COST 526

"Automatic Process Optimization in Materials Technology"
(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.1.2003 – 31.7.2003**
Project title	Optimisation of casting of corundobaddeleyit material EUCOR
Project leader Organization	**Prof.Dr.Frantisek Kavicka**
Main collaborators involved	Dr.J.Heger, Prof.K.Stransky, Prof.J.Dobrovska, Dipl.Ing.J.Stetina,Prof.V.Dobrovska,Dr.Sekanina, Dipl.Ing.P.Ramik

2. Funding Situation	
Amount of money received specifically for COST	9.100,- kEuros
Other resources partially used for the project	0,- kEuros

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

Participation in the Working Group Meeting in Saint-Dié des Vosges and Budapest

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

EUTIT, L.t.d., Stara Voda, Czech Republic, TU-VSB Ostrava, Czech Republic

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

6. Progress within the reporting period
(Not exceeding 3 pages, including tables and figures)

Corundobaddeleyit 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. This material is produced in several plants throughout the world under different trademarks, in three different types, differing mainly in the ZrO2 content.
CBMs are applied mainly in the construction of glass furnaces, in certain steel-works aggregates, especially within heating furnaces, etc. They have a high resistance to glass as well as liquid metal, they are also suitable for great temperature changes.

Slabs from this material are therefore very suitable for the walls and floors of melting aggregates, linings, pouring filters, isolation plates and for a number of other uses which can be accessible after mastering the optimising of the technology of their production and utility properties.

From the foundry viewpoint it is possible to compare the properties of EUCOR with those of commonly cast metals, especially steels and cast steel. For example, the solidification coefficient of steel when cast into a sand mould is approximately 0.07, here EUCOR is 0.065 and the solidification coefficient of steel when cast into a cast-iron mould is 0.13, here EUCOR is 0.163 [m.h$^{1/2}$], etc. This relationship can not be assumed generally. The proposed project will either confirm or disprove this.

The main objective will be to optimize the casting technology with the aim of ensuring a solidification process capable of minimizing the occurrence of internal defects within the CBM casting. Two numerical models will be developed, the first model of a transient 3D temperature field and the second the model of a chemical heterogeneity. The model for the investigation into the temperature field of a casting is based on the Fourier equation. The model for the measurement of dendritic segregation of constitutive elements and additives is based on Fick's 1st and 2nd law. It includes the law of preservation of mass, and the actual solution is based on Nernst's law, which quantifies, during crystallization, the distribution of chemical elements in the region between the solid and liquid states (i.e. between the solidus and liquidus). Both models simultaneously utilize the theory of similarity (the criteria of similarity), they deal with precisely physically/chemically specified quantities and neither contain nor introduce any empirically determined constants.

Simultaneously, with the numerical computation, the experimental research and measuring have to take place not only to be currently confronted with the numerical model but also to make it more accurate in the course of the process.

The procedure and method of investigative work

a) The selection of the operation for the application of both models and experimental research

After consulting the management of the foundry, a 200 x 350 x 400 mm massive plate casting (so-called 'stone') was selected for a detailed experimental investigation. The dimensions of the mould frames were 690 x 600 x 200 and 690 x 600 x 400 mm. The mould mixture was water glass and sand, and the base of the mould was magnesite. The manufacturer disclosed the forming procedure and casting, including the documentation, in order to conduct the generation of the network for the numerical calculation of this shape, and also to prepare the plan for experimental measurement using thermocouples.

b) The 3D numerical model of a transient temperature field of a casting

The numerical model of the temperature field was completed – as part of the preparation for the calculation, the initial derivation of the boundary conditions for the solution on all boundaries of the system had been conducted and the thermophysical properties of the cast and forming materials had been collected.

