

Research and optimization of the technological process of manufacturing a GTE blades using computer-aided design

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Abstract. This paper discusses an approach to prediction of the generation of pouring defects using the example of a technological process of manufacturing GTE blades. A computer-based modeling system for foundry processes, ProCast, was used as a tool for this research. Possible reasons of the formation of defects were considered and the recommendations for their elimination were provided.

1. Introduction

GTE blades are the most stressed and critical parts of a gas turbine engine. They are manufactured using special heat-resistant and highly durable steels, titanium- and refractory alloys featuring stringent requirements to precision and quality of the surface layer. Therefore the manufacturing processes for the production GTE blades must be efficient and must ensure the required precision parameters [1, 2].

The cost of manufacture of each blade is several thousand Russian rubles, therefore a set of full-scale experiments in order to determine the optimum parameters of the entire manufacturing process may turn out to be cost prohibitive.

Thus, there emerges a need to perform computer modeling of the existing manufacturing process (MP) of casting with the purpose of selecting the optimum process parameters.

The advantages to perform a stage of computer modeling are obvious: design optimization, reduction of processing costs, improved product quality, reduced operational expenses, etc. The mathematical modeling of foundry processes is based on heat and mass transfer equation: Heat flow equations, Navier-Stokes, diffusion, kinetic equations of crystalline transformations, etc. [3].

2. Selection of the modeling tool

There is a wide range of special software focused on foundry processes. The following systems are most widely used in the world: Magmasoft (Germany), WinCast (Germany), ProCast (France), QuickCast (France), PAM-Cast (France), CalcoSoft (France), Flow3D (USA), PowerCast (USA), SolidCast (USA), CastCAE (Finland), LVMFlow (Russia, Izhevsk), Poligon (Russia, St. Petersburg), FlowVision (Russia, Moscow), and Castflow (Australia).

Unfortunately, only a few of these software solutions proved to be efficient in the manufacturing process, i.e. Magmasoft, ProCast, SoldCast, as well as two Russian software products: Poligon and LVMFlow.

The method of finite elements is the best solution for computer modeling of the MP for casting blades of GTE. This is because this method enables to most accurately describe the geometrically



complex model of a blade airfoil. Therefore, at this stage it is expedient to exclude the software products based on the methods of finite differences and control volumes. We also excluded software suites which failed to perform as powerful tools for the modeling of foundry processes aimed to produce parts of a gas turbine engine [4].

As a result of their comparison we identified three powerful CAE software suites for modeling of the foundry processes: Poligon, SolidCast, and ProCast. It is expedient to further compare these software suites based on their individual functionality.

A literature-based review of the practical experience of using the computer modeling software enables to make conclusions regarding functionality of each system [5-10]:

- ✓ Poligon software product is recommended for use together with another foundry software as a verification of critical castings;
- ✓ SolidCast software product is entry-level foundry software. It enables to model main tasks to be tackled by the existing technology. It is recommended for companies manufacturing a wide range of **not very complex** castings;
- ✓ ProCast software product has unlimited number of axes in the system, a number of units and elements in the lattice, a calculator of thermodynamic properties of materials, and all of its results may be analyzed and demonstrated in real time mode (thanks to its multicore processor). It is best suited for tackling complex engineering problems in the area of materials science and resistance of materials as it is able to reliably and accurately model the task of a strain-stress state of a casting and predicts the formation of crystallite structure in a casting.

Based on the above analysis of CAE systems of computer modeling we concluded that ProCast software is the most optimal solution for optimization MP of a GTE blades using a computer-based experiment.

3. Description of the modeling method

Below is a good case of identification and analysis of foundry defects in a casting of a GTE blades using the process of computer modeling in ProCAST software suite. As of today, the company experts have developed a technology for casting blades. However, this technology is far from ideal: after pouring-ins, the foundrymen end up with 60% of quality castings and 40% of rejects due to microporosity in the upper and lower flanges of blades and microporosity in blade airfoils. The aim of this work was to research and optimize the existing technology of manufacture of GTE blades with the purpose of increasing the quality of part blanks.

The computer modeling methodology reviewed consists of four stages [11]:

Stage One: Building a 3D geometry in a CAD system and preparation of an estimated finite-element lattice. In order to build the geometry one can use any CAD software product because the conversion to ProCAST is performed via an intermediary format, for instance, Parasolid or Step. In our case UGS NX 8.5 (figure 1) was used to build the geometry of a casting and mold.

