Technological Process Modeling For Castings According To Specified Parameters Of Output Production Quality Based On Production-Frame Model Of Knowledge Representation*

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Abstract. *The article considers the modeling technique of casting technological process according to the required quality indicators of output products. They proposed the structure of an intellectual information system based on the presentation of knowledge using the frames and the rules of product selection. The system is designed to create and select the process parameters according to the required output product quality indicators, as well as to optimize the existing casting technological processes. The implementation of the developed system for the casting technological process from cast iron with vermicular graphite is presented using the built-in CLIPS programming language. As the initial information for the formation of the knowledge base the test results provided by PJSC "KAMAZ-Metallurgy" were used. The modeling of the technological process on the basis of the production-farm model of knowledge representation allows to eliminate the main disadvantages of the automated design systems used in the foundry industry at the present time: high requirements for necessary machine resources and personnel qualification. The application of the developed system will allow to reduce significantly time and financial costs for the preparation of production due to the reduction of real tests number necessary for the selection of optimal technological process parameters.*

Keywords: cast iron with vermicular graphite, frames, production model of knowledge representation, base of rules, knowledge base

Introduction

The physical-chemical processes that take place during the casting of metals are closely interrelated. Therefore, the change of even one parameter of the technological process can significantly affect the quality of the resulting casting. This opens the prospect of the foundry process optimization, and also provides the possibility of a final product quality problem solution and the improvement of production economic performance.[1]

The possibility of modeling the process of casting obtaining reduces the number of real tests in practice during the preparation of production and reduces the efforts spent on the selection of technological process parameters for the organization of product output. Thus, it is possible to consider the problems of a method development for quantitative estimation of a casting real quality on the basis of trial tests and the technique of technological process optimization for casting obtaining, which requires a minimum number of experiments as relevant ones.[2]

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[1] I. Hahn, J. C. Sturm, "Versuchspläne in der gießtechnischen Simulation," in *GIESSEREI*, IVC (2009), no. 7, p. p. 86–100.

[2] C. Heisser, J. C. Sturm, I. Hahn, "Autonomous optimization of casting processes and designs," in *Transactions of the American Foundry Society. One Hundred Fifteenth Annual Metal casting Congress*, Aachen, Schaumburg, 2011, p. 1–20.

The modeling of casting obtaining process is a standard procedure nowadays performed by a qualified specialist in the field of foundry. Almost all large enterprises use CAE (Computer Aided Engineering) technologies to solve the problems of foundry process modeling. The results of simulations conducted in CAE systems supplement and clarify the practical skills of a specialist. Using the results of the performed simulation, it is possible, for example, to assess whether the selected process parameters provide the required casting quality. In addition, CAE systems allow for optimization - to sort out all other possible combinations of technological process parameters in order to achieve the best result.[3]

However, there are also problems when you use CAE systems in the foundry industry.[4] The most significant among them are the following ones:

- the need for a highly qualified specialist experienced in working with these systems;
- high requirements of CAE systems to computer system resources;
- high cost of software products of this category, and the modules for optimization are often delivered and paid separately.

The modeling of casting technological process according to the required quality indicators of output products will be considered using the example of cast iron with vermicular graphite (CIVG), which has a number of specific properties that make it one of new promising construction materials for the castings of various purposes. This material can be used instead of gray cast iron for a number of critical parts of general engineering, the material of which has high requirements by strength and plastic characteristics according to the conditions of their work. The combination of high mechanical properties and increased thermal conductivity for cast iron with vermicular graphite makes the use of this material for castings operating under thermal conditions and a significant temperature difference very promising, for example, in diesel building.[5]

The main difficulty in the production of CIVG is a narrow range of the modification effect stability. An incorrect selection of the technological process parameters leads to the development of either a purely spherical or plate-shaped graphite.[6] Besides, this material has an increased tendency to bleach, increasing the

[3] H. Bramann, L. Pavlak, "Innovatives Produktdesign und robuste Prozessausle-gung durch virtuelles Experimentierenmit der Gießprozess-Simulation," in *GIESSEREI,* CII (2015), no. 2, p. 87-89.

[4] L. R. Yusupov, V.V. Abramova, "The study of information systems to forecast the properties of materials," in *Collection of reports from scientific-practical. Conf. "VI Kamsky readings",* Part 1. - Naberezhnye Chelny: Publishing house of Central Polygraphic Naberezhnye Chelny Institute KFU, 2014, p. 134-139.

[5] N. Girshovich, *Handbook on cast iron*, 3rf. Edivion, Leningrad, Mechanical Engineering, Leningrad Branch, 1978.

