UDC 621.740.74:620.1.313 669.14:658

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COMPOSITE CASTINGS WITH DIFFUSION BONDS BETWEEN ELEMENTS

В.В. Ясюков, Т.В. Лисенко, І.В. Прокопович, О.І. Воронова, М.П. Тур. **Композиційні виливки з дифузійним зв’язком між елементами.** Стаття присвячена актуальній на сьогоднішній день проблеми підвищення конкурентоспроможності ливарного виробництва. При безперервному зростанні навантаження, швидкості, потужності, температури, впливу агресивних середовищ та інших чинниках спостерігається адекватне зростання вимог до експлуатаційних властивостей деталей. Композиційне лиття дозволяє отримувати високоточні виливки відповідно всім вимогам, які ним пред’являються. При композиційному литті синтезуються окремі елементи деталі, які можуть бути вироблені найбільш ефективними методами формоутворення для даного елемента, а також з оптимальних матеріалів в залежності від пропонованих вимог до деталей. Основний зміст дослідження становить аналіз та деталізація параметрів економічної технології виробництва композиційних виливків високої точності з диференційованими фізико-механічними властивостями окремих їх частин і високою експлуатаційною надійністю. Значна увага приділяється контактним процесам, які здійснюють зв’язок між елементами. У переважній більшості випадків це дифузійні взаємодії, які визначаються дефектами кристалічної структури. Контактна зона повинна бути однорідною та керованої по геометричним параметрам і властивостям в зонах, де протікають складні фізико-хімічні процеси при нестаціонарному тепловому режимі. Виділяються і описуються характерні особливості виробництва композиційних виливків з урахуванням вибору елементів для кожного конкретного випадку з визначенням параметрів, що визначають зв’язок між ними на конкретних прикладах отримання композиційних виливків. Результати дослідження підтвердили стійку працездатність, зменшення витрат на виготовлення відливок, економію металу (наприклад, до 2 кг на одну шарошку). Отримані результати говорять про високий потенціал композиційного лиття як засобу підвищення конкурентоспроможності ливарного виробництва шляхом виготовлення високоточних виливків з підвищеною експлуатаційною надійністю литих деталей.

Ключові слова: композиційне лиття, контактні процеси, адгезійні зв’язки, дифузійні процеси, пористі металокерамічні оболонки, поверхневе армування, об’ємне армування

V. Yasyukov, T. Lysenko, I. Prokopovych, O. Voronova, M. Tur. **Composite castings with diffusion bonds between elements.** The article is devoted to the current problem of improving foundry competitiveness. With a continuous increase in load, speed, power, temperature, the influence of aggressive environments, and other factors, an adequate increase in the requirements for the operational properties of parts is observed. Composite casting allows us to obtain high-precision castings following all the requirements that apply to them. Composite casting synthesizes individual elements of a part, which can be performed by the most efficient farming methods for a given element, as well as from optimal materials, depending on the requirements for the parts. The main content of the study is the analysis and detailing of the parameters of an economical technology to produce high-precision composite castings with differentiated physical and mechanical properties of their parts and high operational reliability. Considerable attention is paid to contact processes that communicate between elements. In most cases, these are diffusion interactions determined by defects in the crystalline structure. The contact zone should be homogeneous and controllable in geometric parameters and properties in areas where complex physicochemical processes occur under unsteady thermal conditions. The characteristic features of the production of composite castings are highlighted and described, taking into account the choice of elements for each specific case, with the determination of the parameters that determine the relationship between them on specific examples of the preparation of composite castings. The results of the study confirmed stable performance, reduced costs for the manufacture of castings, metal savings (for example, up to 2 kg per cone). The results indicate a high potential of composite casting as a means of increasing the competitiveness of foundry by manufacturing high-precision castings with an increased operational reliability of cast parts.

Keywords: composite casting, contact processes, adhesive bonds, diffusion processes, porous cermet shells, surface reinforcement, volume reinforcement

Introduction

Foundry is rightfully ranked among the main basic manufacturers of workpieces for mechanical engineering. This technological redistribution is one of the most important areas of technology that determine the level of metal consumption of the national income. In comparison with forging and stamping, casting has a higher yield and metal utilization rate (MUR), low metal waste into chips (forging – 0.32 %, stamping – 0.24 %, casting – 0.16 %). Also, attention is drawn to the labor intensity, man-h/t: forging – 245; stamping – 194; welding – 130; casting – 120.

DOI: 10.15276/opu.2.61.2020.03

Much attention is paid precision castings foundry and operational reliability of the cast parts. The real advances in this direction are the introduction of technologies that make it possible to obtain cast surfaces with an arithmetic mean profile deviation Ra equal to 3.2 microns or less. This improves the durability of cast parts operating under cyclic stress loads. Thus, an increase in Ra from 2.5 to 10 μm changes the endurance limit σ_{-1} for steel 30 HNML (ХНМЛ) from 550 to 190 MPa. The effect of the surface quality on σ_R is the stronger, the higher the strength characteristics of the steel. Reducing the roughness of the cast surface, which is not subjected to mechanical treatment, increases the efficiency of hydraulic equipment parts, pump impellers, propeller blades, blades of low-pressure hydraulic turbines of power plants, stators and rotors of turbodrills.

