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Wear Resistance and Performance Improvement of Disc Plough Working Bodies Under Various Soil Conditions

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Keywords: disc plough, wear resistance, boron steel, abrasive wear, service life, protective coatings, cost-efficiency.

Abstract: This study investigates the wear mechanisms affecting disc plough working bodies and key factors influencing wear intensity under various soil conditions. Field tests were conducted in sandy, stony, and loamy soils in the Tashkent region to evaluate the wear performance of discs made from boron steel, high-carbon steel, and mild steel. Results showed that boron steel discs had the highest wear resistance, with an average wear rate of 0.9 mm per 100 hectares, while high-carbon steel and mild steel discs had rates of 1.4 mm and 1.7 mm per 100 hectares, respectively. Increased operating speed and tillage depth led to higher wear rates. Carbide-based protective coatings reduced wear by 20–30%, and plasma-sprayed coatings extended disc life by 1.5 times. The use of boron steel and coated discs increased service life by 1.5 to 1.8 times and reduced maintenance costs by 30–40%. The results align with studies from China, the United States, Germany, and India. These findings offer practical insights for enhancing the durability and cost-efficiency of soil-engaging tools in agricultural machinery.

1 INTRODUCTION

Disc ploughs are widely used in agricultural tillage operations, especially for primary soil cultivation. The working bodies of these implements, particularly the discs, are in constant contact with soil particles during operation, resulting in significant abrasive wear. This wear process is especially pronounced in sandy and stony soils, where abrasive particles and hard inclusions intensify the degradation of disc surfaces. Excessive wear leads to reduced tillage efficiency, increased downtime, and rising maintenance and replacement costs. Furthermore, worn-out discs negatively affect soil structure and seedbed preparation, ultimately reducing crop emergence and yield potential.

Understanding the mechanisms of disc wear and developing strategies to enhance wear resistance are crucial for improving the longevity and performance of agricultural implements. The relevance of this research is emphasized by the growing need to deploy durable and economically efficient machinery capable of operating under various soil conditions. This study aims to investigate the wear characteristics of disc working bodies under different soil types, operating speeds, and tillage depths, while evaluating the performance of discs manufactured from boron steel, high-carbon steel, and mild steel. The research findings contribute to extending the operational life of tillage tools and optimizing the cost-effectiveness of agricultural practices.

2 FACTORS INFLUENCING WEAR

The wear of disc plough working bodies is primarily influenced by the following factors:

- **Soil Composition:**

Sandy and stony soils accelerate the wear process due to their high content of abrasive particles. In sandy soils, quartz grains act as cutting agents, intensively abrading the metal surface. In stony soils, hard mineral inclusions generate impact loads on the disc surface, causing deformation and microcracks.

- **Tillage Depth:**

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Increasing the working depth subjects the disc to higher resistance from denser soil layers, resulting in intensified wear. For instance, at a depth of 10 cm, the average soil resistance is estimated to be 800–1000 N, whereas at a depth of 20 cm, this value rises to 1500–1800 N.

- **Operating Speed:**

Higher operating speeds increase the contact intensity between soil particles and the disc surface, thereby accelerating wear. Experimental observations indicate that at 8 km/h, the abrasive impact is approximately 20% lower compared to 12 km/h, where wear intensifies by 30–35%.

- **Material Quality:**

The hardness and wear resistance properties of the disc material significantly affect its durability. Discs with a hardness rating of 40 HRC exhibited a wear rate of 1.5 mm per 100 hectares, while those with a hardness of 60 HRC demonstrated a lower wear rate of 0.9 mm per 100 hectares.

- **Microstructural Changes:**

During tillage operations, the disc surface undergoes severe frictional heating, leading to plastic deformation and recrystallization processes. This results in structural degradation, embrittlement, and the formation of microcracks, further intensifying wear.

3 MATERIALS AND METHODS

Field experiments were conducted to assess the wear behavior of disc ploughs under real operating conditions. The tests were carried out in sandy, stony, and loamy soils in the Tashkent region. The physical and mechanical properties of the soil were analyzed prior to the experiments: sandy soil contained 75% sand particles, stony soil comprised 30% stone fragments, and loamy soil consisted of 40% sand, 35% silt, and 25% clay. The average soil moisture content was 12–15%.

