

Wear Performance of Agricultural Harrow Discs Coated by Plasma-Jet Thermal Deposition

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Abstract: A comparative analysis of wear performance of coated harrow discs by plasma-jet thermal deposition was evaluated under agricultural conditions to assess the performance of atmospheric plasma spraying systems. This paper presents a long-term comparative field evaluation under identical operating conditions on a quartz-rich argic luvisol soil. Disc wear was quantified by periodic measurements of mass loss and diameter of the studied discs.

The uncoated disc showed the most severe degradation, with a total mass loss of approximately 700 g and a rapid acceleration of wear after the first 5-10 ha of harrowing. The results obtained under field conditions demonstrate that the microstructural integrity of the coating is more critical than the nominal hardness and highlight the superior effectiveness of APS ceramic coatings for extending disc life in abrasive agricultural soils.

KEY WORDS: WEAR PERFORMANCE, HARROW, DISCS, PLASMA-JET THERMAL DEPOSITION, PLASMA SPRAYING SYSTEMS.

Introduction

Agricultural machinery components that interact with the soil, such as disc harrows, plowshares, tines, and other soil-cultivating elements, operate under conditions characterized by high abrasion and impact loads. During soil cultivation, the harrow disc blades are also subject to significant wear due to abrasive soil particles such as sand, small and big stones, and other hard materials that accidentally get into the soil.

Modern agricultural production relies on mechanized soil cultivation tools, such as plowshares, cultivators, disc harrows, cultivator blades, seed drill disc coulters, etc. These soil-engaging tools loosen, aerate, and mix the soil, and are essential for preparing the seedbed and ensuring crop emergence. Constant exposure to abrasive soil, rocks and agricultural residues inevitably leads to wear, which has a direct impact on operational efficiency and costs. Research shows that wear and tear is responsible for over 50% of agricultural machinery failures and can usually only function optimally after replacement.

Analysis of recent research and publications

All soil-working machines wear out faster with increasing sand content in the soil. This requires improving the mechanical properties of the working surfaces of the working parts of the machines mentioned above [1]. So, their constant exposure to soil, mineral particles, crop residue, and stones leads to progressive material degradation, affecting cutting efficiency and increasing fuel consumption to maintain consistent tillage quality [2].

Disc harrows require frequent replacement of heavily worn discs, which increases both downtime and maintenance costs, factors that are particularly important on large farms [3]. Increasing the wear resistance and service life of discs is essential for economically and environmentally sustainable agricultural production.

Insufficient wear resistance reduces the reliability and productivity of mechanized agriculture, potentially jeopardizing the efficiency of field work and even crop yields. Excessive wear of tillage machines changes the geometry, rounding the cutting edge or reducing their functional dimensions with an impact on the efficiency of soil work, increasing traction, and fuel consumption.

Extending the service life of agricultural machinery components is directly related to increasing energy saving, agricultural efficiency, and ultimately, economic sustainability. Therefore, the wear resistance of tillage tools is a priority for modern agriculture. It can be concluded that the best solutions should aim to increase surface hardness and structural strength to resist abrasion, while maintaining sufficient impact resistance [4].

Roşu et al. point out that the reduction in thickness and the loss of diameter of disc coulters of seed drills strongly depend on

the physical, mechanical and technological properties of the soil, including the presence of hard mineral inclusions (stones) [5].

Despite numerous studies on the wear of agricultural discs and soil tillage tools, most published work focuses on laboratory tests, short-term field studies or evaluations of a single coating system. However, comparative studies conducted under identical field conditions over the long term, including both coated and uncoated reference discs, remain limited.

The novelty of this study lies in the simultaneous long-term comparison of coating systems and an uncoated reference disc, operating under identical working conditions such as mechanical loads, soil profiles, working depths and speeds. Unlike previous studies, the discs were evaluated on an area of over 50 hectares per disc in quartz-rich argic luvisol soil, which allowed to identify nonlinear wear behavior and degradation mechanisms in advanced stages.

The most common solution for protecting tillage implements from wear used in practice remains hardening with Fe-Cr-C alloys, usually referred to as sormite or white high-chromium cast iron coatings. These coatings, usually applied by arc welding or plasma arc welding, extend the service life of workpieces several times compared to uncoated steel components. This is due to the presence of hard chromium carbides Cr_7C_3 or $(Cr,Fe)_7C_3$ embedded in a martensitic or austenitic matrix. Compared to sormite coatings, atmospheric plasma spraying (APS) allows for the application of thinner, more uniform, and more controlled coatings with minimal thermal impact on the substrate.