In the manufacture of waveguide elements of microwave - radio devices, it is important to reduce the surface roughness in order to reduce the length of the path of current flow (taking into account the skin effect). The nature of the surface of castings affects the quality of enameling, which is important for petrochemical and plumbing equipment.

Foundry workers are actively involved in the intensification of the miniaturization of power units. For example, in the manufacture of internal combustion engines, the volume of the engine is reduced by reducing the number of cylinders while increasing power and torque. This tendency is also noticed in aviation, where downsizing allows reducing the mass of engines tenfold [1].

Foundry products serve as a structural basis for machines, mechanisms, units in various industries. With a continuous increase in loads, speed, power, temperatures, corrosive environments and other factors, there is an adequate increase in requirements for the level and variety of working properties of alloys. It is necessary to take into account the demands of new industries - nuclear, space and others, as well as the depletion of natural resources and the increase in the cost of alloys [2]. These changes leave an imprint on the synthesis of alloys [3], where, in addition to the experience and intuition of researchers, the use of computer modeling, the use of new materials, additive technologies, out-of-furnace metal processing and control of the crystallization of alloys by external action when introducing nanosized materials, etc. is required.

Analysis of publications and problem statement

The alloy composition depends on the operating conditions of the future casting and the need to solve special technological problems. The variety of requirements for castings often cannot be met by any one material. Therefore, it becomes necessary to produce them from several metals with different properties. Thus, the object (composition) consists of separate parts that retain their individuality, but, thanks to the connection with each other, jointly form a new quality, which is lacking in separate elements [4].

Composite casting synthesizes individual elements of a part, which can be made by the most effective methods of shaping for a given element, as well as from optimal materials, depending on the requirements for the parts. Also, the elements installed in the casting mold after pouring with the base (matrix) metal are combined into a single whole – a composite casting (CC). Composite casting is heterogeneous in nature, which makes it possible to obtain a sum of service properties of a new quality that is inaccessible to the individual elements that make up the composition.

Composite castings are used in developments aimed at creating compact units and assemblies with a high power density due to the complication of the design of parts with thin internal cavities with a high surface finish. Such cavities are characterized by a ratio of the minimum flow area to the length of at least 1:50; to the wall thickness of the casting 1:1; the absolute dimensions in the cross-section are 0.6...3 mm. These include closed impellers with radially spaced blades, cooled pistons of internal combustion engines, waveguide elements of microwave radio devices, cooled turbine blades of non-stationary installations, etc.

Composite casting provides ample opportunities for obtaining the required performance properties from various combinations of components. For the formation of high-quality castings, contact processes are decisive, which carry out the connection between the elements. In most cases, these are diffusion interactions determined by defects in the crystal structure. The contact zone should be homogeneous and controlled in terms of geometric parameters and properties, where complex physicochemical processes take place under non-stationary thermal conditions. For foundry professionals who design and maintain a technological process, this stage is the least predictable due to the presence of boundary, temperature and geometric barriers. Such barriers include: the temperature of the transition zone, the ratio of the mass of liquid and solid metal, the presence of a laminar sublayer, a crust of solidifying metal, non-metallic inclusions on the surface, gas inclusions of a hydrogen nature, an air gap between phases, etc. Therefore, in each specific case, it is necessary to develop stable conditions for the formation of composite castings, taking into account the thermal and physicochemical processes occurring at the contact boundary [5].

The aim of the work is to detail the parameters of an economical technology for the production of high-precision composite castings with differentiated physical and mechanical properties of their individual parts and high operational reliability.

The essence and methods of research

The development of the technology for the production of composite castings is carried out taking into account the choice of elements for each specific case with the definition of parameters that determine the relationship between them. Let us dwell on several typical examples of the production of CC.

Waveguide elements of microwave radio devices.

The main requirements for castings arise from the operating conditions: low alloy density for non-stationary objects; low specific electrical resistance; minimum roughness of the inner surface of the waveguide element in order to reduce the path of vibration (skin effect), high dimensional accuracy.

To implement these requirements, we used low-pressure casting of hypoeutectic silumin and the design of the internal cavities of waveguides and adapters to them with salt-ceramic rods obtained by solid-phase sintering. Industrial grade sodium chloride was used as a refractory material providing a set of properties. The stabilization of the suspension before firing was achieved by the introduction of surfactants, for example, fatty acids (stearin):

$$C_{17}H_{35}COOH + NaCl \rightarrow C_{17}H_{35}COONa + HCl. \quad (1)$$

In combination with paraffin, the technological properties of the suspension (fluidity, filling of molds, sedimentation stability) increase. Firing rods is carried out in the filling of the adsorbent at a temperature (0.8...0.9) T_{mel} of salt.

