DEVELOPMENT OF THE OPTIMAL COMPOSITION OF THE ALLOYING MIXTURE FOR SURFACE BORATION OF CAST PARTS

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ABSTRACT

This work is devoted to obtaining the optimal composition of an alloying mixture based on boron carbide, titanium, and marshalite, intended for surface alloying of steel castings. The developed mixture makes it possible to obtain a borated wear-resistant coating with a thickness of up to 3 mm.

KEYWORDS: *Wear Resistance, Abrasive Particle, Alloying Mixture, Optimization, Boron Carbide, Titanium Powder, Surface Boration, Conjugate Surface, Excavator Chassis, Expanded Polystyrene Gasified Model, Sand-Clay Form.*

INTRODUCTION

Many years of operational experience show that the details of road construction machines and agricultural machinery are characterized by low durability **[1-4].**

The low service life of such parts as the support roller, the caterpillar link, and the drive wheel, which are the most massive and expensive (at least 10% of the cost of the excavator), leads to a sharp increase in the specific costs of time and material resources to restore the operability of caterpillar engines.

Therefore, it is necessary to increase the durability of these parts by creating wear-resistant coatings on their surface.

Boration was chosen as a wear-resistant coating on the working surface of the support roller and the drive wheel of the excavator crawler since it is known that borides Feb, Fe_2B are characterized by high resistance to abrasive wear **[4,6,7].** This is consistent with the experimental and analytical wear model developed by us **[8],** according to which the borides FeB, Fe_2B are characterized by high energy intensity of destruction. These phases can absorb a sufficiently large amount of energy transmitted by abrasive particles without being destroyed, which increases the wear resistance of rubbing surfaces operating in a free abrasive environment

Surface boration was carried out directly in the mold, during the formation of the casting. Powdered boron carbide B_4C (binary compound of boron with carbon) was selected as the saturating medium since, the concentration of boron in which is the maximum **[9].** A binder (hydrolyzed ethyl silicate) was added to boron carbide powder B_4C

The viscosity of the mixture was brought to the suspension state of 15-25 cSt. The viscosity of the mixture was determined by the VZ-4 viscometer at the expiration.

The finished mixture (suspension) was applied on the surface of a pre-made foam model of the roller, as well as on the working surface of the sand-clay shape of the driving wheel.

The support rollers are cast according to expanded polystyrene gasified models (PGM) [9] and are cast from steel 35GL (GOST 977-88). The driving wheel was also cast from steel 20GL (GOST 977-88) in a sandy-clay form.

The foam models of the rollers were covered with a mixture based on boron carbide (B_4C) with a thickness of 1.0; 1.5; 2.0; 2.5 and 3.0 mm. After applying the mixture, the foam models were dried in a stream of warm air with a temperature of 35-40 °C, for 30-40 minutes. Then they were covered with non-stick paint and dried again. After drying, the foam models were assembled on the collector, which, together with the riser, were installed in the flask and filled with dry quartz sand mark 1K3O2016, which was compacted on a pneumatic vibrating table.

A mixture of similar composition and thickness was also applied to the working surfaces of the sand-clay shape of the driving wheel. After applying the mixture, the molds were dried and subsequently assembled.

The finished mold was filled with molten steel with a temperature of 1570-1600 ^{o}C. After cooling, the castings were knocked out, stumped, cleaned, and removed from the gate system.

It should be noted that surface alloying directly in the casting process has some technological advantages, such as:

- no additional energy supply is required to heat the parts to create wear-resistant boronated (borotitanated) coatings on the working surfaces. Wear-resistant coatings are formed due to the heat released during the crystallization of castings:

- a coating of sufficient thickness (2.2-2.5 mm)

and the required quality is formed;

- the use of casting on expanded polystyrene gasified models allows you to obtain castings with an accuracy equal to the casting on the smelted models, at a cost level comparable to casting in sand-clay molds.

Studies have shown that the coating formed on the vertical walls of the mold was characterized by high heterogeneity in thickness. If on the horizontal surfaces of the samples the size of the cross-section of the coating was in the range from 1.5 to 1.9 mm, (Fig. 1) then on the vertical wall of the roller it ranged from 0.1 to 3 mm (Fig. 2).

