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STUDY OF THE STRUCTURE OF NEW WEAR-RESISTANT STEELS FOR AGRICULTURAL MACHINERY COMPONENTS AFTER OPERATIONAL TESTS

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Mechanical properties of steel 30KhGSA and new domestic steel B1700 specimens cut from agricultural equipment components after field trials are determined. A different wear mechanism is revealed for the steels: elastoplastic deformation with plastic repulsion of metal by soil particles and traces of microcutting of steel 30KhGSA chisels, adhesive-fatigue failure with traces of shallow pitting of a surface layer, and indentation of abrasive particles for a steel B1700 chisel. Use of the test steel makes it possible to increase soil tillage depth from 17–19 to 20–22 cm, which significantly increases the quality of agricultural operations or permits an increase in soil tillage rate.

Keywords: *medium carbon steels, martensite, abrasive wear, mechanical properties, agricultural machine components.*

Components of agricultural working tools during operation are subject to intense wear. Wear of these working tools depends on soil mechanical conditions, moisture content, ratio of abrasive hardness and component material, and structure of the component material working surface. One of the greatest amounts of component wear appears in conducting operations in sandy soils and sandy loam.

As a result of various agricultural engineering operating conditions, three main forms of wear are realized in the components and working tools: abrasive, as a result of wear of a cutting edge; diffusion, when a treated surface and tool are subject to reciprocal diffusion (or dissolution); so-called adhesive fatigue, which is accompanied by crack formation as a result of friction. The most widespread abrasive wear is caused by reaction of hard soil particles. The abrasive wear mechanism includes processes of surface microcutting, elastoplastic deformation, and fatigue failure [1]. Surface breakdown with abrasive wear is determined by mechanical action of soil particles on a component surface layer under conditions of potential heating with friction and physicochemical action of the environment [1].

Wear resistance depends on operating regime, on processes occurring within a material surface layer, and on the nature of reaction of abrasive with component surface. Under severe conditions, hard particles cause direct local breakdown of a component surface layer, leaving traces in the form of scratches.

The most widespread steels for rapidly wearing components of cultivation machine components within Russia developed in the 1950–1960s are steels 30KhGSA, 65G, and 40KhS [2–4], and also new wear-resistant steels, including those with good strength properties and hardness [5].

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TABLE 1. Test Steel Chemical Composition, wt.%

Steel	C	Si	Mn	Cr	Ni	Cu	Mo	Rest	S	P
30KhGSA	0.33	1.08	0.99	0.95	0.17	0.17	–		0.003	0.008
B1700	0.45	0.36	1.13	1.26	$\Sigma = 1.70$			B, V, Nb, Al, Ti	0.008	0.005

TABLE 2. Mechanical Properties of Test Steel Specimens

Steel	$\sigma_{0.2}$, MPa	σ_u, MPa	δ_5, %	δ_r, %	Ψ, %	KCU^{+20}, J/cm^2	*HRC*
30KhGSA	1480	1800	9.8	3.2	32	24,36,47	44–51
B1700	1720	2180	10.2	4.5	25	37,39,41	54–56

The aim of this work is to study the wear mechanism during operation of agricultural machine working tool components manufactured from domestic steel 30KhGSA and from a new wear resistant steel with guaranteed yield strength of 1700 MPa.

Steel 30KhGSA selected for study was prepared under industrial conditions of a large metallurgical combine and the new test steel B1700 was developed by TsNII KM Prometey. Steel chemical compositions are given in Table 1.

Steel B1700 was melted in an induction furnace with a crucible capacity of 250 kg and poured into ingots each 40 kg. Ingots were forged in a hammer with a dropping load weight of 3000 tons. Forged billets were rolled in reversible duo 600 and quarto 800 mills into sheets 80-mm thick. Rolling was conducted in the temperature range 1100–900°C after heating in a chamber furnace up to 1200°C. Forging of billets cut from rolled product was carried in a steam and air hammer type M-2145A followed by trimming in a closed simple operation cranked press type KA-9536 with a force of 400 tons. Heat treatment (quenching and low-temperature tempering) of workpieces was carried out in a laboratory chamber furnace, after which components were prepared using machining.

Field tests were conducted in order to compare quality and evaluate the life of components manufactured from the new high-strength and traditional steels. The quality of plowshare chisels was compared after operation on a PLN-4 plow. Operating conditions: sandy soil and loam with high (up to 5.0–5.5 MPa) density, presence of stone inclusions, and pebbles.

