Elaboration of a casting defects prediction technique via use of computer-aided design systems

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Abstract: In today's highly competitive world modernization of the already known production processes and design of new ones is the main tendency in improvement of any kind of production. Computer and innovative technologies allowing a cost-effective adjustment of a technique for development of the best-quality castings play quite a significant role in advancement of the parts production process. All this finally results in saving of materials, energy resources, working time, decrease of equipment wear rate and in return we'll get a considerable amount of unique information on the production process.

Key words: casting, production process, computer model, cast product, feeder gate system, ProCast, computational grid, initial and boundary conditions, casting defects, production process optimization, numerical modeling.

The current economic conditions resulted in considerable decrease of production output both in the aviation industry as a whole and the aviation engine-building sector in particular which caused obvious changes in production technologies and process engineering. Besides entry of the home aviation engine-building sector into the world markets and participation in the international cooperation in the sphere of aviation equipment design necessitate approximation, i.e. harmonization of the aviation equipment design processes inclusive of technology with the foreign ones. Integrated use of information technologies for the foreign aviation equipment design requires from a home aviation engine-builder to change towards the same [1].

By now various casting methods have been mastered well enough and are being used, it is necessary to mention the following among them: investment casting; permanent-mold casting; pressure die casting; regulated-pressure die casting; centrifugal casting; other specific kinds of casting (consumable-pattern casting; casting with patterns made by laser stereolithography; continuous and semi-continuous casting etc.).

Investment casting (IC) holds a specific place for it is one of the innovative methods for half-finished products manufacture. Use of this method results in significant reduction of metal consumption, time of a part production and its production cost. If it was not for investment casting some of the industries would not achieve the present level of development. Investment casting is successfully employed in the following industries: aircraft engineering and engine-building; machine-tool building and mechanical engineering; implanted medical devices production.

Complexity and high value of the facilities and products of the modern growing aviation and machine engineering sectors precondition mandatory use of virtual modeling for every cycle of an industrial process.

Computer-aided analysis of the casting processes at the stage of casting technique design (before cast products manufacture) allows minimizing eventual miscalculations and errors inevitable for every design process, reducing financial and time expenditures, increasing efficiency, competitive ability, quality and reliability of the products being designed.

Replacement of expensive and resource-intensive development works by almost free-of-charge computer experiments is one of the most efficient ways to achieve the above mentioned goals. It ensures saving of materials, energy resources, working time, decreases equipment wear rate and in return we'll get a considerable amount of unique information on the production process. Nothing but computer modeling allows to "look inside" a product, to get to know the nature of inner processes and to understand the reasons of defects occurrence. It is comprehensiveness of the received information that turns modeling into the promptest way to achieve the intended result. Alternatively a full-scale experiment is always associated with unawareness, when even the most experienced production engineer deals only with the end result based on which he tries to deduce the whole course of the process.

Implementation of computer technologies brings about reduction of costs, decrease of labor intensity involved in designing and mastering production of new complex items. Costs connected with production documentation preparation are being reduced by 30…40 %. Terms of output of new complex items are being reduced by more than 35%.

Software for modeling the process of a cast product hardening and macro- and microstructure formation is a key element of virtual production of castings. Selection of software depends on the employed casting processes and the range of output products.

At the moment there can be found more than ten computer-aided design systems for casting process modeling (CAD CP). The specialists well know the German program Magma and American Procast, it is necessary to mention here as well American SolidCast, Finnish CastCAE and German WinCast. Two projects (“Polygon” and LVMFlow) originate from Russia.

This article plans to analyze suitability of ProCast CAE software product for modeling of a casting production process for the parts designed for application in the aerospace industry [3]. A sleeve part was used as an exploration object (Fig. 1).

Fig. (1). CAD model of a sleeve part

The finite elements method (FEM) allowing more accurate simulation of a cast product geometry and which is used in ProCAST software product is the most advantageous for casting of parts with thin-walls, thin ribs and irregularly-shaped conduits.