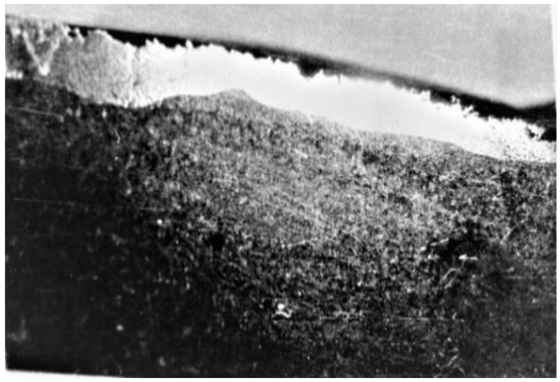


Fig. 1. Microstructure of borated coating on horizontal surfaces. X5

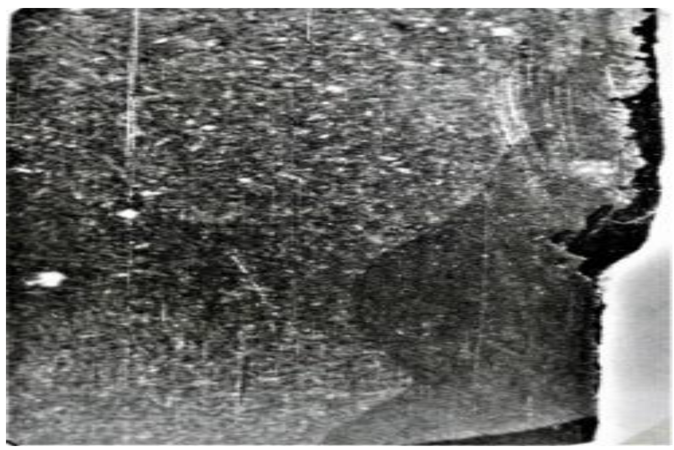


Fig. 2. Microstructure of borated coating on vertical walls. X5

In addition, there was a violation of the geometry of the casting shape in the upper zone of the vertical wall (Fig. 3).

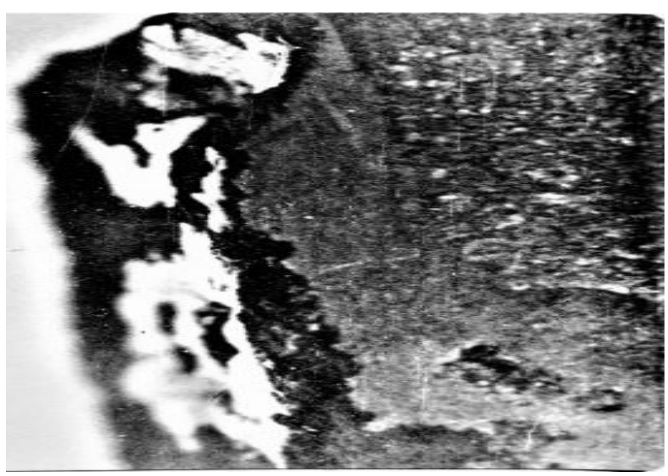


Fig. 3. Microstructure of the borated coating with a violation of the shape of the casting. X5

To eliminate these undesirable phenomena, studies were conducted to determine the optimal composition of the applied mixture.

The composition of the alloying mixture was optimized using the regression equation **[10].**

When setting the task of optimizing the composition of the mixture, it was assumed that in the contact zone of the melt with the mixture, the dissociation of boron carbide B_4C occurs with the release of active boron (B) and carbon (C) atoms. The latter, interacting with the crystallizing melt, forms a low-melting eutectic of the Fe-B-C system.

The formation of a liquid phase on a vertical wall is accompanied by its runoff, which causes a violation of the uniformity of the coating and the shape of the casting.