The proximity of the sintering and melting temperatures of the salt (T_{melNaCl}=808 °C) can lead to the formation of a grain size difference (Fig. 1*a*), increased and unstable fire shrinkage. This problem is eliminated by modifying the salt powder by introducing α-Al_2O_3 in an amount of 1.5...2.5 %, which makes it possible to obtain a uniform-grained structure (Fig. 1*b*), to reduce the standard deviation of shrinkage variation from 2.1 to 0.73, and to obtain a shrinkage value of 2.8 %. In this case, the lower ultimate bending strength of the rods is $30 \cdot 10^5$ Pa.

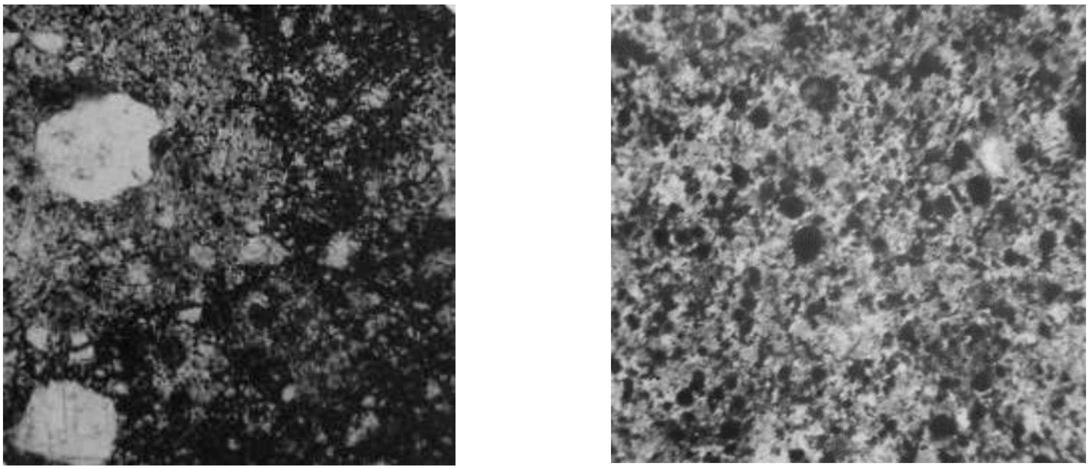
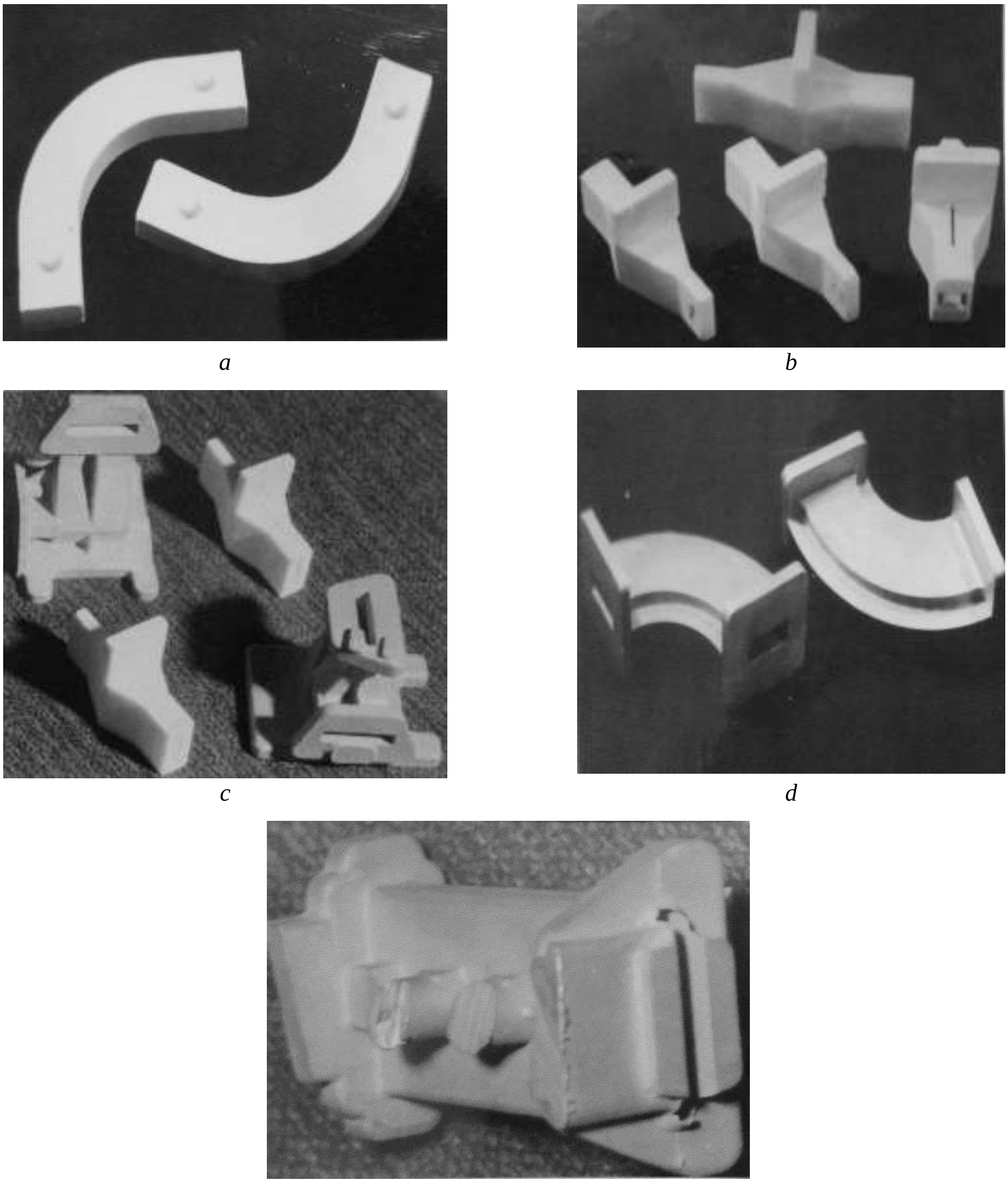

