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NUMERICAL SIMULATION IN OPTIMIZATION OF THIN-WALLED EN-GJL-200 CASTING

Abstract

Implementation of new strategies and concepts such as "Near net shape castings" and "Right for the first time" represent an imperative for nowadays foundry production. High material utilization, with minimal number of forming operations and defects avoiding is the main goal for casting producers. Therefore, numerical simulation as a part of CAD/CAE technologies represents an indispensable tool for achieving competitiveness on global market.

Numerical simulation of casting poring and solidification represents a description of physical phenomena based on mathematical model. The application of computer numerical simulations, which are based on complex and comprehensive mathematical models such as Fourier law, found its significant application in consideration of thermal processes in the foundry. Numerical simulation enables analogical display of metallurgical processes by calculation and graphical disposition of the process from the pouring to the final casting solidification. Solidification process is very complex process which comprehends knowledge related to material and technology behaviour and interactions. Complexity of metal casting consists from element interactions and mass transfer during solidification, and technological development including heat transfer. The most useful numerical method is finite difference method due to its simplicity, but the finite element method is more accurate and does not have any limitation with respect to the complexity of geometric shapes.

The focus of this investigation was optimization of pouring and solidification process of thin-walled EN-GJL-200 casting using numerical simulation. Complex geometry of thin-walled casting represents the challenge due to crusted parts and stress bending of casting in existing technological set up. Numerical simulation optimization reveals changes in technological parameters of gating system, venting system and support. Optimization enables even filling of castings in order to prevent an extensive thermal overload and consequently stress of particular parts of castings.

Keywords: *numerical simulation, EN-GJL-200, thin-wall casting, solidification*

Introduction

Numerical simulations are increasingly used to control metallurgical process such as pouring and solidification. Depending on the time processing required for each task, the simulations can be divided into two groups: on-line processes (numerical operations in a very short time such as process management, preparations of mold sand, dosing of furnaces, blowing of white pig iron in converters, burner operation mode, etc.) and off-line processes (solving numerical operations over a very long period such as casting, solidification, heat flow, fluid flow, material deformation, etc.)

There are different approaches of solving the above problems, such as experimental, theoretical and numerical. The most acceptable approach is numerical due to its accuracy, applicability, and costs. The general problem of heat conduction lies down in determination of the temperature at each point of a rigid body, for which the initial temperature and heat flux distribution are known with defined limited and boundary conditions according to the *Fourier law*. The dependence of geometric and physical quantities in continuum mechanics is established on the differential element. The solution of differential equations is reduced through appropriate discretization to the solution of a system of linear algebraic equations with nodal unknowns. The most commonly applied method of discretization of differential equations of heat and mass transfer are numerical methods [2]: finite difference method (FDM), finite element method (FEM), control volume method, edge element method.

The most commonly used numerical methods are: finite difference methods due to their simplicity and finite element methods due to lack of limitation regarding the complexity of geometric shapes [2].

Depending on the requirement of the posed problem being, an appropriate numerical method is selected, using appropriate numerical simulation software.

The finite element method belongs to the methods of discrete analysis and is based on the physical discretization of the considered continuum domain. The basis for the calculation is a part of the domain of finite dimensions, i.e. the finite element, and the continuum is a network of finite elements. According to the way of deriving and formulating equations that describe the state of an element, there are four basic aspects of the finite element method: direct methods, variation methods, the weight residue method, and the energy balance method. In the numerical analysis of heat conduction, the weight residue methods and the variation method are used. Each finite element is characterized by the shape of the element, the number of nodes, the number and type of unknown quantities (parameters) in individual nodes. Depending on the shape and unknown sizes, different types of finite elements are derived, namely one-dimensional (linear), two-dimensional (triangular and quadrangular) and three-dimensional (tetrahedral and prismatic) elements. Two-dimensional triangular and three-dimensional tetrahedral elements are most often used in geometries with curved surfaces [3].

In nowadays, self-sustainable foundries must adjust to the high demands of the global market and therefore seek a solution to meet them based on the concept *Right for the first time* [4]. In the last decades, the most important management tool introduced in foundries is *Lean manufacturing* [5,6]. The principles of such production are to shorten the adoption time of the product, improve the quality and to be adaptable to the customer. One of the economical ways of producing cast components is the *Near net shape process* concept of casting to an almost finite shape / dimension [7]. For the customer, this means a reduction in secondary operations on components that have a narrower tolerance, and for the manufacturer, maximum profit.