[6] O. S. Komarov, V. N. Kovalevsky, A. S. Chaus (eds.), *The technology of structural materials: a textbook*, Minsk, New knowledge, 2005.

fragility of the product and hampering its machining, which causes special problems in the production of thin-walled castings.[7]

In this regard, the development of new techniques for casting technological process modeling from CIVG according to the required output quality indicators is an urgent task.

Materials and methods

The starting material for the work was the certificate-report on the lots of CIVG nomenclature castings, which were cast on the automated molding line of PJSC "KAMAZ-Metallurgy".

On the basis of the experimental data, universal dependences of modified cast irons on their chemical composition and process parameters were obtained using regression analysis methods.[8]

The statistical analysis of the initial data was carried out in SPSS Statistics program.[9] CLIPS language[10] was used to implement the base of rules.

Results and discussion

The modeling of casting technological process is carried out in 3 stages according to the required quality indicators of the output products.

Creation of initial data

In order to develop a prediction model the input of the unit is supplied with the following original data:

- required output product quality indicators;
- the values of the input criteria specified by a user (percentage of charge components, cast chemical composition, casting type).

The technological process of casting obtaining is modeled according to these values.

Depending on a task (the simulation of a new technological process or the optimization of an existing one), the initial data are generated for processing. At this stage, the data entered by an operator is checked for correctness. The decision on correctness is taken on the basis of check results for compliance with the acceptable ranges of chemical element content, the required norms by carbon equivalent and eutectics degree.

The data that passed the validation test is involved in the formation of the initial data, by which the process parameters will be predicted or the search is performed using the case base. All the parameters necessary for the development of the technological process, which were not specified by an operator, are taken from the database.

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[7] A. G. Panov, V. V. Konashkov, V.S. Tsepelev, D. A. Gurtovoy. A. E. Kornienko, "The study of cast iron melt structuring," in *Foundryman of Russia,* III (2010), p. 32-37.

[8] A. Gallo, H. Weekly, "A Refresher on Regression Analysis," in *Harvard Business Review*, 2015: https://hbr.org/2015/11/a-refresher-on-regression-analysis, accessed 14. 04. 2017.

[9] A. Field, *Discovering statistics using SPSS*, Dubai, Oriental Press, 2009.

[10] Joseph C. Giarratano, Gary Riley, *Expert Systems: Principles and Programming,* 3rd edition, Thomson Course Technology, 2005.

Modeling of technological process parameters

Using the database rules, a technological process is generated that will contain all the information needed to organize the production. The main tool for technological process modeling is the genetic algorithm (implemented in the base of rules).[11] Its main function is the selection of the technological process parameters by the means of mutation mechanisms. The choice of a casting method depends on the following product parameters: material, weight, structural complexity and overall dimensions. The determination of the rate and the conditions of solidification of cast iron is necessary, since the shape and the amount of inclusions of graphite depends not only on the modifiers, but also on crystallization time. The nature of cast iron solidification is determined by its composition and cooling rate. A delayed cooling promotes the formation of graphite, an accelerated cooling suppresses the release of graphite and promotes the formation of cementite partially or completely. The speed of cooling depends on the thickness of a product wall directly, therefore, the mechanical properties of the CIVG depend on it. The forecasting of an optimal quantitative ratio of chemical elements at different stages is based on the information entered by a user.

Technological process optimization

When the technological process is formed, its optimization is carried out using the base of rules. Alternative technological processes are developed, adhering to the conditions and the restrictions imposed by an operator. The parameters of the process are determined by the simulation results. If several technological processes are found according to the search results in the knowledge base, the best of them is determined using the genetics algorithm belonging functions.

Since the composition of theoretical and empirical knowledge is used to solve a problem, the combined methods of knowledge representation are used - frames which are an expedient form of rule base organizing.

The main components of an intellectual system knowledge base[12] are the base of facts and the base of rules presented in Figure 1. At that, the fact base reflects an initial state of a problem, and the base of rules contains the rules that help to analyze a problem state and find its solution.

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[11] L. R. Yusupov, K. V. Klochkova, L. A. Simonova,"The technique of cast iron chemical composition modeling with vermicular graphite based on a genetic algorithm," in *Mater. of Intern. scientific-tech. Conf. "Innovative machine-building technologies, equipment and materials - 2016"*, Part 2. – Kazan, Tome, 2016, p. 180-185.

[12] K. V. Klochkova, S. V. Petrovich, L. A. Simonova L. R. Yusupov, "Stages of vermicular cast iron properties modeling in the intelligent design system," in *IOP Conf. Series: Materials Science and Engineering*, LXXXVI (2015), no. 1.

