The use of a computer modeling system for foundry processes in blank production

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Abstract. The article focuses on the analysis of the results of computer simulation of the technological process of casting the part "Stub". In the work, the elements of the gating-feeding system were calculated. Based on the calculated data, a digital model was built. An important stage of the work was the digital modeling of the technological process of casting the plug part in the ProCast CAE system. The simulation results were viewed and analyzed in the Visual-Viewer postprocessor module. An analysis of the simulation results made it possible to evaluate the efficiency of the gating system, determine the areas of turbulent flow, the nature of filling the zone with a high flow rate, possible places of mold erosion, places of formation of air pockets that can affect the occurrence of gas inclusions in the casting. The nature of the distribution of the temperature gradient in the casting, the time and uniformity of the solidification of the casting were also studied.

1. Introduction

Computer simulation and optimization of parts manufacturing technologies is an important direction in the development of software products for numerical engineering analysis. Computer analysis of foundry processes at the stage of digital design of casting technology (before castings are made) makes it possible to minimize possible miscalculations and errors that inevitably arise in the development process, reduce financial and time costs, increase efficiency, competitiveness, quality and reliability of the products being developed. Only computer simulation of the technology allows one to "look" inside the product, to understand the causes of defects [1, 2].

In this work, the object of study was a thin-walled part - a plug, which is made of structural carbon steel grade St45L (figure 1).

The plug is installed along the outer ring into the motor housing and fastened with fasteners - studs.

The plug experiences axial and radial stresses, as well as alternating stresses from vibration loads and minor thermal loads.

From a design point of view, a part blank can be obtained both by stamping and casting.

Calculations of the unit cost of the manufactured part showed that the most effective method is investment casting, which allows to obtain a complex shape of the workpiece. Table 1 presents the main dimensions of allowances, overlaps and rounding radii necessary for designing a digital model of a part casting (figure 2).

In accordance with the technique of the technological process of modeling metal shrinkage in the manufacture of aerospace engineering parts, developed by the team of authors, implemented as a software module and intended for use in computer simulation systems for foundry processes, it was...
found that the total volumetric shrinkage for a workpiece of a plug part made of carbon steel mass 0.42 kg is 2%.

2. Description of research models

| The largest overall dimension of the casting, mm | LT1 | LT2 | LT3 | LT4 | LT5 | LT6 | LT7 |
|------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|
| Up to 60                                       | 0.5 | 2.0 | 2.5 |
| From 60 to 100                                  | 0.5 | 2.0 | 3.0 |
| From 100 to 160                                 | 0.5 | 2.5 | 3.5 |
| From 160 to 250                                 | 0.7 | 2.5 | 4.0 |
| From 250 to 400                                 | 1.0 | 2.5 | 4.0 |
| From 400 to 630                                 | 1.5 | 3.0 | 5.0 |

* The smallest machining allowance must be greater than the tolerance.

For further analysis of the casting process and obtaining a casting of a stub part, it is necessary to calculate the elements of the gating-feeding system.

Pouring molds of small and medium-sized castings on conveyor and automatic lines, i.e. in serial and mass production, is carried out from rotary buckets with a capacity from 100 to 800 kg.

In this case, the consumption of steel from the ladle is controlled by the angle of its inclination. The limiting element of a closed or tapering system of ladle-gating channels-mold cavity are feeders with the smallest cross section.

In accordance with the methodology of B. Ovann, the design of the gating-feeding system, shown in Figure 3, was calculated and designed.

An important stage of the work performed was the digital modeling of the technological process of casting a plug part in the CAE software product ProCast.

The simulation results were analyzed in the Visual-Viewer postprocessor.

During the analysis of the process of pouring an alloy into a casting block, it is possible to determine the nature of the filling, evaluate the efficiency of the gating system, determine areas of turbulent flow, zones with high flow rates, possible areas of erosion of the mold or core, places of formation of air pockets that can affect the occurrence of gas inclusions in casting [3 – 5].
3. Results and discussion

Based on the picture of the mold filling hydraulics (Figure 4), we can conclude that the optimal metal pouring speed was selected (it is 0.9 m/s), since the metal level in the sprue bowl is kept at a constant level, its flow occurs without unnecessary bursts and braking.