Analysis of the nonmetallic inclusion content according to GOST 1778 and a study of the microstructure was carried out on microsections prepared in transverse section of the cutting edge of each blade after full-scale tests. Microstructure was studied by means of an Axiovert 40 MAT light inverted metallographic microscope, fitted with a digital video camera and a VS CTT 205C system for producing images.

Evaluation of mechanical properties in tensile and impact bending tests was carried out in accordance with the specifications GOST 1497 and GOST 9454. Hardness was measured in a Rockwell hardness meter according to GOST 9013.

Results of mechanical tests for specimens cut from components are given in Table 2.

As tensile testing, impact strength, and hardness tests, yield strength and ultimate strength indices for the test steel showed, they exceed by more than 200 MPa similar properties for steel 30KhGSA. The relative elongation and relative reduction of area are at the same level, but the value for relative elongation for the test steel is greater by 1.3%, which indicates better capacity of the material to withstand deformation without failure. Average values for impact strength for both steels are approximately identical, although for steel 30KhGSA the scatter of values is broader, which points to an effect of property anisotropy over the components surface area. Due to the high content of carbon and microalloying elements, including boron (up to 0.003 wt.%), the test steel provides higher hardness (up to 56 *HR*C) compared with steel 30KhGSA (not more than 51 *HR*C).

Test components of steel B1700 operated at a significantly greater tillage depth compared with standard components of steel 30KhGSA. The average operating depth using standard components was 17–19 cm, and for test components it was 20–22 cm. The appearance of a new and worn chisel of the tests is given in Fig. 1.

A chisel of test steel B1700 was worn over the length by 27–32% less than a similar chisel of steel 30KhGSA. Test chisels after operation are in an entirely operative condition, and chips and deformation are not detected. Chisel operation of

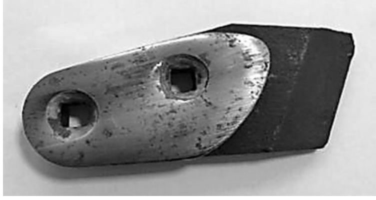

Fig. 1. Appearance of an applied plowshare chisel made from test steel before and after tilling 8 ha on plow body.

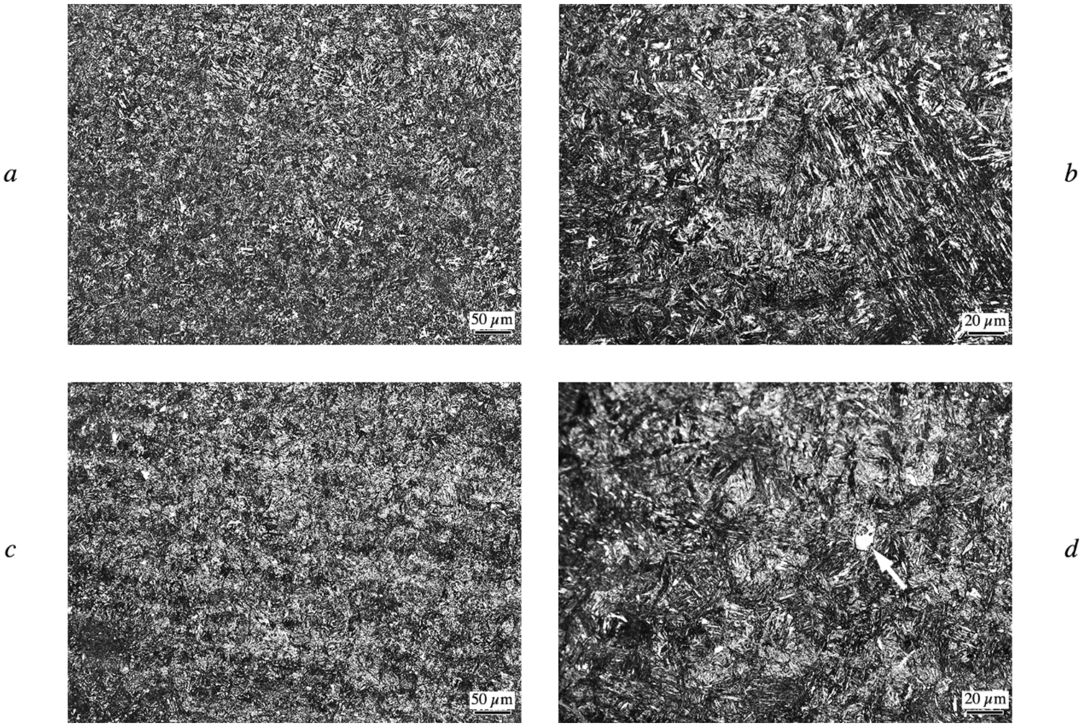

Fig. 2. Microstructure of steel 30KhGSA (*a*, *b*) and B1700 (*c*, *d*) chisels at different magnifications.

the test steel in ultra-heavy soil and climatic conditions with significant rock inclusions was more than 7.5 ha per component, and the predicted residual life was 35–47%.