In this context, the present study investigates the wear performance of coated harrow discs by plasma-jet thermal deposition with three powders: Metco 71NS, Metco 136F and Metco 45C-NS, applied using a Sulzer Metco 9MCE atmospheric plasma spraying system [4].

The aim of the research is to conduct a comparative analysis of the wear performance of coated harrow discs by plasma-jet thermal deposition by plasma-jet thermal deposition method in field conditions, followed by an assessment of the effectiveness of atmospheric plasma spraying systems.

Materials and Methods

At the beginning of the study, the elemental composition of a new, uncoated harrow disc was determined using a spark optical emission spectrometer Spark-OES equipped with the SparkTiffe analytical software package [5].

Three 610 mm diameter disc specimens were prepared for coating. The method of preparing and coating the discs has already been described in several works [4, 6, 7].

Seven radial specimens were cut from the cutting edge towards the central area of the new harrow disc (Figure 1). The resulting chemical composition values were used as initial data for

correlating the substrate material with coating adhesion, microstructural behavior, and field wear performance.

Uniform melting of the powders produces dense, well-bonded deposits:

- Metco 71NS ($W_2C/WC-12Co$) supply a hard carbide surface suitable for use in highly abrasive soils;
 - Metco 136F ($Cr_2O_3-SiO_2-TiO_2$) provides a ceramic coating with high hardness, good impact absorption due to its silicon dioxide content, and excellent corrosion resistance;
 - Metco 45C-NS ($Co-Cr-Ni-W-C$) produces a metallic coating called Stellite with balanced strength and wear resistance, suitable for surfaces subject to combined abrasive and impact loads.
- These powders cover a broad functional spectrum of ceramic, carbide and cobalt metal systems, allowing for comparative evaluation of different harrow disc wear protection strategies in the field.

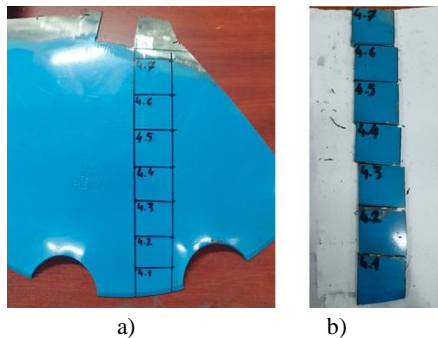


Figure 1. Studied radial samples:
a) radial marking and segmentation of the disk surface before cutting; b) extracted radial samples.

The coatings were applied to both sides of each harrow disc, forming a continuous ring-shaped coating around the entire working perimeter [6].

The coatings were applied to both sides of each harrow disc, forming a continuous ring-shaped coating around the entire working perimeter. Microstructural characterization of coated and uncoated disc samples was performed by scanning electron microscopy (SEM), which can provide detailed information about surface morphology, coating microstructure, wear patterns, and particle distribution [7].

An OTMA heavy disc harrow with a 4.0 m working width was used for field testing. These harrows are equipped with four groups of 10 concave discs (two groups in front and two in the rear). The test discs, both coated and uncoated, were mounted on the harrow's front axle at an attack angle of 15° relative to the direction of travel. This configuration improves soil penetration, crop residue removal, and lateral soil movement, as well as ensuring effective stubble incorporation and uniform soil cultivation across the entire working width. The disc harrow under study was coupled with a medium-sized John Deere 7230 tractor with a power of 230 hp.

The test disc harrow was coupled to a mid-size John Deere 7230 tractor with 230 hp and a powershift transmission with high hydraulic capacity, providing consistent traction and allowing precise control of working speed and tillage depth.



Figure 2. Installed testing discs on the harrow before field testing:
1) three coated discs; 2) uncoated discs.

During field trials, stubble disking was performed after grain harvesting (Figure 3). The disc harrow under study cultivated 1,000 hectares of land, meaning each disc on the two front axles cultivated 50 hectares.

According to agronomic recommendations, the main operating parameters were:

- working depth of 0.15 m;
- forward speed of 7-8 km/h.



Figure 3. Tractor and 4-metre OTMA disc harrow during stubble field work

Since all discs were exposed to the same soil profile and operating parameters during the discing operation, differences in wear can be attributed primarily to surface characteristics rather than positional influences.