Virtual foundry implemented on the basis of the up-to-date ProCast CAE-system both simulates hardening of cast products (heat problem) and allows to predict macro- and microstructure of the cast products and to create an informational pattern of the cast product electronic analog.

The stages of modeling of the casting production process for the sleeve part include preparation of a geometrical pattern (3D-model of a casting block and 3D-grid), determination of thermophysical properties of the materials, setting of boundary conditions (simulation of real production process), setting of physical and shrinking (thermophysical) properties of the cast product material.

For design of 3D model of the cast product and a feeder gate system of the sleeve the already existing process was used (Fig. 2).

Fig. (2). 3D model of the cast product with the feeder gate system

Figure 3 shows the results of hydrodynamic calculation for filling the shell molds.

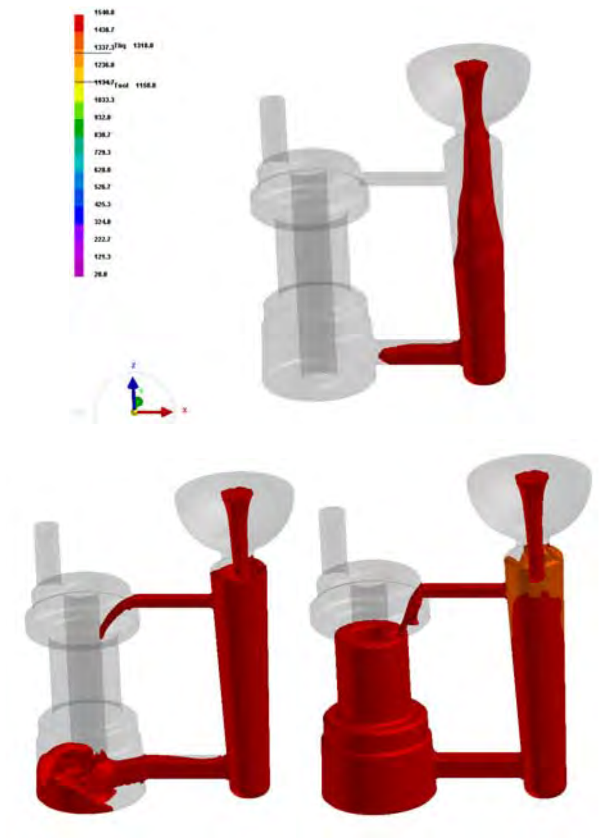

Fig. (3). Presentation of the mold filling results

X-ray control images demonstrate that molten metal is supplied relatively in a smooth flowing manner into the cast product feeders, this evidences efficiency of the flow gates, risers and feeders in particular, and of the feeder gate system as a whole.

Figure 4 presents the process of the cast product filling and crystallization.

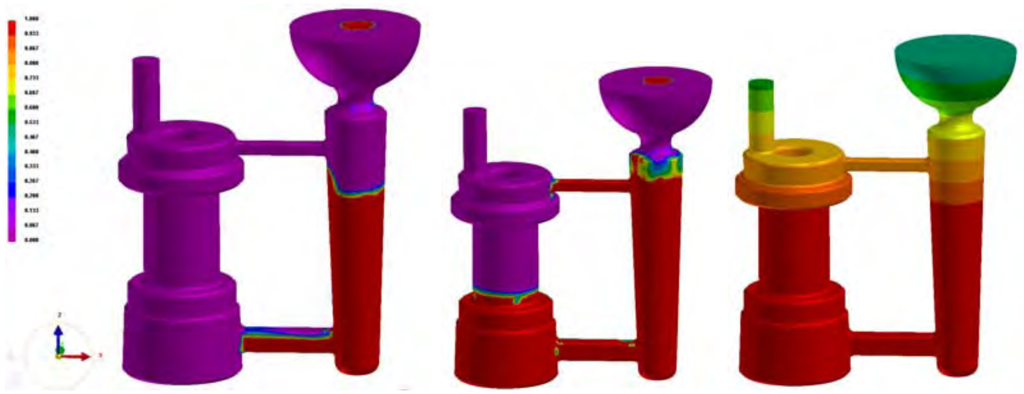

Fig. (4). X-ray control image of the cast product crystallization

The results of modeling show even crystallization front and its direction.

