MAGMA 6.0 – toolkit and capabilities of the latest version Of the **MAGMASOFT** software package

Georgi Evt. Georgiev

Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre "Akad. A. Balevski",
Bulgarian Academy of Science,
evtimovg@abv.bg

Abstract: The possibilities for simulation and optimization of foundry technologies using the latest MAGMA6.0 version of the world-famous software package MAGMASOFT are presented. The capabilities of the software are illustrated both for the quick and efficient construction of the 3D geometric models and for the diagnosis of almost all possible defects in a wide range of casting methods. Special attention is paid to the possibilities for autonomous and automatic optimization of casting technologies in order to reduce defects and increase the profitability of castings.
KEYWORDS*: MATHEMATICAL MODELING, COMPUTER SIMULATION, OPTIMIZATION, FOUNDRY TECHNOLOGIES*

1. Introduction

MAGMASOFT is one of the world-famous software packages for computer simulation and optimization of a wide range of foundry technologies. It has long become an integral part of research, design and development activities related to the refinement and optimization of casting technologies, the creation of castings with high operational qualities, the reduction of metal consumption, the realization of energy savings, the sharp reduction of time for the design-implementation cycle, fast and accurate, qualitative and quantitative diagnosis of a wide range of possible defects [1].

Created by the company MAGMA Giessereitechnologie based in Aachen, Germany [2], the package is continuously developed and enriched by the company's employees, through the development of numerous scientific projects with various units of leading German institutes such as the Foundry Institute in Aachen, Max Planck Institute, etc. The mathematical models included in the program are constantly updated, reflecting most of the most important scientific developments in the field of materials science, whether they are the subject of doctoral dissertations or scientific publications. Both the mathematical models are being extended and improved, covering an ever-wider range of phenomena and processes, as well as the database, which allows the treatment of an ever-wider range of materials and alloys, as well as casting methods. It is a well-known fact that MAGMASOFT has no competition in terms of the built-in database in the package. In this way, it successfully competes with the most famous and powerful programs in the industry, such as ABBACUS, PROCAST, ANYCASTING, NOVACAST, 3D-FLOW, LM-FLOW, PATRAN, etc.

In our country and more precisely at the Institute of Metallurgy at the BAS "Acad. A. Balevski" (Imet-BAS) in Sofia has been using MAGMASOFT for more than 10 years. Since 2005, IMSTCHA-BAN is the exclusive and official distributor of MAGMA GmbH software products for Bulgaria and has their latest versions available. It is authorized both to sell licenses for the use of the programs and to conclude contracts for the provision of technological assistance and the realization of specific projects with simulations and optimizations of specific foundry technologies. This issue aims to present the latest capabilities of the latest version of MAGMA6.0 software for computer simulation and optimization of foundry technologies.

Every casting technology simulation and optimization project begins with geometric modelling of the product and casting equipment. That's why MAGMA pays special attention to the geometric modeler included in the software.

2. Geometry modelling in MAGMA6.0

The geometric modeler in this latest version of the software offers a full set of tools to quickly and easily build surfaces and bodies with complex geometry - Fig.1.

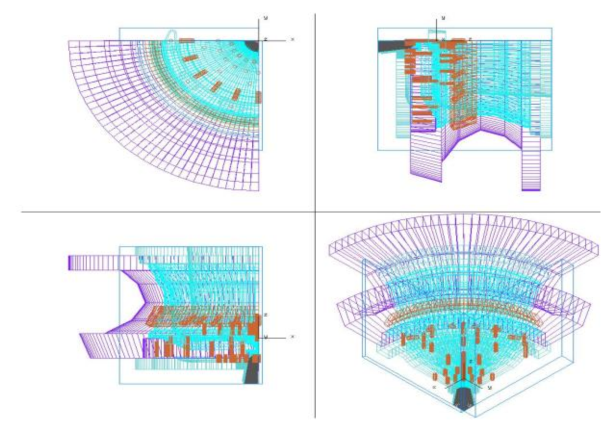


Fig.1.