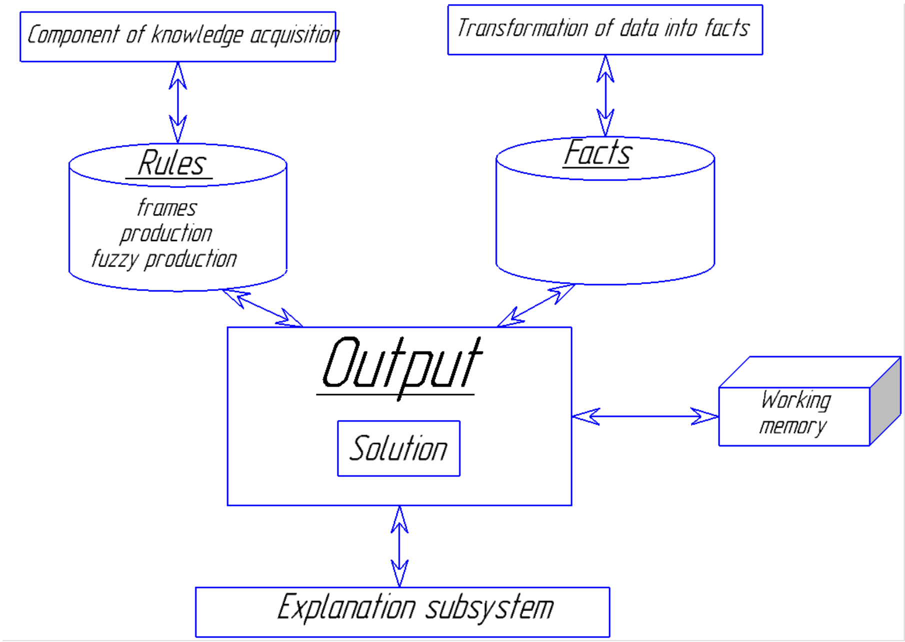

Fig. 1. Rule-based structure

The knowledge acquisition unit is responsible for the development of rules based on the database intellectual analysis, the processing and the generalization of expert assessments.

The data conversion unit is responsible for database rules integration with other applications so that the data can be presented in the form of facts.

The rules according to which the choice of a processing method is performed, the casting method and the choice of heat treatment, etc. are implemented using frame models.

As a rule, the frame model of knowledge has a complex hierarchical structure reflecting real objects (concepts) and the relations (the links) of a certain subject area. Slots are the elements of frame model knowledge representation. The rules are set for each slot to fill it in or/and attached procedures are established. When a request is interpreted into a particular frame sample, the required slot values and terminal data are determined.

The mechanism of logical inference is based on the exchange of values between the same slots of different frames and the execution of the attached procedures "if - added", "if - deleted" and "if - necessary". A conditional diagram of such actions is shown on Figure 2 for the simplest version.

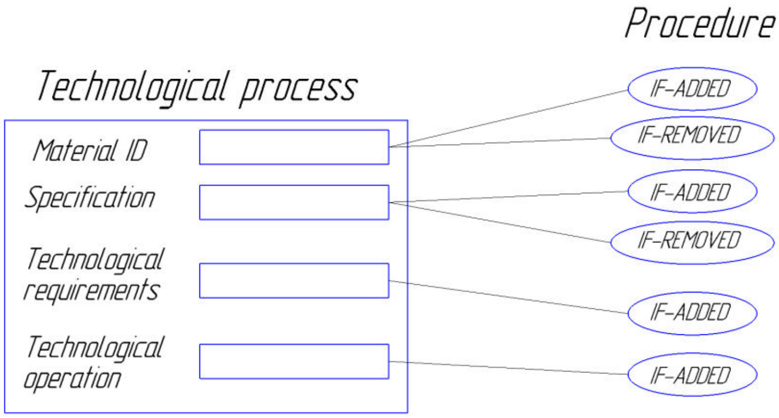

Fig. 2. Part of the Frame Description of a «Technological process»

The frame system functions as follows. For example, the system received a request from an authorized user: "It is necessary to model the technological process for the part "Interaxial differential carter".

The information is passed through a linguistic processor, analyzed and is entered in the "Description" slot of the "Technological process" node in the form of "Interaxial differential carter" value. Then, the attached procedures begin to work:

- "If-added" procedure associated with the "Description" slot is executed, since a value was entered in a slot. This procedure performs the search for information about a material code in a database (in this case - 5320-2506111) and enters this name in "Material code" slot.

