Software for modeling the casting process

V A Kukartsev¹, A A Rukosueva², A R Ogol³, V V Kukartsev¹,², V S Tynchenko¹,² and V V Khramkov¹

¹Siberian Federal University, 79, Svobodny pr., Krasnoyarsk, 660041, Russian Federation
²Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russian Federation

E-mail: sarabernar777@mail.ru, vlad_saa_2000@mail.ru, vadimond@mail.ru

Abstract. The permanent improving of physical and mechanical properties of cast alloys, the improving of old processes and the introduction of new processes allowing to get a precision casting with a soft surface and not demanding the machining and, finally, a constant increasing of the productivity of applied processes change not just technological but economic case of the modern foundry. The computer modeling becomes an inalienable part of processes of the new model design and the engineering of technological processes for its production. It gets a status of an important and often a decisive competitive advantage. The computing of the gating system for casting of 20x5ML steel was completed and the most optimal option allowing getting castings without defects was found with LVMflow modeling program. Output of valid casting was computed, there were finding out a needed metal filling of furnace and selecting batch’s material to get the necessary chemical compound of alloy. Based on condition that the smelting will be carried out on return and fresh materials, a spending of acquisition has been defined. Then the way of computing was used as an initial variant to the checking modeling with ProCAST program which allowed to obtain higher amount of valid castings due to the changing the design of gate system. It let change metal filling of furnace and pick up a need in fresh materials in the different way. The calculation of costs for acquisition is revealed that the using of ProCAST let to achieve the reducing to get casting with saving needed quality of alloy.

1. Introduction
The most important task of modern production of semi-finished products and products made of casting is reducing of its and coefficient of using metal increasing [1]. The one of ways of it is the applying the modeling casting processes program.

The computer modeling becomes an inalienable part of processes of the new model design and the engineering of technological processes for its production [2, 3]. It gets a status of an important and often a decisive competitive advantage [4]. Increasingly, customers of foundry require in their requirement list that the computer modeling will be indispensable applied. It gives the possibility of testing nuances of foundry technology on a virtual machine of the producing casting, it reduces or completely liquidates the necessary of an testing castings producing, shortens the technology process design and cut down a first cost of casting. A visualization of physical processes of the foundry technology, such as a mold cavity filling, the cooling and the solidification of metal, its hogging under
the influence of thermal pressures allows to find out features of these processes, but consequently a
managing it for reducing casting spoilage and increasing an amount of valid casting in input is more
effective.

Nowadays, countries developed the most famous programs of the casting processes modeling are
Germany, France, the USA, The Great Britain, Finland and Russia [5]. In table 1 presented the short
information about programs of the casting processes modeling, which are offered by firms of these
countries.

| The program title | Country-developer | Firm | Possibilities | The solving method | Minimal cost per work position, euro |
|-------------------|-------------------|------|---------------|-------------------|-------------------------------------|
| Magmasoft         | Germany           | MAGMA GmbH | GTTeS         | FDM               | 65000                               |
| WinCast           | Germany           | Simtec Inc | GTTeS         | FEM               | 65000                               |
| Procast           | France            | ESI Group | GTTeS         | FEM               | 60000                               |
| PAM-CAST          | France            | ESI Group | GTTeS         | FDM               | 30000                               |
| Flow3D            | The USA           | Flow Science | GTTe         | MOM               | 28900                               |
| SolidCast         | The USA           | Finite Solutions Inc | GTO       | FDM               | 26500                               |
| CastCAE           | Finland           | Oy, Espoo | GTTe          | FDM               | 15000                               |
| LVMFlow           | Russia            | LLC «NPO MCM» | GTTe          | MOM               | 29500                               |
| Полигон Софт     | Russia            | Sysoft polygon plus | GTTeS     | FEM               | 34600                               |
| Mavis-Flow        | The Great Britain | Alphacast Software, Swansea, UK | GT       | FDM               | 11000                               |

Programs are characterized by the next features: G – the carrying out of a hydrodynamic
calculation of the filling a form with a melt; T – the calculating temperature fields during the
crystallization and the detecting shrinkage defects; Te - the calculating of tensions in the casting and
the residual deformation; S - the modeling of structure (a grain texture, the distribution of ferrite and
perlite, a size of graphite inclusion, etc.); O – a parameter optimization of gate system in automatic
mode. In programs to solve the casting process modeling there is using methods: FDM - the finite
difference method, FEM - the finite element method, MOM - the multi-objective optimization
method.

Nowadays, in our country there is applying of programs of the casting process modeling:
Magmasoft is in 15 enterprises, WinCast is in 3 enterprises, Procast is in FSUE «MEPE “Salyut”» in
Moscow, SolidCast is in PC “The Rostov Foundry” in Rostov-on-Don, LVMFlow is in 67 enterprises
and 17 educational institutions and Polygon Soft is in 8 enterprises and 10 educational institutions.