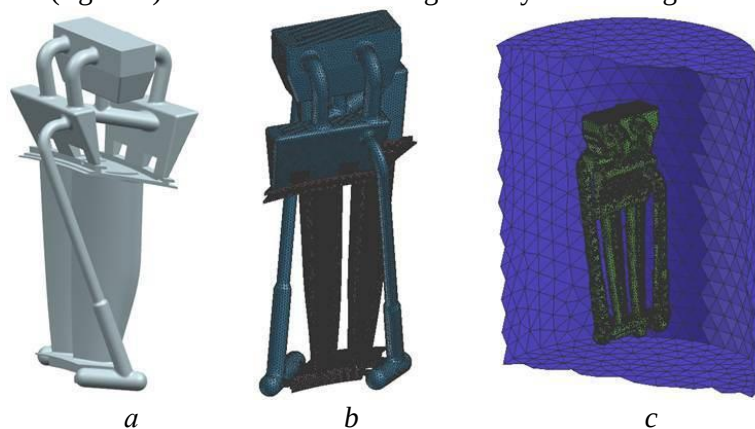


Figure 1. General view of geometry of mold piece and form:

a – 3D casting model; *b* – estimated lattice of the casting; *c* – estimated lattice of the casting and virtual mold

Stage Two: Selection of materials, borderline conditions and initial conditions of the process, and calculation parameter. We should emphasize the relevance of a thermodynamic database of ProCast which solves the problem of searching for properties of domestic alloys or selection of their foreign analogs. Using the thermodynamic database it is possible to calculate thermophysical- and mechanical properties of an alloy using its chemical composition. Calculation of properties was performed for the alloys based on Fe, Al, Cu, Mg, Ni, and Ti using the main alloying components. The resultant properties have variable values in the required temperature interval which ensures high level of accuracy of the calculation.

Stage Three: Launching the task for calculation. We should note that all the modules work simultaneous, and calculation of hydrodynamics is performed concurrently – a mold is filled with an alloy, crystallization and cooldown of a casting, formation of stresses and deformation of the casting. This scenario describes the foundry processes in the most comprehensive manner.

Stage Four: Review and analysis of the calculation results. It is possible to show the results of modeling in the postprocessor both during and after the calculation.

4. Analysis of the modeling results

In the process of observation of filling the alloy in the mold one can determine the type of filling and evaluate efficiency of the gating system determine the areas of turbulent flow, the areas of high velocity of flow, possible areas of erosion of the mold or rod, and the areas of formation of air inclusions which may contribute to the formation of gas inclusions in the casting.

Based on the type of hydraulics of the mold filling (figure 2) it is possible to say that the pouring-in initial velocity was selected in the optimum way (approximately 20 seconds) because the level of metal in the pouring basin is constantly maintained, and there is no excessive splashing and inhibition effect.

The dynamics of filling the mold with metal testifies to the need of changing the metal feeding, namely the gating system. Since the side gates are not operational it is necessary to make a forced-feed riser to feed the metal from below, so that the pouring is initially performed only from the bottom, and then to ensure that a certain level of metal is fed into the risers, heating them. This is how it is possible to generate directional crystallization (bottom-up) and to ensure smoother pouring-in of a blade hollow, i.e. to make a riser with a two level feeder to the lower- and upper sections. In this case feeding of the lower flange of the blade can be improved.