- "If - added" procedure associated with the "Material code" slot is executed, since a value was entered in the slot. This procedure begins to compose the technological process and appeals to the nodes "Technological operation" and "Technological requirements.

The rules according to which the choice of the processing method, the casting method, the choice of heat treatment, the choice of modifiers are also realized using production models. Using the attached procedures, the database and the database of rules are accessed. Thus, a complex modeling process takes place, during which only the final result is recorded in the slots.

The development of the base of rules was carried out using CLIPS Object-Oriented Language, the built-in language of the CLIPS environment, which provides object-oriented capabilities.

The frame structure of the rule base is represented in the form of product rule set, the left part of which is the frame daemons, and the right part is responsible for the attached procedure performance.

The procedures running inside the CLIPS environment are written in the form of facts that fall into the working memory of the rule database after their activation.

The procedures that refer to other tools of an intelligent system (the integration of a rule base is required) are prescribed as external-address values representing the address of the data structure that are returned by an external function. An address is written as follows:

<Pointer-XXXXXX>

Where XXXXXX is the number representing an external address

Table 1 shows the structure of "Technological process" frame.

Table 1. – Frame structure Technological process

Slot name	ata type	Demons		
		IF-NEEDED	IF-ADDED	IF-REMOVED
Material id	ymbol	Accessing the Database	-	Fact reset
Specification	ymbol	Request from the user	Starting demon IF-NEEDED.Slots: Material id	Fact reset
Technological requirements	rame-list	Starting demon IF-NEEDED.Slots: Ball-Hardness, Durability, Chill.	Starting demon IF-NEEDED.Slots: Technological operation	Fact reset
Technological operation	rame-list	Starting demon IF-NEEDED.Slots: Burden, Smeltingfurnaces, Holdingfurnaces, Mold filling, Cooling.	Message to the user	Fact reset

The production rules consist of a left and a right part. The left part of the rule is the "Condition", and the right part is "Action". A condition may be the existence of a fact, the presence of variables, the observance of the required conditions. An action includes the adding of a fact, the calculation and the result display on a screen or in a file.

A production rule example implemented in CLIPS:

(defruleC :: korrektirovka-PK-Cu-nije; Copper adjustment rule in the Transfer Bucket when copper is below the required level according to the technological process

(PK (temperaturaPK ?T) (V-PK? V-PK) (Cu-PK? Cu-PK))

(TP (Cu-PK-TP ?Cu-PK-TP));; Unordered facts should be introduced. Then the assignment of slots to the templates of certain variables

takes place (test(<?T 1560));; According to the required conditions, the temperature of the alloy should be no more than 1560 degrees

(test (>?T 1500))

(test(< ?Cu-PK? Cu-PK-TP));; This rule is valid only if the copper content in the Transfer Bucket is below the required level according to the established technological process.

=>

(printout file "The copper in the transfer bucket is below the required value". It is necessary to add " (* 1.34 (* ?V-PK (* (-?Cu-PK-TP? Cu-PK) 10)))" kg Cathode copper "crlf));; The output to a message file. The calculation of a required additive.

The structure of the frame has the following form:

Φ {(c1, з1, n1), (c2, з2, n2),… (cк1, зк1, nк)},

where: Φ - a frame name; c is a slot name; з - values (data structure maybe); n is the name of the procedure associated with this slot.

The downloading the rule database is performed in the following scenario. Each unit of rules has its own file in .clp format, which includes rules, templates and created modules. The file in which the entered facts are stored is a dynamic one. The values of the facts depend on the values that an operator added through an interface.

The downloading of rule database in the CLIPS environment:

(open "otvet.txt" file "r +");; a file opening with reading and writing permissions

(loadbz1.clp);; The creation of modules, the downloading of rules and templates.

Initialization of the facts entered by an operator and received by an intelligent system;

(reset);; The downloading of facts

(focusA);; The transition to Module A (Melting Furnace)

(run);; the running of rule database

(closefile);; the closing of a file with the received responses

Conclusions

The developed base of rules, based on the product-frame model of knowledge representation, showed quite high accuracy and explanatory ability. In particular, when you process the contents of the report on the lots of CIVG nomenclature castings that were cast using the automated molding line of PJSC "KAMAZ-Metallurgy", the modeling accuracy was 95% and the explanatory power made 93%.

Summary

In the course of the work, the technique was proposed to model the casting technological process according to the required output quality indicators, illustrated by the example of cast iron with vermicular graphite. The use of the elements of an artificial element allowed to eliminate the main disadvantages of currently used CAE systems: high requirements for machine resources and personnel qualifications. The results are planned to be implemented in the foundry industry.