Fulfilment of customer requirements can only be achieved with an *Integral approach*. This means that the total lifetime of a component should be considered as a system in which individual life cycle segments should be reviewed together with all influencing factors as interdependent parts in their entirety. The life cycle of a component distinguishes the following phases [8]:

- development (ideas, sketches, constructions, choice of materials and procedure, calculation, prototyping),
- production (preparation, casting, machining, installation),
- use (operation, maintenance, servicing),
- recycling (dismantling, collection, sorting, utilization, waste disposal).

The most important segment is the first phase, i.e. the development of the component, because it determines the lifespan of other segments and phases. *Simultaneous engineering* contributes significantly to the reduction of development time and the improvement of product quality [9, 10]. This approach encourages the production of correct castings with a zero defect approach in the first attempt first and correctly (*Right for the first time*). With this approach, most key decisions are made before constructing a product, when changes are easiest and cheapest. Essential elements of simultaneous engineering are: CAD / CAM / CAE technologies, rapid prototyping, central production data management, cross-functional teams, analytical methods, expert systems and knowledge bases.

Optimization of the casting process is achieved using CAE technology. The goal of such optimization is to save material, minimize mass, maximize the allowable load, stress, stiffness, etc. This optimization is approached by creating a model using various computer-aided technologies. CAD technology is used for the virtual production of 3D castings, based on which the required product requirements are examined: stresses, deformations, casting ability, etc. [11]. In the last twenty years, the use of mold filling simulation has been a mandatory segment of CAE technology. Numerical simulation with incorporated thermal-technical calculation determines the heat transfer from the casting to the mold, a graphical representation of the thermal field and stress development. From the obtained results, it is possible to determine solidification, mold filling rate, temperature and thermal stress distribution, microsegregation, hot spots, etc. [12]. When the virtual casting meets all the required requirements, rapid prototyping can be approached in various available materials including original casting material and corresponding casting technology [13]. All the required tests should be performed on the obtained prototype, after which the production of the component is started. Number of examples of similar approach is available in literature [14, 15].

The focus of this investigation was optimization of pouring and solidification process of thin-walled EN-GJL-200 casting using numerical simulation as a important part of simultaneous engineering. Numerical simulation optimization reveals changes in technological parameters of gating system, venting system and support. Optimization enables even filling of castings in order to prevent an extensive thermal overload and consequently stress of particular parts of castings.

Experimental

Grey iron quality EN-GJL-200 due to the flaky structure of graphite, possess low tensile strength, hardness, toughness, elongation and modulus of elasticity [16-19]. One of the main disadvantages of this material is the sensitivity to wall thickness (cross-sectional size), which can result in significant variations in mechanical properties within the casting. Target complex geometry casting is shown in Figure 1.

Figure 1. Complex geometry of investigated casting (top nad bottom side)

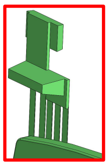
The usual production process of target casting was performed using DISAMATIC® line for molding and casting. Complex geometry of thin-walled casting represents the challenge due to crusted parts of casting and stress bending of casting in existing technological set up.

Numerical simulation was performed using ProCAST software in existing material and technology set up and with optimized parameters. According to identified defects the focus of optimisation was placed to technological parameters such as correction of inflow system, venting system and existing support. Numerical simulation and also casting process was performed with original and optimized parameters in order to compare the influence of changed parameters on defect occurrence.