The geometric modeler is equipped with all types of Boolean operations with 3D objects, enabling quick and easy construction and formation of new objects - Fig.2.

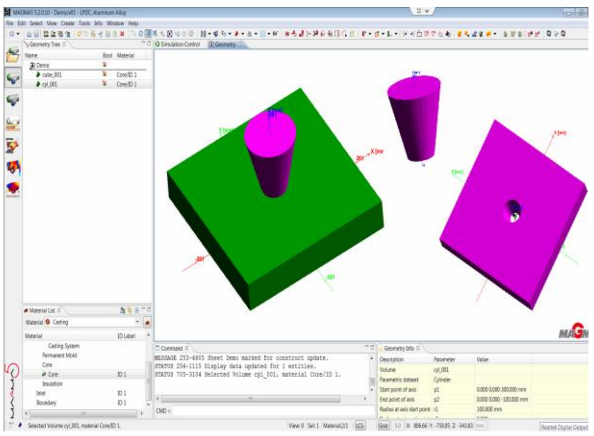


Fig.2.

In addition, MAGMA6.0 offers a full range of tools for building 3D bodies with complex geometry and it already supports almost all used formats for 3D design, as opportunities have been created to import geometric objects created with CAD products such as ProE, STEP, IDEAS, CATIA, NX, Solid Works, etc.

The software offers its own rich database of geometric elements such as feeders, runners, inlets, feeders, etc. while enabling customers to supplement this database with their own geometric elements – Fig.3.

***Fig.3**. Geometry data base*

In addition, it also offers components and materials of world-famous databases such as FOSECO, ASK, GTP Schafer and CHEMEX.

The main advantages of the geometric modeler include:

- Visualization in the style of leading CAD programs;
- Ability to work with Boolean operations on geometric objects;
- Ability to read and export the geometric objects;
- The funnel system inlet boundary condition is generated along with the “Tracer” tool points automatically – Fig.4;
- Setting control points on a given plane;
- Ability to create your own geometric base of bodies and objects;
- Easy and convenient access to FOSECO's geometric databases;
- A rich set of tools for operating with geometric objects: rotations, extrusion, sections, multiplication and many others.
- Tooling disassembly check, geometric error indication and disassembly visualization – Fig.5

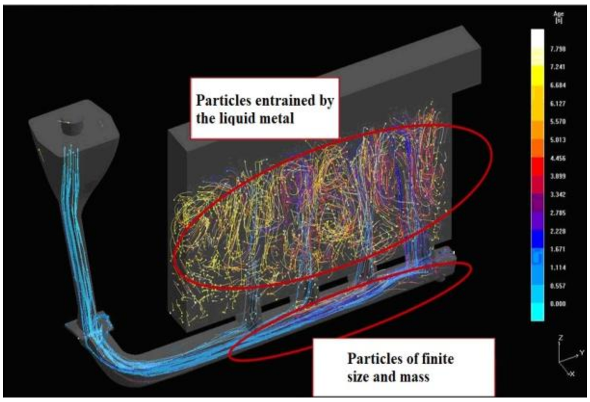


***Fig.4**. "Tracer" tool for particles of finite size and mass*

In the geometric modeler, some additional functions have been added, such as "shearing knife", object multiplication, vector or curve extruding, automatic "dressing" of differently oriented sections with a complex surface, separation and merging of objects, which make the modeler very useful.

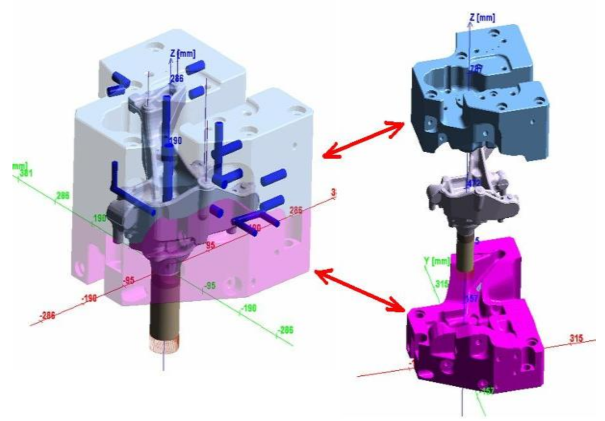


***Fig.5**. Disassembly visualization*

3. *For the world of steel*

Steel casting processes are characterized by:

- High pouring temperatures;
- Often large wall thicknesses;
- High levels of alloying elements.