Based on this assumption, it was decided that, on the one hand, to reduce the concentration of boron in the mixture by introducing a neutral component of marshalite (pulverized quartz), and, on the other hand, to add components to the composition (Ti titanium powder) forming refractory borides (TiB, Ti_3B4, TiB_2) not involved in the formation of fusible eutectic and disturbing the concentration equilibrium in eutectic. Both of these additives were designed to solve the problem of obtaining a uniform and workable coating.

At the main level, the intervals of variation of factors were chosen based on data from numerous preliminary experiments, studying the composition, structure, and properties of borated coatings formed on the surface of the support roller and the drive wheel.

The results of the implementation of the planning matrix are shown in Table 1, according to which the regression coefficients of the linear equation are calculated. The optimization parameter - $\bar{Y}$ was the thickness of a uniform borotitanized coating.

$$\bar{Y} = 1{,}2 + 0{,}15\ X_1 + 0{,}1\ X_2 - 0{,}175\ X_3 - 0{,}05\ X_1\ X_2 + 0{,}175\ X_2\ X_3 - 0{,}175\ X_1\ X_3 \quad (1.)$$

To check the statistical significance of the coefficients of the equation, confidence intervals were determined by the formula [11]:

TABLE 1 CONDITIONS OF THE EXPERIMENT

№ п/п	**Factors studied**	**The thickness of the mixture layer, mm**	**Titanium powder content, %**	**The content of the marshalite, %**
1	Basic level X_O	1,0	3	20
2	Variation interval	0,5	2	10
3	Upper level	1,5	5	30
4	Lower level	0,5	1	10
5	Code	X_1	X_2	X_3

$$Sy_i = \frac{\sum_{i=1}^{n} \cdot (Y_i - \bar{Y}_i)^2}{n} \quad (2)$$

$$Sb_i = \frac{Sy^2}{N} \quad (3)$$

$\Delta b_i = \pm\, t\alpha{:}N \cdot Sbi$ (4)

where $t\alpha{:}N$ - Student's criterion, $t_{0,05:8} = 2,306$

α - level of significance, α=0,05

$\Delta b_i = \pm\, t0,05{:}8 \cdot 0,037 = \pm 0,0853$

(5)

Then the regression equation with significant regression coefficients takes the form:

$\bar{Y} = 1,2 + 0,15\ X_1 + 0,1\ X_2 - 0,175\ X_3 - 0,05\ X_1\ X_2 + 0,175\ X_2\ X_3 - 0,175\ X_1\ X_3$ (6)

TABLE 2 PLANNING MATRIX OF TYPE 2^3

№ of experiments	X_O	X_1	X_2	X_3	$X_1 X_2$	$X_2 X_3$	$X_1 X_3$	$\bar{Y}$
1	+	+	+	+	+	+	+	1,2
2	+	+	–	+	–	–	+	0,8
3	+	–	+	+	–	+	–	1,4
4	+	–	–	+	+	–	–	0,7
5	+	+	+	–	+	–	–	1,6
6	+	+	–	–	–	+	–	1,8
7	+	–	+	–	–	–	+	1,0
8	+	–	–	–	+	+	+	1,1

Verification of the regression equation for adequacy was carried out according to the Fisher criterion:

$F^{calc}_{f2:f1} = \frac{S_a^2}{S_v^2} = 0,625$ (7)

The tabular value of the Fisher criterion is.

$F^{tabl}_{f2:f1} = F^{tabl}_{4:16} = 3,01$ (8)

Since the calculated value does not exceed the tabular values

$F^{tabl}_{f2:f1} > F^{calc}_{f2:f1}$ (9)

then, the regression equation is adequate.

Interpreting the obtained adequate linear regression equation, it can be concluded that the first two factors – the thickness of the applied mixture and the titanium content in its composition contribute to an increase in the size of the cross-section of the coating, and the third - the content of marshalite in the mixture, on the contrary, reduces its thickness.

Moreover, the effect of the influence is approximately the same coefficients at X_1; X_2; X_3 is respectively equal to - +0.15; +0.1; -0.175.

Analysis of the results of the multifactorial experiment shows that optimization of the parameters of the technological process is possible.

