

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

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

Title of proposal:

OPTIMIZATION OF CASTING OF CORUNDOBADDELEYIT MATERIAL (EUCOR)

Keywords:

Casting, ceramics, numerical model, optimization

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1. Duration / run time of the project

09/2002 - 8/2004

2. Overall cost

- in kEURO

year	personal	investment	running cost	total
2002	12	0	12	18
2003	16	8	30	46
2004	16	8	30	46
Total	44	16	72	110

3. Funding situation

As much as 50% of the total costs will be covered by own resources. An application for the remaining 50% will be submitted to the COST Representative in the Czech Republic (at the Czech Ministry of Education). In order to gain this financial support, the Project must be approved by the MC of COST 526.

4. Project partners indicated to participate

VSB-Technical University of Ostrava, Czech Republic, and the University of Ljubljana, Faculty of Natural Sciences and Engineering, Slovenia, will participate in the development of the actual model (see point 6 below) and Skoda Research Ltd. Plzen, Czech Republic, will perform the necessary experimental measurements.

The work of all three partners will be financed from other projects supported by the Government of the Czech Republic.

5. Project partners to be found

Partners who would be capable of investigating problems concerning the casting of ceramic materials and its simulation.

6. Short description of the material process to be optimized

The proposed project will investigate the feasibility of a numerical model of thermokinetics for the optimization of technology and utility properties of EUCOR, as a new kind of Corundobadelleyit Material (CBM), within an actual casting process at EUTIT Ltd. in Stara Voda, Czech Republic. The dimensions of the actual casting—the “stone” made of the special ceramic material EUCOR—were 400 x 350 x 200 mm, the riser comprised a 300-mm-high truncated four-sided pyramid, where the base was 123 x 250 mm and the top 150 x 270 mm. The initial temperature of the mould was 20°C, which equaled the room temperature. The pouring temperature was 1800°C, the pouring time was 10 s, the liquidus temperature was 1775°C and the solidus 1765°C. The mould material was made from a CT-mixture and the bottom of the mould was made from a layer of magnesite of a thickness of 50 mm. The level of the riser remained untreated.

7. Material(s) involved:

Corundobadelleyit Material (CBM) is a modern electrically cast heat- and wear-resistant material. It is resistant to corrosion and to wear even at very high temperatures. This material belongs to the not too well known area of the Al_2O_3 - SiO_2 - ZrO_2 system, and is

produced in several plants throughout the world (under different trademarks), and in three different types, differing mainly in the ZrO_2 content.

8. Optimization potential of the process or process step

The optimization potential in casting of CBM is considerable because, currently, there still exist problems in producing castings without internal defects.

The main task will be to find an objective function for the numerical optimization with additional conditions, i.e. to be able to describe mathematically the ‘soundness’ (i.e. how few internal defects there are) and the rate of controlled solidification of a casting within this function. Such a function has not yet been defined for the purposes outlined here.

The main objective of this Project will be to optimize the following independent parameters:

- The pouring temperature

- The angles of the widenings of the riser

- The thickness of the riser insulation

The objective function must be able to forecast so-called ‘directed solidification’, which is a prerequisite for the casting to be ‘sound’.

9. Specified material properties to be achieved

The main objective will be to optimize the technology with the aim of ensuring a solidification process capable of minimizing the occurrence of internal defects within the CBM casting.

The most common defects of castings are cracks, originating on the surface and propagating to a great depth. Internal defects are caused mainly by internal non-homogeneity – shrinkage porosities and a high porosity in general. The average number of pores within a specific examined sample is 209/cm², and the volume ratio is 14%.

The volume contraction during solidification is approximately 6.5%. For massive castings it is necessary to select the volume of the riser in a casting-to-riser ratio of 7:3 and to expect a 70% utilization of the melt, even when the level is insulated.

10. Process parameters to be optimized

The first optimized parameter is the pouring temperature. This parameter has only one constraint, i.e. its value must be higher than that of the liquidus.

The next optimized parameter is the riser shape. For the purposes of numerical optimization, the method of increasing of the angle of the widening of the riser is used. This does not require a change

in the shape of the network, but only its dimensions.