For these reasons, the convective heat and mass transfer during cooling and solidification in many steel castings should not be neglected. It strongly influences the temperature distribution during the solidification process. Segregation of alloying elements exists at the grain or dendrite scale. Through the melt movement, these result in large concentration differences in the casting (macro-segregation).

At first, the local temperature differences in the melt are the driving force of the thermal convection. In Fig.6 you can see the thick-walled section of a casting in sectioned view. The warm and, thus, light material fractions shown in the center flow upwards, whereas the cold and heavy fractions at the edges flow downwards. This leads to the typical thermal convection movement.

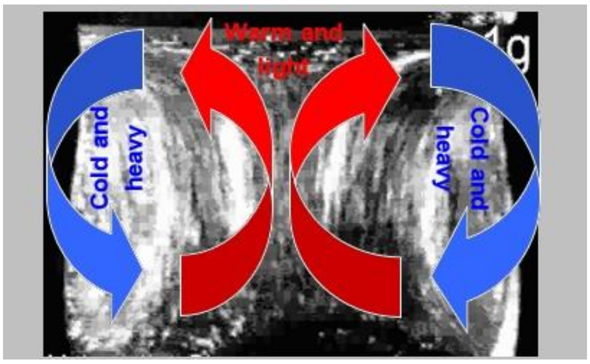


***Fig.6**. Thermal convection*

The flow motion is hindered by the progressive solidification. In the solidification interval, below the liquidus temperature, the liquid fractions increasingly convert to solid fractions. The resistance to the flow in the so-called 'mushy zone' is characterized by the permeability (Fig.7). It is stored in the material data set of the cast alloy according to the fraction solid.

If convection is considered for the solidification simulation of steel castings, the local values and directions of the velocity of the melt ('velocity') are additionally generated as simulation result. Similar to the flow occurring during the filling of the mold, also the flow movements caused by convection can be displayed by means of tracer particles. Particularly the possibilities arising through tracer particles having both a size and a mass can be used to calculate, for instance, the movement of inclusions or slag particles with the convection. As in reality, particles in a "freezing" area are retained there and remain in the solidified casting.

The solver of MAGMA6.0 includes physical-mathematical model that realistically and adequately describe these phenomena.

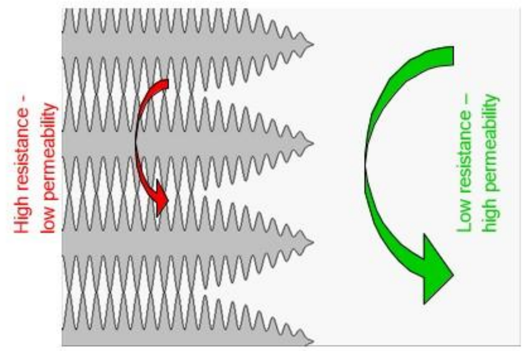


Fig.7*. Resistance to the convective flow through growing dendrites: Permeability K*

Fig.8*. Modelling of the thermo-solute convection*

MAGMA6.0 is also equipped with a model describing macro-segregation in castings. For every alloying element, the solubility both in the solid state and in the melt changes based on temperature. The resulting concentration differences in the solid state can only be balanced by means of diffusion processes, which requires a certain time. Cooling usually occurs so fast that this balance cannot be fully achieved.

Alloying elements not incorporated into the solid during solidification accumulate at the solid-liquid interface. The result is a concentration gradient in the solidified material. This so-called micro-segregation occurs at the crystal/ dendrite scale.

