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Numerical Analysis of Casting Process of the Diesel Engine Compressor Rotor

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Abstract

Application of simulation analysis has become increasingly inseparable part of the design process of casting technology. The possibility of a virtual observation of the temperature distribution, heat transfer between the liquid metal and the mould, evaluation of the nature of the liquid metal flow are values that are impossible to monitor during real-time production. Through the computer simulations, there is a possibility of a preliminary assessment of the phenomenon without the need for expensive and time consuming trials. On the example of the diesel engine compressor rotor the process of preparation of foundry technology, simulation analysis, the visualization of filling of the mold cavity and solidification of the liquid metal was presented. The casting was performed on the VC3000D INDUTHERM furnace that uses the phenomenon of POV (Pressure over Vacuum).

Keywords: PoV, Casting, Computer simulations, Aluminum alloys

1. Introduction

The use of numerical simulation analysis of the phenomena occurring during the casting process has become a very common procedure. Launch of production of the part almost always is preceded by pre-production verification. Observation of the temperature distribution, heat transfer, the nature of the flow of the liquid metal are values that are very difficult to observe during real casting process. Through the computer simulations, there is a possibility of a preliminary assessment of this phenomenon without the need for expensive and time consuming trials. Results obtained in the simulation in the form of the visualization of the process of filling of the mould cavity, temperature changes during the crystallization and solidification allows to optimize the approach in the design of foundry technology using CAD tools. The modification of the technology concept on "*an ongoing basis"* based on the results of the simulation allows to make the necessary changes in order to obtain the best possible method of filling of the mold cavity and the creation of an appropriate feeding system providing directional solidification in the casting.

In the example of the diesel engine compressor rotor the preparation of simulation analysis, visualization of the process of filling the mould cavity, and solidification of liquid metal in a furnace VC3000D INDUTHERM was presented.

The first step in this casting process is the preparation of a plaster mould by using a silicone model of rotor shown in Fig. 1.

Fig. 1. Silicone model of the rotor

In the case of such complex casting, it was necessary to use such elastic model. The casting technology used in this device also allows to use wax models as well.

The next step is to place the model in a steel sleeve and filled it with liquid plaster material. A plaster material with trade name M028, which is recommended for the investment casting of thin-walled aluminum alloy casting was used. The plaster mixture was degased two times. The first degasing procedure takes place directly after mixing with water in relation with plaster material 27:100. The second degasing takes place after filling of steel sleeve. The whole degasing process last for about 8 minutes. On the Fig. 2 the sleeve and plaster mould are presented.

Fig. 2. Sleeve and plaster mould

The next step is the elimination of excess moisture from the volume of the plaster mould, in the two step heat treatment process. The first step of heat treatment the mould reaches temperature of 200°C. The second step the temperature is elevated to 700°C. The times of the various phases has been selected experimentally due to the lack of guidelines, which should be based on the dimensions of the applied steel sleeve. After removing of the properly prepared plaster mould, it is placed in the VC3000D furnace chamber, which was presented in Fig. 3.

Fig. 3 VC3000D furnace with an open chamber

The furnace is divided into two chambers. In the upper chamber the melting of aluminium in a graphite crucible is carried out. In the lower chamber is the plaster mould is placed for casting. In the lower chamber is the possibility to create a vacuum or low pressure state. The crucible located in the melting chamber is equipped with a stopper. After the lifting of the stopper the pouring process of the molten metal takes place. The flow process of the liquid metal is forced by the pressure difference between the lower chamber and the pressure that is working on top of the liquid metal. Prepared 2,4 kg of AlSi9Mg alloy was melted at a temperature of 680^{O}C. After reaching the optimal temperature the stopper is raised. The use of the stopper allows the elimination of impurities in the melting in the form of dross, which in the pouring remains on the surface of the liquid metal. Additionally, in order to eliminate oxidation the melting process is conducted in the argon atmosphere. The advantage of this procedure is to maintain the liquid metal in the proper purity [1,2]. The chemical composition of the liquid metal is presented in table 1.

Table 1.
Chemical composition of AlSi9Mg alloy

Element	Si	Cu	Mg	Mn	Fe	Ti	Al
[% mas.]	9.12	0.21	0.23	0.34	0.63	0.01	bal.