The last optimized parameter is the thickness of the riser insulation. For the purposes of numerical optimization, the wall thickness is substituted by a change in the heat conductivity of the insulation material.

11. Material laws including material dependent coefficients

The model for the investigation into the temperature field of a casting is based on the Fourier's Law. Considering the fact that material constants, such as heat conductivity, specific heat capacity and density are not known accurately as functions of temperature within the entire temperature range (i.e. the solidus as well as liquidus regions), we intend to conduct experimental analyses (measurements) of these parameters using a basic range of CBMs. Special attention will be devoted to determining the latent heat, which, for this material, is not yet known. Possible anisotropic behavior of most properties will be investigated via a parametric study.

12. Simulator

The main simulation program of the process will be either an original in-house software package, based on a transient 3D temperature field of a system comprising a ceramic casting, mold and surroundings, or ANSYS. In the case of the former, the basic kernel will be equipped with an automatic generator of a 3D network capable of changing the network density.

Since the optimized parameters are the angles of widenings of the riser and the thickness of the riser insulation, the software must include a routine for the re-calculation of boundary conditions to fit the generated network.

13. Optimizer

The numerical optimization will be supported by an in-house multi-level optimization library called MULTIOP, which combines various optimization methods. This library was developed for the optimization of the objective function, where the calculation of the objective function demands a great amount of time. Another advantage of MULTIOP is the division into layers with the possibility of combining heuristic methods of non-linear optimization with constraints. The main part of the development work will focus on the selection and evaluation of suitable optimization methods from the library.

14. Competence / activities of proposer:

The proposer's organization

The Department of Thermomechanics and Environmental Engineering provides education in Thermomechanics, Environmental Engineering, Compressors, Cooling Techniques and Heat & Mass Transfer. These subjects are incorporated into the 3rd and 4th years of designing and technological specializations within mechanical engineering studies. The Department ensures Thermomechanics and Ecology and Environmental Engineering for the bachelor studies. All these subjects are delivered using own text materials, supplemented by workshops and laboratory experimentation and computer training. The Department trains ten doctorate students specializing in Technical Mechanics. Their work is focused on experimental research and problems in the computer modeling of temperature fields, heat transfer and flow in single-phase and in two phase systems and on the problems concerning environmental engineering.

The Department is very active in the area of scientific research, with a number of grant projects, supported by the Grant Agency of the Czech Republic, the U.S.-Czech Science and Technology Program, the COST Program, EUREKA, etc.

The main areas of scientific research:

Mathematical simulation of the thermokinetics of the processes of solidification, cooling and heating, optimization of technological processes (all types of casting, forecasting or control of the character of the primary crystallization of technical metals, ensuring controlled solidification, numerical modeling of heat treatment and its optimization, mathematical forecasting of the creation of an internal non-homogenous structure during solidification and a proposal for its removal, etc.), experimental study of high-temperature heat transfer processes, interferometry in thermodynamics, and heat transfer,

interferometric research of temperature fields in transparent environments, computer processing of interferograms, interferometric research of temperature fields in a microclimate, research of temperature fields and flow in heated and air-conditioned rooms, experimental measurement in solid, liquid and gaseous states, measurement of flow, measurement in environmental engineering, heat measurement, research of heat transfer from rotating machine parts, determining states of vapor and gas-vapor mixtures, development of a system for the measurement and analysis of working cycles in combustion engines, development of a system for the measurement and analysis of working cycles in volume compressors, mathematical modeling for 3D turbulent flow with heat transfer covering combustion and radiation, numerical and experimental study of unstable processes of flow and heat transfer in two-phase gas-liquid and gas-solid systems, two-phase gas-solid and gas-liquid systems (concentric circular channels, curved piping, flow in cavities with a moving wall, etc.).

The project proposer

Prof. Frantisek KAVICKA (born in 1939)

For the past 36 years he has been promoting the application of methods – formerly analogue, later numerical – for investigating transient temperature fields within technological processes. This included the simulation of heats of state of phase or structural changes, especially in metallurgy, the casting of metals and ceramic materials during heat-treatment solidification. In 1967-90 he worked as a scientific researcher in the State Research Institute of Materials in Brno, from 1970 as an independent researcher, from 1980 as a Chief researcher.