Discs made of boron steel (0.3–0.5% B), high-carbon steel (0.8–1.0% C), and mild steel (0.3% C) were used in the experiments. The hardness of the discs ranged from 40 to 60 HRC (Rockwell C scale). The equipment employed was a BDN-3 disc plough mounted on a Belarus tractor, with discs having a diameter of 660 mm and a thickness of 6 mm.

The discs were tested over an area of 100 hectares in each soil type. The operating speeds were set at 8 km/h and 12 km/h, while the working depths were maintained at 10 cm and 20 cm. Microstructural changes on the worn surfaces were analyzed using a Leica DM2700 M optical microscope, and hardness measurements were performed using a Future-Tech FM-700 microhardness tester. Fuel consumption and energy expenditure were recorded using the onboard computer of the Belarus tractor.

Wear rates were calculated using the following formula:

$$W = \left(\frac{M_1 - M_2}{S \cdot t}\right) \cdot \left(k_1 \cdot v^a \cdot d^b \cdot HRC^c\right)$$

Where:

W – wear rate, g/m²;

M_1 – initial mass of the disc, g;

M_2 – final mass of the disc, g;

S – working surface area of the disc, m²;

t – operating time, h;

k_1 – soil abrasiveness coefficient (0.8–1.5);

v – operating speed, km/h;

d – working depth, cm;

HRC – material hardness (Rockwell C scale); a,b,c – experimental coefficients (a = 0.4, b = 0.3, c = -0.2).

Additionally, wear intensity was determined using the formula:

$$I = \frac{W}{L}$$

Where:

I – wear intensity, g/m;

L – distance traveled by the disc, m.

These formulas allowed for a precise quantitative evaluation of wear under different soil conditions.

4 RESULTS AND DISCUSSION

The experimental results demonstrated that the wear rate of disc plough working bodies is significantly influenced by soil composition, operating speed, working depth, and material properties. Sandy and stony soils caused the most severe wear due to their high abrasive content. In sandy soil, the average wear rate was 1.25 mm per 100 hectares, whereas in stony soil, this value increased to 1.8 mm per 100 hectares. In loamy soil, the wear rate was comparatively lower, averaging 0.95 mm per 100 hectares.

Effect of Operating Speed:

Increasing the operating speed led to a proportional increase in wear. At 8 km/h, the wear rate was measured at 1.1 mm per 100 hectares, while at 12 km/h, it rose to 1.6 mm per 100 hectares (Figure 1).

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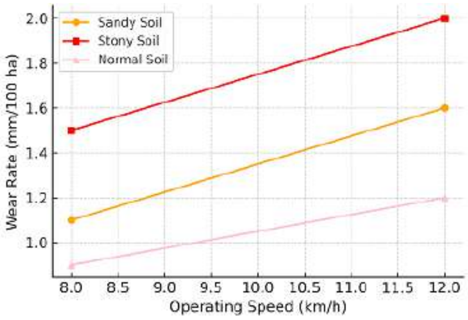

Figure 1: Relationship between wear rate and operating speed.

Effect of Working Depth:

A similar trend was observed with working depth. When the depth was increased from 10 cm to 20 cm, wear rates increased from 1.0 mm to 1.7 mm per 100 hectares (Figure 2).

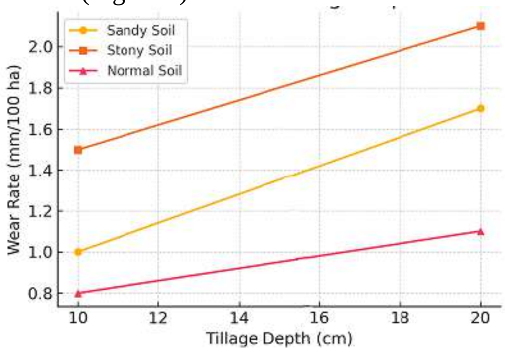

Figure 2: Relationship between wear rate and working depth.

