SECTION 7. MECHANICAL ENGINEERING

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7.1 Increasing the service life of cutting elements of motor grader working parts

Ensuring sufficiently high durability of cutting elements (CE) used in motor graders and other earthmoving machines (EM) is considered to be one of the compulsory conditions determining the reliable operation of earthmoving machines (EM) and the highest efficiency of their operation. This is due to the fact that the decrease in the durability of (EM) occurs due to the excessive abrasive wear of their (CE) [310, 311].

EM in most cases develop sandy, clayey, coarsely ground and semi-rocky soils. At the same time, the work of bulldozers, motor graders, loaders, and scrapers is based on the principle of frontal cutting of such soils. In turn, the operation of soil development using EM consists of introducing CE into the soil and its subsequent gradual cutting. Therefore, the CE is affected by bending and compressive forces, frictional forces and dynamic loads that arise when solid particles collide with cutting elements. The degree of impact of such particles on CE depends on the category of soil, which is characterized by an abrasiveness coefficient. At the same time, the cutting elements of EM are subject to intense wear, which is accompanied by the action of many loads, which include: shock, abrasive and thermal. In addition, with increasing service life of the CE, the influence of the fatigue and oxidative wear components increases. Thus, during operation, CE are constantly exposed to the influence of the developed environment, which is expressed mainly through the influence of shock-abrasive and alternating loads under conditions of temperature changes against the background of a decrease in corrosion resistance and fatigue strength, which leads to a significant decrease in the physical and mechanical properties of the material of the cutting elements (softening, decrease in hardness and wear resistance).

It is important to note that CE are also subject to corrosion destruction. First of all, this is explained by the fact that the soil constantly contains a certain amount of water. Therefore, the soil, accordingly, has moisture, which is the ratio of the mass of water to the mass of mineral particles. In dry sands, humidity varies from 1 to 2%, and in fluid clays and river silt – up to 200% [310, 311].

The formation of corrosion manifests itself through intense oxidation of the metal of cutting elements by atmospheric oxygen, during which the formation of metal oxides (FeO, Fe_3O_4, Fe_2O_3, Cr_2O_3, etc.) occurs. After the oxides settle on the metal surface, a loose and dense film of corrosion products forms [310, 311].

In connection with this, there is a search for new, as well as improvement of the existing methods for reducing abrasive wear of CE materials used for their manufacture. It is possible to reduce the abrasive wear of CE by several methods (by hard surfacing with various alloys, volumetric hardening, surface strengthening, etc.). However, these methods have a number of shortcomings, since they worsen the stress-free state of the material after the application of a particular technology and, as a consequence, lead to insufficient resistance to abrasive wear during operation of CE in the operating environment (dredging soil).

The solution of the problem can be expected by using an ion-plasma coating (IPC) TiN-Cr_2N on the surface of the CE [312]. However, at present there is no information in the literary sources about the use of such coating for the CE of EM. In case of a positive result of such a solution to the problem, it becomes possible to increase the service life of the EM in difficult operating conditions, to cut downtime on repair, as well as the cost of restoring or replacing worn-out electronic devices with new ones.

To assess the efficiency and obtain quantitative specifications confirming the positive effect of IPC application in real operating conditions, the corresponding tests of DZ-180 motor grader were carried out (Fig. 1).

Figure 1. General view of the auto grader DZ-180 with cutting knives hardened by high frequency currents (HFC) (1) and HFC + TiN-Cr_2N (2)

Operational tests of auto grader DZ-180 were carried out in two stages. At the first stage of testing, the grader blade was installed at the angle of 90 °, at which loading on the knives was maximum [313], and therefore their durability was the smallest. In addition, such entrance angle ensures uniform abrasive runout of the knife along the entire length.

At the second stage of testing, the auto grader was operated in regular operation mode without any limiting, so it performed all types of work in which the blade entrance angle varied from 10 to 90 °.

During the first stage of testing, two middle knives made of 65G steel after hardening with high frequency current were cut into two parts each (Fig. 2). By doing so, the smaller two parts of the knife (Fig. 2 b) were grinded to a surface of roughness 0.32 μm and then subjected to IPC TiN-Cr_2N under the conditions presented in Table. 1 [313, 314]. The applied coating consists of a fusion of alternating five layers of Cr2N and four layers of TiN. In the process of applying multilayer coating there occurs tempering of steel 65G, which leads to a decrease in hardness to HRC 30. After thermal treatment, the hardness of the substrate constitutes HRC 50-54 [315].

