Investigation of nanometallokeramic composite coatings obtained by vibro-arc surfacing

A V Kolomeichenko1, N V Titov1, Yu A Kuznetsov1, L V Kalashnikova1, O O Bagrintsev1, O Sharifullin2,3

1 Orel State Agrarian University named after N.V. Parakhin, Russia
2 Kazan Federal University, Russia
3 Kazan state agrarian University, Russia

Saidchist@mail.ru

Abstract. The paper presents a description of the method of hardening the working bodies of agricultural machines, working in conditions of abrasive wear. The method includes vibro-arc surfacing of nanometallokeramic composite powder materials with simultaneous thermal diffusion hardening. The optimal composition and concentration of components of the material, ensuring the best physical and mechanical properties and resources of the hardened working bodies tillage machines.

1. Introduction

In all countries of the world the investigations on obtaining highly effective metal ceramic hard alloys that are able to increase the resource of working organs of tillage tools into several times are being carried out. But the first results of foreign metal ceramic plates application for hardening of plow shares running on sandy and loamy soils did not provide their wear resistance increase because of higher brittleness of plates [1-2].

In this connection nowadays the works on creation of new metal ceramic materials having high wear resistance and impact elasticity in the conditions of intensive abrasive wear at considerable static and dynamic loadings are continued. Now at the result of the complex of the carried out scientific investigations nanometal ceramic composite material (NMCM) allowing solving the set problem is elaborated. It consists of steel matrix (deposite powder), with incorporated aluminium oxides Al2O3 or silicone SiO2 boron carbide B4C, pounded to nanodimensional condition, and also alloying elements: boron, nitrogen and aluminium. Boron is included into powder composite content in the form of borax Na2B4O7, nitrogen is included into nitric acid sodium [3]. Aluminium is used for ferrum deoxidation and formation ceramic phase by means of its conversion into aluminium oxides Al2O3 and at the following fusion into corundum. The latter in the mineralogical table by hardness occupies the 9th place it is very close to diamond hardness. Matrix is shockproof, consolidate and composite carcass NMCM. That is why steel filler powders with high hardness and abrasive resistance, for example PG – 10N - 01, PR - N70X17C3P4, PG - SR4 can be used reasonably as a matrix material.

2. Methods.

To obtain wear resistant hardening coating from the suggested NMCM we developed the short-circuited arc surfacing method with application of graphite electrode. At its simultaneous usage
together with surfacing thermodiffusion hardening of the working organ surface by means of boron, nitrogen and carbon (boronnitrocementation) occurs. At depositing carbon is emitted at the account of sublimation of graphite electrode. Arc vibration of electrode provides the obtaining stronger and denser coating for the sake of the working organ material fusion and mixture of ceramic and alloying components NMCM [4]. More than that at short-circuited arc surfacing usage not so strong heat embedding as some other surfacing types usage takes place. Before surfacing NMCM in the paste form is applied on the working organ surface.

Preliminary done investigations stated that every component of NMCM considerably influences on the effectiveness of the working organs hardening. In this connection the researches on the influence of the NMCM components on hardness, microstructure and wear resistance of the hardened surfaces were carried out. To carry out the researches several pastes (table 1) were prepared. The pastes were prepared by mechanical mixture of the components some of which were broken to nanosized condition in a centrifugal mill in advance. As a bounding material 20% water solution of sodium silicate solute $\text{Na}_2\text{SiO}_3$ was used. After preparation the paste was applied on a sample surface prepared from steel 65Г. The given material selection is provided that it is used for production of the majority of working organs of tillage tools. The thickness of the applied paste layer was approximately 2,5…3,0 mm. Then the paste was dried to hardening. At the temperature of 90…95°C hardening time does not exceed 8…10 min.

Table 1 – Chemical composition of metal ceramic pastes

| № paste | Chemical composition of paste | Mass ratio of components in paste, % |
|---------|-------------------------------|-------------------------------------|
|         |                               | №1  | №2  | №3  | №4  | №5  | №6  |
| Steel powder PG – 10N - 01 | 15 | 15 | 15 | 13 | | |
| Borax $\text{Na}_2\text{B}_4\text{O}_7$ | 25 | 15 | 10 | | | |
| Boron Carbide $\text{B}_4\text{C}$ | 45 | 55 | 65 | | | |
| Nitric acid sodium $\text{NaNO}_3$ | 4 | 4 | 4 | 4 | | |
| Silicon oxide $\text{SiO}_2$ | 5 | 5 | 5 | | | |
| Aluminium powder Al | 6 | 6 | 3 | | | |

| Steel powder PG – 10N - 01 | 50 | 10 | | | |
| Boron Carbide $\text{B}_4\text{C}$ | 50 | | 70 | | |
| Borax $\text{Na}_2\text{B}_4\text{O}_7$ | 9 | | | | |
| Cryolite $\text{Na}_3\text{AlF}_6$ | 5 | | | | |
| Aluminium powder Al | 6 | | | | |

| Steel powder PG – 10N - 01 | 20 | 12 | 5 | | |
| Boron Carbide $\text{B}_4\text{C}$ | 63 | | | | |
| Borax $\text{Na}_2\text{B}_4\text{O}_7$ | 12 | | | | |
| Aluminium powder Al | 5 | | | | |

Short-circuited arc surfacing of the samples was done on device VDGU-2, which is developed and produced in Federal agro engineering centre of all-Russian institute of mechanization. The device includes inverter thyristor current source of type MASTER 162 for 200…250A, operating console and vibrator with graphite electrode of diameter 6…10 mm fixed in it. Surfacing was done at the burning of direct arc in the following modes: current rate $I=70…80$A, voltage $U=60$B, vibration frequency of graphite electrode – 100…110 vibrations per second.