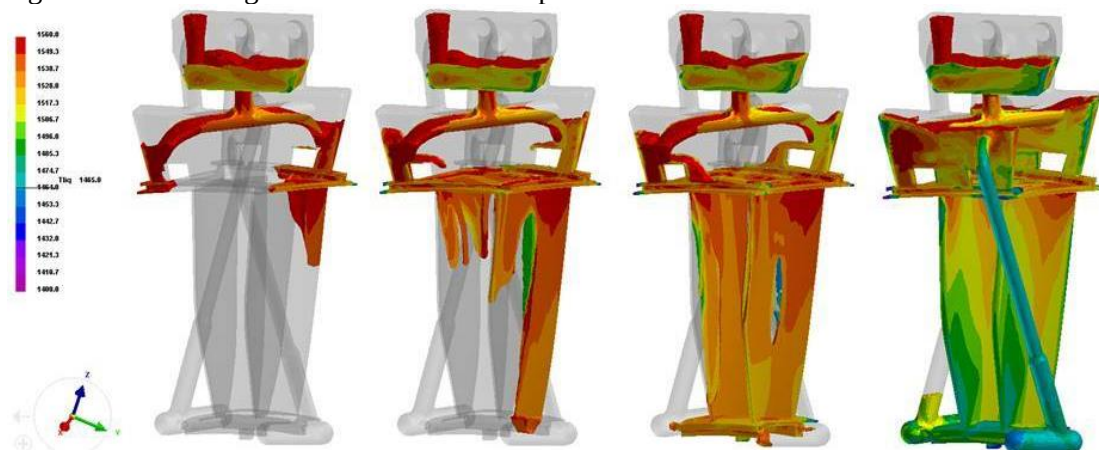


Figure 2. Pattern of filling of the casting with liquid metal.

It is important to pay attention to the pattern of filling the mold with metal (figure 3): the metal is divided into two flows inside the blade body. During pouring-in (outdoors condition) in this setting

gas bubbles may appear and, consequently, this may result in the formation of an oxide film. In our case when pouring-in in a vacuum it is possible to predict the emergence of cast seams.

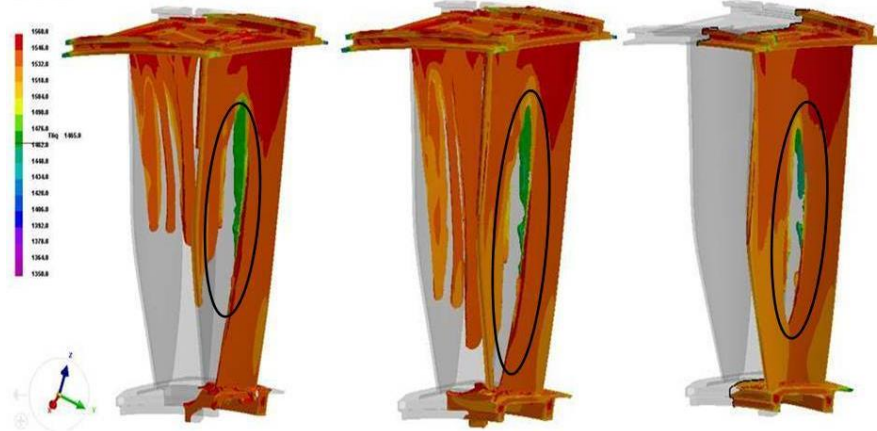


Figure 3. Formation of cast seams during the pouring-in.

Figure 4a shows the pattern of distribution of the filling velocity. Based on this velocity one can determine that velocity only increases in the blade which is due to the change in the flow section when the flow diminishes. The average velocity pressure is around 1 m/second which is not a critical value that is able to wash away the electric corundum sinterskin.

Figure 4b shows the metal flow vectors. The flow is slowed (shown in black) hence the metal is cooled. This phenomenon takes place, most likely, due to a contact with the rod in the central area.

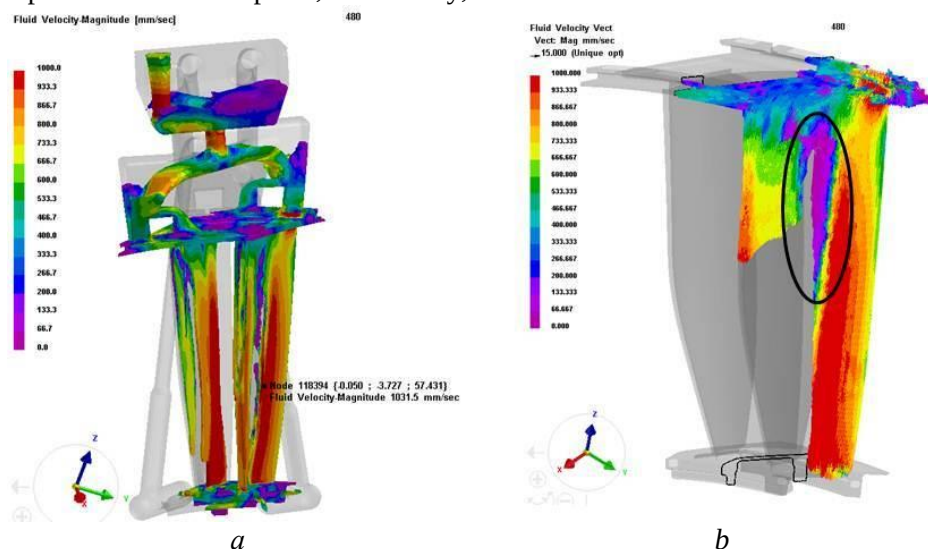


Figure 4. Pattern of distribution of the metals dynamic pressure:
a – metal flow velocity; b – velocity vectors