If it was possible to quickly balance the concentration differences in the crystal, a constant concentration would be reached here as well – namely, the equilibrium concentration. In reality, however, a balance of the concentration can only be achieved through the process of diffusion. This process is very slow, resulting in varying concentrations in the crystal based on the distance from the solid-liquid boundary. As solidification progresses, the solid-liquid boundary moves in the direction of the arrow.

Through the convection of the molten steel, the inhomogeneities existing in the crystal produce concentration differences, which are widely spread throughout the casting (macro-segregation). Fig.9 schematically shows the convection flow which entrains the segregated area of a solid-liquid interface. Fig.10 depicts the Cr concentration in a casting as a simulation result.

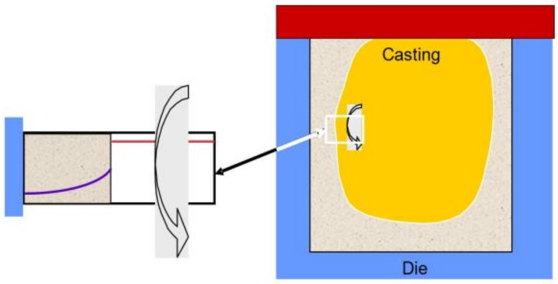


Fig.9*. Through the convection in the casting, the micro-segregation (to the left) is widely spread and is converted to macro-segregation*

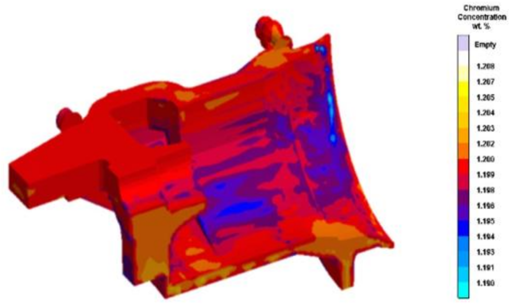
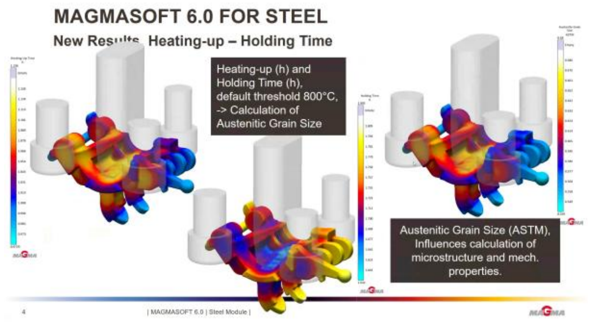


Fig.10*. Macro-segregation shown using the example of the Cr concentration*

MAGMA6.0 calculates and visualizes also the distribution of austenitic gain size and steel microstructure - Fig.11.



Фиг.11.

Two new characteristic temperatures are also offered in the version -A3 and martensite start temperature, based of segregation calculations – Fig.12.

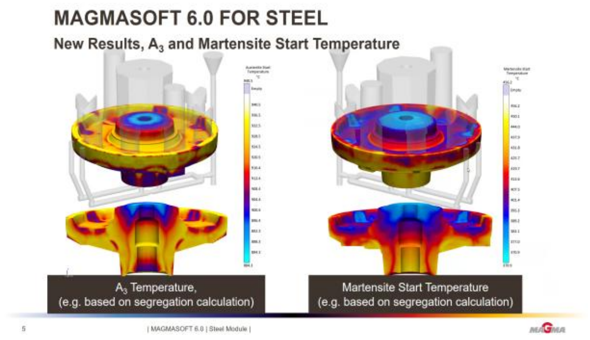


Fig.12

The software also offers a prediction of the hardness distribution in different units (Vickers, Rockwel and Brinell) of the formed casting at each of its points - Fig.13.

