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Virtualisation of casting engineering

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Manufacturing and processing

ABSTRACT

Purpose: Fast response to an enquiry, minimization of costs of identification of best-suited process solution, as well as a capacity to tackle new challenges is the shortest description of the requirements posed by the contemporary market of machines and equipment. These, in consequence, called for making use of mathematical models and their solution by means of simulation algorithms.
Design/methodology/approach: The notable effectiveness of numerical methods streamlined the production preparation process. Maintaining competitiveness, even more tough because of economic factors, is only possible due to cost-effective operation, high quality and well-timed order completion. These, on the other hand, can be facilitated by a broad application of IT tools aiding production management and preparation.
Findings: Integration of systems aiding design processes, systems used for simulating selected elements of technologies, as well as of systems supporting instrumentation manufacturing calls for a need to solve a number of complex problems related to IT, mathematical modelling, logistics and knowledge management. Software packages for a simulation of processes that are indispensable in order to achieve the designed distribution of matter structures and condition are of particular importance.
Research limitations/implications: Despite the fact that there is a wide range of software for these purposes available on the market, there is a need to build and integrate into IT systems new purpose-developed solutions customised to technologies applied and non-standard problems.
Originality/value: Virtualization of casting engineering
Keywords: Manufacturing and processing; Casting

1. Introduction

Currently, the most modern method connecting with preparing and producing casting is the virtual prototyping. The method consists of optimization of the casting technology through computer modelling and simulation. Application of simulation calculation enables virtual visualisation of phenomena course of a cast formation and a prognosis of its quality. It enables the constructor to make corrections and to optimize the material, technology or construction type.

Cost-effective operation, high quality and well-timed order completion can be facilitated by a broad application of IT tools aiding production management and preparation. Integration of systems aiding design processes, systems used for simulating selected elements of technologies, as well as of systems supporting instrumentation manufacturing calls for a need to solve a number of complex problems related to IT, mathematical modelling, logistics and knowledge management. Also in Poland there are, however, examples proving the applicability and cost-effectiveness of such solutions. It could be demonstrated that the benefits thereof are in direct proportion to the complexity of a system implemented at a given company. Software packages for a simulation of processes that are indispensable in order to achieve the designed distribution of matter structures and condition are of particular importance. Simulation of the fluid metal flow in a mould and then its solidification and crystallisation enables an experienced process engineer not only to immediately generate the best and most cost effective technology available, but also, thanks to appropriate simultaneous couplings with designing phases, to influence the optimal shape and parameters of the product. Despite the fact that there is a wide range of software for these purposes available on the market, there is a need to build and integrate into IT systems new purpose-developed solutions customised to technologies applied and non-standard problems.

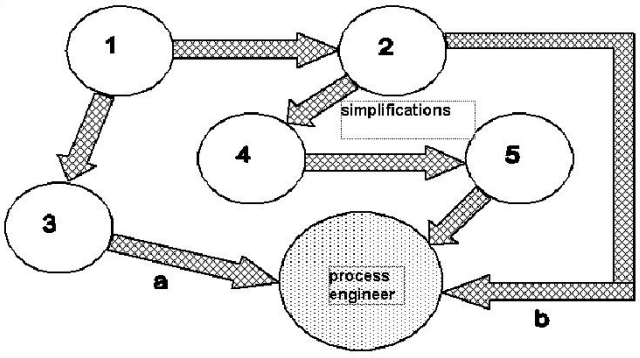


Fig.1. Modelling and simulation
1 – real system (e.g. solidifying casting);
2 – basic model being a full description, not necessarily formal one, of the real system;
3- experiment; simplified model in the form of a formal mathematical description;
5 – simulation algorithm; a – experimental results; b – technological experience.

Implementation of the aforementioned state-of-the-art tools is not an easy task, though. It requires expenditures, often times - large organisational changes in an enterprise and, what's fundamental, getting to know and understanding of the system by the staff. Additionally, it should be noted that non-standard problems can only be tackled in close co-operation with a scientific institution. An it is here where one can see a large contribution of Department of Modelling of Foundry Processes at the Faculty of Foundry Engineering of the AGH University of Science and Technology in Kraków. Thanks to a considerable academic output, in particular with respect to mathematical description of processes of heat and mass exchange, the Department's team is prepared to co-operate with industry and to educate competent engineering staff required to implement and operate systems for processing descriptions of manufacturing processes in foundry engineering.

