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Small-scale production of cast porous and composite materials

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Abstract. Modern foundry production should be equipped with advanced technologies, equipment and materials, have a significant reserve for its development in the future, which is unthinkable without a transition to digital production, which includes integrated automation of technological processes, digital control of technology parameters, materials and quality indicators of the finished products by the non-destructive control methods, as well as the use of new foundry materials obtained with the help of nanotechnologies.

1. Introduction

The creation of a new enterprise should be aimed at meeting the existing significant needs in the society, equipped with advanced technologies and equipment, lay the significant groundwork for its development in the future. Russia's choice to develop a digital economy is unthinkable without the industry switching to "digital" production, which includes comprehensive automation of technological processes, digital control of technology parameters, materials and quality indicators of finished products using non-destructive control methods.

The foundry production can be referred to customized small-scale production.

The foundry industry is dominated by obsolete technologies created by the middle of the 20th century; there is a low level of technological and innovative development in this area.

Creation of a foundry enterprise requires:

- significant capital costs for the construction or reconstruction of production facilities;
- expensive equipment;
- very high energy intensity of the cast products manufacturing;
- low coefficient of metal utilization, high allowances for machining, lack of flexible production (quick remounting for new products manufacturing), severe restrictions on the range of manufactured products depending on the selected casting technology;
- high price competition;
- stringent requirements from Rostekhnadzor and environmental specialists;
- lack of qualified personnel in the region;
- the need for a large amount of working capital;
- long payback period of financial investments (8-12 years).

2. Results and discussion

The foundry production is an integral part of the production cycle in mechanical engineering. More than half of the enterprises in machine building and military-industrial complex of Russia have their own foundry shops. Foundry production as a sector of the national economy, of course, requires innovations. Most enterprises do not have a single information space, that would help all enterprise



automated control systems, as well as industrial equipment and production personnel quickly and timely exchange information; automation and robotization of technological processes is not sufficient; at a basic level, technologies of virtual modeling and engineering analysis have been mastered, which does not allow the digital mockup of the product to be controlled; there is no interdisciplinary modeling at different levels of abstraction (from a conceptual design to a detailed single model); only in single enterprises a PDM system (product data management system) is used [1, 8, 9, 12-15].

Currently, the most promising direction in foundry is the introduction of additive and digital technologies at all stages of the production of cast products. The rapid growth of the market for additive and digital technologies – approximately by a quarter annually, is directed towards greater automation in the framework of “Industry 4.0”.

These technologies successfully work at enterprises of various industries, such as:

- automotive industry;
- aerospace industry;
- tool engineering;
- military industry;
- medicine (including dentistry);
- gold work;
- art and architecture.

Within the framework of the created enterprise, it is supposed to form a team of specialists and scientists, which in practice will develop the content of the “fundamental transformations” of an ordinary enterprise into a digital one, which uses information technology as a competitive advantage in all areas of its activity: production, business processes, marketing and interaction with customers.

Moreover, the newly created enterprise will operate in the real sector of the economy, produce final products, provide services to the population, teach and train personnel for various areas of the digital economy [2,10].

One of the problems of modern society is the repair, namely the restoration of good condition and the extension of the equipment life:

- restoration of worn parts, the repair and replacement of which is difficult or expensive;
- restoration of original products discontinued or manufactured in other countries.

In both cases, the most difficult process is the restoration of parts obtained by casting.

The second problem is the development of new and innovative conceptual approaches for transferring an industrial enterprise to a higher technological level – the level of a digital enterprise.

A small foundry enterprise is the most versatile testing ground for this kind of fundamental and applied research, because it combines a whole range of related technologies of other industries: melting and casting, heat treatment, shaping, chemical technologies, powder metallurgy, automation, product quality control, etc. The first step can and should combine all of the above into a single information infrastructure.

For this, the key condition is the use of the MDC system (MachineDataCollection – collection of machine data), which allows data on the work of all production facilities (equipment, workplaces of the main workers, service and control services, etc.) to be collected in order to manage a small enterprise and to make more optimal technological decisions in real time [1, 3, 11].

At SibSIU it is proposed to create a research and production self-supporting innovative center for foundry additive and digital technologies and manufactures – customized small-scale production. The main activities of the center should be as follows:

- production of single cast products from non-ferrous metals and cast iron (investment casting);
- production of single molded products from plastics and plastic (cold casting);
- production of composite cast billets based on aluminum alloys, including porous, by vacuum suction;
- production of unique single products;

- teaching and training of personnel for the implementation of digital and additive foundry technologies in industry;
- development and promotion of digital, additive and foundry technologies for consumers;
- development and testing of “transformations” of operating models into new digital models for the concept of digital production.