a *b*

Fig. 1. The structure of sintered sodium chloride: with excessive grain growth (a); equally grainy (b)

Fig. 2 shows rods for waveguides (*a*), adapters (*b*), and castings from silumin AK7ch (АК7ч) (*c*, *d*, *e*). The roughness of the surface of the casting cavity was measured by the arithmetic mean deviation of the profile Ra and amounted to 1.6...1.25 μm.



a *b*

c *d*

e

Fig. 2. Salt-ceramic rods and castings of waveguide elements: rods for waveguides (a); adapters (b); castings from alloy AK7ch (АК7ч) (c ,d, e)

The loss of power of the transmitter of microwave oscillations largely depends on the specific electrical resistance ρ, μOhm m. For pure aluminum, this value is 0.028 μOhm m; however, its use for shaped casting is problematic due to its low technological properties. Silicon and magnesium, which are part of silumin, impair electrical conductivity. Therefore, it is advisable to cover the inner surface of the waveguide elements with a metal with high electrical conductivity with a minimum content of impurities and crystal lattice defects. This metal is silver. The specific electrical resistance of Ag is 0.006 μOhm m, which is more than 5 times lower than silumin. Obtaining a composite casting consists in plasma spraying of silver powder in an argon atmosphere on the surface of a salt-ceramic rod. Argon, in the presence of a thermal and magnetic pinch effect, increases the plasma temperature to 14000 K. To create a reducing medium, the enthalpy of a gas mixture was calculated [6] by the formula:

$$H_{\text{mix}} = H_1\left(\frac{M_1 r_1}{M_{\text{mix}}}\right) + H_2\left(\frac{M_2 r_2}{M_{\text{mix}}}\right) + \ldots + H_n\left(\frac{M_n r_n}{M_{\text{mix}}}\right), \quad (2)$$

where H_1, H_2, H_n – enthalpy of mixture components;

M_1, M_2, M_n – molecular weight of the mixture components;

M_{mix} – the molecular weight of the mixture;

r_1, r_2, r_n – volume fractions of mixture components.

The molecular weight of the mixture is determined by the formula:

$$M_{\text{mix}} = M_1 r_1 + M_2 r_2 + \ldots + M_n r_n. \quad (3)$$

For application, a universal plasma installation УПН-3 was used, which allows:

– to apply various powders and their mixtures to any base material;

– change the energy characteristics of the plasma depending on the thickness of the shell;

– the ability to obtain shells of equal thickness of any complexity without limiting the area.

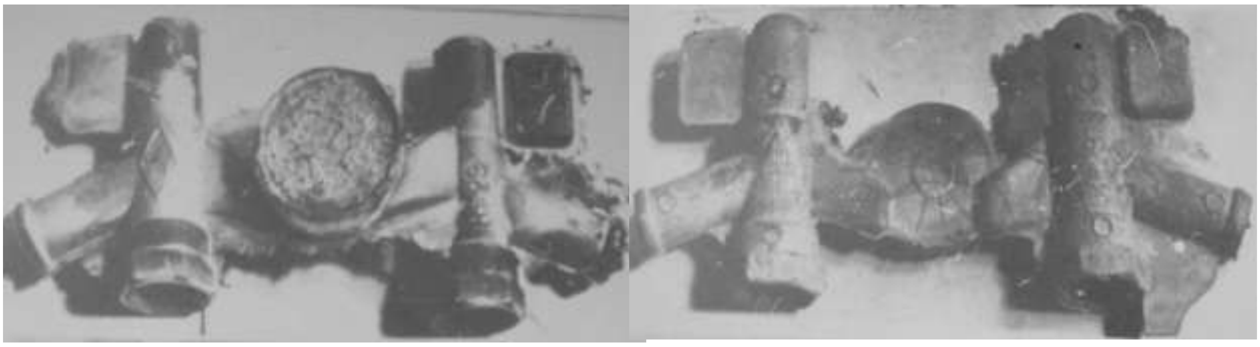
The heating of the rod surface does not exceed 1073 K, which preserves the geometry and structure of the engraving. The simplicity of the choice of the plasma-forming gas reduces the gas saturation and oxidation of metal powders. Before pouring liquid metal, the surface of the rod was covered with a layer of flux (a mixture of sodium tetraborate decahydrate with potassium carbonate) to improve wetting. In the stage of diffusion interaction, the decisive role is played by defects in the crystal structure [7, 8], which are more developed in metal powders in comparison with contact materials.