The software for the calculation is applicable for any size of prism (*a* x *b* x *c*) and a non-cylindrical mould. It also solves the temperature field of the mould as well as the actual casting. The software, using sub-programmes, considers the non-linearity of the task, i.e. the dependence of the thermophysical properties, primarily the material of the casting and mould on temperature, just like the temperature dependence of the heat-transfer coefficients on all boundaries of the casting-mould system with the surroundings and also the casting mould interface. Furthermore, it is equipped with an original generator of the network (for the use of the method of finite differences)

i.e. so-called pre-processing as well as post-processing – graphical output. The software, therefore, represents a comprehensive piece of equipment for the generation of the network, through the preparation of the thermophysical parameters (including the assessment of their influence) and the definition of boundary conditions (including the assessment of their influence) up to the numerical model of the temperature field. The user obtains the temperatures in all nodes of the network at any point in time of the process, and can select a longitudinal or cross-section through the solidifying casting or mould, of which a 3D temperature field can be plotted. The 3D diagrams can be displayed on the screen or sent to a colour printer whenever necessary, just like the calculated iso-lines or iso-zones. The 2D temperature-time graphs, which show the temperature history of any point of the system, are also very useful.
The calculation determines the overall time of the solidification of the casting and the position of the last solidifying. It is possible to evaluate the values of the temperature gradients in any part of the casting and at any point in time. It is also possible to determined the time, during which any point of the solidifying casting can be found within the solidification interval – in the so-called 'mushy zone'. This time is one of the input parameters for the numerical model of chemical heterogeneity.

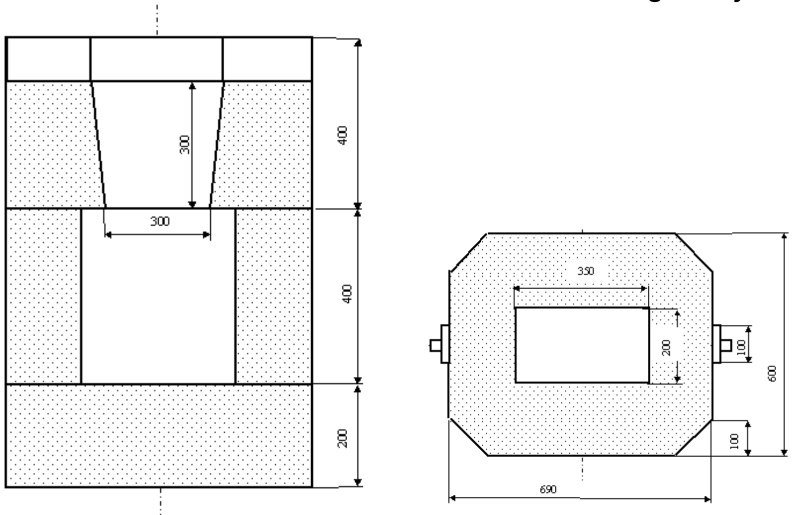

Fig. 1: The casting-riser-mould system

The assignment was aimed at investigating a transient 3D temperature field of a system comprising a casting-and-riser, the mould and the surroundings, using a numerical model. Figure 1 illustrates the main dimensions. The dimensions of the actual casting—the "stone" 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 equalled 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.

c) The optimisation task

- To define the objective function – a single function that depends on one or more independent variables. The purpose is to find the value of those variables where f takes on a maximum or minimum value.
- To define the following independent variables:

  - The pouring temperature
  - The riser shape
  - The thickness of the riser insulation
- To define constraints
- To select a suitable optimisation method

The objective function must be able to forecast so-called ‘directed solidification’, which is a prerequisite for the casting to be ‘healthy’. In order to monitor the process, the function **Z**, via which the minimum value must be found, is introduced:

$$Z=G/\sqrt{R} \quad R=(t-t')/\Delta\tau$$

G…. the maximum temperature gradient within the casting [K/m]

$\Delta\tau$ .. the time during which the node temperature drops below the solidus t_s [s]

$t>t_s$ ...the temperature at the beginning of the time step $\Delta\tau$

$t'<t_s$ the temperature at the end of the time step $\Delta\tau$

The calculation of the objective function requires the computation of the temperature field within the casting, which is very time consuming. Therefore, the initial stage of the optimisation process was focused on optimising only one variable (i.e. one-dimensional optimisation).