Standard components of steel 30KhGSA had a maximum life with respect to wear under comparable conditions of 6.5 ha. Breakage occurred by wear of the tip and presence of an occipital bevel on the chisel. The majority of standard components (up to 70%) failed within operating limits of plowing 2–3 ha for the reason of massive deformation and breakage, which occurred both in the area of the nose and also in the chisel zone, and even in the heel. All standard chisels reached a limiting condition or were scrapped.

The microstructure of a steel chisel after etching in accordance with GOST 5639 is shown in Fig. 2.

The structure of all test specimens was predominantly lath bundle martensite formed in original austenite grains with size up to 30 μm in steel 30KhGSA and up to 20 μm in steel B1700. Within the structure of steel 30KhGSA, there is also lamellar martensite, with plate length of 30 μm distributed arbitrarily, and occupying up to 15% of the test area of a microsection. Within the structure of steel B1700, areas are revealed of residual austenite whose size is within the limits of 3–7 μm (marked with an arrow in Fig. 2*d*). Residual austenite occupies not more than 6% of the microsection test area.

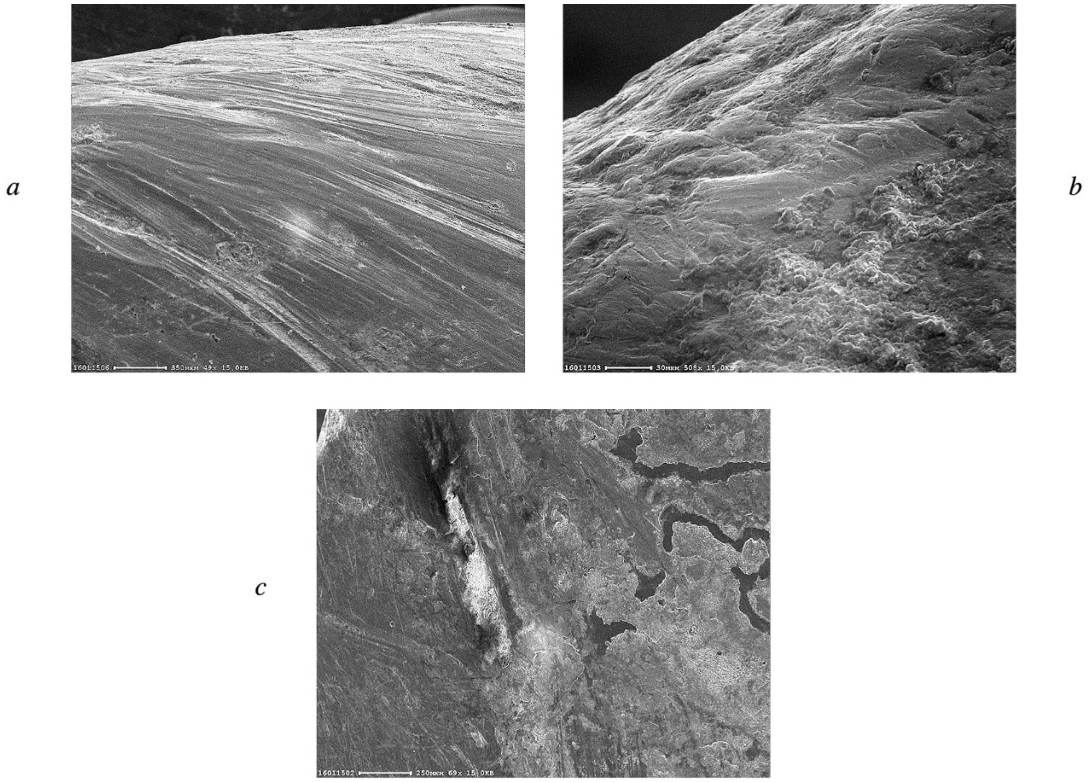

Fig. 3. Appearance of steel 30KhGSA chisel surface after operation: *a*) traces of microcutting and elastoplastic deformation; *b*) traces of elastoplastic deformation and fatigue failure; *c*) traces of soil particle indentation in component surface layer.

Results of evaluating the size and distribution of nonmetallic inclusions showed that metal of both components exhibits satisfactory metallurgical quality. Local oxides and silicates are revealed in microsections whose size and distribution does not exceed point 2 according to GOST 1778.

