value of the « exact » functions (provided by a finite element model) in a few points of the design domain, and must be explicit or easy to compute.

Classical methods use mainly least-squares fitting, and some recent improvements of this technique (moving least squares or diffuse approximation) seem very promising for minimization. The choice of the points where the exact functions are to be evaluated (design of experiments) is a difficult problem because it must be a compromise between cost and precision. Therefore, it is more efficient to build local approximations; the initial optimization problem is then replaced with a sequence of local, approximate sub-problems which can be solved at low cost with a descent method using the analytical expression of the response surface.

As can be seen in figure 3, the algorithm is very robust since different starting points, sometimes very far from one another all lead to the same final optimum. As can be seen in that figure, fast and stable convergence is achieved.

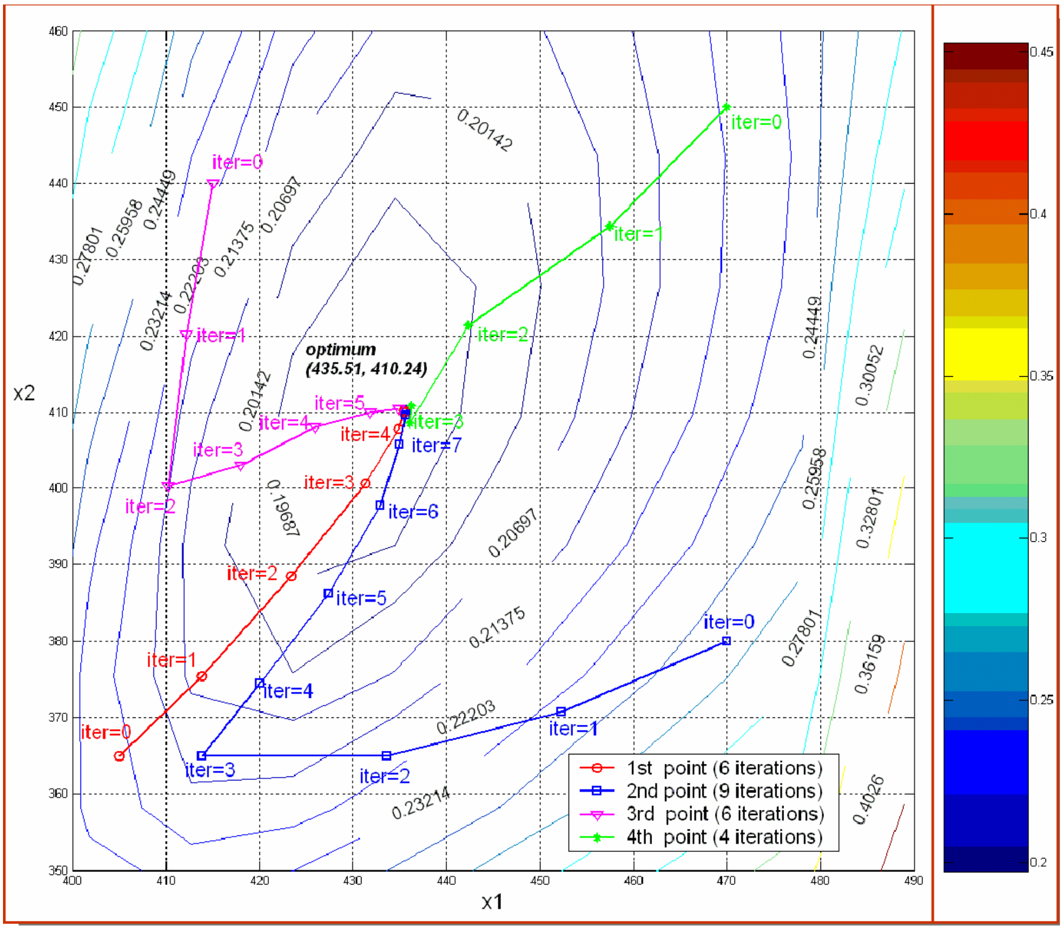

Figure 3: Iso-level curves and convergence path in the optimization variables plane

Another important point to mention is the **excellent and active cooperation** that existed in the group, especially between projects F4 (Prof. Potiron), F1 (JM Faure), project F3 (Dr. Knopf-Lenoir), project G1 (Prof. Grauer) and B1 (Dr. Stainier) regarding the optimization definition (objective/quality function, parametrization of design variables) and methodologies based on the response surface method.