Many results are made in the cooperation with the research working team from the former foundry department of the Silesian Technical University. Today, the department chaired by prof. Leszek Dobrzański is the continuator of their history.

It is also important to promote methods and solutions for virtualisation of production preparation processes. Participation in research on modelling solidification kinetics and other thermal processes in foundry engineering facilitates tracing changes and trends with respect to methods for solving complex heat and mass exchange-related issues.

2. Simulation of the macrosegregation process

Heat transfer in the domain of solidifying and cooling metal is accompanied by the process of the mass diffusion. Connected with this phenomena changes of alloy components concentrations are called the macrosegregation process. From the mathematical point of view the macrosegregation process is described by a system of partial differential equations determining the mass transfer in solid and liquid state sub-domains and adequate boundary-initial conditions. The very essential parameter determining the temporary alloy components distribution is the partition coefficient [2]. Its value results from the equilibrium diagram, but on the other hand the macrosegregation proceeds in the unbalance conditions. There can be find, in the literature, the suggestions of effective partition coefficient introduction [3, 4] but the definition of this parameter is rather ambiguous. The second parameter determining the course of macrosegregation process is the diffusion coefficient in the molten metal sub-domain. In this paper the mutual connections between the perturbations of partition coefficient and diffusion one and the course of macrosegregation are discussed, in particular the methods of parameter sensitivity analysis are applied [5, 6].

The macrosegregation process can be treated as a coupled one and then the crystallization rate results from the course of solidification (this means the course of thermal diffusion) but one can find the problems for which the process is treated separately. The typical example of such as this one phenomenon can be a directional crystallization proceeding with a constant rate (e.g. production of crystals using the Bridgman method). In this paper this simpler problem is discussed, this means the task for which the crystallization rate is known and results from the technological conditions of the process considered. The numerical model of macrosegregation is constructed on the base of a certain variant of the boundary element method called in literature [7, 8] the BEM using discretization in time. The special procedure called the artificial source method [9, 10] has been used in order to take into account the additional component appearing in the diffusion equation (written in moving coordinate system).

The sensitivity analysis of macrosegregation process, described in [1] is a modern tool for numerical simulation results description.

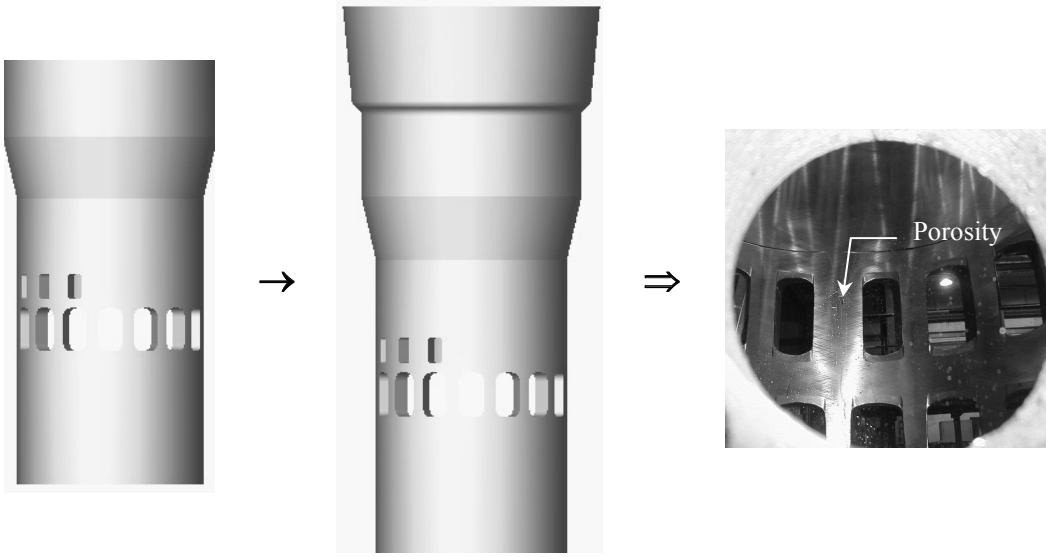
Because the sensitivity model is very similar to the basic model of macrosegregation (from the mathematical point of view, of course) therefore the numerical algorithms concerning the computations of segregation and sensitivity functions are practically the same. So the application of the sensitivity analysis method (the direct variant [5, 6]) does not require the 'construction' of the new computer programs and it is the essential advantage of approach proposed

3. Preparation of casting production

Virtualisation of production preparation process is the essential feature of modern casting. A quick answer for inquire, minimalisation of costs of finding the optimal technological solution and possibility to realize the new tasks, this is the profile of the requirements of the contemporary.