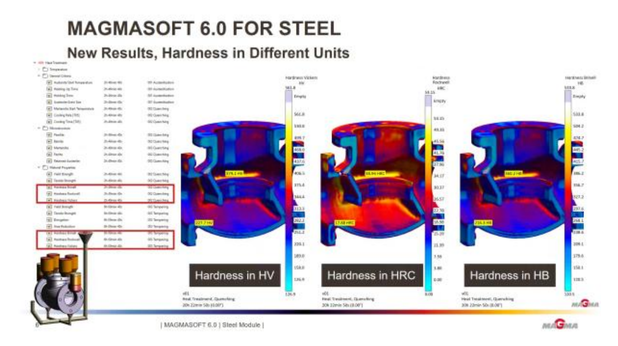


Fig.13.

Additional it give as a phase distribution based on CCT diagrams – Fig.14.

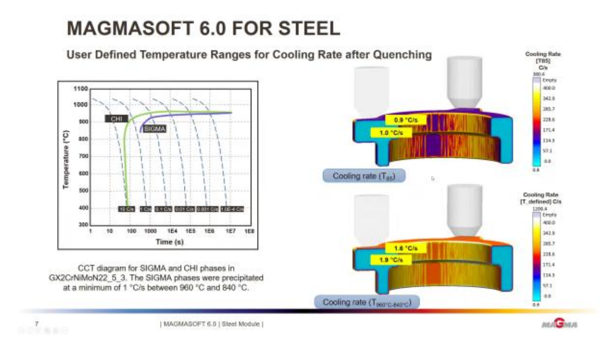


Fig.14.

4. Autonomous and automatic optimization

MAGMA is the first of the software products for the simulation of foundry technologies, offering, in addition to the classic approach for their optimization through an interactive - iterative computer-operator process, the implementation of automatic and autonomous optimization of the components of the casting-mold system, as well as of the technological parameters. An algorithm is build and followed for this purpose for optimization of the foundry technological process [3]. It starts with a heuristic version of the technology, goes through an internal cycle of automatic optimization, realizing goals set by the operator in advance, and is closed by an iterative circle, including the judgment of the specialist - technologist.

For the purposes of automatic optimization, the geometric objects are parameterized, which makes them useful to be vary these parameters in pre-set intervals. One such parameterization is presented in Fig.15 on the example of a simple feeder.

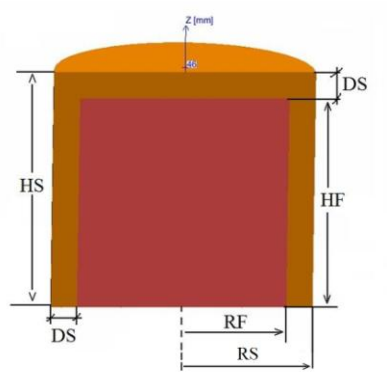


Fig.15*. Parametrized Feeder*

To select the optimal solution, a special toolkit is applied, one of its components being the diagram presented in Fig.16.

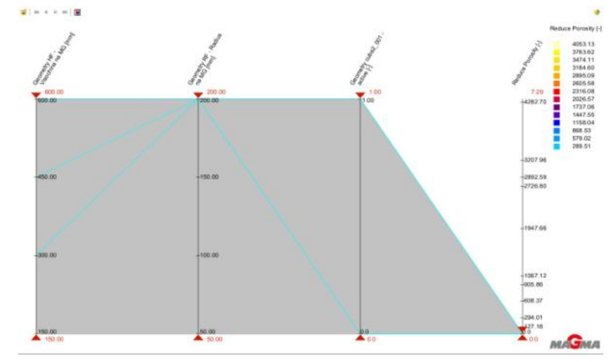


Fig.16.

4. New casting methods in software viewNew foundry technologies are

4.1. Continuous casting

From several years, MAGMA has been actively and successfully developing modules dealing with the formation of ingots under continuous casting conditions for aluminum and steel alloys.

It is schematically presented in Fig.17.