Cavities distribution for the start and the end of the filling process is shown on Figure 5.

The results of modeling demonstrate presence of cavities inside the cast part as well as of shrinkholes (Fig. 6) which eventually will lead to misruns in the part and as a consequence to defective quality. Therefore it is possible to conclude that the chosen feeder gate system is not effective. In order to avoid casting defects it is necessary to optimize the production process of the sleeve filling, namely to change the feeder gate system configuration, to change the filler neck flow section since metal solidifies before the mold is filled out completely as well as to change the initial and the boundary conditions of the filling process, namely filling temperature and speed.

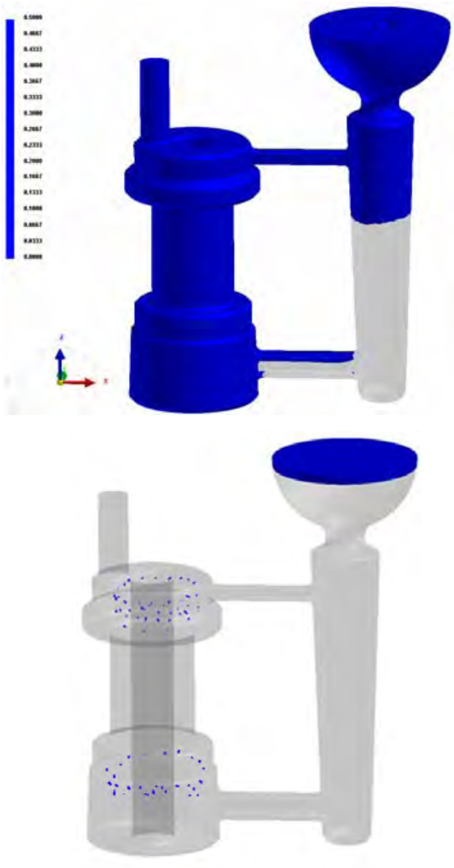

Fig. (5). Cavities distribution inside the cast product at the start and at the end of the filling process

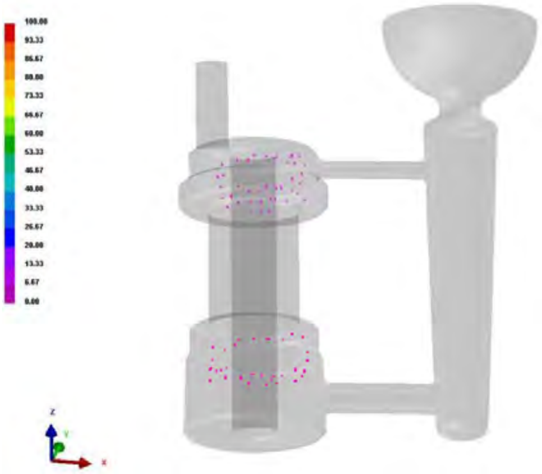

Fig. (6). Shrinkage at time of the sleeve filling

Experimental fillings of the sleeve part showed casting defects (Fig. 7), namely presence of microporosities and shrinkholes which were predicted by computer modeling. This fact evidences appropriateness of the applied software product in the sphere of computer modeling of the casting processes which predisposes its use for prediction of casting defects before the casting process itself.

Fig. (7). The sleeve with casting defects

The formed casting defects confirm necessity to optimize the existing sleeve casting production process [2]. Due to this the feeder gate system configuration was slightly changed (Figure 8).