In this case, the possible diffusion mechanisms are exchange and vacancy.

The rods are removed in water without any harmful effect on the surface of the casting.

Composite inserts of pressure mold casting (injection molding).

Further development of injection molding depends to a large extent on increasing the durability of molds. This is especially noticeable in the manufacture of castings from high-temperature alloys. Mold elements in contact with liquid metal (inserts, rods, etc.) are destroyed for the following reasons: thermal fatigue, limited heat resistance, irreversible changes in shape, dimensional stability, wear resistance. Only the enumeration of the reasons for the failure of molds gives an idea of the complexity of the processes occurring under cyclic effects of temperature, surface oxidation, vacancy movement, aging, diffusion, saturation of the surface with gases, (Fig. 3) or up to its permissible value.



a *b*

Fig. 3. Deterioration of the surface of castings during the operation of molds: 10 removals (a); 2000 removals of castings from LS-49 (ЛС-49) brass (b)

In addition to the high heat mesh, form stability and wear resistance are added to this, which leads to the withdrawal of the equipment from operation. Virtually none of the alloys used for the manufacture of mold inserts fully meets the requirements of modern injection molding production. Composite casting is one of the ways to obtain inserts with predictable surface properties. There is a real possibility of replacing the traditional surface layer of the casting formed during its crystallization with a porous cermet shell made of powders of metals and / or their compounds, which makes it possible to control the shaping process. The filling of the pores of the shell occurs during pouring with the formation of a composite casting. Decisive for this technology are contact processes that provide communication between elements. They can be adhesive or diffusion. With a large number of ingredients, diffusion bonds can proceed via a crowdion mechanism. In this case, in the manufacture of mold inserts for casting copper alloys, a composition of a porous metal-ceramic shell (a mixture of powders corresponding to the chemical composition of intermetallic hardening steel) was used, combined by pouring liquid cast iron of the SCh21-40 (СЧ21-40) brand into a mold. The most difficult stage is the formation of the transition zone between the porous metal-ceramic shell and the liquid metal. A necessary condition for filling the pores of cermet is heating the shell to (0.8...1.0) the crystallization temperature of the melt, which is achieved by overheating of cast iron, pouring temperature, heating the mold before pouring, increasing the ratio R/r (R is the thickness of the melt layer, r is the thickness of the cermet). All this complicates and increases the cost of the process, increases casting rejects.

To stabilize the modes of consolidation of the transition zone, cast iron was modified with titanium carbonitride TiCN in the nanosized state. There is an increase in the strength of the connection of ceramics with cast iron, depending on the method of modification, the R/r ratio and the pouring temperature (Fig. 4).

Low sensitivity of cast iron to fluctuations in chemical composition and the duration of the modifying effect during holding the metal in the ladle were recorded. The structure of the metal in the transition zone is shown in Fig. 5.

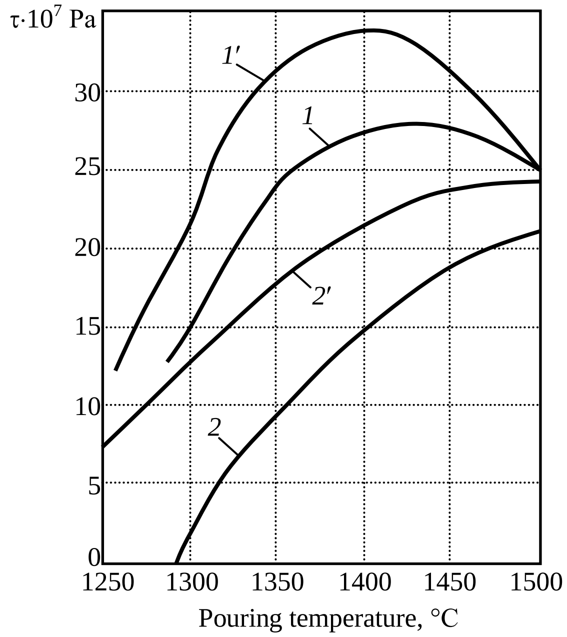


Fig. 4. Influence of the pouring temperature on the strength of the joint of the porous metal-ceramic shell with cast iron: 1 – R/r = 10 (without TiCN); 2 – R/r = 2 (without TiCN); 1′ – R/r = 10 (in the presence of TiCN); 2′ – R/r = 2 (in the presence of TiCN)

Fig. 5. The structure of the transition zone porous metal-ceramic shell – matrix

In the study of the thermal stability of the tooling, the cycles of thermal change (c.t.) were counted until the appearance of the first crack. In Fig. 6 shows an insert for making a “bracket” casting from LS-49 (ЛС-49) brass.

