DOI: 10.63550/ICEIP.2025.82.14.103

Study of Metal Samples in an Abrasive Environment

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Keywords: wear resistance, high-strength steel, heat treatment, service life, agriculture.

Abstract: The paper presents the results of experimental study of the influence of heat treatment modes on the change of geometrical characteristics of the surface of steels 0.43 %C, 1.60 % Si, 0.01 % Mn, 1.1 % Cr, 0.95 % Mo, 0.08 % V, 0.05 % Nb, 0.04 % Ti (steel 40CrSi2MoV) and 65G subjected to abrasive wear. The tests were carried out on a circular soil stand simulating real conditions of operation of agricultural machinery subjected to abrasive impact of soils. A mixture of clay and sand was used as an abrasive medium, the composition of which was selected to ensure maximum compliance with the conditions of field work. The working time of the samples amounted to 160 hours, which allowed obtaining statistically significant results. The results of experimental studies showed that the intensity of weight wear of steel 40CrSi2MoV was 1.3 times lower, and linear wear - 2.9 times lower compared to the intensity of wear of steel 65G. The obtained results allow us to conclude that the use of steel 40CrSi2MoV for the manufacture of working elements of tillage machines operated under conditions of intensive abrasive wear is a promising solution for improving the wear resistance of heavily loaded parts and, consequently, increasing the service life of agricultural machinery.

1 INTRODUCTION

Soil tillage tools are one of the key components of agricultural machinery, determining the efficiency and quality of soil tillage. The performance characteristics of working tools directly depend on the properties of the material used. During operation in the soil environment these elements are subjected to intensive abrasive wear (Wang, Li, Nie, Gong, Yang, Hu, Li, Ma, 2023), which necessitates the use of materials with increased strength, resistance to deformation and destruction.

Currently produced by domestic manufacturers of steel, often do not fully meet the requirements for modern agricultural implements, which is associated with an insufficient level of mechanical properties. For example, cultivator tines made mainly of 65G steel, after hardening and subsequent tempering have hardness in the range of NV 321-541 kG/mm^2, which may be insufficient for work on heavy soils (Bartenev, 2013; Seregin, Valuev, Nikitchenko, Asaturyan, 2021). Increasing the service life can be achieved by surfacing with hard alloys (e.g., sormite) or boron-containing materials (Krivochurov, Ivanaisky, Ishkov, 2018). However, the service life of such tines is, on average, 40-100 hours (80-200 ha), which is significantly lower than that of foreign analogs.

In foreign practice, low-carbon, low-alloy steels enriched with microadditives of boron, molybdenum, titanium, vanadium and other elements are widely used for the manufacture of soil tillage machinery working elements. Heat treatment allows these steels to achieve outstanding strength and impact toughness, which significantly increases the service life of parts.

The chemical composition of steel is an important factor determining its wear resistance. The introduction of alloying elements such as chromium and nickel increases corrosion resistance, which is especially important when operating in aggressive soil conditions. Molybdenum and tungsten increase hardness and wear resistance, providing abrasion resistance (Ren, Fu, Xing, Yang, Tang, 2017; Ding, Fan, Yang, 2022). Carbide-forming elements, such as

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DOI: 10.63550/ICEIP.2025.82.14.103

vanadium and titanium, promote the formation of hard carbide phases that further increase wear resistance (Zhang, Qiu, Cao, 2022).

Optimization of heat treatment regimes has a significant impact on the structure and, consequently, on the wear resistance of steel. To achieve an optimal combination of properties, it is necessary to take into account the complex interaction between the chemical composition, heat treatment regime and the emerging steel microstructure, which is a prerequisite for achieving maximum performance (Blinov, Bannykh, Kostina, 2007; Bogodukhov, Kozik, Svidenko, 2016; Astrashab, Grigorchik, Kukareko, Belotserkovsky, 2020).

In this connection, the research aimed at development of new steel grades possessing an optimal combination of high wear resistance and impact toughness is relevant. This will significantly increase the service life of tillage tools and reduce the cost of their replacement.