As a follow-up of this action, a three-month stay of a researcher from the group of the WG leader (Université de Liège) will start next November. This researcher will be hosted in the group of Prof. Batoz in Saint-Dié des Vosges (GIP-InSIC), France.

Dissemination has been important in the COST526 Action. The projects of WG1 have been fully or partly presented in International Conferences (ECCOMAS 2004 in Finland, COMPLAS 2003 and 2005 in Barcelona, Spain, NUMIFORM 2004 in Columbus, Ohio, USA, ESAFORM 2004, Italy) Around 20 Communications and 10 papers in International Journals partly resulted from the Action.

Working Group 2 – Summary Report: Liquid-Solid Processing

Working group leader: Prof. Jean-Claude Gelin
Deputy: Prof. Norbert Hofmann

Objectives of WG2

The goal of WG2 is to simulate the solidification of liquid materials during the production process. Important process parameters should then be identified and optimized in an automated fashion. The 9 participating projects in WG2 cover 4 different process technologies: Investment casting (4 projects), continuous casting of steel (2 projects), injection die casting (1 projects) and special production processes (2 projects)

The following table shows the projects in WG2:

Project	Members	Project Title
CH 2	Dr. Martin Balliel	Numerical Calculation of the Process Parameters which Optimize the Gas Turbine Blade Coating Process by Thermal Spraying for Given Spray Paths
CH 4	Prof. Dr. Norbert Hofmann	Optimization of EQ Casting for Gas Turbine Blading Using a Database
CZ 1	Dr. Antonin Dlouhy	A Numerically Based Optimization of a Near-g TiAl Precision Casting Process
CZ 5	Prof. Frantisek Kavicka	Optimization of Casting of Corundobaddeleyit (EUCOR)
D 4	Dr. Jürgen Jakumeit	Numerical Optimization of the Brigdman Casting Process for Stationary Gas Turbine Blades
F 2	Prof. Jean-Claude Gelin	From Final Properties of Components to Mould and Process Design in Metal Injection Moulding
FIN 1	Dr. Erkki Laitinen	Optimization of Cooling Parameters in Continuous Casting Processes
SI 1	Dr. Bogdan Filipic	Advanced Parameter Optimization Methods Preliminary Used for Casting Processes
SI 4	Prof. Bozidar Sarler	Modelling and Optimization for Competitive Continuous Casting

Status of Most Advancing Projects in WG2

Due to the increasing competitions in the world market for continuous steel casting and the investment casting industry, the projects in these fields are more advanced in optimisation technologies and process control than the other projects in the WG2. They generate more direct product relevant results for industrial partners. Additionally these projects collaborated intensively with other COST526-projects.

The following projects show significant improvements in the field of process and product optimisation:

- **Dr. E. Laitinen: Optimization of Cooling Parameters in Continuous Casting Process**

  Dr. E. Laitinen has developed an on-line process optimisation technology that uses a program with CORBA-architecture to distribute the process simulation & control to several computers. The goal is to improve the quality of continuous cast steel slabs. Instead of simulating the material properties of the steel slap with fluid flow simulation (long simulation time), Dr. E. Laitinen predicts the microstructure and the properties of the cast slab from the cooling curves.

  The simulation results (cooling curves) have been validated at the Rautaruukki steel work company. Based on the validated process simulation, new quenching devices and new process control strategy have been established at the steel work company.

  During the project there was a good collaboration in the field of optimising continuous casting processes between Prof. B. Sarler (SI), Prof. Dr. E. Laitinen (FI) and Dr. B. Filipic (SI).