Photographs of a worn blade surface are shown in Figs. 3 and 4, manufactured from steels 30KhGSA and B1700.

Comparison of the surface breakdown shows that steel wear during operation occurs by different mechanisms. In the surface of a blade manufactured from 30KhGSA, there are scratches, i.e., microcutting and elastoplastic deformation with plastic repulsion of metal by soil particles (see Fig. 3*a*, *b*), and also traces of particle impression into the component surface layer (see Fig. 3*c*).

In the worn chisel surface manufactured from steel B1700, traces of elastoplastic deformation are only seen at the surface of adhesion-fatigue failure, and in areas of shallow chipping of a surface layer (see Fig. 4*a*). Impression of abrasive particles leads to formation between them of shallow microcracks in the friction surface (see Fig. 4*b*, *c*) whose combination leads to formation of adhesive-fatigue failure.

Comparison of the nature of breakdown of the surface of test components points to better wear resistance of the new test steel.

A study of the microstructure of chisel surface layers of steels 30KhGSA and B1700 also shows that steel wear during operation occurs by different mechanisms. The microstructure of surface layers of a plow chisel is shown in Fig. 5. The layer of metal close to the chisel surface prepared from steel 30KhGSA is markedly deformed and has traces of scratches (see Fig. 5*a*, *b*), whereas the microstructure of a chisel of steel B1700 close to the surface is almost undeformed, but at a depth of 10–70 μm within there are small impressed soil particles (see Fig. 5*c*, *d*).

Conclusions. Full-scale field tests under severe soil and climatic conditions have shown the advantage of the new high-strength wear-resistant manufactured by TsNII KM Prometey with respect to component operating life manufactured

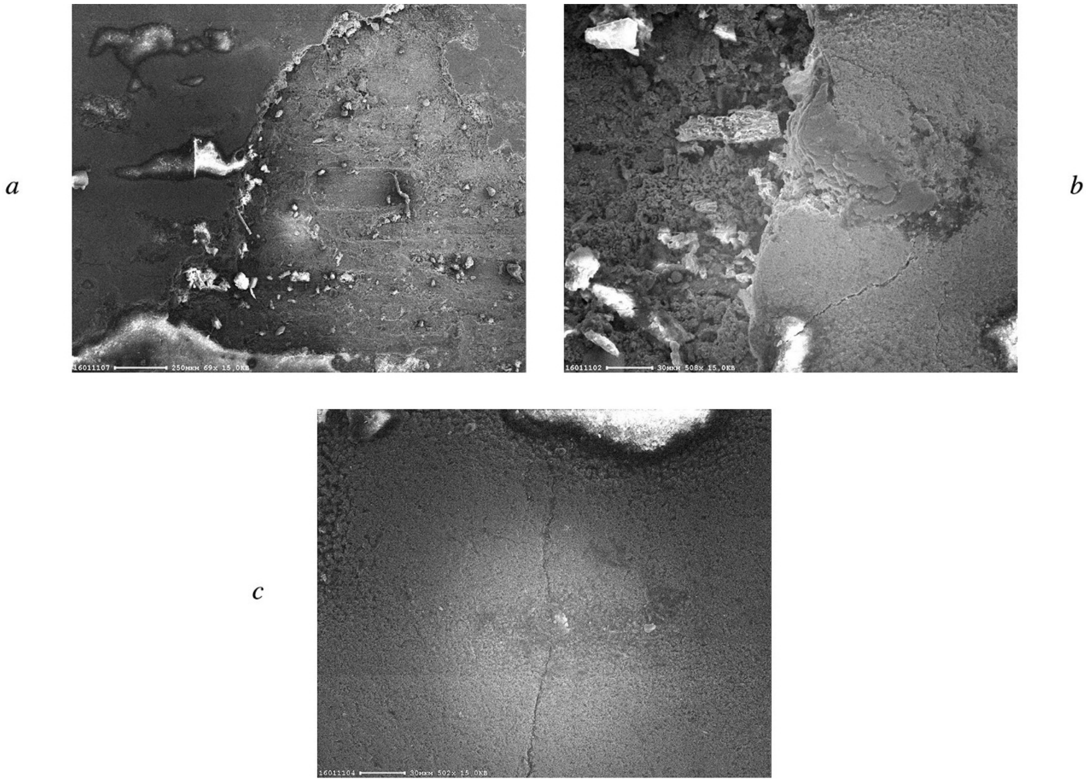

Fig. 4. Appearance of steel B1700 chisel surface after operation: *a*) traces of elastoplastic deformation only at a surface of adhesion-fatigue failure; *b*) indentation of soil particles in an area of adhesion-fatigue failure; *c*) microcrack formation with friction.

from this steel. After operation for more than 7.5 ha, the residual life of the steel B1700 component was 35–47%. The life of a component of steel 30KhGSA was exhausted after operation for 6.5 ha. Use of the test steel makes it possible to increase soil treatment depth from 17–19 to 20–22 cm, and this considerably increases the quality of agricultural work and makes it possible to increase soil tillage rate.

