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Development of Promising Technology for Manufacturing Parts of Gas Turbine Engines

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Abstract. This article discusses the results of the development of a promising technology for manufacturing parts of gas turbine engines. First of all, this technology is promising due to the use of the PolygonSoft system utilized for computer modeling of casting processes, which made it possible to evaluate the efficiency of the gating and feeding system, as well as to predict the appearance of casting defects (porosity and macrostructure discrepancies) and to develop a set of measures for their detection and elimination; second of all, due to the use of rapid prototyping which employs 3D printing of the master model, thus reducing the time and financial costs for the preparation of technological equipment. According to preliminary estimates, the use of rapid prototyping has reduced the cost of manufacturing 250 wax models by 15% in comparison with the traditional technology, and also reduced time costs by an average of 5-6 months.

1. Introduction

In the context of import phase-out and proactive import substitution, the rate of the technological process becomes crucial. The competitiveness of the finished product will depend on how quickly and efficiently the technological process will be implemented.

The use of computer modeling systems for casting in existing production helps, through iterative computer analysis, to predict the occurrence of casting defects at various stages of the technological process, as well as to propose measures and recommendations aimed at minimizing and eliminating defects. Therefore, the domestically developed PolygonSoft computer modeling system was chosen as a tool for casting analysis. This system helps to analyze the hydrodynamic nature of the melt flow, investigate the solidification of the casting block, predict the appearance of porosity in casting products, and simulate the stress-strain state of the casting and elements of the gating and feeding system. [1-9]

Another element of this promising technology being developed is the use of modern manufacturing trends such as 3D printing of products from various materials, which helps to eliminate financial and time costs associated with the setup of equipment. The use of 3D printing for master models of blanks will make it possible to obtain products of the required quality in a short time, which is especially important in conditions of generic manufacturing and manufacturing in small batches. [10-16]

Thus, the use of computer modeling and rapid prototyping constitutes a promising technological process for manufacturing parts of competitive gas turbine engines.

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2. Relevance and scientific significance

Currently, the most important task of competitive engine building is to improve the reliability of gas turbine engines. Therefore, the main efforts should be aimed at improving the manufacturing of the main engine parts, such as turbine blades, since they bear the biggest loaded and determine the life of an engine. Turbine blades are characterized by a complex geometry, as well as strict requirements for the accuracy of geometric parameters and the quality of the surface layer.

A review of the existing manufacturing processes of rotor blades of turbines [17-22] showed that the manufacturing of non-allowance blanks of turbine blades is extremely unstable and is characterized by a significant percentage of waste (approximately 50%). This is primarily due to the instability of the manufacturing process' conditions. A significant part of the total volume of defects is macrostructure discrepancies.

A qualitative assessment of the manufacturing process of turbine rotor blades, determined by the accuracy factor which establishes the relationship between the scattering band and the dimension tolerance [23-24], showed that the manufacturing process of blade castings is unstable and with a small margin of accuracy.

Thus, the relevance of this paper lies in developing measures aimed at reducing waste castings associated with macrostructure discrepancies. The scientific significance of the problem consists in developing reliable mathematical models of the blade casting process, designing complex digital models of copies, which allow virtual modeling and optimization of technological modes, as well as introducing rapid prototyping into the existing manufacturing process of blade blanks.

3. Theoretical problem statement

The following initial parameters were used for computer modeling of casting turbine rotor blades:

melting and pouring in the ПМП-2 batch pusher-type furnace using the ЖС30-ВИ heat-resistant alloy;

dusting material (for ceramic molds) is alumina Al2O3;

pouring time is 4 to 6 seconds;

pouring temperature is 1510 ^{0}C;

temperature conditions in the corresponding zones of the ПМП-2 furnace:

zone I 1290 +10 ^{0}C; zone VI 1510 +10 ^{0}C;

zone II 1370 +10 ^{0}C;	zone VII 1450 +10 ^{0}C;
zone III 1400 ±10 ^{0}C;	zone VIII 1390 +10 ^{0}C;
zone IV1510 +10 ^{0}C;	zone IX 1370 +10 ^{0}C.

The temperature patterns obtained from solving the problem of the initial heating of the graphite flask were used as the initial thermal conditions for all elements of the computational region.

For layered growth of master models of turbine rotor blades, the authors have chosen the PolyJet technology. It helps to obtain products with an accuracy of ± 0.02 mm by means of ultraviolet curing of the photopolymer material. It is important to note that the thickness of the grown layer is 0.016 mm and the average roughness of the surface layer after growing is Ra = 1.45 ... 3.7 µm, which helps to avoid additional polishing to obtain the required surface finish.