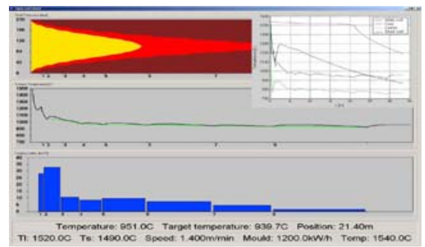

Fig. 1 Dyncool client software for the visualisation and control of the continuous casting process

- **Dr. Jürgen Jackumeit: Numerical Optimization of the Bridgman Casting Process for Stationary Gas Turbine Blades"**

  This project demonstrates an advanced optimisation strategy to simultaneous minimise casting defects and the production time of expensive single crystal components. Figure 2 shows the result of a study of an optimisation of a dummy turbine blades minimizing freckles and single crystal structure break down.

  The optimisation strategy (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.

  Prof. Dr. Norbert Hofmann and Dr. Dirk Büche supported that project in the field of application integration and optimisation algorithm.

Fig. 2 Merging 3 quality criteria. Nodes showing freckle tendency are shown white, nodes of too high a curvature are shown light gray, and nodes of too low a G/v ratio are shown dark gray.

- **Dr. Jean-Claude Gelin: From Final Properties of Components to Mould and Process Design in Metal Injection Moulding"**

  The project of Prof. Dr. Jean-Claude Gelin and Dr. Th. Barriere displays an excellent work and theoretical background regarding filling simulation. They present a fast new simulation technique for screening analysis for the injection tool development.

  There was a good collaboration between the work of Prof. Dr. Jean-Claude Gelin and Prof. Dr. J. L. Batoz.

Dr. Antonin Dlouhy: A Numerically Based Optimization of a near-g TiAl Precision Casting Process

The project focused on the VIM (cheap) processing route and on the issues associated with macrocracks, nucleation and growth while cooling the cast - mould system down to room temperature.

The goal was to minize the tensile stresses induced into brittle TiAl intermetallic casts while cooling. The optimized process parameters comprise the amount of superheat, the mould preheating, thermal expansion coefficient of different moulding materials and the cooling kinetics were considered.

It is apparent that the numerical modelling and optimization clearly contributed to the technology progress. The damage of the cast components due to the intensive stress state in the cast-mould system has been completely suppressed and the technology is now ready to yield reproducible cast parts.

Fig. 3 Comparison of the quality of the VIM-based cheap precision casting technology from December 2001 (upper picture) and from October 2004 (lower picture)

Summary for WG2

The projects in the field of continuous and investment casting will support the other project teams with knowledge in the field of “designing objective functions” and “optimisation technologies”. The projects demonstrate relevant achievements for industrial partners.

Furthermore in the WG2 open source software was developed to integrated simulators with optimiser and to optimise arbitrary parameter sets. Further information and the software are on the APOMAT web page (Links -> Optimization Algorithms).

Publications

- Patents: 2 (Shell mould mesh generator)
- papers published 79 : 6(CH4), 5(CZ1, 2(FIN1), 47(CZ5), 5(D4), 6(F2), 3(SI1), 5(SI4)
- papers submitted 3: 1(CZ1), 2(CZ5)
- papers in preparation 2: 1(CZ1), 1(D4)

Working Group 3 – Summary Report: Bulk Product Processing

Working Group leader: Dr. Lionel Fourment
Deputy: Prof. Tomaz Rodic

Working Group Projects		
Code	**Leader**	**Title**
CH 3	Dr. Laloui	Optimisation of cooling processes in geomaterials
CZ 2	Dr. Horsky	Optimization of forging characteristics of metal in mushy state
CZ 4	Dr. Zak	Optimization of heat treatment of magnetic materials applying the thermomagnetics curves data
F 5	Dr. Fourment	Forging process optimization
PL 1	Prof. Pietrzyk	Optimization of model describing rheological and mechanical properties of metallic alloys
SL 1	Dr. Gresovnik	Optimization of fatigue resistance of cold forging tools by considering damage mechanisms at micro-scale
SL 2	Prof. Rodic	Formulation of objective functions for estimating fatigue damage of cold forging tools steels at micro-scale

This Working Group gathers 7 research laboratories working on bulk materials of different types: geomaterials that are processed by different types of works or loads applied to the ground (Laloui), semi-solid materials that are utilized in special processes or that appear during cooling, as in continuous casting (Horsky & Pietrzyk), magnetic materials (Zak), and solid metals in metal forming operations and more particularly in forging (Fourment, Gresovnik & Rodic). It so provides a quite interesting range of encountered problems in materials technology, from process simulation, to process optimization, through process evaluation.