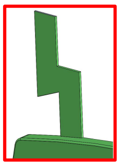
Results and discussion

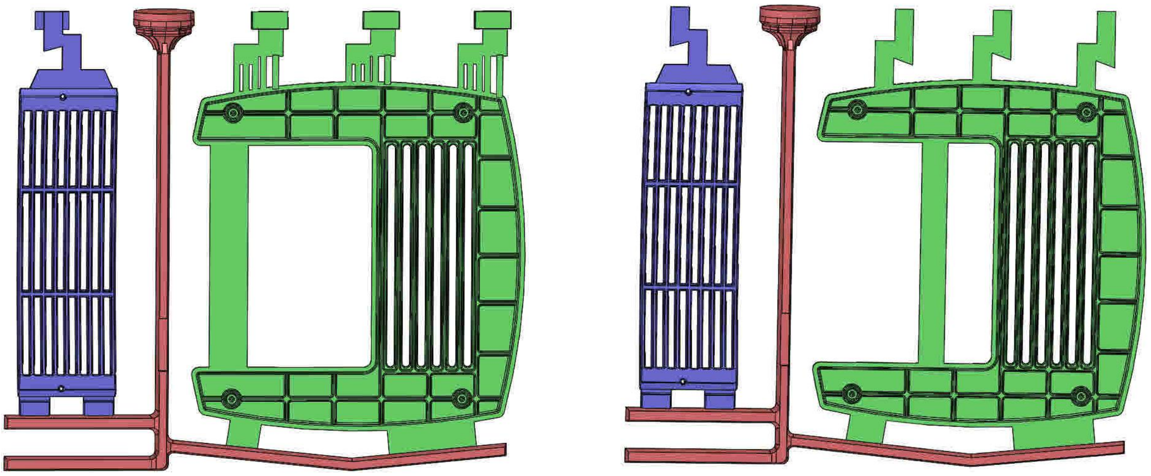
Optimization process started with evaluation of complete casting weight and filling mode which resulted in tendency to achieve laminar and uniform flow over inflow system as well as elimination of excess weight on the venting parts. Complex geometry of investigated casting requires support in order to avoid free parts curvature. This support also enable additional filling, although it depends from the inflow ability to support the mold cavity. Original (V1) and optimized version (V2) of changed geometry is presented in Figure 2.

V1 d=0,5 mm



V2 d=2 mm



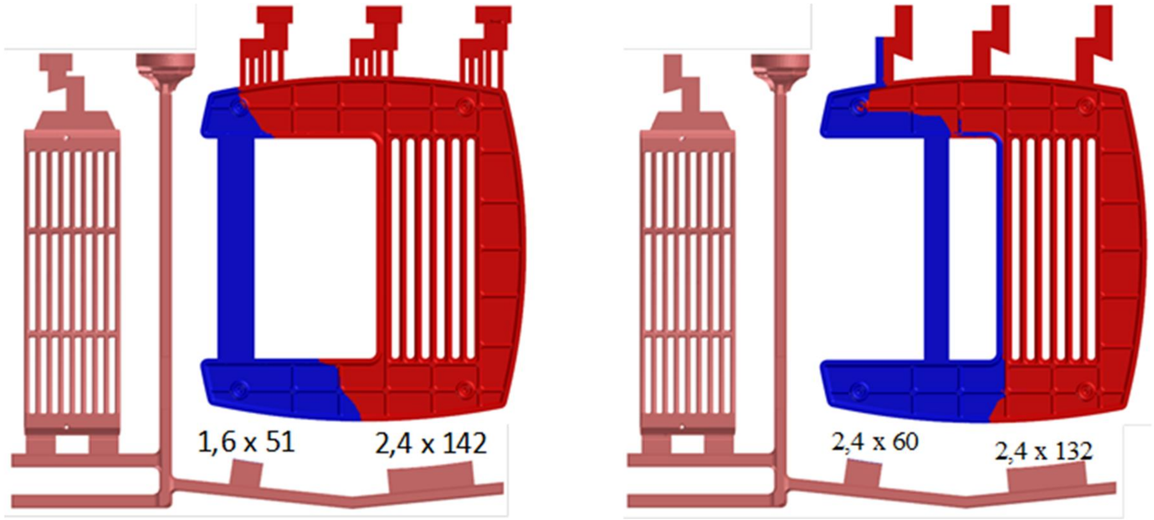


Total casting weight = 25,7 kg

Total casting weight = 24,3 kg

Figure 2. Original (V1) and optimized version (V2) of changed geometry

Scrolling the support toward rib part casting enables its active role in uniform filling of casting cavity as shown in Figure 3. Reduction the vent size and changing the geometry resulted in total weight reduction remaining its original role.



V1

V2

24 % (2,5 kg) + **76 % (7,9 kg)**

Casting and venting weight = 10,4 kg

35 % (3,2 kg) + **65 % (6 kg)**

Casting and venting weight = 9,2 kg

Figure 3. Filling mode for both original (V1) and optimized (V2) version

According to the identical initial casting parameters: pouring temperature T_p= 1400 °C and filling time t=5 s in green sand bentonite mixture, numerical simulation of pouring and solidification revealed different thermal distribution in casting and therefore resulted in different time to solidus in critical nodes as presented in Figure 4.

