

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

## Cost 526: Automatic Process Optimization in Materials Technology (APOMAT)

## TEMPLATE FOR PROJECT PROPOSAL

**Filled in template to be sent to:**

Dr. Isabel Vergara  
 Scientific Officer COST Physics EUROPEAN COMMISSION  
 Research Directorate-General  
 European Research Area: Structural Aspects  
 COST Materials and Physics  
 Mail: Rue de la Loi, 200 SDME 1/52  
 B- 1049 Bruxelles  
 Belgium  
 Office: Square de Meeùs, 8  
 B- 1050 Bruxelles  
 Fax: +32 2 296 42 89 E-mail: [Isabel.VERGARA-OGANDO@cec.eu.int](mailto:Isabel.VERGARA-OGANDO@cec.eu.int)

**Title of proposal:**

*OPTIMIZATION OF EQ CASTING FOR GAS TURBINE BLADING USING A DATABASE*

**Keywords:**

*EQ CASTING PROCESS; GAS TURBINE BLADES; FINITE ELEMENT SIMULATION, ABAQUS, CASTS, DATA BASE*

**Organization/Company:**

University of Applied Science  
 Klosterzelgstr, CH-5210 Windisch

**Project leader: Prof. Dr. N. Hofmann**

**Tel.:** +41 56 462 40 61  
**Fax:** +41 56 442 94 68  
**E-mail:** [n.hofmann@fh-aargau.ch](mailto:n.hofmann@fh-aargau.ch)

**1. Duration / run time of the project**

2.5 years, from April 2003 to Oct 2005

**2. Overall cost**

470 kEURO

1.5 Assistant Worker (FH-Windisch 0.75, FH-Solothurn 0.75)

0.5 Scientific Worker (FH-Windisch 0.25, FH-Solothurn 0.25)

**3. Funding situation**

- National funding to be applied by Bundesamt für Bildung und Wissenschaft BBW

- Partly funded by ALSTOM (Switzerland) Ltd, Switzerland

**4. Project partners indicated to participate**

- ALSTOM (Switzerland) Ltd, Baden, Switzerland

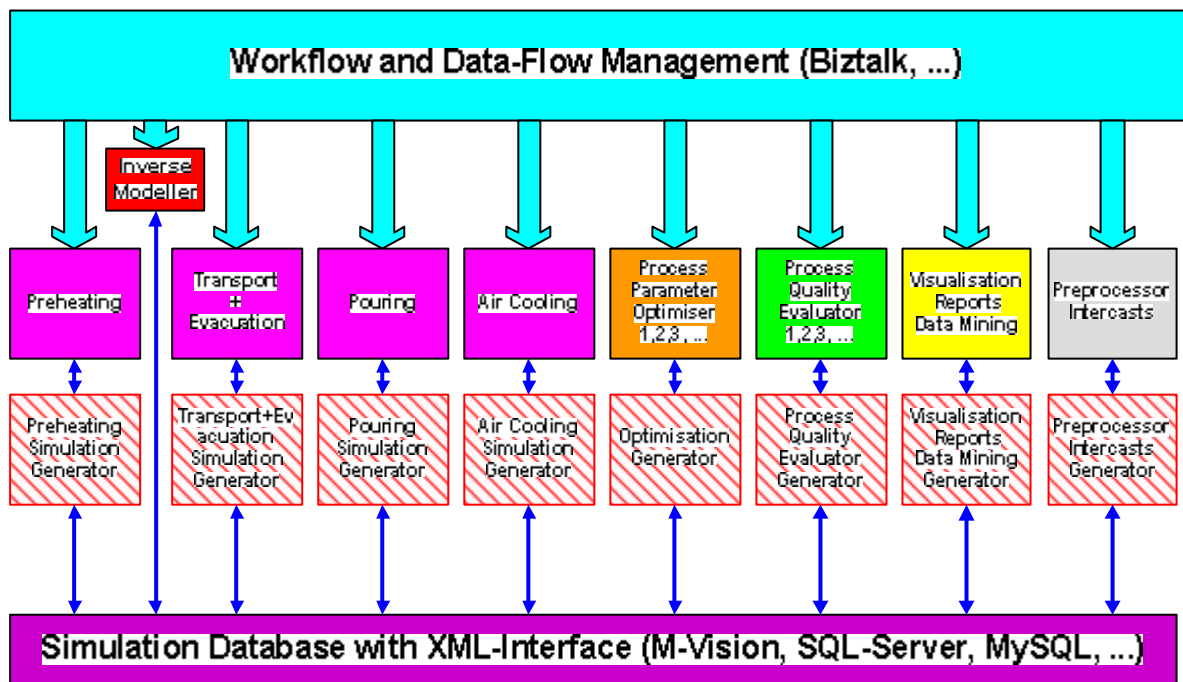
- ACCESS e.V., Germany

**5. Project partners to be found**

- Casting vendor (not yet determined)

## 6. Short description of the material process to be optimized

A major part of the increasing demand for EQ turbine blades for stationary gas turbines requires that both turbine manufacturers and casting vendors improve their casting process quality [1,2,3]. These blades are made of Ni-base superalloys and produced by the conventional EQ solidification process in a vacuum casting furnace. The EQ-casting process base on four steps: 1. preheating of empty shell under atmospheric pressure, 2. transportation to vacuum furnace (heat loss), 3. casting of superalloy under vacuum and 4. cooling under atmospheric pressure. Technically relevant casting parameters, such as preheating temperature, transportation time, wrapping thickness & location and heater pouring temperature are the most sensitive casting parameters.