Process simulation and parameter identification:
Some processes have been studied since many years, so simulation software are available and allow accurate and reliable simulations, as in forging. However, for more recently studied problems or for more complex ones, it is first necessary to select reliable models, then to develop efficient software and finally to identify appropriate material data. During Apomat, the Thermo-Hydro-Mechanical behaviour of polyphasic geomaterials was first mathematically formulated, using a fully coupled three-phase formulation, and then solved by a newly developed finite element code MHERLYN (Laloui). The next step consisted into properly identifying the parameters of the material model, using an inverse approach. Several experiments have to be carried out to measure as many data as possible, under different process conditions. The accuracy of the measurements is quite important, and was the focus of the works on semi-solid materials at high temperature (Horsky). Then, the coefficients of the material model must be adjusted to obtain satisfactory agreements between the experimental results and the numerical ones that are provided by finite element software. This methodology requires proper design of the experiments in order to make the identification possible. For semi-solid materials, this problem can require utilizing different tests, such as the needle one and the double cup one (Horsky). In order to allow identifying both the material behaviour and the friction coefficient with a single experiment close to the process conditions, a new double cup extrusion test was designed, using optimization techniques. It so required solving a shape

optimization problem by evolutionary algorithms (Pietrzyk). Then, the identification problems have been tackled using either a combination of a local quasi-newton algorithm with a global probabilistic one (Laloui), or artificial neural networks (Pietrzyk & Horsky). Therefore, both for semi-solid metals and for geomaterials, satisfactory material models have been proposed, accurate parameters have been obtained and predictive simulators have been made available.

Process evaluation:
In order to optimize a process, a key issue is to properly define a qualitative measure of this process. In the production of magnetic materials, the heat treatment process governs the creation of the magnetic properties. Consequently, it is very important to identify the derivatives of the temperature curves from experimental data, which is a complex issue because of the experimental noise. A filtering technique based on artificial neural network has shown to be the right way to automatically identify these critical temperatures (Zak). In a similar way, in cold forging, the damage of tools plays a major part in the cost of the process. It is the main phenomenon to minimize, but it is quite difficult to quantify because of significantly different behaviour of different materials under same loads. A micro-macro, multi-scale model was so developed in order to correlate the peak stresses and strains with hysteresis loops and determine failure probability (Rodic). Under hot forging conditions, a difficulty is to find a quantitative measure of possible surface flow defects, such as fold or pipes, and a strain rate based criterion was proposed and studied (Fourment).

Process optimization:
Then it is possible to optimize the process. It so requires defining a proper optimization environment, which is a complex issue (Gresovnik), possibly computing the sensitivities of the optimization functions to the optimization parameters, either numerically (Fourment) or automatically (Gresovnik) by formal calculations. All studied processes are quite complex, very often they are non-steady and three-dimensional, so resulting in large computational times that require quite robut and efficient optimization algorithms. Evolutionary techniques, possibly combined with gradient calculations and meta-modelling, allows developing a set of algorithms that can be applied to these problems (Fourment) in an integrated approach (Gresovnik).

Conclusion:
The Apomat project has been a very efficient frame for fruitful collaborations between laboratories (for filtering noisy experimental data, for conducting complex experimental tests, for automatically identifying material parameters and for exchanging optimization algorithms), which has so stimulated and allowed the success of many projects. In this working group, most of the issues encountered in bulk material process optimization have been investigated. Innovative and attractive solutions have been proposed, so significantly contributing to the development of optimization techniques in material related processes.