V1 V2

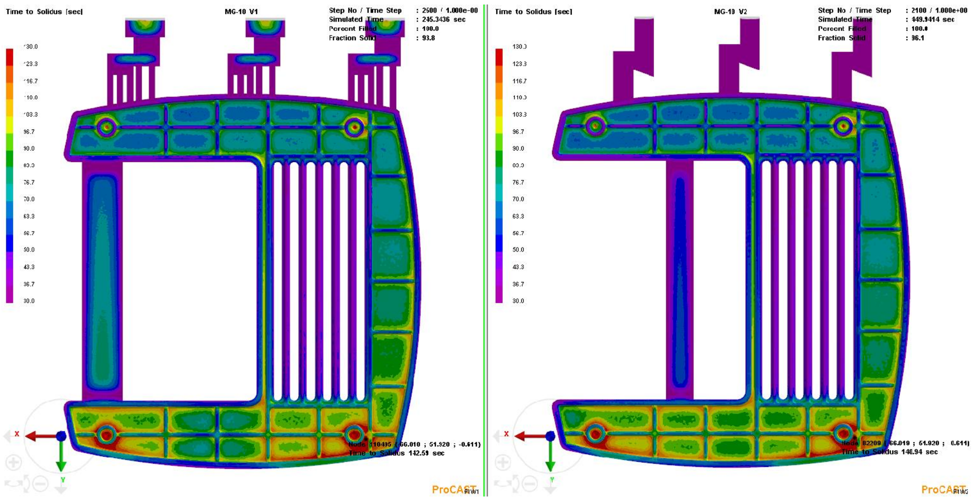


Figure 4. Time to solidus distribution for both original (V1) and optimized (V2) version

The area in lower part of casting indicated shortening of solidification time in general. Time to solidus is the longest but still rather uniform 80-110 s since these area is in direct junction to inflow. Although, shortening of solidification time for 2 s has been noticed in critical thick-walled sections. Ribs and support indicated 30-60 s to solidification end. Upper part of casting also show shortening of solidification time revealing wider areas dedicated to cca 60 s time mark. In general, faster solidification enables shorter time of heating avoiding crust appearance. Lowering the vents size and volume and widening the inflow size as well as scrolling the support toward ribs enable lowering the melt volume, and therefore casting weight and also faster filling and solidification

The hot spots indicated porosity occurrence which has been confirmed with simulation in graphical representation in Figure 5.

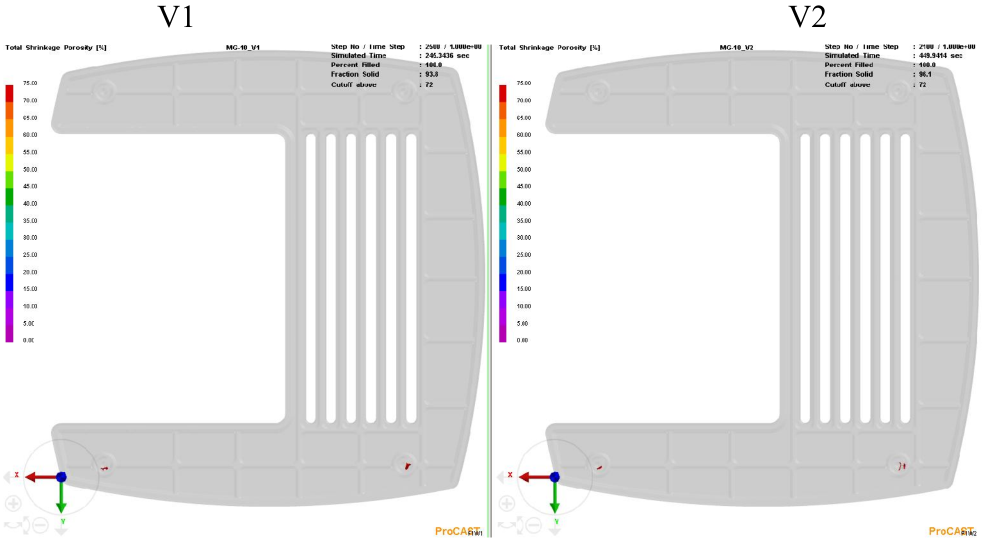


Figure 5. Porosity occurrence calculation for both original (V1) and optimized (V2) version

Porosity calculation did not shown difference in position of appearance, although the size in optimized version was smaller. Also this position is acceptable if the porosity is inside the casting.

