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CHOICE OF THE OPTIMAL COMPOSITION OF NON-STICK COATINGS ACCORDING TO THE CONDITIONAL CRITERION OF FILLING MASS ACTIVATION*

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ABSTRACT

Development of the technique for choice of the optimal composition of non-stick coatings based on the filling mass quality evaluation (taking into account the results of differential scanning calorimetry) is the aim of this research. Non-stick coating for iron casting based on filling mass and polyvinyl butyral lacquer was taken for investigations with the following relation – filling mass : polymer composition (2% polyvinyl butyral lacquer) = 1:1. The mixture of natural and mechanically activated graphite with their different correlation was used as a filling mass. Calculation of the conditional activation criterion displayed that the most optimal relation between self-drying coatings of natural and mechanically activated graphite in a filling mass is 50:50. It was established in this case that increase of activated graphite in a filling mass of non-stick coatings leads to increase of density, toughness and reduced strength. The most essential improvement of the properties is observed if the content of activated graphite in a filling mass increased up to 50%. Additional increase of GLS-2A graphite content does not lead to substantial improvement of the properties. The developed non-stick coatings were tested during fabrication of the casting "Centrifugal soil pump. Internal pump shell" with mass 70 kg and size 510×615×128 mm, made of 320Kh20N (320Х20Н) iron. Use of non-stick coating on the base of the mixture of natural and mechanically activated graphite (with their relation 50:50) is characterized by decrease of burning-on thickness by 1.8 times (on the bottom surface of a casting) and by 1.9 times (on the side surface of a casting) in comparison with thickness values for non-painted castings. The obtained results can be explained in the following way: if we apply the coating containing 50% GLS-2 (ГЛС-2) and 50% GLS-2A (ГЛС-2А), large particles of natural graphite don't penetrate in mould pores and remain on the surface, what leads to decrease of burning-on on the casting surface.

Introduction

Fighting with burning-on remains one of the most important problems of casting and foundry production, because chipping and cleaning operations on castings take up to 30–50% from total labour intensity of their fabrication. Use of anti-stick coatings is one of the routine methods for prevention of burning-on forming on the surface of castings [1–5]. The correct choice of their compositions can provide not only complex prevention of this defect, but also support solving of such actual problems of modern production as recycling and utilization of wastes. Thereby the larger attention is paid to development of the new compositions of anti-stick coatings, meeting the requirements of up-to-date casting and foundry production [6–11].

Development of the new compositions of coatings and ptimization of the known ones are the difficult operations required a lot of time and resources. In he most cases choice of composition is made experimentally, while their optimization — using the methods of mathematical planning. It can be explained by the concept that the processes ocurring in a mould are very complicated and they are running in complete mutual relation with each other — mostly often during the short time period, at large rates and with non-stationary features, what creates, in its turn, additional difficulties in conducting the investigations and analyzing the results [11–14].

Thereby the aim of this research was formulated as development of the technique to choose the optimal composition of non-stick coatings on the base of evaluation of filling mass quality, taking into account the results of differential scanning calorimetry (DSC).

The technique of experiment

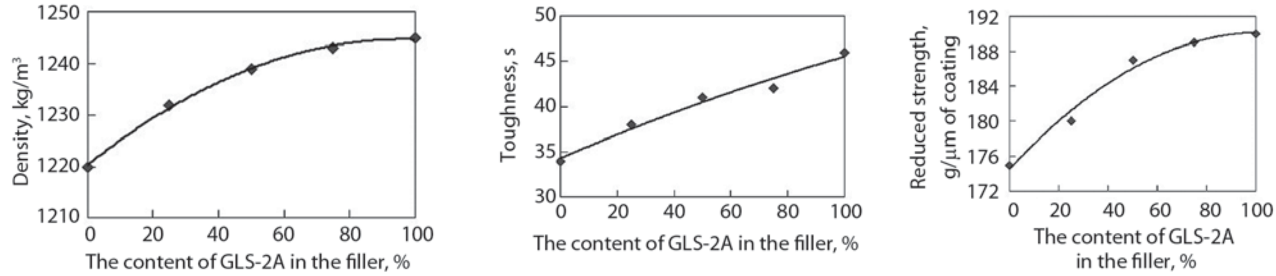
Non-stick coating for iron casting based on filling mass and polyvinyl butyral lacquer was taken for investigations with the following relation — filling mass : polymer composition (2% polyvinyl butyral lacquer) = 1:1. The coating was prepared in the following way: polymeric composition was being dissolved in alcohol during 24 hours, then graphite was added. Mixing was executed in a covered vessel during 30 min.