4. Analysis of experimental research results

Computer modeling of casting of turbine blades begins with loading the preprocessor (Master module) of PolygonSoft software and positioning the geometric model of the blade so that the Y axis (geometric axis of the blade airfoil) is directed vertically upward, i.e. opposite to the vector of the melt pouring rate.

After the geometric model has been imported, it is important to define its volume and borders. In the future, the volumes will be assigned the properties of materials, and the heat transfer conditions will be assigned at the borders. There are two types of volumes in PolygonSoft systems. These are casting and molds. Molds can consist of different materials (in our case, it is a flask, filler, or ceramic mold). Castings are marked red and molds blue (see Fig. 1).

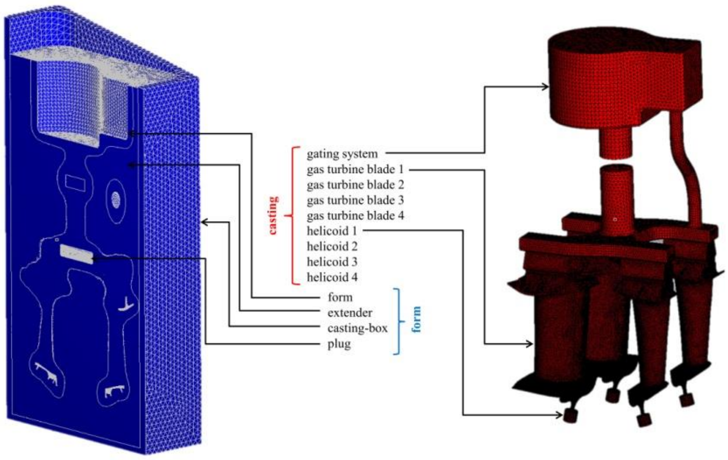

Figure 1. Purpose of the geometric model of volume types.

In order to perform correct calculations, it is necessary to set the corresponding parameters for all volumes of the “Mold” type. In our case, the volume indicator template is redundant and is intended for investment casting. Within the framework of this problem, we are only going to use index #2 «Al_2O_3-based ceramics» and index #9 «Graphite, density of 1,720 kg/m^3». When simulating the investment casting process, metal takeover point and the diameter of the poured melt stream must be specified.

The target function of computer modeling of manufacturing turbine blade blanks with a monocrystalline structure in the ПМП-2 discrete-continuous unit was to optimize the existing technological modes that affect the quality parameters of the casting (such as macrostructure and stability of geometric parameters).

The results of computer modeling of casting turbine blades in PolygonSoft software was analyzed in the Mirah-3D postprocessor.

An important component of the analysis is the pattern of filling the mold with metal (see Fig. 2). It occurs sequentially, while the flow is split in the central part of the blade airfoil, as evidenced by the resulting voids. Therefore, when pouring in the presence of oxygen, gas bubbles and, as a consequence, oxide films may appear. When pouring in a vacuum, it is possible to predict the appearance of cold shuts.

Fig. 3 shows shows distribution patterns of heat fields on the surface of the casting block during solidification at different points in time, taking into account the thermal interaction of the elements of the furnace – flask – filler – mold – metal – stop system. Due to the presence of a bottom water cooled crystallizer in the ПМП-2 casting unit, a directed crystallization front along the blade airfoil and a monocrystal structure may appear.

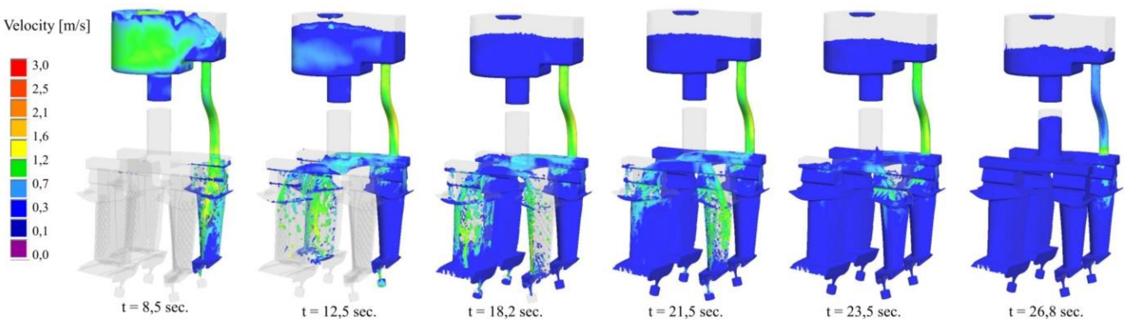

Figure 2. Patterns of distribution of melted metal in ceramic molds at different points in time.

