Reinforcement of the bulk crowns excavator technology by dispersion hardening of titanium carbide to increase wear resistance

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Abstract. Dispersed particles embedded in the metal, improve the mechanical properties, particularly wear resistance. Introduction of the metal particles in a controlled and their distribution is difficult because of the density difference and the metal particles introduced. This article provides a method for the introduction of particles in the volume of metal, it contains a proposed strengthening technique described experiment course. During the experiment, the volume-reinforced castings from wear-resistant steel, the results of studies of the microstructure by optical and scanning electron microscopy, and mechanical tests of prototypes have been obtained.

1 Introduction
Open development is the most efficient way of mining. The most important link of the open-pit mining technological chain is the process of excavation, continuity of which is largely determined by the durability of replaceable teeth of the bucket quarry excavators that experience direct interaction with the rock. During excavation of the exploded array particularly hard and abrasive rock crowns of bucket excavators are working in extreme conditions of abrasive wear (a large number of favorably oriented cutting edges on the surface of the blasted rock fragments, the dominant role of metal micro cutting, intense shock loads, etc.), which cause their rapid failure [1, 2].

2 Materials and methods
The bucket crowns of excavators are traditionally made of steel grade 110G13L (Hadfield steel). This highly manganese steel combines qualities such as toughness and wear resistance, low thermal conductivity, sufficiently large linear rate of crystallization and shrinkage, has an increased tendency to columnar crystallization, has a coarse-grained structure with carbides that are predominantly located along the grain boundaries of the metal. The analysis of defective parts’ for various purposes fall out that are made of this particular grade has shown that, despite the different conditions of the castings, the main reason of their failure/fall out is the deterioration in the abrasion in contact with abrasive material. One of the ways to increase the abrasion resistance of a metal is grinding the metal grain, but to crush the structure of the subsequent of the following with heat treatment is almost impossible, since the steel does not undergo phase transitions. Significant improvement of the primary structure of cast steels of this type can be achieved through integrated operations deoxidation and modification [3]. However, the introduction into a crystallizable melt of dispersed particles (or modifiers) is associated with the problem
of uneven distribution of metal particles in the input volume, resulting in unevenness of chemical composition and properties distribution [4-7].

The department of “Technology and materials’ technology production” FGAOU VO “South Ural State University (NIU)” branch in Zlatoust city, one of the areas of activity, which is the hardening of existing steels by introduction into the crystallizing melt particles of dispersed carbides, the method of introduction of dispersed particles directly into the Styrofoam model was proposed. The company “Uralpromdetal”, which is specializing in the production of molded parts for industrial purposes, a series of experiments on the production of the excavators’ crowns with the high wear resistance due to introduction of titanium carbide has been held.

As a reinforcing piece the crown of the tooth “1U-3352” mark (the estimated weight of 5.8 kg) for the dredge “Caterpillar 313”, mark adapter “Cat J350” has been chosen (Figure 1).

![Figure 1. Drawing crown brand «1U3352»](image)

The holes in the sides of the crown are needed for fixing it on the adapter using the “finger” with the horizontal mount. As the material of the tooth the commonly used Hadfield steel has been chosen (C 09-15%; Si 0,3-1%; Mn 11,5-15%; Ni NB 1%; Cr NB 1%; S NB 0,05%; P NB 0.12%). The models were made of polystyrene, painted with nonstick foundry and then dried. The titanium carbide was selected as the hardening phase, the density of which is 4.92 g/cm³ and the dispersity of which is 0,02-0,35 mkm. Inside the fabricated models the cylindrical holes were cut, into which the carbide particulate was filled up in different amounts (Table 1), after which the holes were sealed with polystyrene.

| Sample number | The content by weight of carbides casting, % | Number of introduced particles, grams |
|---------------|---------------------------------------------|--------------------------------------|
| 0             | 0                                           | 0                                    |
| 1             | 0.5                                         | 29                                   |
| 2             | 0.75                                        | 43.5                                 |
| 3             | 1                                           | 58                                   |

3 Discussion

One of the challenges, which the researches group had to face, was the task of ensuring cooperation between the titanium carbides and the metal – to ensure wetting of carbide. Many researchers deal with the issues involved in the wetting process of various materials [8-13], since these issues are among the
To ensure the interoperability of titanium carbide and metal melt the reducing atmosphere was used, which contributed to an increase in the contact angle [14].

These models with embedded titanium carbide were connected to the gating system and were fitted into the flask at an angle of 45 degrees. This casting arrangement was necessary to disperse particles after melting polystyrene, due to the difference of densities and the metal carbide, surfaced on one of the working surfaces of the crown of the excavator. The dry quartz sand was used when backfilling flask models, the shape was reinforced with vacuum, and the metal casting was produced on top for 35 seconds. The flask after filling was heated for 3 hours in order to avoid cracking of parts due to the obtained rapid cooling. Then the flask was removed from the cast crowns and was separated from the gating system. The obtained crowns had a satisfactory surface quality, the right geometry, and the absence of surface defects (Figure 2).