Since the support needed for avoiding the deformation of free casting parts was moved, the deformation simulation for casting in the mold and in the air, was also performed, as shown in Figure 5.

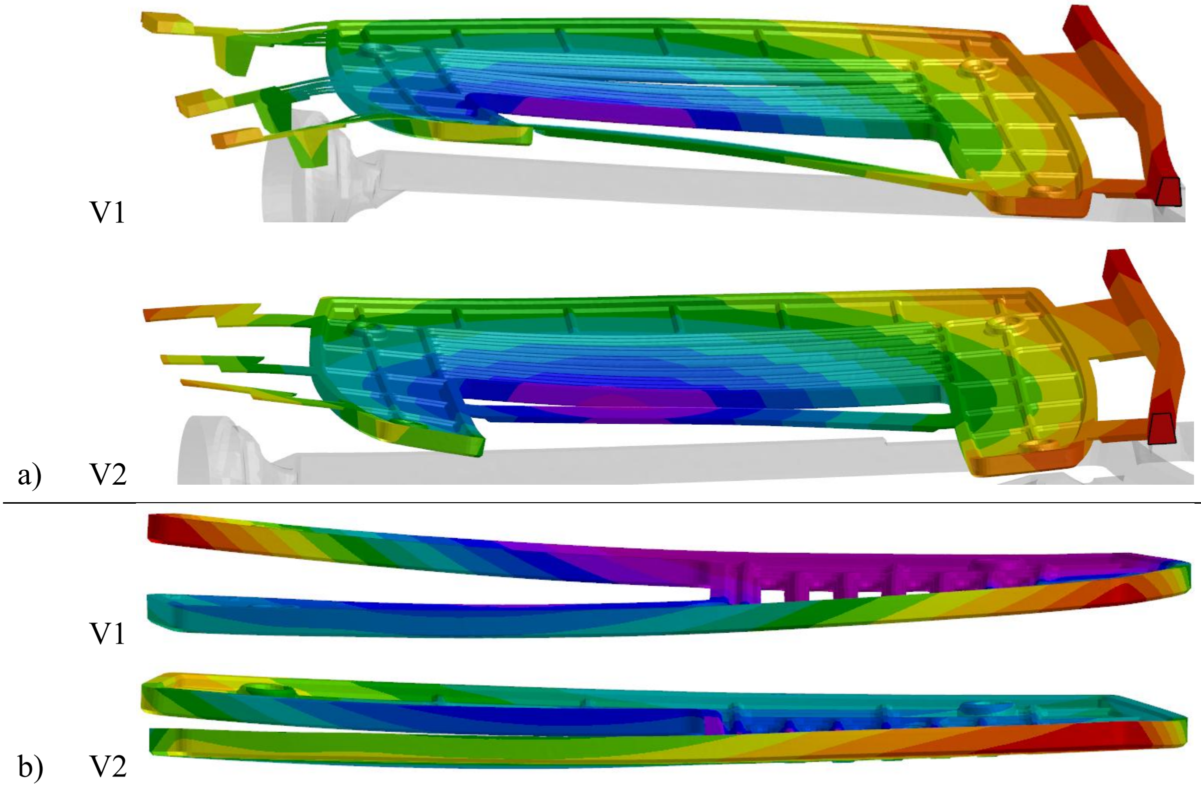
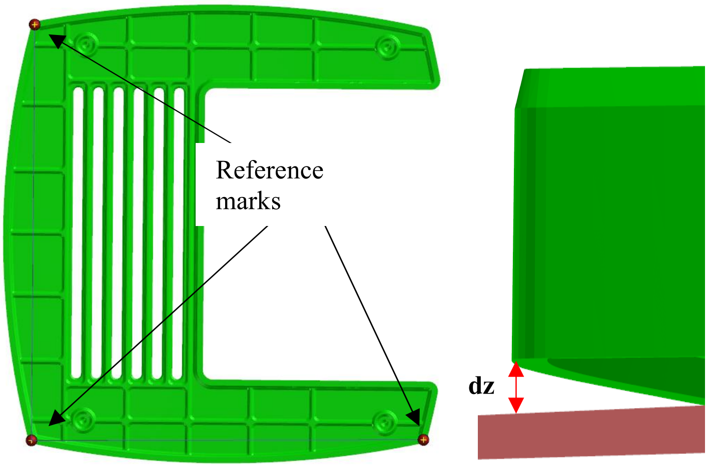