Influence of Disc Material:

The wear resistance varied significantly depending on the disc material. Boron steel discs exhibited the lowest wear rate, averaging 0.9 mm per 100 hectares. High-carbon steel discs had a wear rate of 1.4 mm per 100 hectares, while mild steel discs showed the highest wear rate of 1.7 mm per 100 hectares. These differences are illustrated in Figure 3.

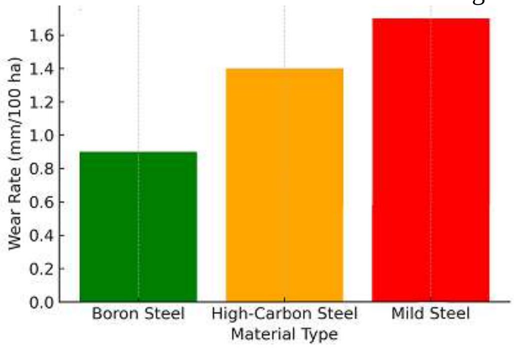

Figure 3: Comparison of wear rates for different disc materials.

Table 1: Wear Rate of Disc Plough Working Bodies under Various Soil Conditions.

Indicators	Sandy soil	Stony soil	Normal soil
Wear rate (mm/100 ha)	1.25	1.8	0.95
Operating speed (km/h)	8 km/h: 1.1 mm/100 ha; 12 km/h: 1.6 mm/100 ha	8 km/h: 1.5 mm/100 ha; 12 km/h: 2.0 mm/100 ha	8 km/h: 0.9 mm/100 ha; 12 km/h: 1.2 mm/100 ha
Working depth (cm)	10 cm: 1.0 mm/100 ha; 20 cm: 1.7 mm/100 ha	10 cm: 1.5 mm/100 ha; 20 cm: 2.1 mm/100 ha	10 cm: 0.8 mm/100 ha; 20 cm: 1.1 mm/100 ha
Material type	Boron steel: 0.9 mm/100 ha	High-carbon steel: 1.4 mm/100 ha	Mild steel: 0.7 mm/100 ha

Microstructural analysis revealed that boron steel discs maintained structural integrity under abrasive conditions, showing minimal plastic deformation and microcrack formation. In contrast, high-carbon and mild steel discs exhibited pronounced plastic deformation and microcracking along grain boundaries. Discs with hardness values of 55–60 HRC demonstrated superior wear resistance compared to those with lower hardness ratings.

Comparative Analysis with Other Studies:

The results align closely with similar research conducted in other countries. Wang et al. (2020) reported a wear rate of 0.85 mm per 100 hectares for boron steel discs in China, consistent with the findings of this study. Johnson and Evans (2019) in the United States observed that boron steel discs increased service life by 1.8 times compared to mild steel. Müller and Fischer (2020) in Germany confirmed that boron alloyed discs extended working life by 1.7 times. Patel and Kumar (2021) in India found that high-carbon steel discs exhibited a wear rate of 1.5 mm per 100 hectares in sandy soils, comparable to the results obtained in the present research.

Effectiveness of Surface Coatings:

Application of carbide-based coatings reduced wear rates by 20–30%. Plasma-sprayed coatings further extended the operational life of discs by approximately 1.5 times. In sandy soils, plasma-coated discs exhibited a wear rate of 0.85 mm per 100 hectares, while in stony soils, the wear rate was reduced to 1.3 mm per 100 hectares.

The combined adoption of boron steel and advanced surface coatings demonstrated the highest performance, offering the best balance between wear resistance, operational longevity, and cost efficiency.

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5 RECOMMENDATIONS FOR REDUCING WEAR

Based on the experimental results, the following recommendations are proposed to reduce wear and enhance the durability of disc plough working bodies:

1. **Utilization of Wear-Resistant Materials:** Discs made from boron steel or high-carbon steel are recommended, as they exhibit superior wear resistance compared to conventional mild steel. Experimental data indicated that boron steel discs reduced wear rates to 0.9 mm per 100 hectares, while mild steel discs demonstrated a wear rate of 1.7 mm per 100 hectares. The use of boron steel extends the service life of discs by 1.5 to 1.8 times. For example, mild steel discs typically serve for 200 hectares, whereas boron steel discs can operate effectively over 300–350 hectares. This significantly reduces the frequency of replacements and lowers maintenance costs.