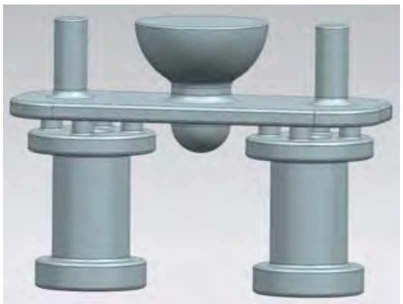

Fig. (8). CAD models of the cast products with the feeder gate system

Figure 9 presents a flow pattern of velocity pressure of the process of filling an investment mold with metal along Z axis.

Movement velocity of molten metal particles along Z axis grows from the start moment of filling the investment mold. By the end of the filling process molten metal has even particles velocity profile across the whole volume along Z axis which smoothly reduces up to 0 m/sec.

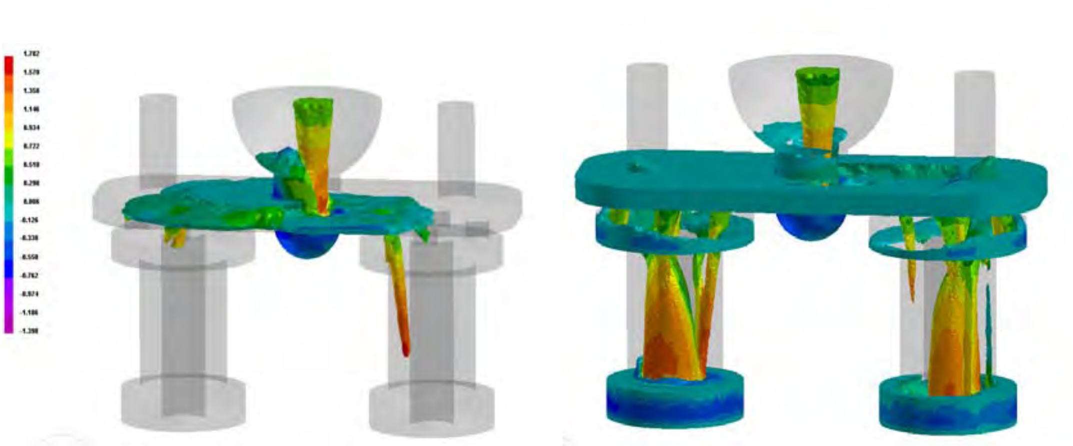

Fig. (9). Distribution of alloy speed along Z axis at time of the shell filling

The process of crystallization and the volume of filled in alloy is shown on Figure 10.

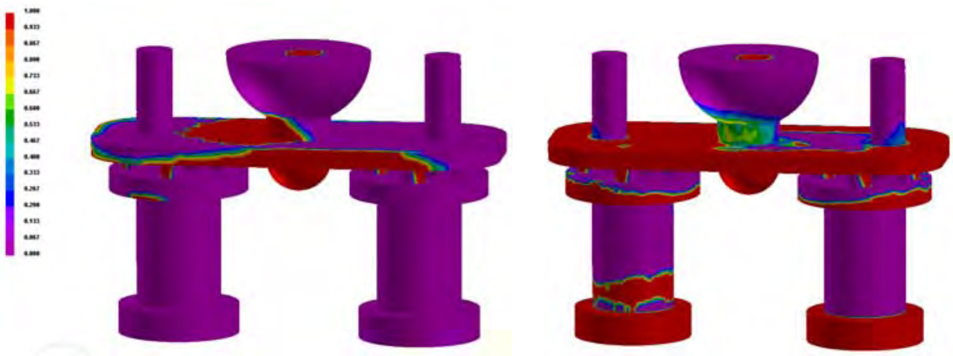

Fig. (10). Distribution of alloy liquid fraction at time of the shell filling

X-ray control images show that liquid fraction makes 100% of inner volume of all of the cast products at the end of filling process, therefore modeling of the process of filling demonstrates high quality of filling the explored shell mold with liquid alloy.

Distribution of cavities in the cast product at the beginning and at the end of the filling process is shown on Figure 11.