Figure 5. Numerical simulation of deformation in different time marks:

a) in mold (50 min after pouring)
b) in the air

Deformation simulation indicated distortion of casting in mould also afterward in the air due to complex geometry consisted from thin and thick-walled section and ribs. Since this casting is one part of complete product distortion is not acceptable and should be lowered on minimum. Although, the distortion is not completely avoided its appearance is minimized as shown in Figure 6.



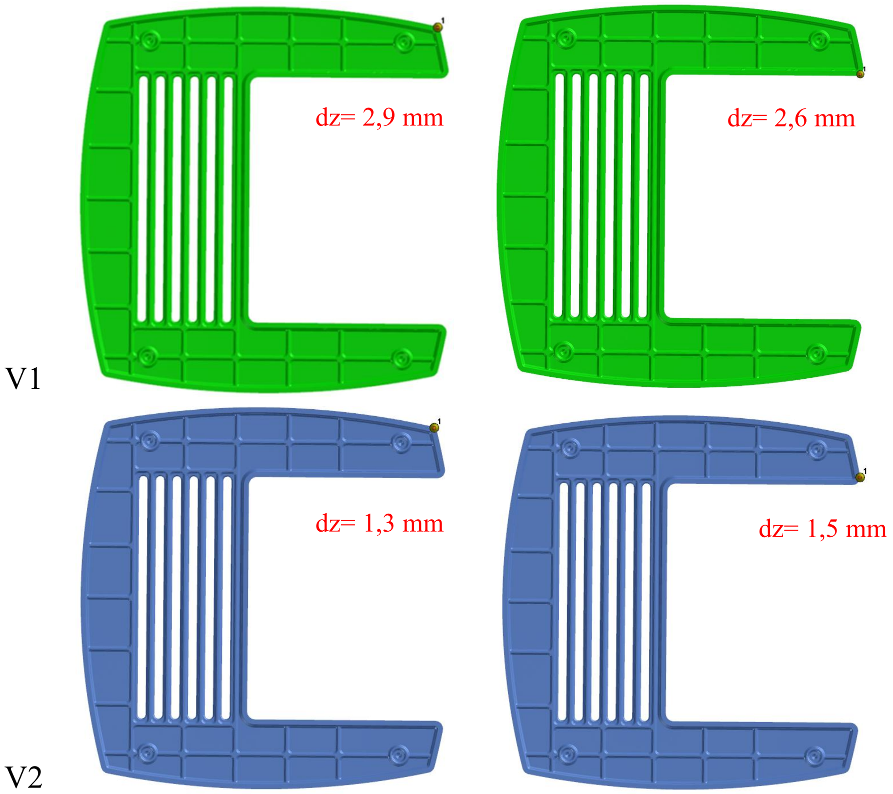


Figure 6. Numerical simulation of casting distortion in reference points

Beside presented results ferrite fraction, yield and tensile strength, dendrite arm spacing and hardness were also calculated. Neither of those properties did not shown significant deviation. Numerical simulation enables useful review in the melt/casting – mold system behaviour. Since obtained results achieved good optimisation relating to pouring and mold filling, but not so satisfying relating to solidification and obtained deformations, it imposed the need for additional optimization.

Conclusions

Importance of new strategy and concepts was confirmed through this investigation. Calculation time and engineer knowledge and effort using numerical simulation as a part of CAD/CAE technologies can comprehend to the lowering of defects ratio and make product more competitive on the global market. In this investigation numerical simulation of existing of thin-walled EN-GJL-200 casting was optimized using ProCAST software. The focus was placed toward optimizing the pouring and solidification process though modelling the inflow system, vents and support. Optimizition indicate uniform filling with better distribution of inflow activity and reduced thermal overload in particular positions of the casting. Casting weight was significantly reduced and total solidification time was shortened. Complex geometry of thin-walled casting represents the challenge due to deformation tendency. Optimization did not completely reach the goal of deformation avoidance but it reveals positive feedback for significant positions (reference marks). Although, optimized casting revealed improvement, this casting geometry require more optimization technological set up in order to achieve Right for the first time.

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