To expand the reach of customers, an online store of customized products will be used that performs the functions of accepting the initial order, its digital processing, coordination and sending of the finished product to the customer – the “client-server” technology.

The base for the functioning of the center has already been created at the SibSIU, the prototyping center “Form” is operating; the technologies of “cold casting”, casting of composite and porous blanks based on aluminum alloys by vacuum absorption have been developed.

3. Materials

The porous cast aluminum was first obtained in the United States by G. Kuchek in 1961, it was used as a structural material for helicopter construction, however, production ceased due to competition with foamed aluminum. The second birth of porous cast aluminum occurred simultaneously in Japan (S. Nagata, Kyushu University), Switzerland (A. Mortensen, Federal Institute of Technology in Lausanne) and the USSR (E.L. Furman, Ural Polytechnic Institute). These were the people who realized that porous cast aluminum is not a competitor to foamed aluminum, but a competitor to sintered metal powders. In addition, an important incentive for the development of technology in the USSR was the use of porous cast aluminum for the production of weapons (silencers of small arms, active protection of armored vehicles). The technology for porous aluminum production by impregnation at first glance impressed with its simplicity. However, like any new technology, it was replete with hidden problems: defects of unknown origin, extremely low metal utilization, marketing. These problems were too difficult for Japanese and Swiss science. In 1990 the industrial production of porous cast aluminum, which is currently the only one in the world, was organized in the city of Kirovgrad. Since then, the director of Composite Materials LLC has been L.E. Cherny, the scientific consultant is the student of E.L. Furman, Doctor of Technical Sciences, A.B. Finkelshtein, Marketing Director – M.L. Cherny, Ph.D. [4, 5].

Currently, among the organizations using porous aluminum products for various applications are Sibneft OJSC, Kurgankhimmash OJSC, Transpnevmatika OJSC, RAAZ AMO ZIL OJSC, Salavathydromash OJSC, Pnevmatika OJSC and many others – in total more than 300 enterprises in Russia and abroad.

Since 2014 China has actively begun to offer blanks and products from porous aluminum on the world market. For example, Alibaba.com offers anodized porous aluminum plate at a price of \$ 2400-4600 per tonne and porous aluminum plate at a price of \$ 1.3-7.1 per kilogram.

At present, porous aluminum is used to produce gas and liquid filters, air silencers, sound absorbing panels, dampers, bubblers, heat exchangers, flame arresters, heat pipes, wicks, gas and liquid permeable protective housings, liquid evaporators, liquid aeration, vacuum tables, current collectors in new generation rechargeable batteries, structural engineering products with lower weight and thermal expansion, cooling radiators for electronic components, design of high-tech objects, etc. (figure 1).



Filters of various designs



Pneumatic silencer



Heat exchanger



Sound absorbing panel



Ready product



Radiator



Permeable sensor housing



Hi-tech table lamp

Figure 1. Products made of porous aluminum.

The unique properties of the products are as follows:

- Products made of porous aluminum have high permeability, heat resistance, dirt capacity and mechanical strength.
- Stronger, more durable and more efficient than sintered, mesh and polymer silencers.

Porous cast aluminum is demanded by the industry due to its high specific strength and corrosion resistance. Currently, the technology of melt impregnation of a water-soluble filler is the only one that allows a wide range of porous aluminum products to be obtained – from dampers to filter elements, of any size and configuration, combining the porous and monolithic part in one product [4-7].

The schematic diagram of the production of porous aluminum products is presented in figure 2.

Основной проблемой при получении отливок из пористого алюминия является высокий уровень дефектности, не подлежащие заделке. Коэффициент выхода годного находится на низком уровне. Обратное использование пористого алюминия в шихте дает угар порядка 50%, при этом расплав насыщается пленами.

The main problem in obtaining porous aluminum castings is a high level of defectiveness that cannot be sealed. The yield coefficient is low. The reverse use of porous aluminum in the charge gives a burn of about 50%, while the melt is saturated with films.

The traditional introduction of nanomaterials into the melt is fraught with a number of difficulties:

- the formation of a conglomerate of nanoparticles during their mechanical introduction into the melt;
- different densities of nanomaterial and melt and, as a consequence, the emergence of nanopowders upon their mechanical introduction into the melt;
- complexity in the technological provision of uniform distribution of nanomaterial particles in the entire melt volume;
- low reproducibility of introduction of a given of nanomaterials concentration into a liquid melt;

- oxidation and decrease in the wettability of the surface of nanoparticles at high temperatures;
- the presence of oxide films and slags on the surface of the melt;
- low adhesion of the metal matrix with nanoparticles;
- need for cladding nanoparticles with certain metals or substances.