The crystallization process begins in the lower flange of blades and in the side gates (figure 5a). The lower section of the casting – the thinnest spot – is crystallized right after the pouring-in. Crystallization of the casting takes place very quickly (approximately 18.5 seconds) as all the casting elements have thin walls. This proves that the pouring-in time was chosen correctly. The blade is thin, it is crystallized quickly, and the metal in the side gates is cold, so when the casting is not yet fully crystallized the side gates stop operating (figure 5b). Thus, two heat units (spots) appear in the lower flange of the blade (figure 5c), and this is where shrinkage and porosities may be predicted.

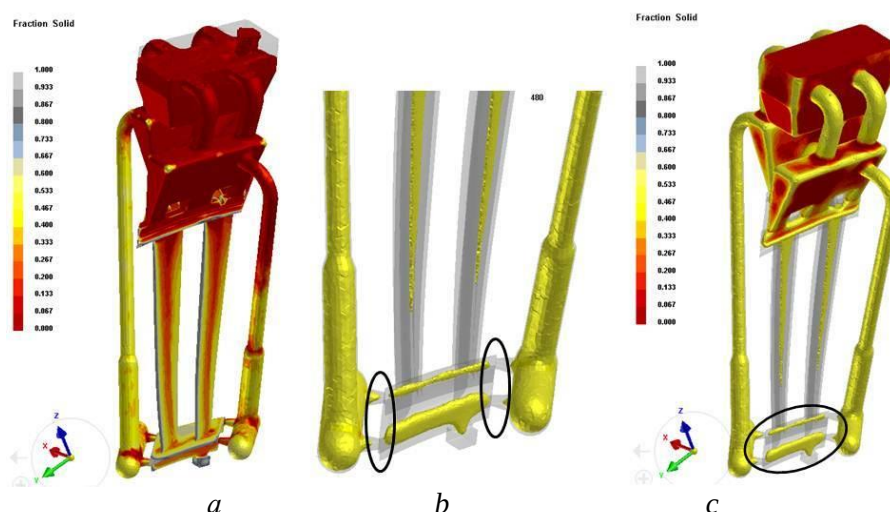


Figure 5. Crystallization of the casting of GTE blades:

a – at the initial moment; *b* – inefficiency of side risers; *c* – formation of hot spots.

Crystallization of a central section of the blade airfoil takes place quite dynamically (figure 6a). Micro-porosity is possible for this type of crystallization which is due to the phenomenon of dimensional crystallization. The blade airfoil does not crystallize evenly and the so-called ‘peaks’ take place – an elongated section of the liquid metal which has an unfavorable impact on the crystallization process because such zones are typified by their lack of crystallization (figure 6b). The upper risers work quite well, however, in the area of the upper flange of blades it is possible to predict minor porosities and internal shrinkage (figure 6c).

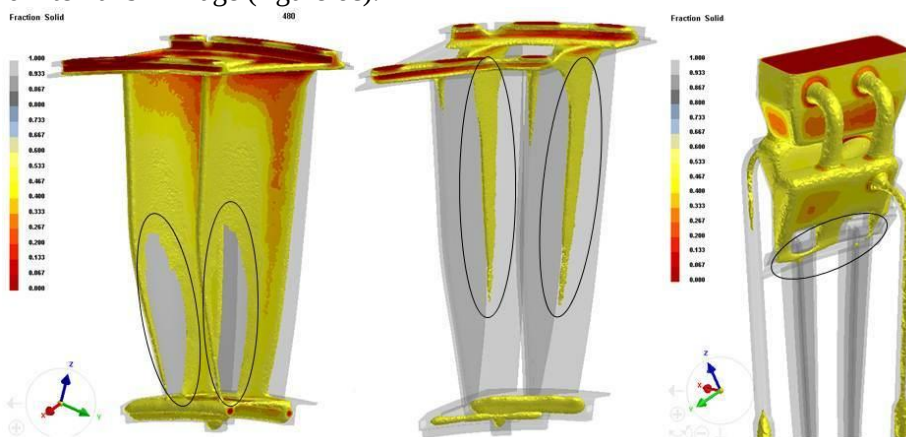


Figure 6. Control for the prediction of defects in an airfoil of blades.