Table 1

Modes of TiN-Cr_2N coating [314]

Emission cathode material	Current on Cr, A	Current on Ti, A	Voltage *U*, V	Current *I*, A	Pressure *P*, Pa	Deposition time *t*, min
1st stage: cleansing, heating and activation by chromium ions						
chromium	80	–	90	2	1,33	7
2nd stage: spraying of coating in nitrogen atmosphere						
2 cathodes: 1st chrome 2nd titanium	80	70	150	3	0,67	25

a) b)

a) – cutting knives with HFC hardening;

b) – cutting knives with HFC and IPC TiN-Cr2N hardening

Figure 2. Auto grader cutting knives made of 65G steel.

Further, the cutting knives with and without coating were installed on the blade of the auto grader DZ-180 in the order shown in Fig. 1, that is, the parts of the knife without a coating (1) and with the TiN-Cr_2N IPP coating (2) were taking turn (interleaving). After that, the auto grader was subjected to operation for 150 machine-hours, which under normal operating conditions provides the cutting knives greatest wear [312].

Before the performance testing of the auto grader, the blade cross-sectional thicknesses were measured using a plaster mix. For this, it was taken a mixture, consisting of gypsum and alabaster in a ratio of 10:1. The method to determine the thickness of the cross-section consisted in fact that motor grader cutting knives were placed in plastic molds, filled with carefully whipped plaster mixture (Fig. 3). Each cutting knife fragment was mounted on three identical plastic containers with a gypsum mixture. In this case, one container with the mixture was placed in the center of the cutting knife fragment, and the remaining two were placed along the edges. In this position, the cutting knives have been kept for 1 hour (Fig. 3). After an hour, all the fragments of the cutting knives were dismantled from the containers together with the hardened gypsum mixture. Then these containers were cut along the cross section of the cutting knife, the trace of which remained after dismantling (Fig. 3).

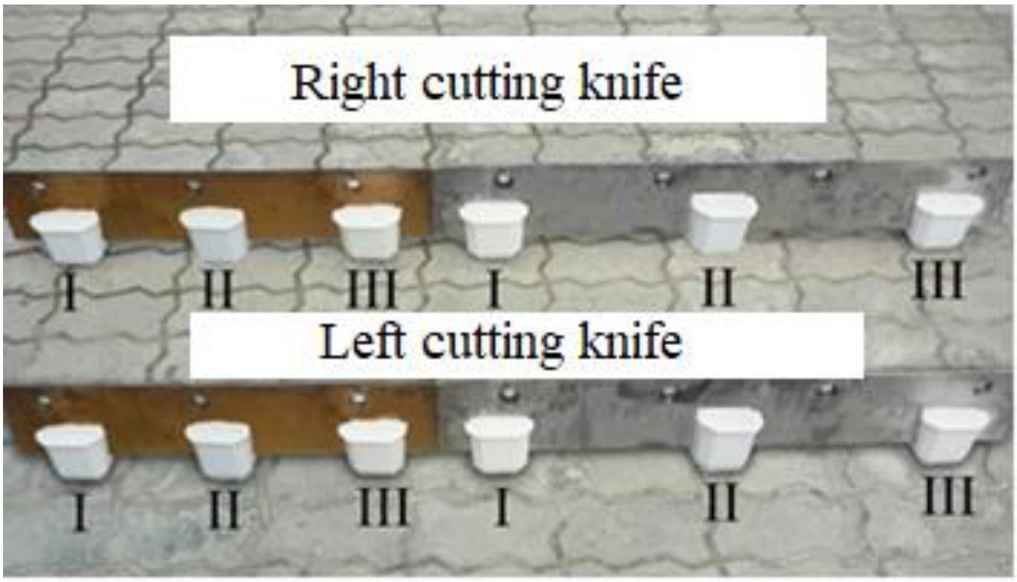


Figure 3. Plastic molds with medium cutting knives before testing on the motor grader DZ-180.

Then, the received cuts of the knife cross-section were scanned using the Canon MP280 multifunctional device. On 12 prints of the cross-section of the cutting knife, obtained as a result of scanning before and on 12 prints after the operation of the auto grader using the KOMPAS-3D V19 program, the thickness of the cross-section of the cutting knife was defined at a height of 12 mm from the top of the print. The choice of this height rate is due to the fact that the wear-out of the cutting knives occurs evenly over the entire surface, which is connected with the installation of the blade at an angle of 90 ° relatively to the direction of the motor grader movement.