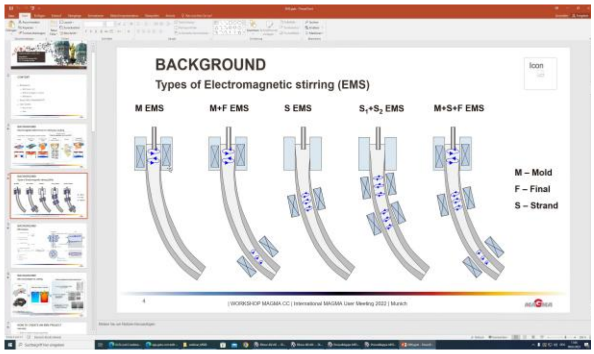


Fig.17.

In the latest version of the MAGMA6.0 software, the mathematical model is enriched with the possibility of electromagnetic stirring of the liquid phase along the length of the ingot - Fig.18 and Fig.19.

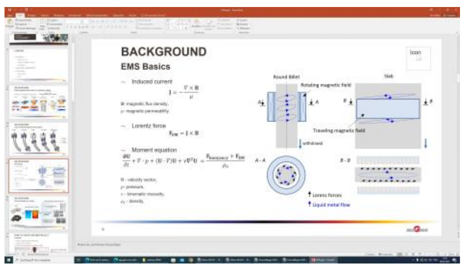


Fig.18.

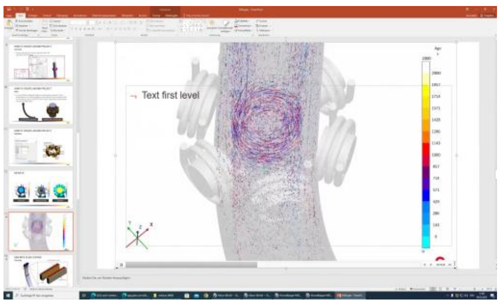


Fig.19.

4.2. MAGMA core – mold simulation

MAGMAc+m is a completely new simulation software designed to model the core production process. It makes core production predictable. Trial and error is replaced with knowledge. The program uses validated models for the multiphase flow during core shooting. It considers the curing kinetics during gassing and purging for the commonly used 'PU-Cold-Box' and also for the increasingly used inorganic binder systems. MAGMAc+m covers the complete core production process: core shooting and core curing. It is perfectly integrated into the MAGMA6.0 environment.

During core shooting, sand is rapidly forced into the core box by a sudden expansion of air. The real machine does not provide any insights into the processes taking place during core production. Little is known about how the processes work. In practice, the design of core boxes and the determination of suitable process parameters are done based on experience and, ultimately, by using trial and error. Core shooting is the most important process step. After shooting, the core sand must be compacted in all relevant core areas. Most of the optimization work is done when optimizing the core shooting process to ensure the required quality of the cores. Expanding air shoots sand through the shoot nozzles into the core box. The sand compacts in the core box and the air escapes through the core box vents (and possibly through the ejector gaps and via the parting line).

A typical scheme for the formation of sand cores by shooting is shown in Fig.20.

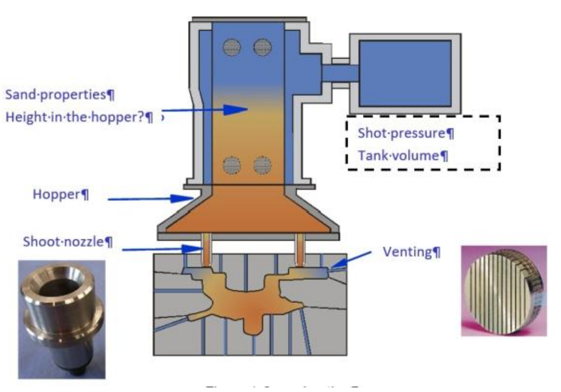


***Fig.20**. Core shooting*

The core curing process depends on the binder system used. For gas curing processes, different curing gas types are used that are either part of the chemical reaction or that are necessary to accelerate the curing through reaction catalysis. Its operation scheme is presented in Fig.21