To solve the optimization problem, the method of steep ascent was chosen **[11-13].**

The content of marshalite (X_3) in the mixture was taken as the base factor. The step of movement during a steep ascent is taken equal to – 2%.

Then for the factor X_1 – the thickness of the mixture layer and X_2 of the titanium content, the movement step is 0.1 mm and 0.25, respectively %.

The conditions and results of experiments using the method of steep ascent are given in Table 3.

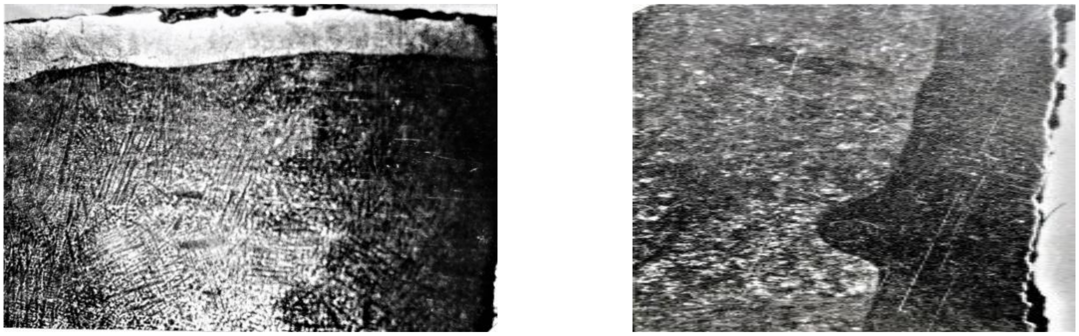
TABLE 3 CONDITIONS AND RESULTS OF EXPERIMENTS TO OPTIMIZE THE COMPOSITION OF THE ALLOYING MIXTURE AND THE THICKNESS OF THE APPLIED LAYER BY THE METHOD OF STEEP ASCENT

Factors	**X_1, mm**	**X_2, %**	**X_3, %**	**$\bar{Y}$**
Basic level X_0	1,0	3,0	20	-
B_i	0,15	0,1	-0,175	-
Variation interval	0,5	2,0	10	-
$B_i \cdot X_0$	0,075	0,2	-1,75	-
Step	0,1	0,25	-2	-
Mental experience (1)	1,1	3,25	18	-
Mental experience (2)	1,2	3,50	16	-
Mental experience (3)	1,3	3,75	14	-
Realized experience (4)	1,4	4,00	12	2,20
Realized experience (5)	1,5	4,25	10	2,35
Realized experience (6)	1,6	4,50	8	2,10
Mental experience (7)	1,7	4,75	6	-
Realized experience (8)	1,8	5,00	4	1,50
Mental experience (9)	1,9	5,25	2	-
Mental experience (10)	2,0	5,50	-	-

As a result of the conducted research and mathematical processing of the obtained static data, it allows us to adopt the following working version of the composition and thickness of the layer of the applied alloying mixture:

1. Boron carbide (B_4C) – 85,0 -86,0 %;
2. Titanium (Ti) – 4,0 - 5,0 %;
3. Pulverized quartz (marshalite) - 10%;
4. The thickness of the mixture layer – 1,5-1,7 mm.

Macrostructural analysis of the borated coating created on horizontal and vertical surfaces based on the developed mixture showed that the surface of the obtained coatings is smooth and rough, and the thickness ranges from 1.5 to 2.5 mm (Fig. 4.). **[14,15]**



a) б)

Fig. 3. Microstructure of borated and boro-titanated coatings obtained on the horizontal (a) and vertical (b) surfaces. X5

CONCLUSION:

In summary, we can say that the developed (optimized) composition of the mixture consists of boron carbide powder (B_4C) (85.0 -86.0%), titanium powder (Ti) (4.0 - 5.0%), ground pulverized quartz (marshalite) (10%) with a thickness of 1.5-1.7 mm mixture layer allows you to create a high-quality and wear-resistant coating with a thickness of up to 3.0 mm on the working surface of the support roller and the drive wheel of the excavator crawler, working in a free abrasive environment.

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