COST 526:
Automatic Process Optimization in Materials Technology (APOMAT)

WG4: Optimization Methodologies

Final Report

Working group leader: Dr. Bogdan Filipič, Jožef Stefan Institute, Ljubljana, Slovenia
Deputy: Dr. Catherine Knopf-Lenoir, Université de Technologie de Compiègne, France

Objectives

COST 526 was promoting interdisciplinary collaboration of material scientist and experts in numerical optimization aimed at designing automatic optimization procedures for material processes. The approach taken was to integrate process simulators for specific material processes with optimization algorithms via quality (cost) functions that relate process parameters with material properties (see Figure 1). The resulting software environments should be capable of finding process parameter values improving the target material properties. In addition, the new values should either contribute to the decrease of experimental or production costs, or increase of productivity or environmental acceptability. There has been no long tradition of collaboration between the two disciplines, hence bridging the gap between them was also a challenge for COST 526.

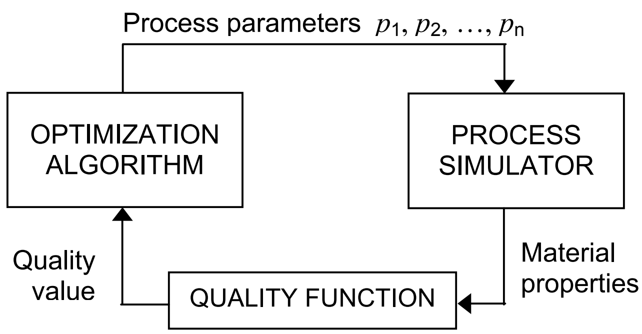

Figure 1: Simulation-based optimization of a material process

Working group activities

The role of the Optimization Methodologies Working Group (WG4) was to provide a forum for the exchange of information on optimization techniques and their applications. All COST 526 projects were invited to contribute to the working group activities as well as benefit from them. WG4 sessions held at the COST 526 joint working group meetings consisted of presentations by invited speakers and project members.

During the entire action, six invited talks and 12 talks by the COST 526 participants were given at WG4 sessions. There were presentations of optimization methodology, such as evolutionary strategies for engineering applications (discussed by Thomas Bäck, Michael Emmerich, Dirk Büche, Stefan Kern), multi-objective optimization (Bogdan Filipič), and response surface optimization (Catherine Knopf-Lenoir). Special approaches useful in time-consuming simulation-based optimization were presented, such as distributed optimization on a network of workstations (Manfred Grauer), and XML communication among applications (Norbert Hofmann). Some speakers presented optimization software packages, for example BOSS Quattro (Patrick Morelle), DesParO (Christof Bäuerle), modeFRONTIER (Jean-Jacques Maisonneuve), and Inverse (Igor Grešovnik). Various case studies from material process optimization were shown, too.

Presentations were followed by discussions on the issues related to material process optimization, such as how to define an appropriate quality function, which optimization method to use, and others. In addition, information on available optimization software was collected, while Dirk Büche contributed a set of downloadable optimization algorithms and test problems. Both materials are accessible from the project web site (Figure 2).