## 7. Material(s) involved:

Superalloy, Ceramic shell mould, core material and wrapping material

## 8. Optimization potential of the process or process step

40 % of the production costs result from the casting and solidification process.

- a) Minimization of casting defects
  - Micro porosity
  - Fine Microstructure
  - Residual stress in blade after casting
  - Tensile stress in shell and core during casting
  - Deformation and dimensional variations of casting cavity
- b) Robust Design: Small variations of casting parameters result in none or minor variation of casting quality [4].

## 9. Specified material properties to be achieved

- Minimum porosity
- Minimum stress in core and shell to avoid run outs and deformation of cast components
- Fine and homogeneous equiaxed grain structure
- Minimum casting stress (hot tearing) in cast components

#### 10. Process parameters to be optimized

- Preheating temperature (1 parameter)
- Transportation time (1 parameter)
- Casting temperature (1 parameter)
- Evacuation and ventilation time (2 parameters)
- Wrapping position (20-200 parameters) and wrapping thickness [5]
- Containment (Yes/No)

#### 11. Material laws including material dependent coefficients

In order to compute some material qualities for the directional solidification process of turbine blades, the following material laws [11,14,15] and criteria have been coupled with CASTS:

- a) Micro porosity (Niyama) and alternative porosity functions:

$$P = G / \sqrt{\dot{T}} \leq P_{Critical}$$

where:  $G$ : local temperature gradient at liquidus  
 $\dot{T}$ : local cooling rate at liquidus

- b) Criterion for dendritic growth: columnar-equiaxed transition (CET):

$$G/V < (G/V)_{critical}$$

where:  $G$ : local temperature gradient at the solidification front  
 $V$ : local velocity of the solidification front  
 $(G/V)_{critical}$ : critical  $(G/V)$  value for CET

- c) Hot tearing criterion for directional solidification:

$$\epsilon' = \epsilon'_{p,max} = \left( \frac{I_2^2}{180} \frac{G}{(1+b)m} \Delta P_c - V_T \frac{b}{1+b} H \right) / F_2(T)$$

$\epsilon'$ : strain rate  
 $\epsilon'_{p,max}$ : maximum plastic strain rate sustained by the mushy  
 $\mu$ : viscosity  
 $\Delta P_c$ : gravitation depression  
 $\beta$ : shrinkage factor

- d) Stress/Strain Laws:

- Superalloy: visco-plastic-material model (isotropic hardening, Norton Creep Law)
- Core, Shell: visco-material model (Norton Creep Law)

- e) Grain structure prediction with Cellular Automaton.

The multi objective function design will be on a sum of least square of the mentioned criterions. The differences between a critical value (e.g. target or constraint) for a criterion will be normalized to prevent that some criterion will dominate the objective function.

$$\min \left( \sum_i \left( \frac{\text{Criterion}_i(\bar{x}) - \text{Criterion}_i^{\text{Critical}}}{\text{Criterion}_i^{\text{Critical}}} \right)^2 \right)$$

## 12. Simulator

The finite element simulation programs CASTS [6,7] and ABAQUS 6.3 will be used to simulate the four casting process steps. A simulation data base with interfaces to CASTS and ABAQUS will be created for easy comparison of simulation results and future data mining of store simulation results. The main reason for using a data base in conjunction with an interface to CASTS and ABAQUS that will create automatically the input for the simulation and storage of simulation results is the risk of errors in the definition of simulation input-file. Nearly 40% of the simulation setups are wrong due to the manual input and the huge amount of associate data.

The automated import & export of simulation data reduce wrong simulation setups and consequently comparable simulation results.

Additionally, the model has been validated by comparison between predictions and the physical output from casting trials.

## 13. Optimizer

Due to the large optimization parameter set gradient based [8,9] methods are not the favoured choice. Evolutionary strategies are the fastest strategies for large parameter sets. Inverse modelling of heat transfer values with measured and simulated temperatures show good and fast convergence for more than 30 parameters.

### - Evolution strategies

A distinction is made between ES (Evolutionary Strategies) and GA (Genetic Algorithm), both of which method according to the same principle. These techniques apply a random-supported search in the optimization field, in which the search is controlled by the application of special methods. Without these methods, the search would be a random one, as in the Monte Carlo methods. The DES algorithm (derandomized evolution strategy) [10], for example, has shown itself to be a particularly interesting model for generating a new generation by means of previous evaluations. The great advantage of this technique is the option of ignoring local optima in order to find better ones.

### - SIMPLEX method / Levenberg-Marquardt

Linear optimization technique currently widely used and highly stable. Application to non-linear problems is possible, but requires adaptation of the technique.

## 14. Competence / activities of proposer:

Since 1995 the applicant has developed Finite Element Software (CASTS, ABAQUS User Interfaces) and has used different optimisation strategies (SIMPLEX, Gradient Methods and Evolutionary Strategies) for different production processes at ACCESS, ABB and ALSTOM (casting, gas cooling casting [12,13], quenching, fibre spinning, material evaluation by simulation [13], ...).

Currently the applicant combines commercial work-flow systems (Microsoft BizTalk) with the simulation package ABAQUS to obtain an automatic process optimisation system with high flexibility to perform changes.

Additionally a open source Document Management System (ZOPE [16]) will support users with standardised reports.

## 15. International state-of-the-art and references

Due to confidentiality agreements the applicant could not publish recent research results. Several former publications [4,7,9,12] are available dealing with basic approaches towards numerical optimization of solidification processes.

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Zope is a unique software system: a high-performance application server, a web server, and a content management system. Zope is a complete and self-contained solution, that includes a robust, scalable object database, web services architecture, and powerful programming capabilities. (Open Source product: <http://www.zope.com/>)