Paper [1] shows two ways of casting: classical and modern. The base of classical way of casting is the knowledge and experience of the technologist. The modern way of casting combines the knowledge and experience of technologist with simulation software. Simulation of liquid metal motion in the mould and next, its solidification process allows the technologist not only quickly to establish the best attainable and profitable technology

a)



b)

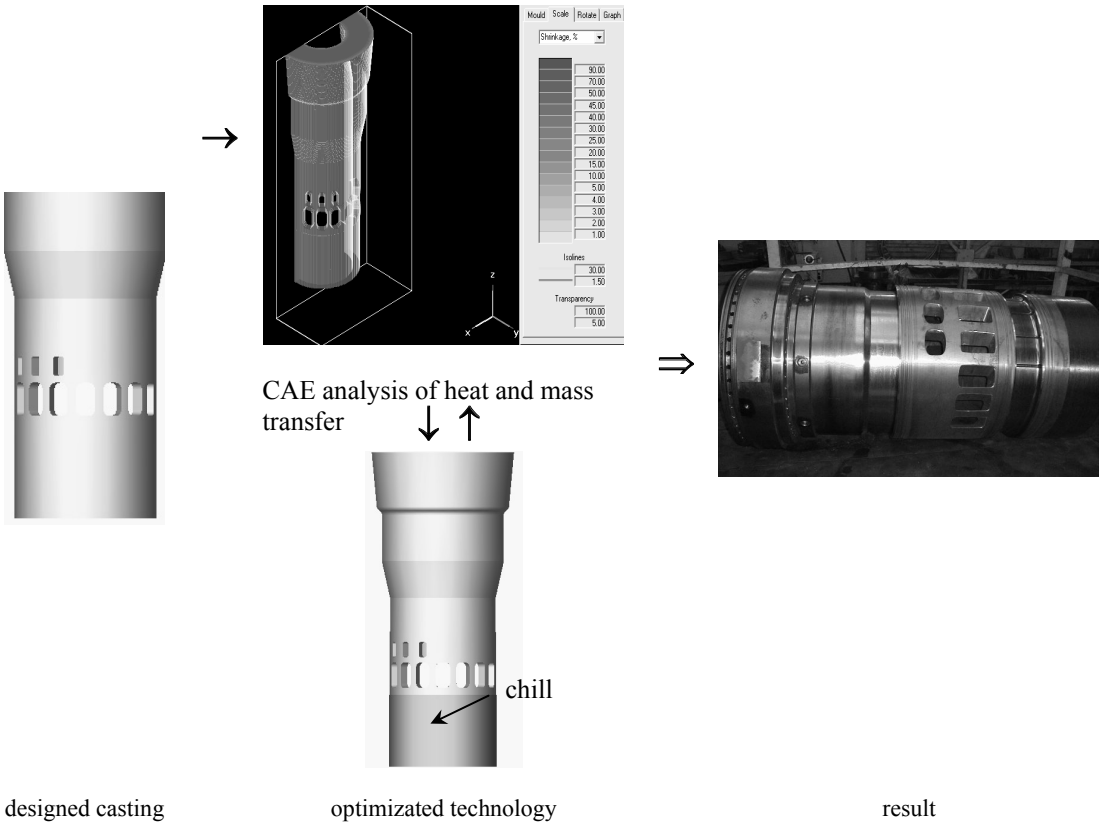


Fig. 2. Two ways of casting: classic (a) and modern (b) [1]