Natural and activated graphite as well as the mixture of natural and activated graphite with their different correlation were used as a filling mass.

The mill RETSCH PM 400 MA was used for graphite activation, its parameters are described in the work [15]. Activation procedures are presented in the works [16, 17]. The average particle size of natural and mechanically activated graphite makes 60 μm and 18 μm respectively.

Conditional activation coefficient (CAC) of natural and activated graphite as well as the mixture of natural and

* Dr. Eng., Prof. I. E. Illarionov participated in this work.



a *b* *c*

Fig. 1. Properties of self-drying non-stick coatings:
a — density; *b* — toughness; *c* — reduced strength

activated graphite was used for evaluation of filling mass activity, according to the technique described in [18]:

$$K = k\frac{\Delta E_{act}}{\Delta E'_{act}} \cdot l\frac{\Delta H}{\Delta H'} \cdot m\frac{T_{ox}}{\Delta T'_{ox}} \cdot n\frac{\upsilon}{\upsilon'},$$

where ΔE_{act}, ΔH, ΔT_{ox} and υ — values of activation energy of graphite oxidation process, heat of graphite oxidation process, temperature of oxidation reaction maximal rate and reduced square of oxidation heat effect peak before activation; $\Delta E'_{act}$, $\Delta H'$, $\Delta T'_{ox}$ and υ' — values of the same parameters after activation; *k*, *l*, *m* and *n* — coefficients (as soon as their values are unknown, they were assumed equal to 1 in the first approximation).

Thermal oxidation destruction of the mixture of natural and mechanically activated graphite was conducted in the air, using thermal analyzer SDT Q600, described in the work [19], during the dynamic procedure in the air atmosphere, with heating rate 10 °C/min up to 1000 °C. Calculation of activation energy (according to Arrenius equation) was done using initial oxidation temperature.

Table 1. **Activation energy of the mixture of natural and activated graphite (analyzed by initial oxidation temperature of the mixture)**

Content of activated graphite in a filling mass, %	Oxidation				ΔE_{act}, kJ/mol
	Beginning		End		
	Temperature, °C	Mass loss,%	Temperature, °C	Mass loss,%	
0	564	4.88	809	76.18	78.02
25	457	0.95	811	77.75	54.05
50	459	1.33	807	80.16	52.87
75	461	1.75	810	78.14	53.91
100	450	1.32	816	79.97	50.40

Table 2. **Calculation of conditional activation criterion for the mixture of natural and activated graphite**

Content of activated graphite in a filling mass, %	Thermodynamical parameters of graphite, evaluated via DSC curve				
	ΔH, kJ/g	υ, °C·min/mg	ΔT_{ox}, °C	ΔE_{act}, kJ/mol	*K*
0	21.87	17.4	683.98	78.02	1.00
25	21.51	17.1	681.49	54.05	1.50
50	20.41	16.3	680.25	52.87	1.70
75	20.89	16.6	675.28	53.91	1.61
100	21.22	16.9	666.57	50.40	1.68

The technique of determination of density and reduced strength for coatings is described in the GOST 10772–78, of toughness — in the GOST 8420–74 using VZ-4 (B3-4) viscosimeter.

Experimental results

Dependence of conditional activation criterion for the mixture of natural (GLS-2) and mechanically activated (GLS-2A) graphite was examined in this research. Content of GLS-2A graphite in the mixture was varied from 0 to 100%. Calculation results are presented in the **Table 1** and **Table 2**.

As soon as content of mechanically activated graphite in the mixture increases, maximal temperature of mixture oxidation moves to lower temperature values by 17 °C, while activation energy decreases from 78.02 kJ/mol (for GLS-2 graphite) to 50.40 kJ/mol (for GLS-2A graphite).

Replacement of natural graphite (25%) by mechanically activated graphite increases CAC (conditional activation criterion) by 1.5 times, while replacement of 50% and 100% of natural graphite increases CAC by 1.7 and 1.68 times respectively.

It can be suggested correspondingly that correlation 50:50 is the most optimal for filling mass of self-drying coatings of natural and mechanically activated graphite.

The effect of content of mechanically activated graphite in a filling mass on the properties of self-drying coatings is shown on the **Fig. 1**.

