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Investment casting: technical solutions to saving of resources

Analysis of a generalized technological diagram of investment casting has permitted to single out its major hitch while being implemented within current facilities — manufacturing of multi-layer shell molds. This lengthy, onerous stage consists of a series of operations, such as, for example, assembly of pattern blocks; preparation and application of slurry and the material of sand fill onto the pattern blocks; drying of shell layers; dewaxing; shell firing; etc. That is why the authors' research focused on solving problems relating to this stage. A task was set to cut energy consumption in firing of shell molds prior to their delivery for steel-melt pouring, which significantly bears on the casting resultant quality. To minimize formation of hard non-metallic inclusions in the casting's body, as well as oxidation and decarburization of its surface layer, the authors believe expedient to ensure decrease in the shell mold material's activity. It may be attained by creation of a regenerating atmosphere in the zone of physics-chemical interaction of the mold with the poured metal melt. Implementation of the above measures will ensure decrease in materials consumption, increase in environmental safety of investment casting — a method of producing parts which is competitive globally.

Key words: *investment casting, firing of shell molds, wax utilization, exothermic reactions, crack forming, non-metallic inclusions, decarburization.*

At present time, Europe awaits introduction of new and more stringent regulations concerning the effective usage of energy. In particular, European Commission proposes introduction of national systems aimed to increase the energy efficiency; those would stipulate obligations to cut energy consumption by 1.5% p.a. Significant attention is paid to the issues of environmental safety.

According to the data by the Russian Foundrymen's Association, the prime cost of casting breaks down like follows: 50–60% for energy expenses, 30–35% for materials expenses. Thus, all industrial enterprises face the problem of effective usage and saving of energy and materials, which will ensure them tangible advantages while expanding to new markets [1].

Currently, quite a number of mechanical engineering enterprises in Privolzhsky Federal Region alone use the investment casting method, which is one of the most promising for producing engineering castings of the highest complexity for many industries (engineering, power engineering, pumps and fittings, aviation, nuclear, defense, etc.).

The main advantage of this casting method is high precision of the obtained castings' geometry, which allows to minimize the expenses on further mechanical treatment to get a finished part [2]. Yet, its wide application is contained by a number of its drawbacks, such as: high consumption of labor, materials and energy by technological operations and transitions; very long production cycle of making castings; and a need for a serious preparation of production, special tooling and equipment inclusive.

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A task was set to cut energy consumption in firing of shell molds prior to their delivery for steel-melt pouring, which significantly bears on the casting resultant quality.

According to the traditional (basic) technique, firing of shell molds without a backup filler is conducted upon heating over 1000 °C and soaking at the temperature maximum for about 4 hours. Total in-furnace time is over 10 hours.

The authors have suggested the technology of quartz-based shell mold low-temperature firing allowing a 1.5-fold decrease in the temperature maximum of mold heating, as well as more than 2-fold cut in the entire cycle of firing.

The concept of this technique is to use an oxygen-bearing oxidizer (for example, potassium dichromate $K_2Cr_2O_7$) and stiffening additives (boric acid H_3BO_3) introduced into the material of the shell mold. It permits to reach the implementation of the firing procedure's major objectives under lower temperature (in comparison with traditional technique) and a cut mold's in furnace time. Due to the evolved oxygen and abstracted heat of the exothermic reactions, the following advantages could be ensured:

a) a complete removal of the wax residue;

b) completion of the main transformations in the shell mold material's binder;

c) baking of quartz-based shell refractory material to ensure mold stiffness [3].

Reactions of interaction of oxygen-bearing oxidizer with wax, of chosen oxidizers' decomposition with evolution of oxygen, and of oxygen interaction with wax under high temperature are presented below:

$$K_2Cr_2O_7 + C_nH_{2n+2} \rightarrow K_2CO_3 + Cr_2O_3 + H_2O\uparrow \quad (1)$$
$$4K_2Cr_2O_7 = 2Cr_2O_3 + 4K_2CrO_4 + 3O_2\uparrow \; (t \geq 610\ ^oC) \quad (2)$$
$$2C_nH_{2n+2} + (3n + 1)O_2 = 2nCO_2\uparrow + (2n + 2)H_2O\uparrow \quad (3)$$

"Healing" of cracks forming in the temperature interval of polymorphous transformations (β-quartz $\rightarrow$ α-quartz) is ensured by introduction into the shell mold material of a small amount of boric acid. During firing, occurs a breakdown of boric acid to boric anhydride via the reaction:

$$2H_3BO_3 = 3H_2O + B_2O_3. \quad (4)$$

The forming boric anhydride (in the temperature interval of shell mold firing) melts, filling macro- and micro-cracks formed in the ceramic shell as a result of polymorphous transformations (conversion of β-quartz into α-quartz) and evolution of oxygen from the oxygen-bearing agent.