The structure of all tests specimens cut from components after full-scale tests shows predominantly lath bundle martensite. Lamellar martensite is present in specimens of steel 30KhGSA within a volume of not more than 15%, but in steel B1700 not more than 6% of residual austenite is detected within the volume of a microsection. Mechanical property tests showed the advantage of the test steel with respect to the level of strength and hardness with an identical level of ductility and impact strength.

Comparative metallographic and fractographic analyses of the working surface of chisels of steels 30KhGSA and B1700 after operation was conducted by a scanning electron microscope showed that component wear during operation proceeds by different mechanisms. Surface layers of a 30KhGSA chisel have traces of micro-cutting and elastoplastic deformation with plastic repulsion of metal by soil particles, and also impression of soil particles into the surface. In a less worn surface of a chisel manufactured from steel B1700, there were traces of shallow chipping of the surface layer and impression of abrasive particles, which points to adhesive-fatigue failure.

The different nature of wear is due to the alloy composition and structural features of the steels compared, which govern the level of blade surface hardness, for steel 30KhGSA of 44–51 *HRC*, and for test steel B17000 of 54–56 *HRC*.

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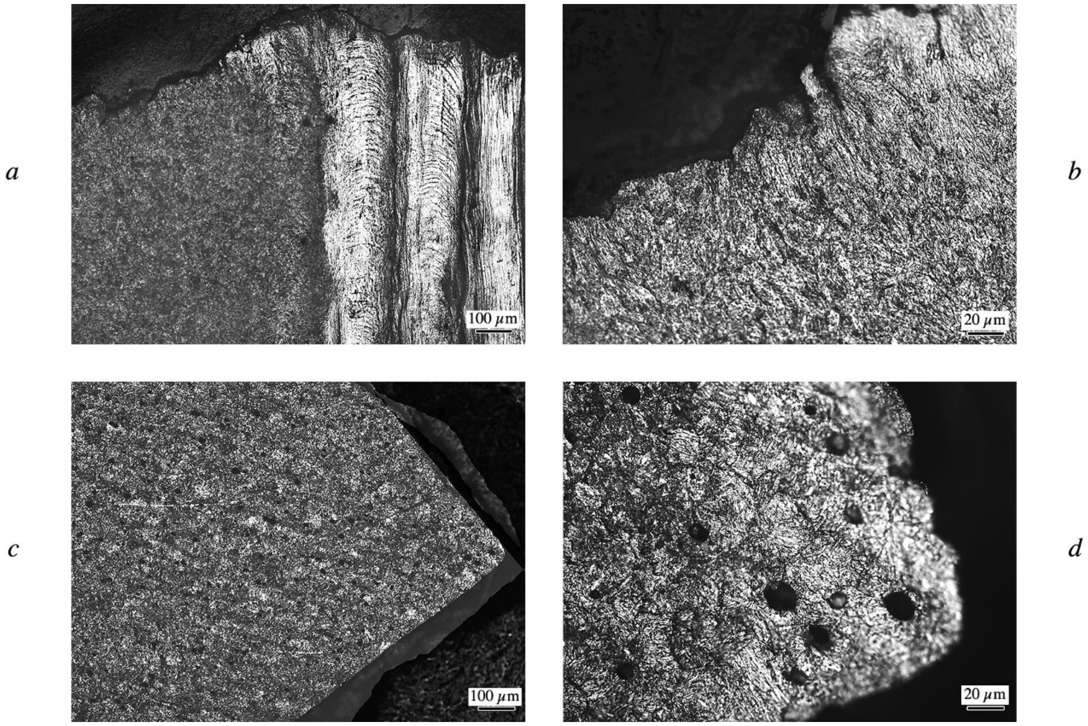

Fig. 5. Steel microstructure at a chisel surface after operation: *a*, *b*) deformed layer of martensite with traces of scratches at steel 30KhGSA blade surface; *c*, *d*) almost no strain-induced martensite structure for steel B1700 chisel with fine soil particle indentations.

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