The purpose of this work is to establish the relationship between heat treatment regimes and changes in the geometric characteristics of the surface of 40CrSi2MoV and 65G steels subjected to abrasive wear under conditions simulating the soil environment.

2 MATERIALS AND METHODS

The study of the abrasive wear process was carried out on a circular soil stand designed by FSAC VIM (Patent RU2613292C1), developed to simulate the conditions of wear of soil tillage implements. The main parts and units of the stand are: a circular soil channel, rippers, compacting rollers and a system of fixation of test specimens. The rotation of samples is carried out at a constant speed of 50 rpm, which corresponds to a linear speed of 2.2 m/s, typical for the operating speeds of most tillage units (Sidorov, Zvolinsky, 2018; Sidorov, Liskin, Mironov, Afonina, 2020). The design of the stand provides modeling of wear of soil-cutting elements in conditions that are as close as possible to the real field conditions of agricultural production, which allows increasing the reliability of the results obtained. The stand allows modeling wear at different installation angles relative to the cultivated surface and direction of movement, which is typical for most of the working tools used for undercutting and loosening of the soil layer, such as plow shares, cultivator tines and cutters.

As an abrasive medium, river washed sand was placed in the soil channel, the granulometric composition of which corresponded to typical sandy loam soils with the content of physical clay 10% and sand 90%. The mentioned soils are characterized by relatively low wearing capacity at moisture content of 10-15 % and hardness of 2-3 MPa. To maintain the moisture content of the abrasive mixture within the specified limits, the specific gravity was periodically controlled. If necessary, water was added followed by a 5-minute period of stand operation to ensure uniform distribution of moisture over the volume of the ring tray. After that, repeated control measurements were carried out.

Partial replacement of abrasivesPartial replacement of abrasives was carried out every 4 hours, and full replacement - every 8 hours. This is due to the fact that when the abrasive mass is compacted by rollers, its abrasive properties change.

The dimensions of the test specimens were determined based on the data obtained in previous studies by the authors (Sidorov, Liskin, Mironov, Afonina, 2020). The width of the specimens, designated as l_l, was 30 mm. Comparing the blade part of the specimen with a similar indicator of a natural plow share, it can be assumed that the value l_l represents the width of the model of the cutting part of the toe of the plow working organ, namely the plowshare. When the plowshare moves in the soil mass, the maximum load is concentrated in the nose part, the width of which varies in the range l_n = 50-70 mm. In real field conditions the depth of tillage reaches h_{rp} = 250-300 mm. Thus, the ratio of the plow working body toe length l_n to tillage depth h will be l_n: h = 50 : 300 = 0,17. Consequently, in the conditions of laboratory modeling, to achieve adequacy, the depth of treatment h_l at the width of the sample blade l_l = 30 mm should be defined as h_l = (l_l : 0.17) = 180 mm. At this depth, the cutting edge of the sample was embedded in the soil mass as it moved in the annular soil trough (Fig. 1).

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a

b

Figure 1: a) image of the circular soil stand designed by FSAC VIM, intended for modeling of soil tillage conditions; b) photograph of the investigated blade soil-cutting working device.

Simultaneous comparative testing of two samples was carried out on the bench: an experimental sample from low-alloy steel 40CrSi2MoV and a reference sample from steel 65G. Heat treatment of steel 40CrSi2MoV (chemical composition: 0.43 %C, 1.60 % Si, 0.01 % Mn, 1.1 % Cr, 0.95 % Mo, 0.08 % V, 0.05 % Nb, 0.04 % Ti) consisted in heating to 900 °C with holding in the furnace at a heating rate of 1 mm/min and subsequent quenching in water. Tempering was carried out at 280 °C for 1 hour with subsequent cooling in air (Gaidar, Vetrova, Barchukova, 2024). The reference sample was made of widely used 65G steel (chemical composition: 0.62-0.70 % C, 0.9-1.2 % Mn), subjected to quenching in oil at 830 °C and subsequent tempering at 400 °C for 1 hour with cooling in air.