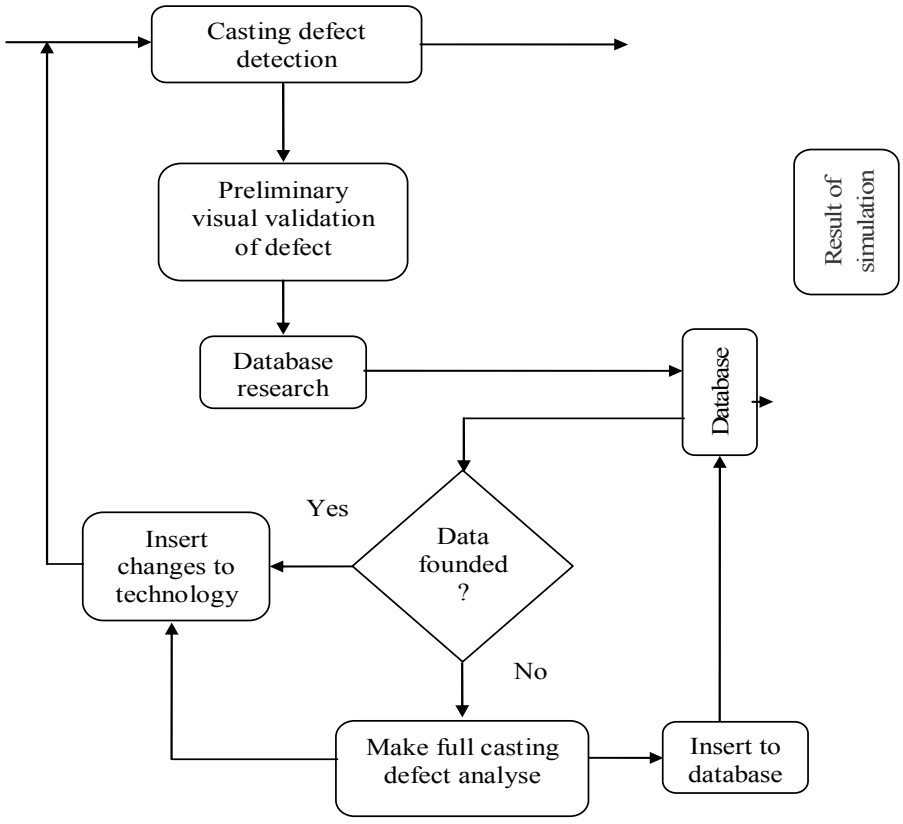


Fig. 3. Structure of the proposed database

but also, thanks to simultaneous feedback with designing, to co-create optimal shape and properties of final product.

The more complete analysis of such phenomenon as segregation of alloying elements in cast requires to analyse the sensitivity of the model for correct parameters selection.

4. Database applications

Presented in [10] database is the tool the servants to quicker optimization of casting technology through the elimination of casting defects and decrease the time of order realisation and decrease costs.

This is the database application which kept the information about the technology of filling process, the solidification of casting, occurrent defects, technological parameters such how the chemical constitution of cast, temperature of filling, kind of mould materials, kind of line moulding etc.

When the cast defect occur, technologist using this database application searching the identical cast, if it is in the database. We can use some of criterious to find the data:

- the kind of defect,
- the chemical constitution of cast,
- the kind of moulding materials,
- the gabarit of cast, etc.

When there is no similar casting in database, we add the record to the database. After that we can start analyse of the data. Comparing the real cast and the data from the database we can optimize the technology and eliminate of casting defects. The programme help us with block diagram and suggests us, what we should do. They are obviously this only hints which can we use. But mainly we should base on our own knowledge and experience. The structure of the proposed database as well as the location into the technological process is presented at the fig.3.
The database include also simulation of the solidification results, metallografical description and other resuls of investigations.

References

[1] J.S. Suchy, B. Mochnacki, E. Majchrzak, J. Lelito, M. Urbanowicz, Virtual prototyping as a way to produkt development, 66th World Foundry Congress, World Foundrymen Organization, Istanbul September 2004.
[2] J.S. Suchy – Segregation of alloy components during the directional solidification. Mechanics 76, 1983.
[3] H.D. Brody, M.C. Flemings – Solute redistribution in dendritic solidification, Transactions AIME 236 (1966) 615-634.
[4] W. Wołczyński, J. Kloch – Solute redistribution after back diffusion in cellular and dendritic growth of binary alloys, Bulletein of the Polish Sciences Academy, Techn. Sc. 3, 46, 1998, 277-288.

[5] M. Klaiber – Parameter sensitivity in nonlinear mechanics, J. Wiley and Sons Ltd., Chichester, England, 1997.
[6] K. Dems, B. Rousselet – Sensitivity analysis for transient heat conduction in a solid body, Structural Optimization 17 (1999) 36-45.
[7] E. Majchrzak – The boundary element method in heat transfer, Press of the Technical University of Czestochowa, Czestochowa 2001.
[8] C.A. Brebbia, J.C.F. TELLES, L.C. WROBEL – Boundary element techniques, Springer-Verlag, Berlin, New York, 1984.
[9] B. Mochnacki, J.S. Suchy – Numerical methods in computations of foundry processes, PFTA, Cracow, 1995.
[10] J.S. Suchy, P. Malinowski, Goal oriented project sponsored by the Ministry of Science, AGH University of Science and Technology, Kraków 2005 (unpublished).