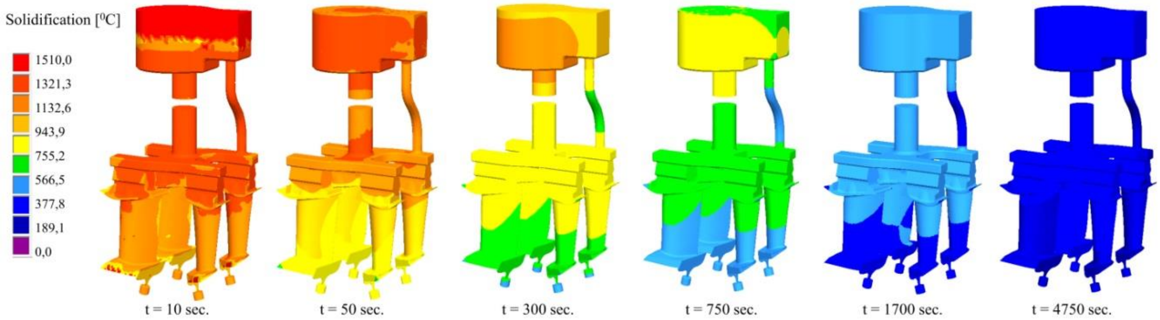

Figure 3. Patterns of temperature distribution at different points in time.

An important parameter influencing the structure of blade castings is porosity and the possibility to predict porosity during computer modeling. Figure 4 shows the distribution of porosity in the casting. Using this figure, it can be concluded that the casting has a porosity of more than 8% distributed over the entire volume, which is unacceptable, especially in the case of a thin-walled blade geometry. A shrinkage cavity forms when the pressure in the melt drops to a critical value [25, 26].

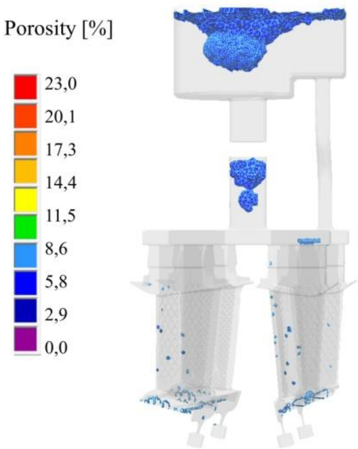

Figure 4. Patterns of porosity distribution in casting.

As already mentioned, the prospects of the technology under analysis lie not only in the use of computer modeling systems for casting processes, but also in the introduction of rapid prototyping into the existing production of blade blanks, which consists in growing of master models using a 3D printer and production of a silicone elastic mold, followed by casting wax model masses into it. Thus, an alternative way of production of wax models of blades is found. Figure 5 shows the developed technological process of manufacturing turbine blades using rapid prototyping. One of the most important advantages of this innovation are the reduction of financial and time costs associated with manufacturing necessary technological equipment. Among the disadvantages, is the low resistance of silicone molds. Depending on the geometric complexity of the product, the resistance can amount to 60-70 models from one mold. Thus, this promising technology will be especially relevant in the context of generic manufacturing and manufacturing of parts in small batches.

#	**Name of operation**
Operation 0	Designing and preparing technological guidelines
Operation 5	Manufacturing of molds
Operation 10	Manufacturing of blade models
Operation 15	Control of blade models and gating system
Operation 20	Assembly of models into blocks
Operation 25	Control of model blocks
Operation 30	Preparing heat-resistant suspended mixture
Operation 35	Preparing the aluminum oxide for dusting blade model blocks
Operation 40	Preparing blocks for molding
Operation 45	Forming model blocks
Operation 50	Drying of each layer
Operation 55	Control of forming of all layers
Operation 60	Cleaning of pouring basin
Operation 65	Elimination of model mass from molds
Operation 70	Annealing of molds
Operation 75	Alloy melting and mold pouring
Operation 80	Shake-out of castings
Operation 85	Labeling of blades and samples
Operation 90	Quality control of blades

#	**Name of operation**
Operation 5	Manufacturing of a blade turbine prototype
Operation 10	Manufacturing of a silicone mold
Operation 15	Manufacturing of wax models
Operation 20	Quality control of wax models

Figure 5. Manufacturing of turbine blades using rapid prototyping.

5. Conclusion

The use of the PolygonSoft casting process computer modeling system during the preparation of turbine blades production made it possible to:

– evaluate the efficiency of the gating and feeding system during the analysis of melt's hydrodynamics without using expensive experimental melts;

– to perfect obtaining suitable castings of turbine rotor blades of gas turbine engines;

– to perfect methods of predicting casting defects (porosity and macrostructure discrepancies) and develop measures for their detection and elimination.

The use of rapid prototyping helped to reduce the cost of manufacturing 250 wax models by 15% compared to the traditional technological process, as well as to reduce the time spent on average by 5-6 months.

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