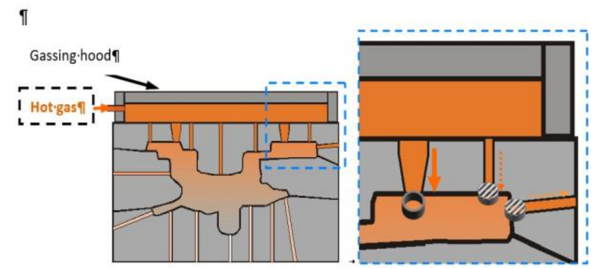


***Fig.21**. Core curing*

The hopper is replaced with a gassing hood. Usually, the complete "open area" at the top of the core box is used for "active" gassing. Hot gas is injected into the core box, and the core is cured. The curing physics and chemistry strongly depend on the binder type. The methodology is used for all common gassing procedures, for PU cold box systems as well as for inorganic binders.

Other systems such as hot box or croning systems are simply cured in a thermally controlled core boxes without additional gassing.

The follow image shows typical core production geometries in the Geometry Perspective's workspace of MAGMA6.0 – Fig.22.

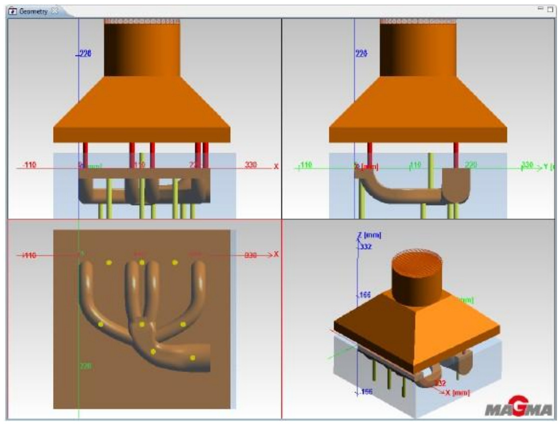


***Fig.22**. Geometry for core shooting wit hopper and inlet in four-view layout*

The simulation with MAGMA 6.0 of both processes leads to a reliable assessment of the quality of the formed core – Fig.23.

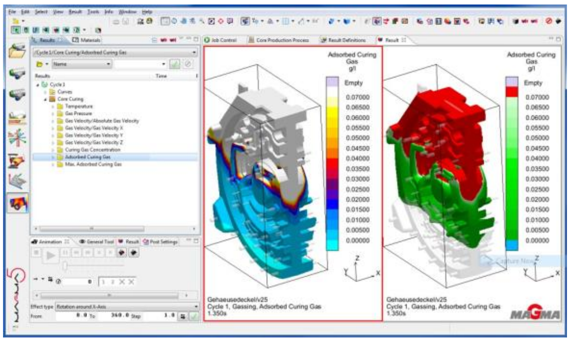


***Fig.23.** The concentration of the adsorbed curing gas constitutes an excellent criterion for the evaluation of core curing*

5. Conclusion

The MAGMA6.0 software package is based on state-of-the-art mathematical models of the physical processes involved in the formation of castings, making it an extremely useful tool for:

- formation of high-quality castings;
- forecasting the structure and mechanical properties of the products;
- optimization of a wide range of casting technologies;
- assessment and control of the quality of the manufactured products;
- increasing the economic efficiency of foundry technologies.

The author is convinced that the new generation of the software will be extremely useful in efforts to improve the efficiency of foundry technologies by forming high quality products with minimal material, energy and human resources.

6. References

1. Flemings, M.C., Solidification Processing, NY, Massachusetts Inst. of Technology,1974.
2. Sahm P. R., P. N. Hansen, Numerical Simulation and Modelling of Casting and Solidification Processes for Foundry and Cast-house", CH-8023, Zurich, CIATF, 1984.
3. Georgiev G. Evt., N. Tonchev, Iv. Georgiev, P. Petrov, V. Videv, Computer Optimization of a Technology for Forming a Steel Casting, Engineering Sciences, ISSN 1312-5702, LII, № 2, pp.73-80, 2015.