Each cutting knife (right and left) of the auto grader was measured six times in total. However, due to the fact that the side cutting knives overlapped the ends of the middle cutting knives during installation (Fig. 1), the wear-out value of the first zone of the left and third zone of the right cutting knife wasn`t taken into account, as cutting knife wear in these zones occurred only on the rear surface. In this regard, in order to obtain reliable experimental results, the wear-out values of the grader knife were taken into account only for five zones of the same cutting knives with HFC hardening and for five with TiN-Cr_2N coating.

The purpose of the second stage of the tests was to establish the wear-limit of the parts of the cutting knife with HFC hardening and TiN-Cr_2N coating under normal operating conditions [316].

At the second stage of the tests, the auto grader performed all the regular work (repair and maintenance of the road surface, profiling of the ground, road construction, etc.), herewith, the cutting knife installation system used was the same as in the first stage of testing the auto grader.

During the entire test period, the cutting knives were dismantled every 50 machine-hours and their thickness was determined according to the method described above. Fragments of the standard cutting knife subjected to HFC hardening were tested until their wear reached the limit value, and fragments of the cutting knife with IPC continued to operate up to the amount of wear corresponding to the limit wear of standard cutting knives.

The results of cross-sectional measurements of wearing values are presented in table. 2, and in fig. 4.

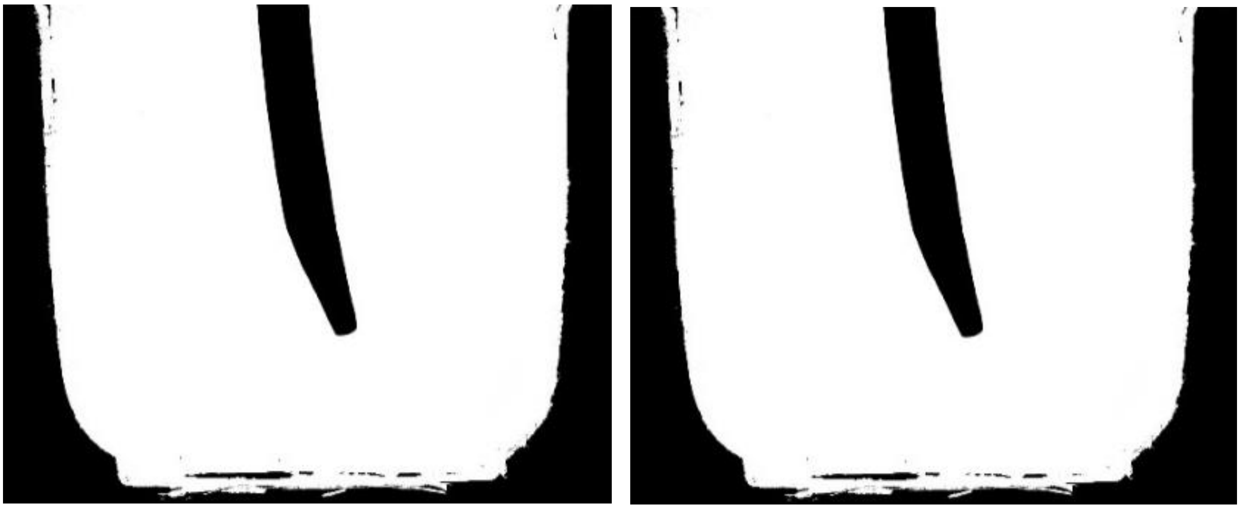
As it can be seen from table 2, the wear on the first zone of the left cutting knife and on the third zone of the right cutting knife have the lowest values. This is due to the fact that in the process of mounting the middle cutting knives, their outer parts are overlapped by the bits (side cutters) installed on the top i.e. only the rear surface of the cutting knife on these zones and the front surface of the bits are worn.

Table 2.

Thickness and wear of the auto grader blade after operation for 150 machine-hours

Parameter	Knife cross-section thickness, mm											
Knife type	Left knife						Right knife					
Knife processing method	With HFC hardening +IPC TiN-Cr_2N			With HFC hardening			With HFC hardening +IPC TiN-Cr_2N			With HFC hardening		
Zone	I	II	III	I	II	III	I	II	III	I	II	III
Before testing	7,331	7,304	7,312	7,283	7,237	7,247	7,290	7,311	7,304	7,223	7,242	7,291
After testing	6,555	5,515	5,553	4,527	4,428	4,415	5,607	5,584	5,534	4,479	4,444	6,065
Wearing, mm	0,776	1,789	1,759	2,756	2,809	2,832	1,683	1,727	1,770	2,744	2,798	1,226