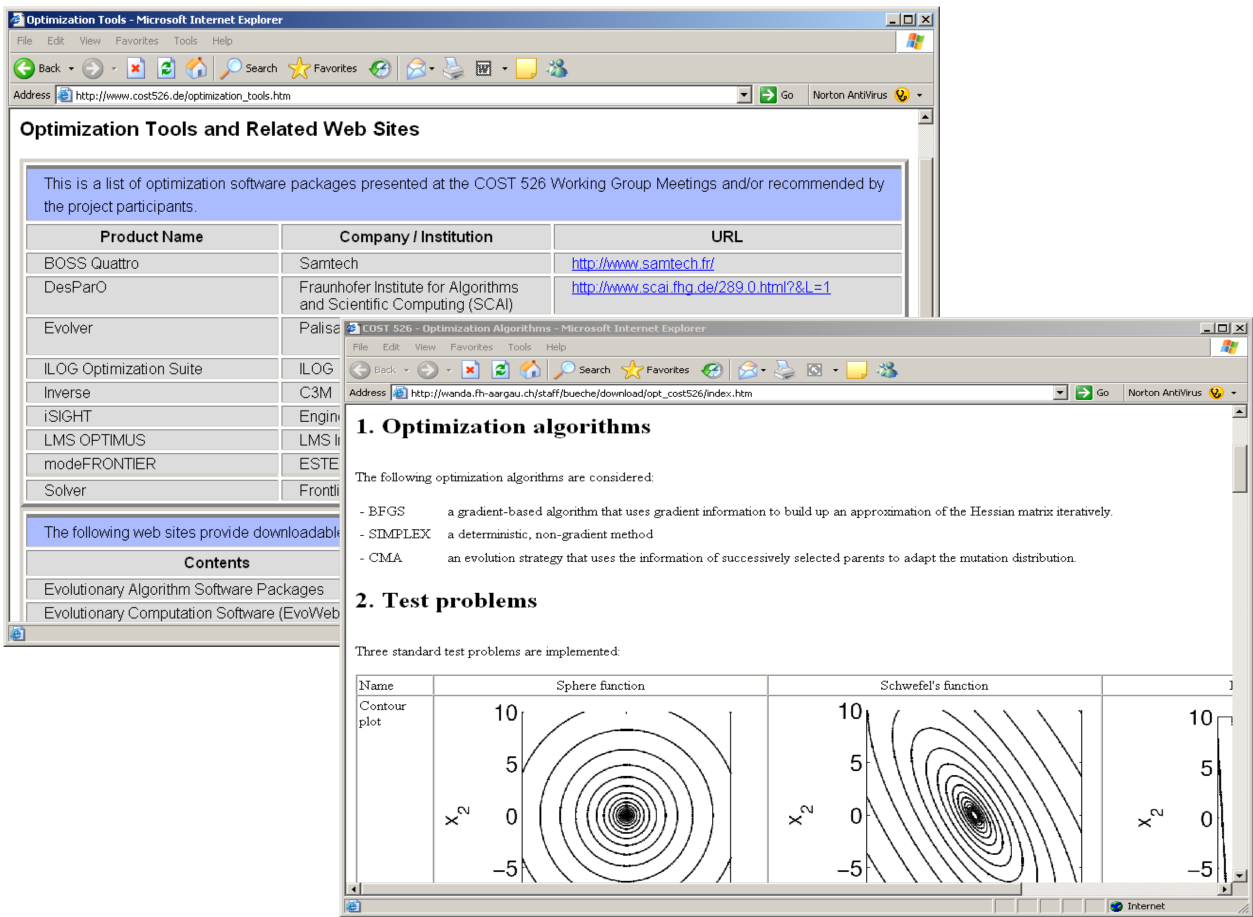

Figure 2: Optimization software pages available at http://www.cost526.de/

Summary of achievements

COST 526 projects were dealing with a variety of material processes and have entered the collaboration at different initial stages. In spite of that, most of them succeeded in establishing an appropriate simulator-optimizer environment for their particular material process, and producing beneficial results either at a laboratory level or even in regular production. Many projects use commercial simulation programs, such as ANSYS, ABAQUS, FORGE, etc., while the employed optimization software is either commercial or own code.

As a result of interactions in WG4, some common practices were established. For example, to identify relevant parameters for optimization, sensitivity analyses are performed before modeling and optimization takes place if there is not much empirical evidence on the role of parameters. Regarding the quality function design, a common approach is to formulate a measure of unwanted material property, or an error measure, which is to be minimized. However, when multiple criteria need to be taken into account, the predominant approach is calculating the weighted sum of normalized criteria values and performing single-objective optimization.

The optimization method chosen as suitable very much depends on the properties of a particular material process and computational complexity of the employed simulator. Among the participating projects, the selection ranges from traditional numerical methods, such as Nelder-Mead (Downhill Simplex), Levenberg-Marquardt, Quasi-Newton, and BFGS, to advanced stochastic methods, including genetic algorithms, evolution strategies and differential evolution. Figure 3 illustrates a result of modeling and optimization of industrial continuous casting of steel where the task is to tune the secondary coolant flows to achieve the target temperatures. The applied software consists of a 3D finite-element simulation model and gradient-based optimization (steepest descent) procedure.