As general, a foundry technologist uses the modeling program for checking a developed way of the
casting production technology. Firstly, it determines a location of shrinkage defects and finds out a
way to eliminate it. Since the market dictates conditions for order fulfillment, the job is completed by
technologist for 1-2 days (otherwise a profitable order will be moved on to another producer).
Especially it concerns producing alloy steel casting of complex configuration, its cost is quite high (at
least 500 rub/kg). According the fast, the enterprise has a sophisticated task of selecting needed
modeling program [6]. In the practice, the best result is given by Polygon, ProCast, WinCast because it
let take into account geometry of casting as much as possible and reveal even slight defects. However,
the complexity of using the solving casting processes modeling method (FEM) results in preparation
of the initial data for computer modeling can take several days or even weeks for a one calculation.
Moreover, it demands highly qualified staffs. Because of it, producing casting programs using FEM
have not been in the mass distribution in Russia. Nowadays, Procast is succesfully applied in FSUE
"Salyut" where the CAD department has been created, it completely optimizes a process of getting valid castings wasting one month for a one alloy [7]. In Russia the only one development using FEM is “Polygon” program which is so complicated in applying and expensive compared programs using FDM. According many parameters, the program may be Russian analog of the ProCAST system. However, the practice applying in alloy enterprises in Russia performs the “Polygon” cannot daily use for developing the casting producing technology. Duration of getting result and the lack of qualified staff lead to low efficiency of using such modeling program systems in ordinary enterprises. The fact that duration of system training in production environment is from six months to one year is affected.

The finite volume method (FVM) combines the simplicity and the factorization of FDM and a good approximation of borders between different materials and different phases. It allows to perform the modeling as quickly as possible without losing the accuracy of calculations. LVMFlow is the only one full-fledged program for foundry used the method and significantly benefits from these programs in capabilities and has a Russian interface and a domestic database. Moreover, the duration of learning SAM CP LVMFlow does not exceed 16 hours then a technologist can start to model casting processes. In the way, a choosing program of the casting processes modeling for enterprise is an important task affecting to preparation of the alloy producing [8].

2. The suggested solution
Because of it, there was decided to counting and adjusting the gate system for casting from 20x5ml with using modeling program as LVMFlow and ProCAST. Then, according the result of valid castings, it needs to determine material inputs for fresh batch materials. As an example it was “The compressor wheel” weighted 84 g (figure 1). According the complexity of configuration and the need of getting sizes with minimal machining allowances, it was chosen the lost-wax casting way.

![Figure 1. A compressor wheel.](image)

Using the method developed by M. L. Hlenkin provides supplying metal to the most massive casting units, the calculation of the gate system of the first type was completed and a modal block with dimensions: a riser diameter is 30 mm, a feeder length is 8 mm, a feeder diameter is 12 mm (figure 2). As an initial one, there was the simplest layout scheme of castings around the riser. The central riser is the basis for creating a complex mechanized technological process of producing small alloys. The applying the unified metal frame as a structure provides convenience of the link assembly for a modal block and its high strength in producing a shell form. In the cast block, the central riser is securely fixed in machines during cleaning and cutting of alloys.
The formation of casting is a complicated process, therefore, taking into account all factors affecting to the process of crystallization is almost impossible task. An experimenting all ways of the gate system to find out the best one is a difficult and durable process. As general, the developing an optimal way for the gate system with getting a valid casting takes several weeks, because of it, to determine is the gate system working there was applying LVMFlow. The result of the modeling showed that the gate system did not provide defect-free filling (figure 3).

Figure 3 shows the result of the modeling in LWMFlow:

- 1 – defects detected in the modeling based on the first calculation.
- 2 – section of castings in the block revealing the absence of defects.

After many unsuccessful fillings, it has been decided to change a construction of the gate system including locations of castings. In the result, it was possible to pick up the most optimal option for the gate system (figure 3.2) with 40 mm of riser diameter and 320 mm of length of it. The input was 30.76%.

The next step was in the performing the modeling with using ProCAST. As the initial data there were results obtained with LWMFlow program. On figure 4 there is a research result.
Figure 4. The result of the modeling ProCAST (the shrink porosity).

Figure 3 shows the result of the modeling ProCAST (the shrink porosity):

- 1 – modeling with a size of gate system from LWMFlow.
- 2 – final result of the modeling in ProCAST.

After the automatic optimization of a grid and a 3D model of casting, it was successfully reduced the riser diameter to 27mm but its length to 310mm, it allowed to increase technological input of valid castings from 30.76% to 31.92%.

Then, based on received values of input, valid fillings was a ratio of metal needed to produce “The compressor wheel” castings from 20x5ml steel (table 2).