The least wear also occurs with TiN- Cr_2N IPC of cutting knives. For example, the wear of the second and third zones of the left cutting knife with TiN-Cr2N is 1.57 and 1.61 times less than the wear of the same zones of the left cutting knife after HFC hardening. The wear of the first and second zones of the right cutting knife with IPC, is 1.63 and 1.62 times less than the wear in the same zones for the right knife with HFC hardening. Comparing the wear values of the out areas (the first zone on the left and the third zone of the right cutting knife), we can conclude that the process of wear on the back surface was less intense than on the rest of the cutting knife. However, the wear of the first zone of the left cutting knife with IPC TiN-Cr2N is 1.58 times less than the wear of the third zone of the right knife. Herewith, the wear of the cutting knives after HFC hardening, averaged 2.79 mm, and the same cutting knives, but with IPC TiN-Cr2N -1.75 mm, i.e. 1.59 times less than the wear of regular cutting knives. In addition, during the operational tests of the cutting knives, an intense rounding of their cutting edge was observed (Fig. 4). At the same time, after 150 machine-hours of testing of the auto grader, the latter had a shape close to cylindrical. This led to a pronounced bluntness of the cutting knife, especially in those areas that were subject only to HFC hardening .



a) b)

Figure 4. Imprint of the auto grader cutting knife cast after testing with IPP TiN-Cr_2N (a) and subjected only to HFC hardening (b).

Thus, at the location of the middle blade of auto grader at an angle of 90 °, the wear of cutting knives with IPC TiN- Cr_2N, on the average, was 1.6 times less than the wear of regular cutting knives after HFC hardening

The results of the second stage of tests during the long service life of the auto grader blades are shown in Fig. 5.

As it can be seen from the graphs presented in Fig. 5, the wear of standard cutting knives reached the limit value (7 mm) after 322 machine-hours of testing. The same amount of wear of cutting knives with IPC TiN- Cr_2N hardening reached after 550 machine-hours, which is 1.7 times more than regular cutting knives.

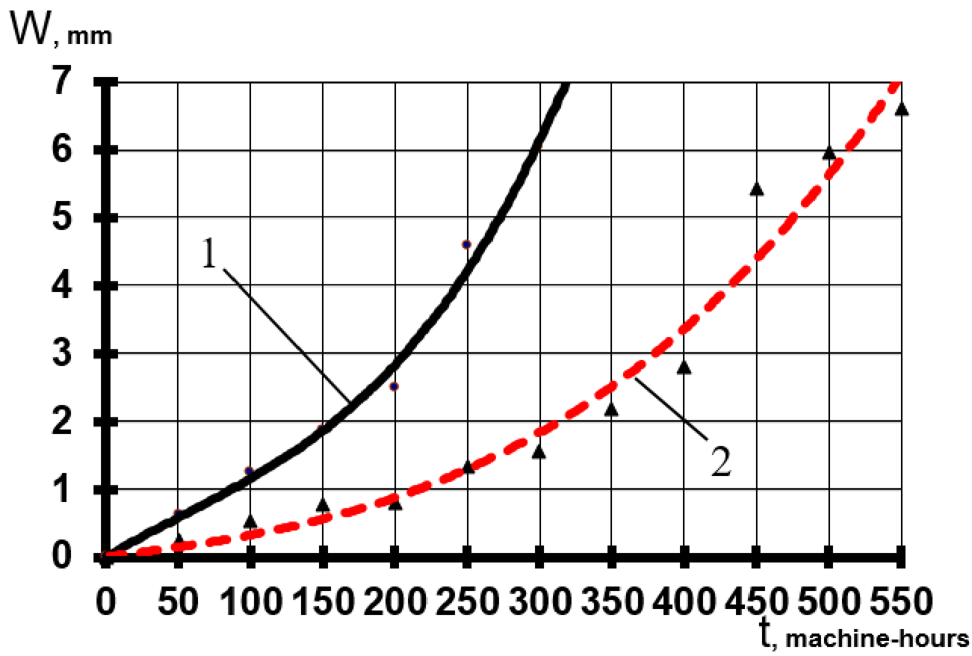


Figure 5. Dependence of wear *W* of a cutting element with HFC hardening (1) and with IPC TiN-Cr_2N hardening (2) on time t of operation.

The operational tests of the auto grader confirmed the positive effect of applying IPC TiN-Cr_2N on the surface of cutting knives with thickness of 4 μm and roughness of 0.32 μm, and the cutting knife material hardness of 50 HRC. This effect is expressed in a decrease in wear (increase in durability) of the medium auto grader cutting knives by an average of 1.6 times at the maximum loading on the blade (at the entrance angle 90°).