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

The next optimised variable is the riser shape. For the purposes of numerical optimisation, the method of increasing of the angle of the opening of the riser is used. This does not require a change in the shape of the network, but only its dimensions.

The last optimised variable is the thickness of the riser insulation. For the purposes of numerical optimisation, the wall thickness is substituted by a change in the heat conductivity of the insulation material.

The main constraint is the requirement that the place of last solidification be outside the actual casting, otherwise a penalisation function is triggered.

7. List of publications

a) Published

1. KAVICKA F., STETINA J.. Anumerical 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

2. DOBROVSKA J., BUZEK Z., DOBROVSKA V., KAVICKA F., STRANSKY K., WINKLER Z.: Contribution to the micro- a macroheterogeneity of a refractory corrundum-baddeleyite ceramics. Proceedings and CD ROM of the 9th International symposium METAL 2000, Czech Republic, Ostrava, May 2000, paper No. 133

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

4. TICHA J., SPOUSTA V.: Measurement of the course of primary cooling of the corrundum-baddeleyite material EUCOR. Proceedings and CD ROM of the 9th International symposium METAL 2000, Czech Republic, Ostrava, May 2000, paper No. 137

5. SALVA O., BŮŽEK Z., HUSAR I.: Application possibility of the corrundum-baddeleyite ceramics in metallurgy. Proceedings of the Czech Fundry Society Conference Czech Republic, Rožnov, April 2000, p.184-188

6. MELKOVA L., MAZANEC K., JONSTA Z.: Report about structure parameters of the corr undum-baddeleyite ceramics used to steel filtration. Research report, TU of Ostrava, Czech Republic, April 2000, 10 pages

7. PTÁČKOVÁ M., JANOVÁ D., BUCHAL A., KAVIČKA F. and STRÁNSKÝ K. Structure and phase characteristics of a corundum-baddeleyite cast ceramics.In Acta Metallurgica Slovaca, 2001, 7, p. 484-486

8. 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 2001, paper No. 29, p. 33

9. SALVA O., BŮŽEK Z. and HUSAR I. About CBC application in metallurgy. In Proceedings of abstracts and CD ROM of the 10th International symposium METAL 2001, Czech Republic, Ostrava, May 2001, paper No. 182, p. 36

10. STRÁNSKÝ K., BAŽAN J., BŮŽEK Z., REK A. and BELKO J. On the filtration of steel by means of different types of ceramics filtres. In Proceedings of abstracts and CD ROM of the 10th International symposium METAL 2001, Czech Republic, Ostrava, May 2001, paper No. 123, p. 37

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

12. KAVIČKA F., BUCHAL A., BŮŽEK Z., DOBROVSKÁ J.,DOBROVSKÁ V.,

STRÁNSKÝ K. and TICHA J. Castings from corundum-badelleyite ceramics, their properties and using for wear resistant materials, piping etc. Slévárenství, 2001 XLIX(2001), No. 9, p.524-529

13. HEGER J., KAVIČKA F., SEKANINA B. and ŠTĚTINA J. Solidification thermokinetics of a block from the ceramic material EUCOR. In Proceedings of the 20th International Conference of the hydro- and thermomechanics departments, Czech Republic, Kouty nad Desnou, June 2001, p.49-54

14. HEGER J., KAVIČKA F., SEKANINA B., ŠTĚTINA J., GONTAREV V. and KOSEC B.Pilot Calculation of the Tmperature Feld of the ceramic material EUCOR. In Proceedings of the Conference Metallurgical Ceramics. Rožnov, Czech Republic, October 2001, p. 107-116

15. STRÁNSKÝ K., BAŽAN J., BŮŽEK Z., DOBROVSKÁ J. and KAVIČKA F. Žáruvzdorná a otěruvzdorná korundo-badelleleyitová keramika, její vlastnosti a užití. In Proceedings of the Conference Metallurgical Ceramics. Rožnov, Czech Republic, October 2001, p. 39-45