As soon as content of activated graphite increases, density, toughness and reduced strength will increase too. It is clear that essential improvement of properties is observed in the case of increase of activated graphite content in a filling mass up to 50%. Consequent increase of GLS-2A graphite content does not lead to substantial density elevation. Thereby we can suggest that correlation 50:50 is most optimal for natural and activated graphite.

To confirm this suggestion, the pilot-industrial tests of the developed self-drying coatings were conducted. These coatings were based on natural graphite GLS-2; mixture of natural and mechanically activated graphite with their correlation 50:50 in a filling mass; activated graphite GLS-2A.

The compositions and properties of the mixtures are presented in the **Table 3**.

Table 3. **Composition and properties of moulding and core sand mixtures**

Component	Mixture type		
	Moulding mixture (green moulding)		Core sand mixture
	Backing sand	Facing sand	
Mixture composition,%			
Quartz sand 3$K_3O_2$016	10	100	100
Reused sand	90	–	–
Moulding clay of P_1T_1 type	2	3,5	–
Technical lignosulphonate	1	–	–
Granulated coal	–	–	3,5
Liquid glass	–	8.5–9.0	8.5–9.0
Sodium hydrate	–	0.5–1.0	1.2
Oil residual	–	0.5	0.5
Properties			
Humidity, %	4.5	3.6	5.0
Mixture strength during compression, MPa	4.2	4.2	4.0
Gas penetration, units	120	115	130

Таблица 4. **Iron chemical composition (TU 48-22-36–79)**

Alloy	Content of elements, mass.%						
	C	Si	Mn	Cr	Ni	S	P
320Kh20N (320X20H)	3.35	0.94	0.54	20.94	1.02	0.03	0.05

During the tests, cores and moulds intended for fabrication of castings “Centrifugal soil pump. Internal pump shell” with mass 70 kg and size 510×615×128 mm were painted. Dominated wall thickness of these castings was 20 mm, material — iron 320Kh20N (320X20H) according to technical specification TU 48-22-36–79. Chemical composition of iron is presented in the Table 4.

The coatings were applied in one layer by a spray jet, after application they are located in uniform mode, without any spotting and lapping. Covering capacity is satisfactory. No cracks or other defects were identified on painted surfaces after drying.

The pictures of casting surfaces are shown on the **Fig. 2**, the effect of quality of non-stick coating on burning-on thickness is displayed on the **Fig. 3**.

Burning-on is characterized as combined.

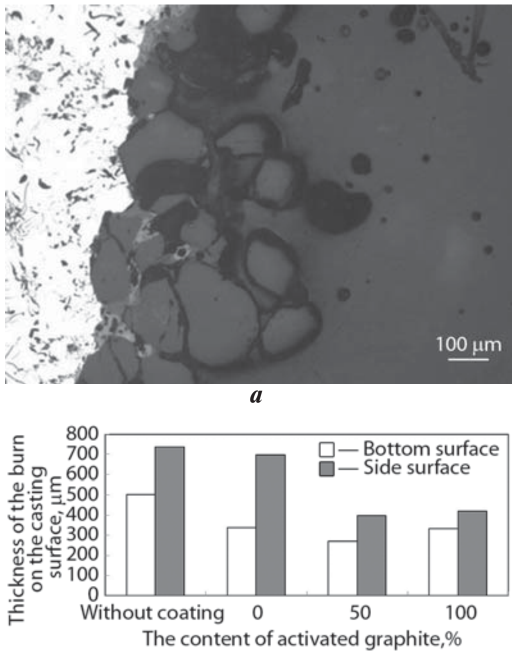
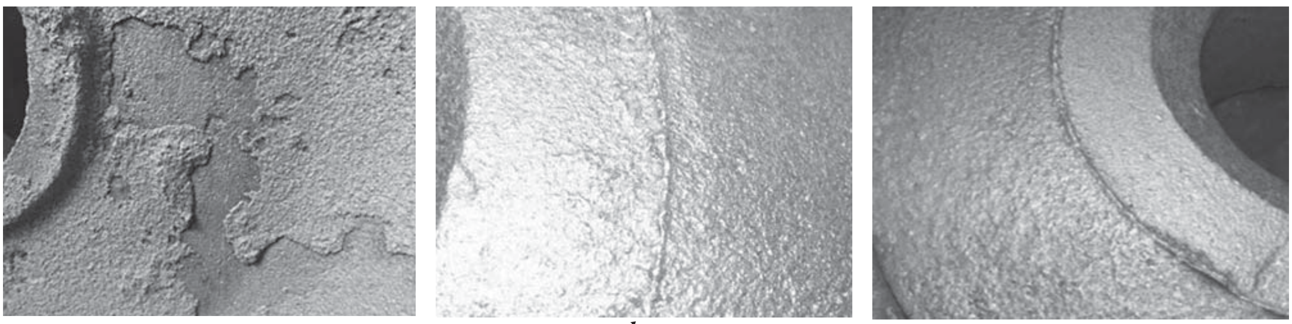