The hardness of the deposited layer and the hardened substrate of the sample were defined with computer microhardness tester KMT-1 according to Vickers method at loading $F=1$H and exposure
time $t=15$ с. At the same time 32 measurements were done: 16 – by the depth of the deposited layer, 16 – by no depth of the hardened substrate. Measurement of imprints was done with video device connected to a personal computer, using special software, with statistical processing and possible automated analysis of image data according to the standards of hardness measurement.

Relative wear resistance of the hardened samples was defined with device ИМ-01 – construction of All-Russian Research Institute of Agricultural Engineering under the name of V.P. Goryachkin (JSCo «ARIAE»). Duration of the tests was 30 min. Every test was done with three replications. As abrasive material high silica sand sizing 0,16…0,32 mm was used. Average contact pressure in the friction zone was maintained 0,33 МПа. Wear rate was defined by sample mass decrease by means of its weighing on balance VLR-200 with precision 0,1 mg before and after tests.

3. The results of the research.

The results of the conducted studies showed that the highest hardness of both the deposited layer and the strengthened substrate is a sample treated with the use of NFCM with a mass ratio of components in the paste: powder of steel PG-10N-01 - 20%, boron carbide $B_4C$ - 63%, borax $Na_2B_4O_7$ - 12% and aluminum powder Al - 5%. Analyzing the compositions of the pastes that were used to harden the specimens, we can conclude that the determining role in obtaining the highest hardness is played by boron carbide $B_4C$ and boron contained in the $Na_2B_4O_7$ borax. As a result of the melting of the paste, the formation of atomic nitrogen also occurs, which together with the carbon formed as a result of sublimation of the graphite electrode during arc combustion diffuses into the hardened substrate, forming a solid solution that increases its hardness.

The resource of working organs being hardened with the short-circuited arc surfacing method and working in the abrasive wear conditions considerably depends not only on hardness, but on the condition of the border of deposit layer and substrate, that is from the effect of substrate material fusion and its mixing with paste fusion [3]. The most complete idea about the deposit layer and substrate structure is presented with microstructure analysis.

The carried out researches allow stating that the microstructure of the hardened samples consists of 3 zones in spite of the content of applied pastes (Figure 1).

Substrate (zone 1) has evident phase changes to boundary line due to diffusion of the elements incorporated into deposited paste and carbon content. The deposited layer consists of 2 zones – transitional and basic hardened. Transitional zone is alloy of melted surface layer of substrate and paste material. Basic hardened zone is the hardest and consists of steel matrix, holding the formed ferrous carbides $FeC$, $Fe_2C_3$, borides $FeB$ and $Fe_2B$ and ceramic phases – ferrous spinel, boron carbide and corundum. Junction line of the deposited layer into the substrate is more obviously detected on the photographs of microstructure at small amplification.

Metallographic tests also showed that the structure of the deposited metal ceramic coating is heterophase and it is represented as space-distributed crystal phases, which form multiphased crystal solid body. Structure heterophase of coating is obvious at amplification 50x, where light phase is steel matrix, that keeps the formed carbides, borides and ceramic phases – dark light inclusions. At the result of phase transformations in the parent phase separate areas or crystals of new thermodynamically more stable phases appear. They grow, interact and as the result form heterophase structure [5].
Different phases have different hardness. This is an explanation of some irregularity at hardness measurement by deepness of the deposited layer.

The results of the comparative tests on wear resistance of the hardened and unhardened samples are presented in Table 2.

Table 2 – Results of the comparative tests on wear resistance of the hardened samples

| Sample number | Sample mass | Mass change | Relative wear resistance |
|---------------|-------------|-------------|--------------------------|
|               | before test | after test  |                          |
| standard      | 47,3400     | 47,3078     | 0,0322                   | 1                         |
| 1             | 41,5440     | 41,5350     | 0,0090                   | 3,58                      |
|   |       |       |       |       |
|---|-------|-------|-------|-------|
| 2 | 41.9614 | 41.9432 | 0.0182 | 1.76  |
| 3 | 51.5975 | 51.5823 | 0.0152 | 2.12  |
| 4 | 41.0270 | 41.0160 | 0.0110 | 2.93  |
| 5 | 42.5786 | 42.5647 | 0.0139 | 2.32  |
| 6 | 43.8791 | 43.8708 | 0.0083 | 3.88  |

**Note:** as a master-sample the sample from steel 65G was taken, it endured hardening and abatement at modes being used at tillage tools production

Analyzing the obtained data it is obvious that the maximum wear resistance possess samples No. 1 and No. 6. It is in 3.58 and 3.88 times correspondingly higher than hardened steel 65G possesses taken as transfer standard.

4. **Conclusion.**

The results of the conducted studies made it possible to establish that hardening, containing boron carbide $\text{B}_4\text{C}$ and borax $\text{Na}_2\text{B}_4\text{O}_7$, is the most optimal for all parameters (hardness, homogeneity of structure, wear resistance).

**References.**

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