![Figure 2. Appearance received crowns of the teeth of the excavator.](image)

In order to objectively assess the impact of input carbides on the structure and qualities of cast metal the heat treatment of the received crowns has not been made [15]. All the crowns were subjected to the study of the structural heterogeneity, hardness, and abrasive wear resistance. The microstructure investigation showed that all crowns have austenite-pearlite structure with excess carbides (Mn, Fe) 3C. The assessment of the changes in size of the dendritic cells (and, therefore, grains points) produced with the method of measuring the lengths of chords of circles with an inverted microscope “C. Zeizz Observer. D1m”, which is equipped with a “Thixomet. PRO” image analyzer complex [16].

The study revealed that in the crowns №1-3 (with embedded titanium carbide) there is a slight refinement in the working structure of the surface areas of the crown (1-2 points) compared to the crown №0 (without carbides). It is worth noting that the entire volume of crowns №1-3 (in addition to the working surfaces) there are local areas of structural heterogeneity (structure refinement for 1-3 points compared to the original structure), which is probably explained by uneven distribution of embedded carbide.

The study of microstructures with the help of scanning electronic microscope “JEOL JSM – 6460 LV” showed that the implanted titanium carbide has been distributed unevenly over the volume of blanks: the largest number observed on the working surfaces of crowns №1-3 (Figure 3a), but also for crowns volume local area with a “loose” carbides are being present. Spectra taken from the detected particles confirmed that it is the titanium carbide (Figure 3b).
The hardness testing was performed on Rockwel Hardness Tester (mark “TR-5004”) and Brinell (mark “TB-5004”). The study showed that the difference in hardness between samples in the middle of the sample is small and varies from 4-30 HB (1-4 HRC). However, the difference between external and internal workspaces of the same crown can reach 128 HB (13.4 HRC). An increase in the hardness of the internal working area of the inner to outer crown has been observed (Table 2).

**Table 2.** The study of the hardness obtained crowns.

| Place of execution | Internal workspace crown | The middle of the crown | External workspace crown | Average value HB/HRC |
|--------------------|--------------------------|-------------------------|--------------------------|-----------------------|
| Performance number | 1 | 2 | 3 | 4 | 5 | 6 |       |
| Sample №0          | HB/HRC 285/32.3 | HB/HRC 313/35.7 | HB/HRC 295/33.6 | HB/HRC 313/35.7 | HB/HRC 306/34.9 | HB/HRC 325/36.8 | 306.1/34.8 |
| Sample №1          | HB/HRC 278/31.5 | HB/HRC 282/32.1 | HB/HRC 317/36.2 | HB/HRC 337/38.4 | HB/HRC 354/40.0 | HB/HRC 350/39.3 | 319.6/36.25 |
| Sample №2          | HB/HRC 313/35.3 | HB/HRC 329/37.4 | HB/HRC 269/30.2 | HB/HRC 325/36.8 | HB/HRC 354/40.0 | HB/HRC 350/39.5 | 323.3/36.5   |
| Sample №3          | HB/HRC 329/37.3 | HB/HRC 275/31.2 | HB/HRC 325/40.1 | HB/HRC 333/37.9 | HB/HRC 354/40.0 | HB/HRC 403/44.6 | 336.5/38.5   |

The determination of abrasive wear resistance was carried out on a laboratory setting by measuring changes in sample weights before and after abrasion of the abrasive cloth under a load. Each sample was performed by three passes through the abrasive pelt 1.5 meters long under a load of 3 kg. The study showed that the sample bits №1 virtually has no difference in the durability of the sample №0 (without carbide), while crown samples №2-3 have abrasive wear to 1.5-1.9 times higher as compared with the sample bits without carbides (Table 3).
Thus, the developed and approved method of hardening excavator crowns is able to increase its operating time in 1.5-1.9 times, thereby reducing the frequency of teeth replacements and increasing the efficiency of the use of excavation equipment.

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**Table 3. The measurement results obtained durability crowns.**

| Sample number | Test sample weight, grams | Sample weight after pass 1, grams | Sample weight after pass 2, grams | Sample weight after pass 3, grams | The total mass of the sample, grams |
|---------------|---------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| 0             | 15.330                    | 15.324                           | 15.320                           | 15.316                           | 0.015                            |
| 1             | 15.923                    | 15.917                           | 15.912                           | 15.908                           | 0.014                            |
| 2             | 16.015                    | 16.011                           | 16.007                           | 16.006                           | 0.010                            |
| 3             | 15.201                    | 15.198                           | 15.196                           | 15.195                           | 0.008                            |
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