The dynamics of filling the casting block with metal indicates the optimal design of the gating-feeding system. This conclusion follows their calm and uniform nature of filling, as well as the correct and timely operation of the structural elements of the gating-feeding system (feeders, risers, risers, etc.).

The crystallization process starts from the bottom of the casting - these are the risers and the thinnest walls of the casting (Figure 5). The solidification of the casting occurs very quickly, because all the elements of the casting are thin-walled.

Figure 3. Computer model of the casting block.

Figure 4. Pattern of filling the casting block with liquid metal at different points in time.
Crystallization of the central part of the casting of the stub part occurs quite dynamically and evenly (Figure 6). With a similar nature of solidification, fine looseness (macroporosity) may occur, which is associated with the phenomenon of volumetric crystallization and, as a result, volumetric shrinkage.

Figure 5. Crystallization of the casting of the plug part: a – at the initial moment; b - before complete hardening.

Figure 6. Pattern of X-ray control for predicting defects in the stub part.

The Chvorinov’s Thermal Modulus parameter allows you to evaluate the geometry of the casting and the nature of its thermal layer (Figure 7). The higher the value of the thermal modulus, measured in centimeters, the longer the hardening time of this area. This module is calculated as the volume of the current node divided by the cross-sectional area. It is often used to evaluate feed efficiency gains and evaluate the crystallization direction of a casting. Ideally, the modulus at the bottom of the casting should have a minimum value, gradually increasing towards the top of the casting. Profit should have the
highest value of the thermal modulus in order to have time to impregnate all the lower parts of the casting. The casting zones have practically the same modulus values. Crystallization is quite fast. This phenomenon contributes to the appearance of small ripples in this zone [6–10].

Figure 7. Thermal modulus evaluation pattern.

Hot nodes (Figure 8a) show the solidification time of the zones in the casting; thermal units that hardened last and where shrinkage is possible. These are places where shrinkage porosity appears as a result of delayed solidification - slower than in neighboring casting areas.

Porosity (Figure 8b) in the casting itself is within the normal range (up to 3%), but in the feeder and riser it is above the norm.

Figure 8. Porosity observation pattern at the macro- and microlevels:

a – formation of hot knots; b – formation of porosity.

The Solidification Time parameter allows you to evaluate the time and uniformity of solidification of the casting. Figure 9 shows that the fastest places of solidification are in narrow sections (uplifts).
After that, you can observe the uniform hardening of the castings themselves, after the feeders and the riser.

![Casting solidification time](image)

**Figure 9.** Casting solidification time.

With the help of the ProCast computer modeling system for foundry processes, it is possible to carry out particle tracing analysis to evaluate the nature of the filling, i.e. view the problem of getting foreign particles, molding components of the mixture or shell elements into the LPS, where they can be carried out by the metal flow during the pouring process (Figure 10). The program forcibly delivers particles to the metal supply zone after a specified time interval and the calculation of the movement of these particles inside the casting block is carried out. As a result, it can be seen that the maximum accumulation of particles occurs in the gate bowl and risers, to a lesser extent, directly, in the casting. However, if there are turbulences during movement (a kind of tangle of tracers), then the probability of accumulation of particles in this area increases. In this case, the particle motion trajectory is relatively directed – from top to bottom [11, 12].

4. Conclusions

Summarizing, it can be noted that the results of a computer analysis of the technological process of casting a plug part made it possible to evaluate the mechanism for obtaining a casting, the structure and causes of the formation of casting defects, on the basis of which comments were given on eliminating defects. The use of computer simulation systems for foundry processes makes it possible to reduce financial, material and time resources for the production of parts.

Thus, the ProCast software package, applicable to various casting processes and having a complex mathematical apparatus, adequately describes the physics of foundry processes and allows you to fully analyze the technology, taking into account the key features of foundry production. The flexibility of this package, combined with the hands-on experience of its developers, ensures that ProCast will meet any new challenges that come with changing technologies in the enterprise.
Figure 10. Tracing pattern of foreign particles in a casting.

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