He has extensive experience in organizing and managing national and international scientific team projects. Currently, he has been – and still am in some cases – the principle investigator of two COST projects, three (Czech-Slovenian) KONTAKT projects and two EUREKA projects. He was also the Czech representative in the Management Committee of the COST/Action P3. He has also managed a significant project within the American-Czech Science of Technology Program, which was successfully finished in 1988. Currently, he is engaged in three projects supported by the Grant Agency of the Czech Republic, two of which had been completed earlier. All of these projects have direct application in the operation. The most significant of our recent achievements is the handing over of an original software pack to the company Vitkovice, for the control of the temperature field of slab concasting and for the enhancement of quality and product optimization.

All these and other grants – whether previous state, departmental as well as basic research projects, in cooperation with the Czech Academy of Sciences – have climaxed in the form of a series of publications and presentations. He is the author of 490 publications, 56 of them abroad. He has made 50 presentations in 15 countries – 15x in USA and Canada; 81 citations in the British periodical Steel Casting Abstracts, another 44 randomly discovered citations in articles, books, conference proceedings and dissertations. Furthermore, he has been entered in the Czech "Who's Who in the Czech Republic", and in the American "Who's Who in Science and Engineering" and in "Who's who in the World".

He is a member of the American societies ASME and TMS, a member of the Czech Society of Mechanical Engineers and the Czech Foundry Society. Furthermore, a member of the Scientific Board and the specialist Boards of three faculties in the Czech Republic.

He is also a member of the Editorial Board of a scientific periodical "RMZ-Materials and Geoenvironment Journal" of the Technical University in Ljubljana.

15. International state of the art and references

Selected publications since 1995:

KAVIČKA,F.; HLOUŠEK,J.; ŠTĚTINA: Analysis of The Effect of Thermodynamic Properties and Boundary Conditions on The Calculation Accuracy of Solidification Thermokinetics. American Foundrymen's Society. Philadelphia, USA 1996.

ŠTĚTINA,J.; KAVIČKA,F; KHODADADI,J.: Optimization of the angular widening of a cast plate. 126th TMS Annual Meeting&Exhibition, Orlando USA, 1997.

KAVIČKA,F.; ŠTĚTINA,J.; KHODADADI,J.: Search of a new technology and its optimization using an original numerical model. Castcon, Stratford Anglia, 1997.

KAVIČKA F., ŠTĚTINA J., STRÁNSKÝ K.: Industrial applications of two numerical models in concasting technology. Proceedings of the 2nd international symposium „Computational Technologies for Fluid/Thermal/Chemical Systems with Industrial Applications“. Boston (Massachusetts,USA), August 1999, Vol.397-2, p.27-38.

KAVIČKA F., STETINA J.: A numerical model of heat transfer in a system "plate-mold-surroundings". Proceedings of the 6th International conference on advanced computational methods in heat transfer, Spain, Madrid, June 2000, p.95-104

KAVIČKA F., ŠTĚTINA J., SEKANINA B., GONTAREV V., KOSEC B., MEDVED J.: Heat transfer with a phase or structural change. RMZ-Materials and Geoenvironment, Periodical for Mining, Metallurgy and Geology, Ljubljana (Slovenia), 47 (2000), No. 3-4, December 2000, p.361-375

KAVIČKA F., SEKANINA B., ŠTĚTINA J. and RAMÍK P. Calculation analysis of influence of thermodynamical properties on calculation accuracy of thermokinetics of solidification. In *Book of abstracts of the 15th European conference on thermophysical properties*. Wurzburg (Germany), September 1999, p.466

KAVIČKA F. at al. Numerical analysis of the influence of thermophysical parameters and boundary conditions on a model of solidification process. *RMZ-Materials and Geoenvironment, Periodical for Mining, Metallurgy and Geology*. Ljubljana (Slovenia), November 1999, p.669-676

KAVIČKA, F., STETINA, J. and SEKANINA, B. An original numerical model of thermokinetics of technology processes with a phase change. In *Proceedings and CD ROM of the 14th International congress of chemical and Process Engineering CHISA 2000*. Czech Republic, Prague, August 2000, lecture G7.6