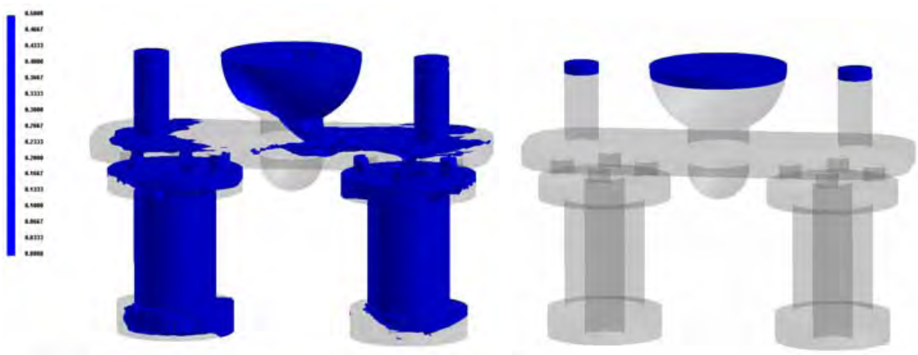

Fig. (11). Cavities distribution in the cast product

Analysis of the modeling results showed absence of cavities in the cast product. The result of filling shows shrinkholes only in the area of vents (Fig. 12). The cast product itself is free from spongy defects which evidences efficient feeder gate system configuration as well as proper parameters and conditions of the filling process.

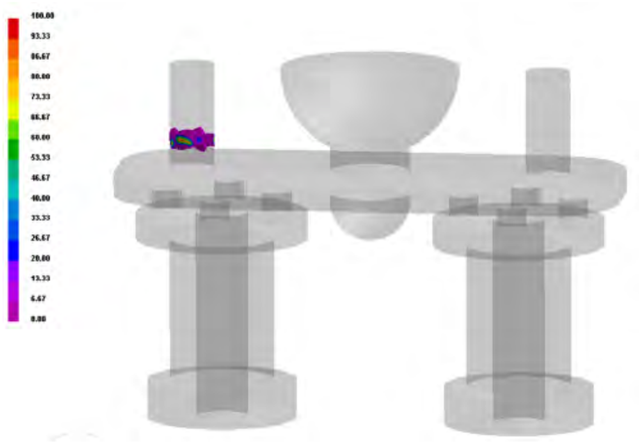

Fig. (12). Formation of shrinkholes after filling the sleeve

Therefore the software system ProCast as applied to various production casting processes and employing a complex mathematical tools technique adequately describes physical properties of the casting processes and allows comprehensive analysis of the technology inclusive of any foundry production conditions. Flexibility of this software suite in combination with practical experience of its developers guarantee that ProCast will make it possible to solve any new problems occurring due to change of the technology at an enterprise [4].

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References

[1] Balyakin A.V. Use of additive technologies in combustion chamber components design [Text] / A.V. Balyakin, V.G. Smelov, L.A. Chempinskiy - Vestnik of Samara State Aerospace University named after Korolev S.P. (of National Research University). – 2012. - № 3-2 – p. 47-52.

[2] Vdovin R.A. Multiproduct manufacture process improvement [Text] / R.A. Vdovin, V.G. Smelov – Izvestiya of Samara Scientific Center of Russian Academy of Sciences, v. 15, № 6(3), 2013 – p. 612-619.

[3] Vdovin R.A. 3D virtual simulation and casting process optimization for "SWIRLER OF II DUCT" part of GTE with use of computer technologies [Text] / R.A. Vdovin, V.G. Smelov –Vestnik of Samara State Aerospace University named after Korolev S.P. (of National Research University). – 2012. - № 3-3 – p. 115-120.

[4] Vdovin R.A. Experimental approbation of rapid prototyping technology using a catalytic combustion chamber as an example [Text] / R.A. Vdovin, V.G. Smelov – Collected papers of “New materials, advanced technologies of metallurgy” symposium. VIAM, 2014.