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High entropy coating on beals coal grinding mills

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doi: 10.18411/scienceconf-03-2021-04

idsp: scienceconf-03-2021-04

Introduction

Currently, in conditions of limited material resources in the industrial complex, technologies that increase the durability (resource) of machine parts and assemblies are of particular importance. 90% of parts and machines fail due to surface wear. This is especially true for the energy complex, where most mechanisms work in extreme conditions and, in particular, in conditions of high abrasive wear. This is the case with the beats of coal-grinding mills.

The choice of the type of coal-grinding mills is determined by the grindability of the fuel, the release of volatile substances, the required fineness of dust. At the Karaganda TPP-3, a hammer mill is used, which has high economic indicators, used in systems with direct injection of fuel and can operate under pressure.

The main problem in the operation of coal-grinding mills is the high abrasive wear and tear, the average continuous service life of which is 500 hours. In the present work, an attempt was made to increase the service life of beater of coal-grinding mills by mechanically activating them in a tumbling drum with the subsequent application of reinforcing highly entropic coatings. Comparison of the properties of beat without coating and with coating showed that with coating: microhardness increases about 1.6 times; wear resistance increases by 7.5 times; the friction coefficient decreases by almost 20 times!

Without pretending to be complete, we give very briefly the results of studies of Hadfield steel, described in [1-12]. These works present the results of work to improve the process of smelting and after-furnace treatment of Hadfield steel at various plants. The results of the complex alloying of this steel with various chemical elements are considered: chromium, molybdenum, nitrogen, titanium, etc. The results of the work of foreign researchers are presented, which are aimed at studying the influence of the chemical composition on the strength properties of high-manganese steel, studying the structure formation after external physical action, as well as a description steel hardening mechanisms under the influence of external factors. The results of numerous works to determine the effect of the cooling rate of castings in the mold on the wear resistance are considered. In addition, the results of work aimed at improving the foundry technology for the production of castings from Hadfield steel, as well as the results of other, no less important, studies on high manganese steel are considered.

In this paper, we review our papers [13–15]. High entropy coatings were not applied to Hadfield steel. The present work is dedicated to this. It investigated coatings obtained by us on samples of unalloyed steel.

Casting, elemental composition, properties of Hadfield steel used at TPP-3

Hadfield steel was manufactured at Power Beton LLP in Karaganda by casting steel melted in an electric furnace. The type of finished castings is shown in Fig. 1. Observations show that the finer the grain of the metal beat the coal mill, the faster the hardening of their working surfaces. In this case, the initial hardness of the steel is not determined by the size of the austenite grain. The control of steel 110G13L for hardness is carried out in the conditions of production due to the assessment of the thermal regime of casting of billets. Mostly castings with a high manganese content occur due to hot and cold cracks and usually they occupy more than 77% of the total number of scraps. Cracks in steel castings 110G13L can have a very different shape. Hardness testing of steel was carried out on an HVC-1000A electronic microhardness tester. The results are shown in fig. 2.

Figure 1 - Beater of a coal mill
of Power Beton LLP

Figure 2 - Microhardness of a beat coal mill
of Power Beton LLP»

In a number of works, it is believed that the occurrence of cracks on castings occurs when they are knocked out of shape at a temperature difference of more than 400 °C than the ambient temperature. We suggest knocking out finished castings only after the temperature of the most heated sections drops to 400 °C. After this procedure, castings marriage was reduced three times. Pictures of defective beaters are shown in Fig. .3. Pictures taken with a MIRA 3 electron microscope.

Figure 3 - SEM - image beat at a resolution of 10 and 5 nm

The elemental composition of steel 110G13L is presented in table. 1.

Despite the large number of works devoted to steel 110G13L, there is still no single theory of its self-hardening under impact loading.

Table 1

The elemental composition of steel 110G13L LLP "Power Beton"

Element	The percentage in steel	Element	The percentage in steel
C	0,9-1,4	P	before 0,12
Si	0,8-1	Cr	before 1
Mn	11,5-15	Cu	before 0,3
Ni	before 1	Fe	~ 83
S	before 0,05		

According to some authors, the grinding of blocks and microstresses plays a large role in the hardening of 110G13L steel. The high viscosity of austenite, along with sufficient strength and wear resistance, makes 110G13L steel an indispensable material for parts

working for wear and shock at the same time. With abrasive wear, when pressure and, therefore, hardening are absent, 110G13L steel does not have significant advantages in terms of wear resistance over other steels of the same hardness.

Wear of Hadfield steel used at TPP-3

The wear of the Hadfield steel used at TPP-3 occurs in 500-550 hours of continuous operation. The degree of wear is shown in fig. 4. The choice of the type of coal-grinding mills is determined by the grindability of the fuel, the release of volatile substances, the required fineness of dust. Mills are classified in several directions:

- impact of grinding organs on particles;
- abrasion of particles between grinding organs;
- combined (shock + abrasion).

At the Karaganda TPP-3, a hammer mill is used, which has high economic indicators, used in systems with direct injection of fuel and can operate under pressure. In these mills, the fuel is crushed mainly by the impact of hammers (beaters), and partially it is also rubbed between the bills and the mill body. The main problem in the operation of coal-grinding mills is the high abrasive wear and tear, the average continuous service life of which is 500 hours.

Figure 4 - The degree of wear of the coal mill grinding at TPP-3

In the present work, an attempt is made to increase the service life of beater of coal-grinding mills by mechanically activating them in a tumbling drum followed by coating of highly entropic alloys.