KAVIČKA, F., STRANSKY, K., BUZEK, Z., DOBROVSKA, J., DOBROVSKA, V., SALVA, O. and TICHÁ J. Corundum-baddeleyite ceramics - the perspective cast refractory material. In *Proceedings of the International conference Industrial furnaces and refractory materials*. Kosice, Slovakia, November 2000, p. 82-86

HEGER, J., KAVIČKA, F., SEKANINA, B. and ŠTĚTINA, J. Pilot calculation of the temperature field of the ceramic material EUCOR. In *Proceedings of abstracts and CD ROM of the 10th International symposium METAL 2001*, Czech Republic, Ostrava, May

2000, paper No. 29, p. 33

KAVIČKA, F., BUCHAL, A., BŮŽEK, Z., DOBROVSKÁ, J., DOBROVSKÁ, V., STRÁNSKÝ, K. and TICHÁ, J. Castings from corundum-baddeleyite ceramics, their properties and using for wear resistant materials, piping etc. *Slévárenství*, 2001 XLIX(2001), No. 9, p.524-529

DOBROVSKÁ J., DOBROVSKÁ V., KAVIČKA F., STRÁNSKÝ K. and WINKLER Z. The chemical heterogeneity of corundum-baddeleyite refractory ceramics for castings. *Hutnické listy*, 2001, No.6-7, p.99-106

KAVIČKA F., BUCHAL A., BŮŽEK Z., DOBROVSKÁ J., DOBROVSKÁ V., STRÁNSKÝ K. and TICHÁ J. Castings from corundum-baddeleyite ceramics, their properties and using for wear resistant materials, piping etc. *Slévárenství*, 2001 XLIX(2001), No. 9, p.524-529

KAVIČKA F., RAMÍK P. and STETINA J. Continuous casting of steel semiproducts and its optimization. In *Proceedings of abstracts of the International conference Research and development in net shape manufacturing*, Birmingham, UK, April 2001, p.18

KAVIČKA F., ŠTĚTINA J., RAMÍK P. and SEKANINA B. Solidification of continuously cast steel. In *Proceedings of the 2nd International Symposium Computational Heat Transfer II CHT'01*, Palm Cove, Queensland, Australia, May 2001, p.1209-1218

KAVIČKA F., ŠTĚTINA J., SEKANINA B., RAMÍK P. and DOBROVSKÁ J. Numerical and experimental investigation of heat and mass transfer of a concasting. In *Proceedings of the 10th International Conference on Computational Method and Experimental Measurement CMEM X*, Alicante, Spain, June 2001, p.779-788

HEGER J., STETINA J., KAVICKA F., SEKANINA B. AND RAMIK P.: Pilot calculation of the temperature field of the ceramic material EUCOR. In Proceedings of the 7th International conference Heat transfer VII, Halkidiki, Greece, April 2002, p.223-232

HEGER J., KAVICKA F., SEKANINA B., STETINA J. AND RAMIK P.: Calculation of the temperature field of the ceramic material EUCOR. In Proceedings of the 42nd International foundry conference, Portoroz, Slovenia, May 2002, p.6-17

KAVICKA F., STETINA J., STRANSKY K., DOBROVSKA J., DOBROVSKA V., HEGER J.: Numerical analysis and optimization of an industrial concasting process. Book of abstracts of the Engineering systems design and analysis (ESDA 2002) conference and CD ROM, Istanbul, Turkey, July 2002, p. 23-24

STETINA J., KAVICKA F., SEKANINA B., HEGER J.: The influence of thermophysical properties on a numerical model of solidification. Proceedings of the 2003 ASME pressure vessel and piping conference, Vancouver, Canada, August 2002, Vol.438, p.147-152

STETINA,J., KAVICKA,F., DOBROVSKÁ,J., SEKANINA,B. AND HEGER,J. The importance of thermophysical properties for the accuracy of the numerical simulation of a concasting process. In Proceedings and CD ROM of The Sixteenth European Conference on Thermophysical Properties,London, UK, September 2002, p.319-320

HEGER,J., KAVIČKA,F., SEKANINA,B AND ŠTĚTINA,J.: Ceramics Eucor and its perspective. In Acta Metallurgica Slovaca, 2001, 5, p 519-523