In the computer simulation the initial temperature of plaster mould and liquid metal was set slightly lower. At that time the technological reasons the temperature of plaster mould was 450^{O}C and the liquid metal was 690^{O}C. After knocking the cast out there were no casting defects on the surface of the blades. On the fig. 4 there is a finished rotor casting.

Fig. 4. Turbine compressor rotor casting

2. Numerical analysis of the casting process of the compressor turbine rotor

The simulation programs are commercially available for use to create a spatial geometry of design casting and casting technology. The simulation of the casting process and solidification of the compressor rotor was performed in the ***FLOW-3D*** software. In the case of the analyzed geometry to obtain a spatial image the reverse engineering technique was used [3-5]. Fig. 5 presents the casting shape and the casting technology designed on the casting geometry.

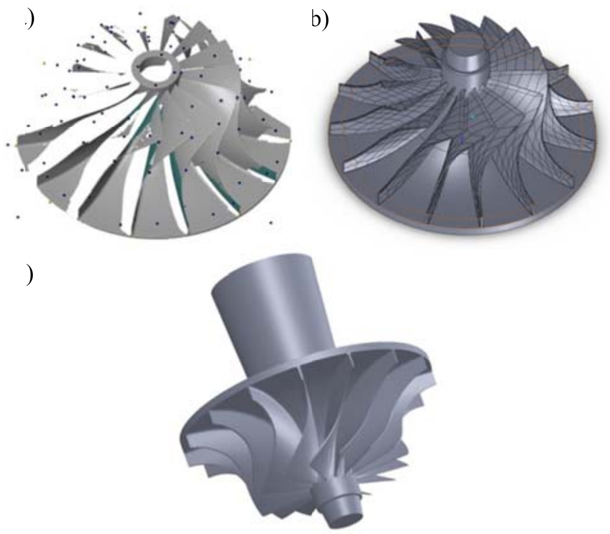

Fig. 5. a) Cloud of points of image of the object, b) CAD object of the rotor, c) the concept of casting technology

Fig. 5c presents the conception of casting technology. The design based on the use of a sleeve, which defines the dimensions of the vacuum furnace chamber. The gating system is also used as a feeder. After analysis of the rotor construction, which is presented in fig. 6, the largest cross section is found in the center of the casting.

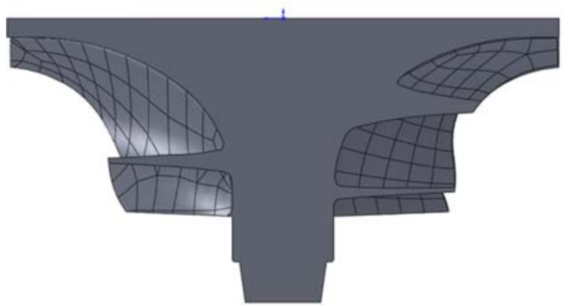

Fig. 6. Cross section of the rotor geometry

Due to the nature of the solidification of the liquid metal the last spot which solidifies in the largest cross-section can be the place where the hot spot is located. The designed riser should an extra volume of liquid metal in order to transfer the hot spot to the volume of the feeder.

The boundary conditions were set to simulate conditions close to real casting process. In the lower chamber of the furnace the conditions of low pressure were set. The initial temperature of liquid metal is Tin = 650°C, the initial temperature of the plaster mould Tm = 350°C, pressure p=1 bar [6]. The physicochemical data of the alloy and mould material was used from ***FLOW-3D*** database.

3. Analysis of the simulation results

Conducted simulation and obtained results allowed to analyze the flow phenomenon and solidification of the liquid metal in the plaster mold cavity. The visualization filling of the mould cavity is shown in Fig. 7.