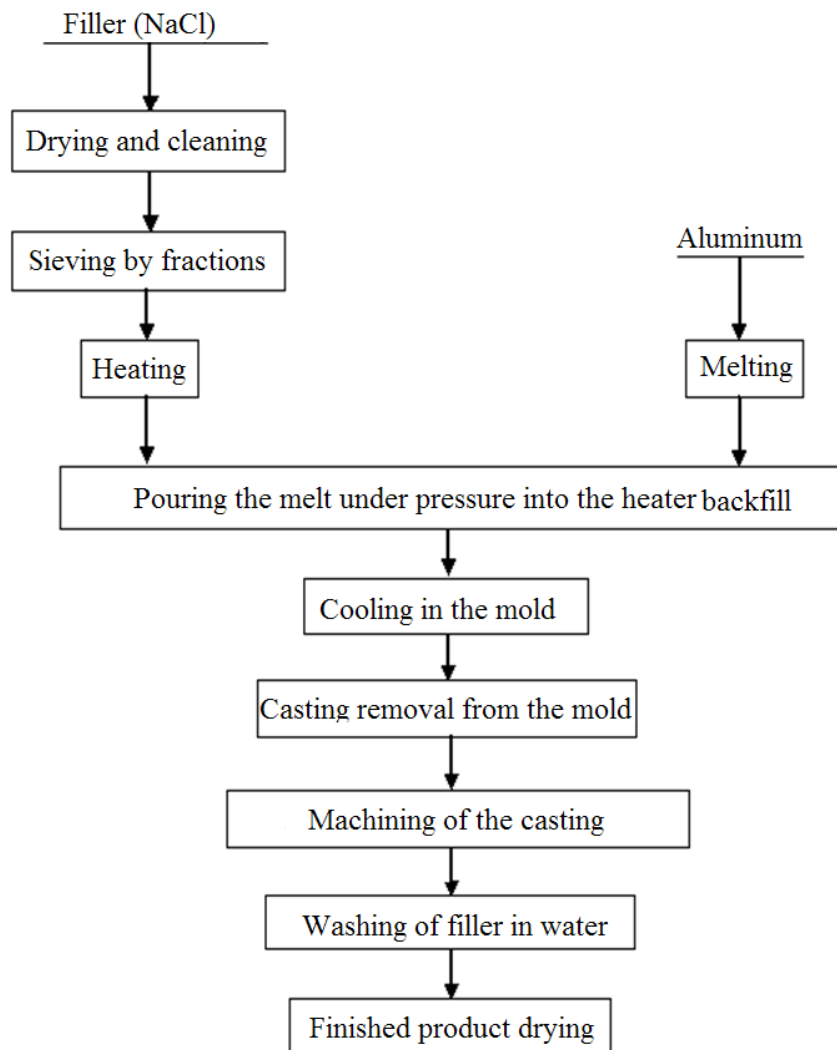


Figure 2. Schematic diagram of porous aluminum products manufacturing.

The technology for the production of porous cast billets from various metals and alloys has been improved at SibSIU in order to use it for the subsequent introduction of nanoparticles into cast alloys and the subsequent production of cast billets with a unique set of properties:

1. Obtaining a porous preform from a mother alloy with predetermined porosity parameters (figure 3).
2. Filling the pores of the porous preform with nanoparticles.
3. The introduction of a porous preform with nanoparticles into a liquid melt in a melting furnace to obtain a lump modifier (ligature) and subsequent modification (alloying) of the required cast alloys with its help.



Figure 3. A porous preform from mother alloy for introduction into ultra- and nanomaterials pores.

The developed technology provides:

- uniform distribution of nanomaterial particles in the entire melt volume;
- controlled concentration of nanomaterials in liquid melt;
- low amount of oxide films and slags in the body of the cast billet;
- does not require additional technological methods for introducing a modifier (ligature) directly into the melt.

4. Conclusion

The technology for the modifier introduction into the furnace and into the ladle does not require significant capital expenditures for its implementation. The technology is also applicable for introduction of ultrafine

and finely dispersed or other specific materials into the melt. The performed studies provide the basis for the development of a new group of fundamentally new types of modifiers and ligatures. From the point of view of fundamentals of foundry, issues such as the hereditary effect of a mixture subjected to nanomodification on the properties of cast alloys, the creation of highly effective compositions of modifiers and ligatures for cast alloys should be studied.

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