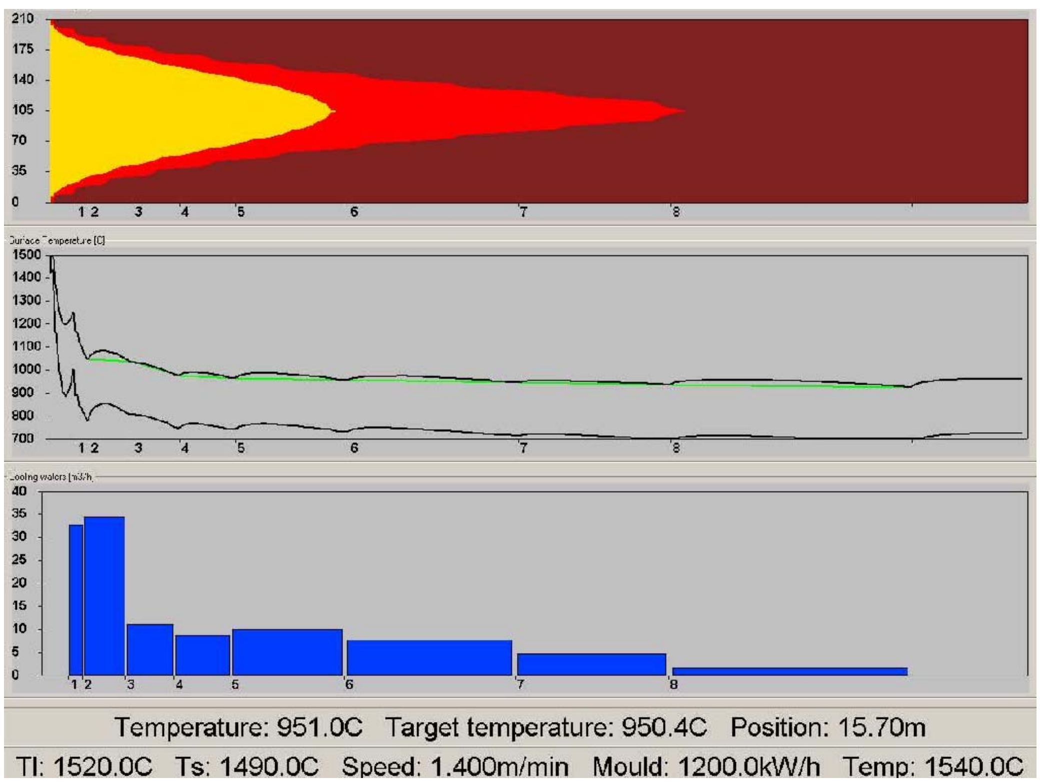

Figure 3: Visualization of industrial continuous casting of steel as modeled and optimized by a program developed at the University of Oulu (Erkki Laitinen)

When computational complexity of process simulation is too high to make iterative optimization feasible, approximations of the parameter search space are constructed and exploited in the optimization process. This has been approached in different ways, e.g. by sequential approximation techniques, with response surface models and meta-model assisted evolution strategies.

In addition, some participants have worked on specific techniques that may utilize complex optimization procedures:

- unified XML communication among applications within the simulator-optimizer environment (Norbert Hofmann),
- parallel/distributed optimization suitable for process simulations of high computational complexity (Manfred Grauer),
- a generic optimization software Inverse (Igor Grešovnik).

Conclusion

In COST 526, WG4 was devoted to providing and exchanging information on optimization methodology and its applications in material processing. Diversity of the considered material processes reflects in a variety of optimization techniques tested and finally accepted into practical use in individual projects. Through contributions of invited experts and optimization specialist participating with their own projects, the awareness of simulation-based optimization potential in material processing increased. Certain common practices were established that helped many projects to accomplish their goals. On the other hand, there are issues that remain to be further explored in a planned follow-up COST action. These include accounting for multi-objective optimization, data visualization for better understanding of results, and practical assessment of the gains resulting from optimized solutions.