In the insert obtained by machining of steel 40Kh5MFS (40Х5МФС), the first crack was found at 400 c.t.; at a composite insert with a porous cermet shell made of a mixture of powders corresponding to the chemical composition of maraging steel 03N18K9M5T (03Н18К9М5Т) – at 800 c.t.

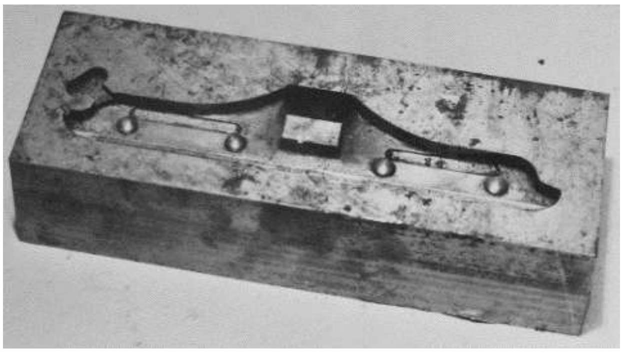


Fig. 6. Insert for making the “bracket” casting from brass LS-49 (ЛС-49)

Composite casting of a rolling cutter.

The cutter is the working body of the bit for wells drilling. The operating conditions of the cutter are complex: growing volumes of drilling operations, variable rock properties, deep drilling, high rotational speeds at high axial loads. This requires the ever-increasing operational reliability of the cutter - the search for materials, technologies and designs that meet high requirements.

The traditional technology consists in mechanical fastening of rock cutting bits made of hard alloys (ВК type) in a body made of forged chisel steel (12ХН2, 10ХН3, 17ХН2). The mechanical fastening of the teeth in the body is a long, laborious, expensive and unreliable process due to the insufficient strength of the fastening of the teeth.

Various requirements are imposed on the elements that make up the cutter - a tooth, a support, a body. Therefore, when casting, it is advisable to make them from different materials with subsequent joining into a composite product with diffusion bonds. Diffusion connections between the cast body made of low-carbon alloy steel and the shank of the bit lead to an increase in the impact strength and fatigue resistance of the body in comparison with the plastically deformed body and the teeth pressed into it [9].

The cutters are cast into a water-cooled chill mold using an external action on the liquid crystallizing metal, which makes it possible to obtain a relative narrowing of 35...40 % and an impact strength of 100 J/cm^2 [10]. When the liquid metal interacts with the teeth of the ВК alloy, their embrittlement occurs. The cause of embrittlement is the migration of carbon in the steel to the hard alloy and the diffusion of tungsten and carbon from the hard alloy into the liquid melt. Crystals of double iron-tungsten carbides (η-phase) are formed in the tooth structure, which embrittle both the tooth and the transition zone. The study of the influence of the main technological factors on the intensity of diffusion and migration paths made it possible to obtain the corresponding expression [11]:

$$\frac{\Delta}{d} = 0.004\left(\frac{M}{m}\right)^{0.436} \cdot \left(\frac{T_{\text{pour}}}{T_{\text{mol}}}\right)^{0.505}, \qquad (4)$$

$$\frac{L}{r} = 9.279 \cdot 10^{-3}\left(\frac{M}{m}\right)^{0.5} \cdot \left(\frac{T_{\text{pour}}}{T_{\text{mol}}}\right)^{0.897}, \qquad (5)$$

where Δ – the width of the transition zone;
L – the depth of migration;
d – the diameter of the clove;
r – the radius of the clove;
M – the mass of the casting;
m – the mass of the clove;
T_{pour} – pouring temperature;
T_{mol} – mold temperature before pouring.

From (4) and (5) it can be seen that both values depend on the intensity of heating of the teeth. Copper refrigerators were used to reduce the intensity. The heating temperature of the teeth working part decreased by about 100 K. This made it possible to completely prevent the migration of carbon and reduce the width of the transition zone by about 10 times. The dependence of the width of the transition zone on technological factors is obtained:

$$\frac{\Delta}{d} = 2.45 \cdot 10^{-4} \left(\frac{m_{\mathrm{ref}}}{m} \right)^{-1.09} \cdot \left(\frac{m_{\mathrm{ref}}}{m} \right)^{-0.99}, \qquad (6)$$

where m_{ref} – the mass of the refrigerator.

The critical values m_{ref}/m and M_{ref}/m are 0.09 and 10.072, respectively. Their increase leads to non-welding of the teeth with the casting due to the non-wetting of the tooth with steel.