Hot spots (figure 7a) indicate the crystallization time of zones in the casting; the heat zones which are the last to crystallize and where shrinkage is possible. These are the areas where internal shrinkage takes place as a result of slowed crystallization – slower than in the adjacent areas of the casting [6].

Porosity in the casting (figure 7b) appears in the blade airfoil, as well as in the area of upper- and lower flanges. This is due to the fact that the lower feeders and the side risers failed to compensate for the metal shrinkage.

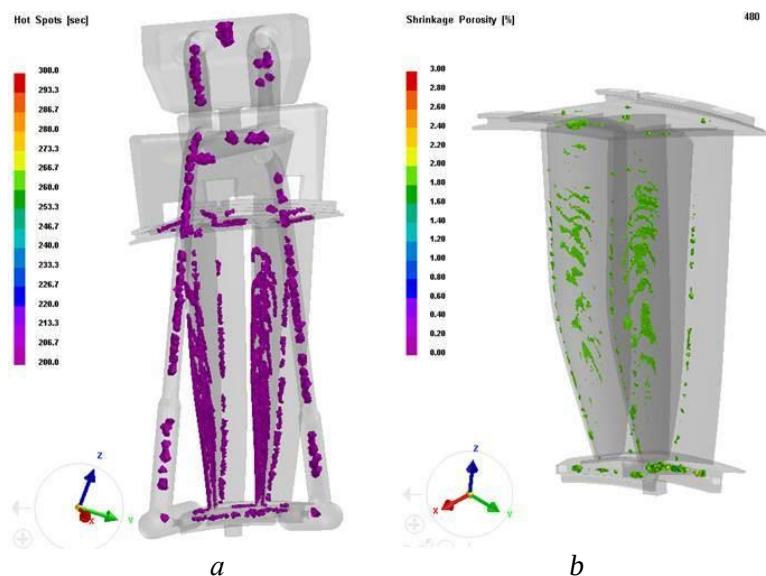


Figure 7. Pattern of observation of porosity at macro- and micro levels:
a – formation of hot spots; *b* – formation of porosity.

5. Conclusion

The research of MP for the manufacture of GTE blades using elements of computer modeling enabled us to better understand the mechanism of formation of a casting, the structure and reasons for the formation of pouring defects, based on which recommendations were made as to ways to eliminate the defects. In order to optimize the MP for casting a blades it was proposed to slightly modify the design of gating system, i.e. to make a forced-feed riser to feed the metal from below which would avoid cast seams, formation of hot spots and porosities in the lower fen and to achieve a more even filling of the blade airfoil. The optimized parameters of the manufacturing process were tested in the ProCast computer modeling medium. The results of this modeling demonstrated lack of certain pouring defects in the casting. Sample castings of the blades were then manufactured using the adjusted MP parameters. These sample castings showed no defects in the form of cast seams and porosities in the upper- and lower fens (figure 8).

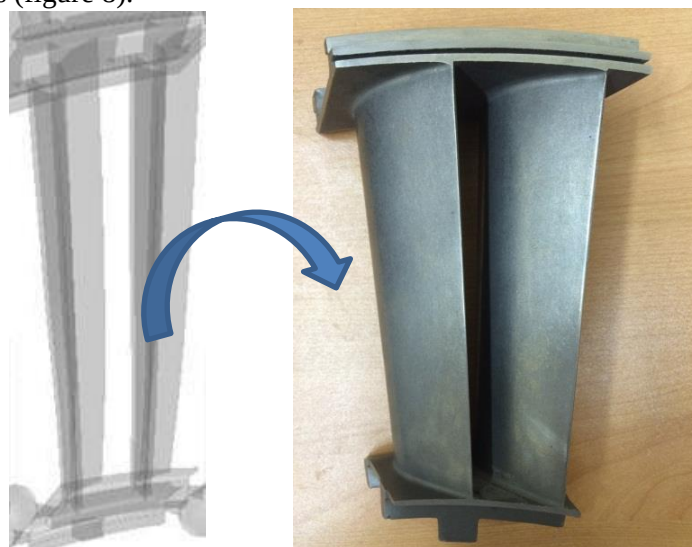


Figure 8 Lack of pouring defects in the casting of a block of nozzle unit.

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