Fig. 3. Burning-on (*a*) and burning-on thickness on casting surface (*b*)

The obtained results can be explained in the following way. When applying the coating containing 50% of graphite GLS-2 and 50% of graphite GLS-2A, large particles of natural graphite don’t penetrate in mould pores, but remain on the surface.

The pictures of core with the coating based on filling mass, containing 50% of natural crypto-crystalline graphite GLS-2 and 50% of activated graphite GLS-2A are presented on the **Fig. 4**. Sand grains *1* are connected with each other via binder material. The core has pores *2* between sand grains *1*. When the coating is applied at the core, the fine fraction of graphite GLS-2A *3* penetrates them through pores down to definite depth. The coarse fraction of graphite GLS-2 is characterized by too large size of particles to penetrate in the core and forms thereby the surface layer *4*. The research of the cover and penetrating layers confirmed this suggestion.

In this way, the coating containing 50% of natural crypto-crystalline graphite GLS-2 and 50% of activated graphite GLS-2A provides the better surface quality.



a *b* *c*

Fig. 2. Surface of the castings “Centrifugal soil pump. Internal pump shell”, fabricated without coating (*a*) and with coatings, containing 50% of graphite GLS-2 and 50% of graphite GLS-2A (*b*) and 100% of graphite GLS-2A (*c*)

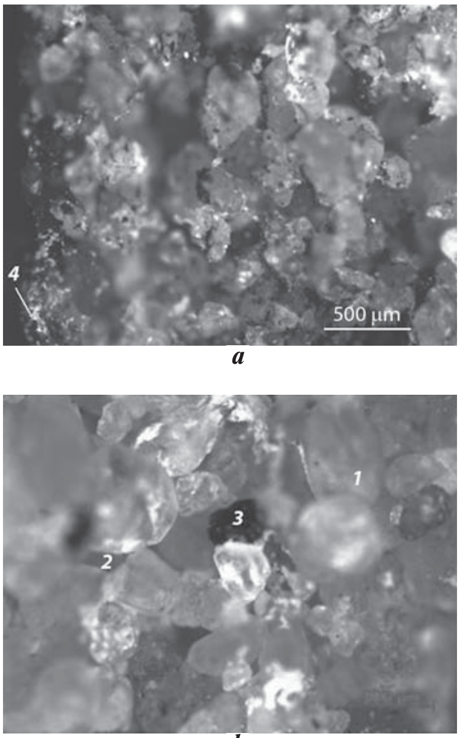


Fig. 4. Schematic image of core section (*a*) and microstructure of samples painted by self-drying coating, containing 50% of natural graphite and 50% of mechanically activated graphite (*a* — edge; *b* — 0.5 mm from edge):
1 — sand grains; *2* — pore in the mixture; *3* — fine graphite particle; *4* — cover coating layer

Conclusion

Thereby, the results of calculation of conditional activation criterion displayed that the correlation 50:50 is most optimal for natural and activated graphite. It was established It was established during the research that increase of activated graphite in a filling mass of non-stick coatings leads to increase of density, toughness and reduced strength. It should be noted that essential improvement of the properties is observed in the case of activated graphite content elevation in a filling mass up to 50%. Additional increase of GLS-2A graphite content does not lead to substantial improvement of the properties. To confirm this suggestion, the castings "Centrifugal soil pump. Internal pump shell" with mass 70 kg and size 510×615×128 mm, made of iron 320Kh20N were fabricated. Use of non-stick coating on the base of the mixture of natural and mechanically activated graphite is characterized by decrease of burning-on thickness by 1.8 times (on the bottom surface of a casting) and by 1.9 times (on the side surface of a casting) in comparison with thickness values for non-painted castings. The obtained results can be explained in the following way: if we apply the coating containing 50% GLS-2 and 50% GLS-2A, large particles of natural graphite don't penetrate in mould pores and remain on the surface, what leads to decrease of burning-on on the casting surface.

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