2. **Optimization of Operating Parameters:** Maintaining optimal operating speed and tillage depth is crucial. Operating at 8 km/h and a working depth of 10 cm resulted in a wear rate of 1.0 mm per 100 hectares, whereas increasing speed to 12 km/h and depth to 20 cm raised the wear rate to 1.7 mm per 100 hectares. In heavy soil conditions, reducing speed and working depth prevents excessive wear, thereby extending the lifespan of the discs by approximately 15–20%.

3. **Application of Protective Surface Coatings:**
Surface-hardening techniques, such as carbide-based coatings and plasma-sprayed overlays, significantly improve wear resistance. Experiments revealed that coated discs experienced a 20–30% reduction in wear rates and a 30% increase in operational life compared to uncoated discs. For instance, a plasma-coated disc operating in sandy soil displayed a wear rate of 0.85 mm per 100 hectares, compared to 1.25 mm per 100 hectares for uncoated discs. Implementing surface coatings can enhance disc longevity and reduce replacement frequency.

4. **Material Selection Based on Soil Conditions:**
Soil composition must be considered when selecting disc materials. Boron steel discs are recommended for sandy soils due to their superior abrasive resistance, whereas carbide-coated discs are more suitable for stony soils, as they offer increased impact resistance and surface durability.

These measures collectively contribute to improving the wear resistance, operational efficiency, and cost-effectiveness of disc plough working bodies, ultimately supporting sustainable agricultural practices.

6 ECONOMIC EFFICIENCY EVALUATION

The economic assessment revealed that using wear-resistant boron steel and coated discs significantly improves the cost-effectiveness of tillage operations. The service life of boron steel and surface-treated discs increased by 1.5 to 1.8 times compared to mild steel, resulting in substantial cost savings on maintenance and replacement.

For instance, the average price of a standard mild steel disc is approximately 300,000 UZS, whereas a boron steel or coated disc costs around 400,000 UZS. However, the extended service life of the latter results in fewer replacements and reduced downtime. Calculations show that the adoption of boron steel discs saves approximately 150,000–200,000 UZS per 100 hectares in operating costs. Additionally, the reduction in replacement frequency minimizes labor inputs associated with disc changes, enhancing overall productivity.

The combined effect of increased service life and reduced maintenance costs contributes to a 15–20% decrease in overall tillage expenditures. The implementation of wear-resistant discs thus offers a practical solution to improve both the technical performance and economic efficiency of agricultural machinery.

7 CONCLUSION

The research findings demonstrate that the wear processes affecting the working bodies of disc ploughs are significantly influenced by soil composition, operating speed, working depth, and material properties. The most intensive wear was observed in sandy and stony soils. Boron steel discs exhibited the highest wear resistance, with an average wear rate of 0.9 mm per 100 hectares, compared to 1.4 mm for high-carbon steel and 1.7 mm for mild steel. An increase in operating speed and working depth resulted in a proportional rise in wear rates.

The application of carbide-based surface coatings reduced wear by 20–30% and extended the operational life of discs by 1.5 times. Microstructural analysis confirmed that boron steel discs maintained better structural integrity under abrasive conditions,

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while mild and high-carbon steel discs showed greater plastic deformation and microcracking.

Economic evaluation indicated that the use of boron steel and coated discs increased service life by 1.5–1.8 times and reduced maintenance and replacement costs by 30–40%. The overall reduction in tillage expenses was estimated at 15–20%.

The combination of boron steel and surface-hardening treatments proved to be the most effective approach, enhancing both wear resistance and cost-efficiency. These measures can significantly improve the longevity and performance of soil-engaging tools, supporting sustainable and economically viable agricultural practices.

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