3 RESEARCH RESULTS

Tests of steels on abrasive wear allowed to establish differences in the wear patterns of the materials under study. Experimental data reflecting the relationship between the duration of operation and linear wear for steels 40CrSi2MoV and 65G are presented in Fig. 2.

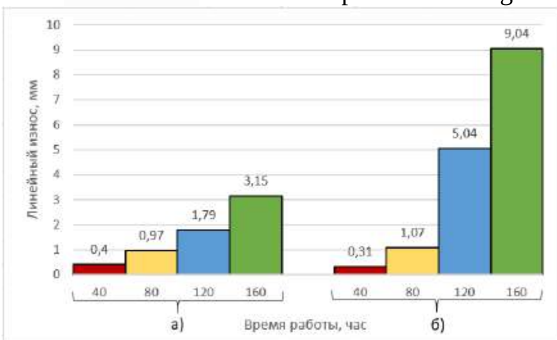

Figure 2: Dependence of linear wear on operating time: a) steel 40CrSi2MoV; b) steel 65G.

Linear wear of 40CrSi2MoV steel is characterized by insignificant and relatively constant wear rate, which is due to the structure of martensite and the presence of residual austenite, stabilizing carbides and preventing them from pitting.

Linear wear of 65G steel demonstrates a jump-like character, which is associated with the lack of carbide phase, providing resistance to abrasive action. For a more complete analysis of the character of wear, along with linear wear, we also studied the indicators of mass wear allowing to quantitatively estimate the total volume of m

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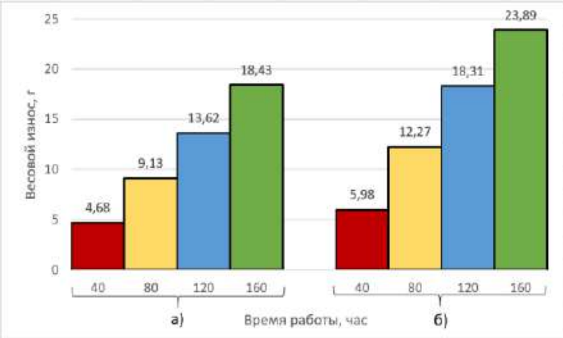

Figure 3: Dependence of weight wear on operating time: steel 40CrSi2MoV; b) steel 65G.

Mass wear studies confirm the differences in wear mechanisms of 40CrSi2MoV and 65G steels. It is found that 40CrSi2MoV steel shows less mass wear compared to 65G, which indicates its increased resistance to abrasive wear. These observations are consistent with the results obtained in the analysis of linear wear and emphasize the role of carbide inclusions in providing wear resistance.

Thus, the results of the research showed that steel 65G, subjected to quenching in oil at 830 ° C and subsequent tempering at 400 ° C, shows significantly greater wear than steel 40CrSi2MoV, quenched in water at 900 ° C with subsequent tempering at 280 ° C. It is quantitatively established that linear wear of 40CrSi2MoV steel was 2.9 times less, and mass wear was 1.3 times less than that of 65G steel.

The obtained results allow to recommend steel 40CrSi2MoV for manufacturing of working bodies of soil tillage machines that will potentially allow to increase their service life.

4 CONCLUSIONS

1. Studies conducted on a circular soil stand, allowed to establish that the heat treatment, including quenching in water from a temperature of 900 ° C and subsequent tempering at 280 ° C for steel 40CrSi2MoV, provides increased resistance to abrasive wear compared to the traditional hardening in oil steel 65G from a temperature of 830 ° C and tempering at 400 ° C.

2. The established reduction of linear wear in 2.9 times and mass wear in 1.3 times relative to steel 65G predicts a significant increase in the operating life of parts made of steel 40CrSi2MoV after the proposed heat treatment, as well as a significant reduction in costs associated with maintenance and replacement of worn components.

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