Comparison of thermo-time modes of firing, presented at **Figure**, shows that a changeover from the traditional technique to the suggested one ensures decrease in shell-mold heating-temperature maximum from 1050 to 650 ^{o}C; decrease in soaking time at temperature maximum from 8 to 2 hours; and decrease in the total shell mold in-furnace time prior to the start of their cooling before delivery to pouring with melt from 15 to 6,2 hours.

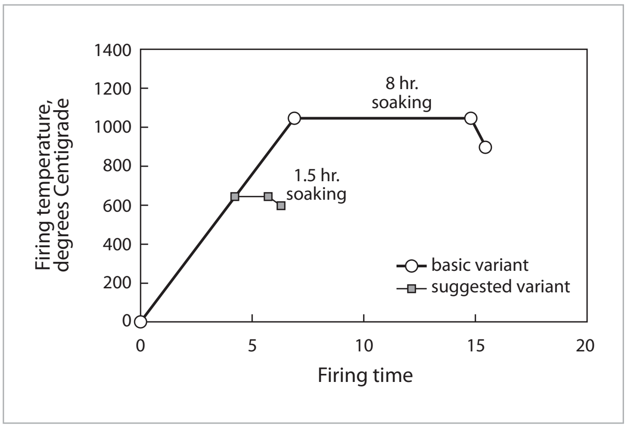
Field implementation of the developed technology permitted to cut the energy consumption in case of steel investment casting on the average 2.0–2.5-fold without compromising the high quality of casting. The suggested technical solution is protected by a patent for invention and documented by implementation certificates at several operations of Nizhny Novgorod region [4].

In the conditions of permanent striving for optimization of resources consumption, the authors conduct works to cut the industry's materials consumption, in particular, by utilizing own and other industries' technogenic wastes in investment casting (recycling).

Using wax to prevent decarburization of casting surface layer during heat-treatment (normalizing) of castings [5] is suggested as an example for utilization.

Nowadays, the authors deem the issues of raising the environmental safety of the investment casting process as very urgent, by means of, for instance, inorganic binder usage.

Besides that, it is necessary to become the investigating efforts into the variants of possible risks of low-temperature firing technique implementation. In spite of all its advantages, the technique possesses a number of expected drawbacks:



Thermo-time modes of shell mold firing

Sharp temperature gradient between the mold and the poured melt may lead to formation of cracks in the shell [6].

Shell baking, which is one of the key objectives of firing, may turn out to be incomplete, thus diminishing its crack resistance.

Low (in comparison with the traditional or "classic") shell firing temperature may prove inadequate for a complete removal of all gases in them, which may further bring about corresponding casting defects.

The introduced (into the material of the shell mold) oxygen-bearing agent, which ensures evolution of an additional amount of oxygen to remove the wax residue, may trigger the formation of non-metallic inclusions, as well as the oxidation and decarburization of the castings' surface layer.

To ensure shell mold crack resistance the following measures are taken:

— usage of boric acid powder in the shell material, which, upon melting, performs the function of a binder, thus stiffening the shell;

— usage of materials (in the shell structure) with a considerably lesser linear thermal expansion coefficient than that of quartz, which reduce possible negative consequences of polymorphous transformations during the firing and melt pouring procedures;

— creation of porous shell structure, which would prevent mold cracking due to a more even distribution of thermo-mechanical stresses in the material and, as a consequence, would inhibit possible deformations during pouring of melt [7, 8].

To decrease the amount of gases evolved during pouring of melt into the shell mold and, as a consequence, to lower gas defects in the casting's body, the following measures are recommended:

— Ensuring the fastest casting skinning while pouring the melt, which hinders gas penetration into the casting's body.

— Provision of a directional take-off of gases through the shell mold backup layers via usage of corresponding additives in the mold material.

— Ensuring a maximum possible evolution of gases from the shell at the firing stage with its simultaneous lowering at the mold pouring stage.

To minimize formation of hard non-metallic inclusions in the casting's body, as well as oxidation and decarburization of its surface layer, the authors believe expedient to ensure decrease in the shell mold material's activity. It may be attained by creation of a regenerating atmosphere in the zone of physics-chemical interaction of the mold with the poured metal melt.

Implementation of the above measures will ensure decrease in materials consumption, increase in environmental safety of investment casting — a method of producing parts which is competitive globally.

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