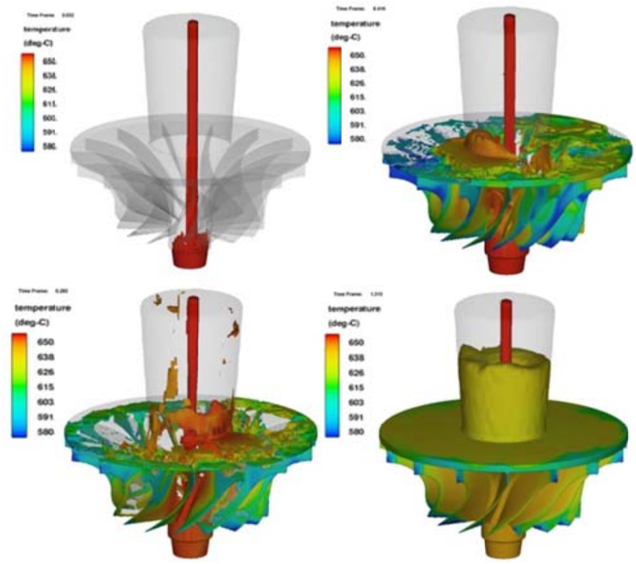

Fig. 7. The visualization of the results of the filling of the mould cavity with liquid metal

The visualization of results of a filling process shows that in the first phase, the flow of liquid metal is turbulent. The low pressure conditions created by the vacuum pump after opening the stopper additionally with gravity force the liquid metal to fill the mold cavity. Also liquid metal is pressured by the atmospheric pressure that acts on the surface of the melt. In the real casting process the turbulent flow is undesirable due to the formation of oxides, which along with the liquid metal front flow the entrainment can occur and form a discontinuity in the casting structure [7]. During the filling process early solidification can occur in the outer area of the blades. This is caused by the very thin-wall of the blade and very fast cooling of that region. The last stage of the filing process is the laminar filling of the feeder. The filling time of the cavity is about t=1,5s. Based on the results of the process of filling the mould cavity and the temperature distribution the restart simulation of the solidification process was run. On the fig. 8 the visualization of the solidification path is presented.

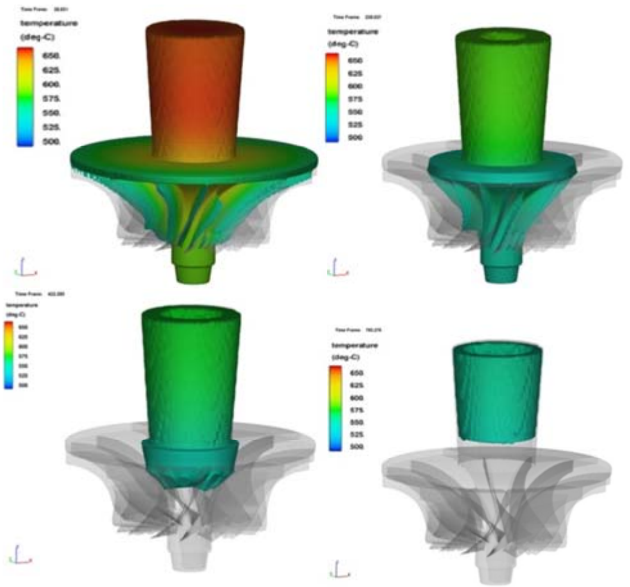

Fig. 8. Solidification path rotor casting

Solidification path analysis shows that the blades solidified as the first area of the casting, which was mentioned earlier during filling of the cavity. Solidification path is directed to the central part of the casting. The solidification front goes towards the hottest volume. The use of efficient feeder by calculating the proper volume of liquid metal that is required to feed the hot spot allows to remove the porosities to the volume of the feeder. During the solidification process the segregation phenomenon is occurring on the front of the solidifying liquid metal. The oxides and inclusions could be located in the regions which are solidifying as last and create shrinkage porosities [8].

4. Conclusions

Numerical analysis is wieldy used in all knows casting technologies. Numerical modelling of the process phenomenon such as casting using a pressurization differences enables to prepare the visualization of the process of filling and solidification of liquid metal into the cavity of the plaster mould. Learning about the phenomena occurring during the flow of liquid metal allows to optimize the concept of the gating system, and the analysis of the solidification process allows an optimal design of the feeding system of the casting. The use of computer simulation in the designing process of the casting of the turbine compressor rotor allowed to evaluate the assumed parameters of the actual casting process. The use of computer simulation helped in the design of the foundry technology to cast a detail without defects and porosities.

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