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

17. HEGER J., RAMIK P., KAVICKA F., STETINA J., SEKANINA B.: Calculation of the temperature field of the ceramic material EUCOR and its importance. Proceedings of the 2nd international conference Industrial furnaces and refractory materials, Podbanske,Slovakia, June 2002, p.198-203

18. MOLINEK J., VACLAVIK L., KAVICKA F., SEKANINA B., STETINA J.: The experimental investigation of the temperature field of the ceramic material EUCOR. Proceedings of the 21st International conference of the departments of fluid mechanics and thermomechanics, Tatry, Slovakia, June 2002, p.86-92

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

20. Heger J., Kavicka F., Sekanina B.and Stetina J.: Investigation of the temperature field of the ceramic material EUCOR. In Proceedings of the 13th international scientific conference "Application of the experimental and numerical methods in Fluid mechanics", Oravsky biely potok, Slovakia, April 2002, p.18-23

21. Stetina, J., Kavicka, F., Sekanina, B., Heger, J.: The influence of thermopyhysical properties on a numerical model of solidification. Proceedings of the ASME PVP conference, Vancouver, Canada, August 2002, Vol.438, p. 147-152

22. Heger,J., Kavička,F., Sekanina,B., Štětina,J. and Ramík,P. Pilot 3-D simulation of the temperature field of the ceramic material EUCOR. In Proceedings and CD ROM of the 15th International Congress of Chemical and Process Engineering, CHISA 2002, Praha, Czech Republic, August 2002, p.202-203 and poster P5.31

23. 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

24. Dobrovská,J., Heger,J., Kavička,F., Sekanina,B., Dobrovská,V., Buchal,A., Stránský,K. and Medved,J. Cast corundum- baddeleyite ceramics - its chemical and mineralogical heterogeneity. In Proceedings of abstracts and CD ROM of the 10th International Metallurgical & Materials Conference METAL 2002, Hradec nad Moravicí, Czech Republic,May 2002, paper No.26, p.35

25. Stránský,K., Dobrovská,J., Dobrovská,V., Kavička,F., Štětina,J., Sekanina,B., Gontarev,V. and Kosec,B. Contribution to chemical heterogeneity and high temperature fracture behaviour of concasting steel slab. In Proceedings of abstracts and CD ROM of the 10th International Metallurgical & Materials Conference METAL 2002, Hradec nad Moravicí, Czech Republic,May 2002, paper No.27, p.32

26. Salva,O., Molínek,J., Václavík,L., Husar,I.and Kavička, F.: Problems of temperature measurement at corundum-baddeleyit ceramics casting. In Acta Metallurgica Slovaca, 2001, 5, p 476-480

27. Heger,J., Kavička,F., Sekanina,B and Štětina,J.: Ceramics Eucor and its perspective. In Acta Metallurgica Slovaca, 2001, 5, p 519-523

28. Dobrovska,J.,Dobrovska,V., Kavicka,F., Stransky,K. : Cast Corundum-Baddeleiyte Ceramics – Its Production, Properties and Use. In Proceedings of the 5th International Conference Metallurgy, Refractories and Environment, Stara lesna, High Tatras, Slovakia, May 2002, p. 19-24

29. Kavicka, F., Stetina, J., Heger, J., Sekanina, B., Ramik, P., Dobrovska, J. : Calculation of the tempearasture field of the solidifying ceramic material EUCOR. In the Proceedings of the ASME PVP Conference, Cleveland, USA, July 2003, Vol. 458, p.135-141

30. Kavicka, F., Heger, J., Stetina, J., Sekanina, B., Ramik, P., Dobrovska, J.: Numerical optimization of a casting technology of the special ceramic material. In proceedings of the World Multiconference on Systemics, Cybernetics and Informatics, Orlando, USA, July 2003, p.74-79

31. Kavicka, F., Heger, J., Ramik, P., Doborovska, J., Stetina, J.: A numerical model of the temperature field of the cast and solidified ceramic material EUCOR. Book of abstracts, International conf. CompTest 2003, ENSAM Chalons en Champagne, France, January 2003