Table 2. The calculating of metal balance.

| Balance sheet          | A technology using LWMflow | A technology using ProCAST |
|------------------------|----------------------------|-----------------------------|
|                        | %  | kg  | %  | kg  |
| Input of valid castings| 30.86 | 1000 | 31.92 | 1000 |
| Reject                 | 4  | 129.618 | 4 | 125.313 |
| Sprues, income         | 58.64 | 1900.19 | 57.58 | 1803.88 |
| Discharge, splash      | 2.5 | 81.011 | 2.5 | 78.3208 |
| Irretrievable losses   | 2  | 64.8088 | 2 | 62.6566 |
| Carbon fumes           | 2  | 64.8088 | 2 | 62.6566 |
| Metal filling          | 100 | 3240.4407 | 100 | 3132.83208 |

The metal balance has a great technical and economic value. The metal consumption, the first cost of liquid metal and casting depend on it. Following indicators are decisive: a type of smelter and a technological rate of enterprise. While new casting is launching, casting reject, carbon fumes (for induction furnaces), irretrievable losses, discharges and scrap will be setting according achieved results in an analog production.

Because of there is the metal balance, there is making a choice of batch materials, taking into consider that the smelting will be in an induction furnace with an acid lining and with the full using of
returns [9]. The choosing of materials is performing in that way that a chemical compound of the alloy for each element will has got average (permissible) value and satisfied the Russian state standard (GOST) requirements for the 20x5 mm steel. The calculation of batch is completing for it with applying the selection method allowing determining the needed combination of initial materials. Then the next is the defining a waste of selected batch materials and a cost of its acquisition. The result is in table 3.

| Title                         | GOST          | Cost per kg  | Consumption and cost of valid casting input 30.86% | Consumption and cost of valid casting input 31.92% |
|-------------------------------|---------------|--------------|--------------------------------------------------|--------------------------------------------------|
| The 15X5 scrap                | 20072-74      | 20           | 32.5                                             | 33.5                                             |
|                               | 5905-2004     | 730          | 1.7                                              | 1.79                                             |
| The X99 metal scrap           | 6008-90       | 140          | 0.186                                            | 0.185                                            |
| The Mn 998 metal manganese    | 2169-69       | 140          | 0.188                                            | 0.194                                            |
| The kr 0 metal silicon        | TU 48-19-73-86| 550          | 0.217                                            | 0.186                                            |
| The MS-2 metal molybdenum     | TU 1911-109-73-2000 | 70 | 0.062                                            | 0.063                                            |
| Common costs                  |               |              | 101,938                                          | 95,893                                           |

### 3. Conclusion
To sum up, conducted studies can show the using program of the casting processes modeling as ProCAST in developing the gate system can allow stepwise visualizing the filling process and the cooling compared to LVMFlow. It gives a possibility to apply more rational way to construct the gating system and gets higher amount of valid castings in input. The calculations clearly reveal the cost saving of buying raw materials in the amount of 6045 rubles per 1 ton of valid alloy of the 20x5mm steel. It allows reducing a cost of the alloy smelting. The using ProCAST gets an ability to successfully compete in the market of the alloy for foundry, due to the reducing its cost.

### References
[1] Borisov V N and Pochukaev O V 2015 Innovative machine engineering as a factor of developing import substitution Stud. on Rus. Econ. Develop. 26 225–32
[2] Bukhtoyarov V V, Tynchenko V S, Petrovsky E A, Dokshamin S G and Kukartsev V V 2019 Research of methods for design of regression models of oil and gas refinery technological units IOP Conference Series: Materials Science and Engineering 537(4) 042078
[3] Bukhtoyarov V V, Tynchenko V S, Petrovsky E A, Kukartsev V V and Kuklina A I 2018 Evolutionary method for automated design of models of vortex flowmeters transformation function Journal of Physics: Conference Series 1118(1) 012041
[4] Kukartsev V A, Tynchenko V S, Kukartsev V V, Chzhan E A and Shepeta N A 2018 Steel smelting in induction crucible furnaces with industrial frequency IOP Conference Series: Earth and Environmental Science 194(4) 042024
[5] Nikanorov A V 2018 The comparative analysis of computer program of the casting processes modeling Ambassador of the Irkustk State Technical 11 200-18

[6] Tyrishchev V V 2005 The modeling of casting processes: what to choose? CADmaster 17 33-5

[7] Devyatov S V 2006 ProCAST - the virtual modeling of the casting technology for those who are not used to be ahead CADmaster 19 36-44

[8] Leushin I O and Reshetov V A 2014 The experience of using the mathematic modeling in technological preparation J. of Siber. Fed.Univ. Engin. and Techn. 4 430-5

[9] Kukartsev V A 2016 The iron and steel smelting in industrial frequency induction furnaces Steel 26-2