Preparation of a CrNiTiZrCu Coating Target

To prepare the CrNiTiZrCu target, micropowders of metals were taken and mixed in equiatomic proportions. Then, the prepared powder mixture was placed in a grinding bowl of a planetary ball mill made of tungsten carbide and grinding bodies (balls with a diameter of 5-10 mm) also made of tungsten carbide, the mass of which was equal to 10 masses of the powder mixture, were added (Fig. 5 a). After the glass was filled with galosha gasoline, the lid was tightly closed and the planetary ball mill was turned on (rotation speed 500 rpm, operating time 5 hours). The resulting homogenized composition was then dried in vacuum and pressed with a mold into a flat disk with a diameter of 100 mm and a thickness in 5 mm. Next, the disk was placed in a vacuum thermo oven and sintered in it for 3 hours. Thus, the fabricated CrNiTiZrCu target (Fig. 5b) was used for further magnetron coating deposition at the NVN 6 facility. The metal micropowders were mixed and placed in a grinding cup of a planetary ball mill (a), the composition was then dried in a vacuum and pressed using a mold into a flat disk with a diameter of 100 mm and a thickness of 5 mm (b).

Coating was carried out on prepared beats of a coal-grinding mill. The vacuum chamber was pumped out to a pressure of 0.003 Pa, then the PINK was turned on, and Ar was puffed up to a pressure of 1 Pa; a negative bias potential of 1000 V was applied to the substrate for 10 min. The surface of the substrate was cleaned and heated.

a)

b)

Figure 5 - Micropowders of metals

After that, the argon pressure was lowered to 0.1 Pa and the magnetron was switched on. The bias on the substrate decreased to 150 V, the magnetron current was kept constant at 3 A. The substrate was located in the chamber at a distance of 15 cm, the spraying time was 1 hour. The beats of a CrNiTiZrCu coated coal mill are shown in Fig. 6

Figure 6 - Beater of a coal-grinding mill coated with CrNiTiZrCu

Properties of CrNiTiZrCu Coatings

Figures 7 and 8 show the chemical composition of the coatings CrNiTiZrCu, at. % in equiatomic proportions per beat of a coal-grinding mill (table. 2).

Figure 7 - XPS CrNiTiZrCu in argon at 2 points

Table 2

Quantitative chemical composition of the coating CrNiTiZrCu, at. %

Element	Cr	Ni	Ti	Zr	Cu
Nominal	20	20	20	20	20
in argon	23,2	21,2	19,9	17,1	6,8

Figure 8 - The microstructure of the CrNiTiZrCu coating on the beater of a coal-grinding mill with a resolution of 20 µm

The microhardness measurements of the coatings are given in table. 3.

Table 3

Microhardness of CrNiTiZrCu Coating on Beater of a Coal Mill

Microhardness	1	2	3	4	5	6	7	8	The average
HV	839	909	964	842	967	853	921	902	906

The friction coefficients were measured on the setup we developed (Table 4). The basic principle of the setup for determining the static and sliding friction coefficients is to measure the static and sliding friction forces of a small test material sample when moving it over the surface of a substrate from another material with a known coefficient of friction. The obtained instantaneous values of the friction force are transmitted to the software of the upper information level for their processing.

Table 4

Coefficients of friction of CrNiTiZrCu coatings for copper and aluminum

Coating	on copper		on aluminum	
	coefficient of friction	error	coefficient of friction	error
CrNiTiZrCu	0,041	0,006	0,066	0,002

Comparison of work beat coal mill before and after high entropy coating CrNiTiZrCu

For one mill, 120 beats are given. Coated beads are shown in Fig. 9. Taking in the response function Φ in our work [16] the coefficient of dry friction and linearizing it, we obtain the following formula:

$$k_t = \tilde{N} \cdot \dot{O} \cdot \frac{A}{\Delta G^0} \cdot \bar{N}, \quad (*)$$

where A is the work (energy) of destruction, T is temperature, ΔG^0 is Gibbs energy, N is the average number of elementary carriers of destruction, C is a constant.

Figure 9 - Bits of a coal-grinding mill coated with CrNiTiZrCu

Thus, we have obtained an equation that shows the nonlinear dependence of the friction coefficient on the Gibbs energy G^0 , on temperature T , on the concentration of the number of electrons and which allows us to predict the formation of highly entropic alloys. A comparison of the properties of beat without coating and coated is given in table. 5 and in fig. ten.

Table 5

Comparison of the work of a coal mill mill before and after the high-entropy coating of CrNiTiZrCu

Parameter	Beater without coating Power Beton LLP	Coated Beater CrNiTiZrCu
Microhardness, HV	580	906
Wear resistance, g/min	$0,4 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
Coefficient of friction	0,76	0,04

Figure 10 - Coated grinding mill bits (after 1600 hours)

Conclusion

From table 5 it is seen that with the coating:

- microhardness increases about 1.6 times;
- wear resistance increases by 7.5 times;
- the coefficient of friction is reduced by almost 20 times!

Formula (*) shows that the work of destruction of the beats of a coal-grinding mill is very strongly (proportionally) dependent on the coefficient of friction of the coating. The wear of the Hadfield steel used at TPP-3 occurs in 500-550 hours of continuous operation (see

above). That is, after the high-entropy coating of CrNiTiZrCu, the resource of beats increases by almost 3 times (1600 hours) for a coal-grinding mill, which is economically very significant.

The work was carried out under the program of the Ministry of Education and Science of the Republic of Kazakhstan. Grants No. 0118PK000063 and No. Φ.0781.

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