At the same time, the microstructure of the transition zone contains compact inclusions of the brittle η-phase. A comparative analysis of the state diagrams of the Co-W-C and Ni-W-C systems showed that when cobalt is replaced with nickel, the probability of the formation of the η - phase decreases, and the resulting crystals will be smaller. The application of a nickel coating with a thickness of 60 microns on the tooth prevented the formation of the η-phase in the body of the tooth, the size of the η-phase crystals in the transition zone decreased by 4...5 times. The 200 μm thick coating completely prevented the formation of compact inclusions of the η-phase. Plating the bit with nickel does not eliminate migration, therefore, to obtain a high-quality connection between steel and the bit, it is necessary to use nickel coating and forced cooling together. The bond strength with the casting in this case is 1.4 times higher than with mechanical fastening.

The developed technology has shown the stable performance of pin bits on soft and medium rocks, a reduction in the cost of manufacturing a cutter, and metal savings of up to 2 kg per cutter.

Thin-cavity castings.

The creation of compact units and assemblies with high energy performance of internal combustion engines, non-stationary gas turbine units (GTU), etc. (downsizing) requires an increase in operating parameters and, therefore, new materials that can withstand high temperatures, pressure, mechanical loads, etc. In units and assemblies of this kind, a significant place is occupied by precision castings with thin internal cavities. Internal cavities (Fig. 7) are necessary to cool the surface during operation in order to increase the ability of the blade to withstand mechanical stress at high temperatures for acertain time.

The constant growth of the temperature-time parameters during operation is constrained by the heat resistance of existing alloys. Obtaining such castings is complicated not only by the need to have high casting and mechanical properties of the alloys, but also by the difficulty of obtaining thin cast cavities. For their design, rods of solid-phase sintering are used from oxides of Al_2O_3, SiO_2, ZrO_2, which are removed from the castings in concentrated solutions and melts of alkalis, fluoride compounds. The removal process is intensified by the use of ultrasound, autoclave, cyclic change of vacuum pressure. The completeness of removal of the cores, even with prolonged exposure to external factors, is not guaranteed, which leads to an increase in casting rejects. Prolonged exposure to a corrosive environment on alloys containing chromium, nickel, titanium, aluminum, boron, nimonic, leads to a decrease in the endurance limit or plasticity limit. Long-term strength (test time 100 hours at 900 °C) of precipitation-hardening heat-resistant alloys in 40 % NaOH solution at 140 °C decreases from 220 to 160...180 MPa, i.e. by 18...27 %. In addition to corrosion, hydrogen embrittlement is observed.

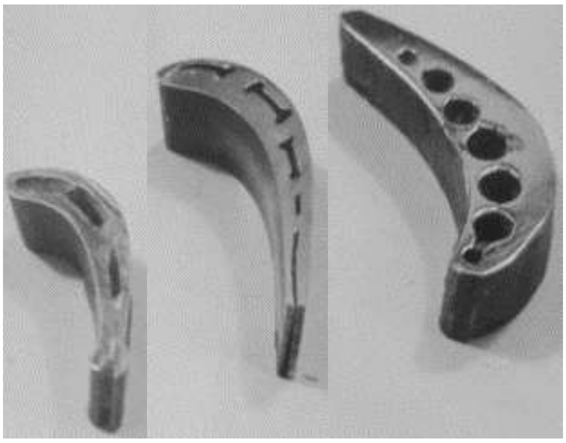
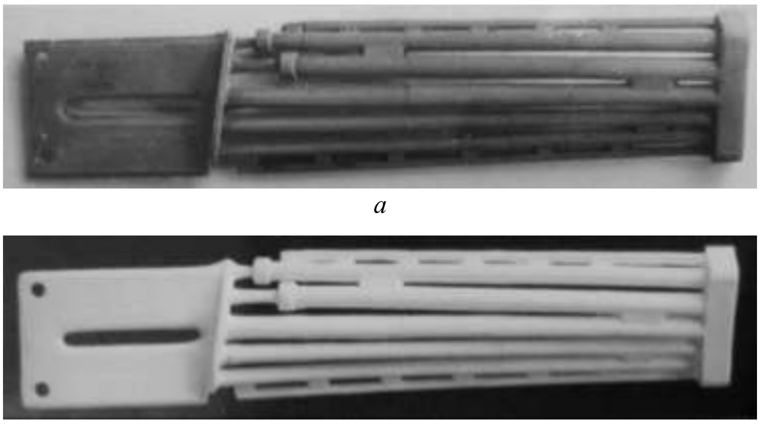


Fig. 7. Templates of castings of turbine blades of various configurations

Therefore, refractory materials of the rods must be removed in a non-aggressive environment in the shortest possible time. The implementation of these conditions became possible when using salt-ceramic rods made of sodium chloride with thermal protection [12]. Taking into account the difference between the melting temperatures of the salt and the casting metal, this function is performed by a protective layer of nickel deposited on the rod by electrothermal evaporation and vapor condensation in a vacuum.



a

b

Fig. 8. Salt-ceramic rods for cast blades: after annealing (a); after applying a protective layer (b)

To obtain a high-quality casting, a large number of initial design and thermophysical options were investigated [13]. When solving the problem, the finite-difference representation of the Fourier differential heat conduction equation was used. The connection of the protective layer of the rod with the metal of the casting occurs by diffusion. Obtaining high-quality castings of turbine blades is confirmed by the calculation of temperature fields, as well as by casting a pilot batch of blades.

Composite molds for glass products.

Glass pressing factories produce a large number of products for various fields of activity: electrical engineering, art products, packaging for drinks, household appliances, the chemical industry, perfumery, etc. For the manufacture of these products, a large number of molds of various configurations with a given relief on the surface are required. To this should be added the requirements for the renewability of the product range in a highly competitive environment, when the paradigm works - to make is not enough – still needs to be implemented. Based on these considerations, the development of the production of glassware should go in three directions:

– reducing the time from the sketch of a new product to the release of finished products;
– minimal costs for finishing machining, especially for manual labor of highly qualified chasers;
– operational reliability of the equipment.

The first direction is realized by making a model from a low-melting model material according to a glass standard. This mod is used as a core box to produce a Shaw ceramic core. After heat treatment, the rod is set in a sand mold and filled with liquid metal.

Thus, the working surface of the future mold is formed by successive negative and positive reflections of the relief of the glass standard [14]. The total loss of a profile consists of the loss of a profile during the manufacture of a pro-model, a ceramized rod, a casting, which is 0.25 mm with a permissible maximum deviation of 0.3 mm. The roughness of the surface forming the engraving, measured by the arithmetic mean profile deviation Ra, is in the range of 2.5...5 μm. This made it possible to exclude the minting operation. Only mating surfaces are machined on mold elements.

During the operation of molds made of gray cast iron SCH20 (СЧ20), fatigue cracks occur during thermal cycling. This is a consequence of the temperature difference over the cross section of the mold, changes in the coefficient of thermal expansion (CTE), tendency to growth, oxidation, and surface quality.

The formation of a grid of heat also depends on the phase and structural transformations of cast iron, graphitization. The thermal resistance of cast iron is positively influenced by temporary tensile strength. However, when using cast iron grade SCh35, casting properties deteriorate, the coefficient of linear expansion increases (from $9.5 \cdot 10^{-6}$ 1/°C for SCH20 (СЧ20), to $11.0 \cdot 10^{-6}$ 1/°C for SCH35 (СЧ35), thermal conductivity decreases (from 54 W/(m·K) for SCH20 (СЧ20), up to 42 W/(m·K) for SCH35 (СЧ35) in accordance with GOST 1412-85).

In order to increase the thermal stability of the tooling, the gray cast iron SCH20 (СЧ20) was replaced by the cast iron with spheroidal graphite VCH 400-15 (ВЧ 400-15) (DSTU 3925-99). This cast iron has a low thermal conductivity (22...28 W/(m·K)) [15], therefore, the inserts of the molds are heated to higher temperatures, the polished surface is oxidized faster, and effective cooling of the molds is required or a decrease in the rate of work with a drop in productivity. Under conditions of high thermal stresses and high ductility of this cast iron, stress relaxation is possible by deformation and warping of the tooling.

To eliminate this drawback by increasing the thermal conductivity of cast iron, a method of reinforcing a cast iron matrix with steel cylindrical elements (wire) of various diameters, uniformly distributed in the casting volume and perpendicular to its working surface, has been proposed and implemented [16]. The diffusion bond of steel cylindrical elements is formed due to the gradient of the carbon content in steel and cast iron. The low thermal conductivity of VCH (ВЧ), explained by the greater disunity of nodular graphite inclusions, is compensated by the high thermal conductivity of low-carbon steel wire and reaches values of 52 W/(m·K). Tooling durability in the composite version (Fig. 9) increases by 25...27 % [17].

Fig. 9. Flower vase: standard (a), promodel (b), ceramized rod (c), casting (d)

Conclusions

Composite casting synthesizes individual elements of a part, which can be manufactured by various technologies, from different materials and combined by pouring metal into a mold into a single whole. The choice of materials depends on the operating conditions. This is especially significant when the working conditions of the part are so complex and dynamic that it is difficult to select any existing alloy in this situation. The heterogeneous nature of composite casting makes it possible to obtain a sum of service properties of a new quality that is inaccessible to individual elements that make up the composition. The quality of composite casting mainly depends on obtaining a homogeneous, predictable and controllable interface between the components, where complex physicochemical processes develop under non-stationary thermal conditions. The interface in different compositions can be formed under the influence of mechanical, adhesion, diffusion processes. This paper discusses some technical and technological solutions in different areas of industry. They are united by the need to increase the competitiveness of the industry: to improve the accuracy of castings and the operational reliability of cast parts.

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Received May 23, 2020

Accepted July 12, 2020