According to the methodology, disk weight measurements were taken regularly, every 20 hectares of the total treated area, corresponding to 1 hectare per disk. Before weighing, the disks were thoroughly cleaned of soil residue and dried. The weight of each disk was measured using a calibrated digital scale with an accuracy of ± 1 g. For each weighing, three consecutive measurements were taken, and the average value was determined. The measurement error for the disk mass was less than ± 2 g, which is negligible compared to the observed mass loss.

Diameter measurements were taken using a digital caliper with an accuracy of ± 0.02 mm. The diameter of each disk was determined by measuring it in two sections and calculating the average value. This procedure allowed to identify uneven edge wear and reduce measurement variability.

To assess disk wear, four test disks (three coated and one uncoated) were weighed every 20 hectares of total cultivated area (i.e., 1 hectare per disk). This allowed us to accurately determine mass loss and increase in disk wear with increasing cultivated area.

Thus, all tested discs were subjected to identical the same operating parameters (field soil profile, operating travel speed, working depth, uniform residue load and disc attack angle), which ensured that any differences in wear could be attributed solely to the material and coating characteristics of the samples.

Results and discussions

Measurements of the disc masses taken before and after the coating process reveal differences in the amount of material deposited on each disc tested (Table 1).

Table 1. Mass of the disks before and after coating application

No	Disc	Coating Type	Initial Mass (kg)	Coating Mass (kg)	Final Mass (kg)
1	Sample 1	$Cr_2O_3-SiO_2-TiO_2$ Ceramic	10.483	0.105	10.588
2	Sample 2	WC/W_2C-Co Carbide	10.492	0.127	10.619
3	Sample 3	$Co-Cr-Ni-W-C$ alloy	10.481	0.116	10.597
4	Uncoated Sample	No coating	10.486	0	10.486

The dynamics of disc wear, expressed as mass loss in the range of 0–50 ha/disc, reveals significant differences between the three coated discs and the uncoated disc (control). All four curves shown

in the graph demonstrate nonlinear behavior, namely, low wear rates in the early stages of operation, followed by a gradual acceleration of mass loss as the total worked surface area increases (Figure 4). This trend reflects the typical behavior of tillage tools, which before the start of work (testing) had sharp edges and smoother working surfaces, but gradually with an increase in the processed field area, wear increases, since, being subjected to increasingly intense abrasion, the edges become rounded and the contact area of the soil with the metal of the disks increases. The uncoated (control) disc exhibits the steepest wear curve.

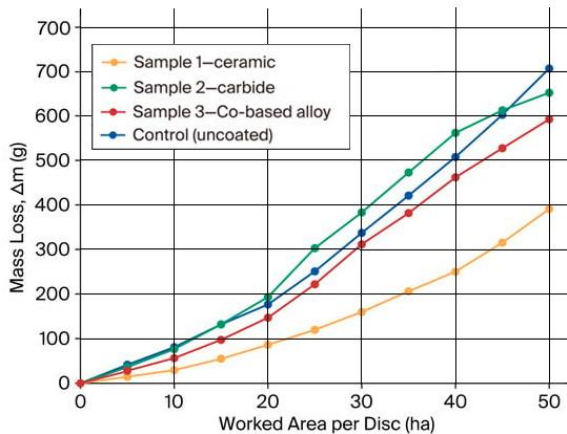


Figure 4. Mass loss of coated and control (uncoated) discs as a function of worked area of the treated surface per disc

Compared to all the samples tested, Sample 1 demonstrates the best results. The wear curve remains virtually flat over the first few hectares (10 hectares), and even over an area of 25 hectares, the weight loss is limited (0.15 kg). After this point, wear accelerates somewhat, but the total weight loss over an area of 50 hectares remains minimal at 0.39 kg. This behavior indicates the excellent long-term stability of the ceramic coating, especially in abrasive soils rich in quartz.

The wear curves, plotted against disc diameter and constructed for an effective operating range of 0–50 ha/disc, provide information on the degradation of the disc samples studied during field work. As expected for components in contact with the ground, all four discs show a non-linear reduction in diameter, with relatively low wear in the initial stage of operation, followed by gradually accelerating degradation towards the end of the the operating range.

This type of wear is typical of abrasive wear, where the disc edges initially retain a sharp geometry, but as the blade becomes dull (rounded), contact with the soil intensifies and material removal accelerates. The control (uncoated) disc exhibits the steepest wear trajectory, resulting in an overall diameter reduction of about 26 mm after 50 hectares of worked area per disc (Figure 5).

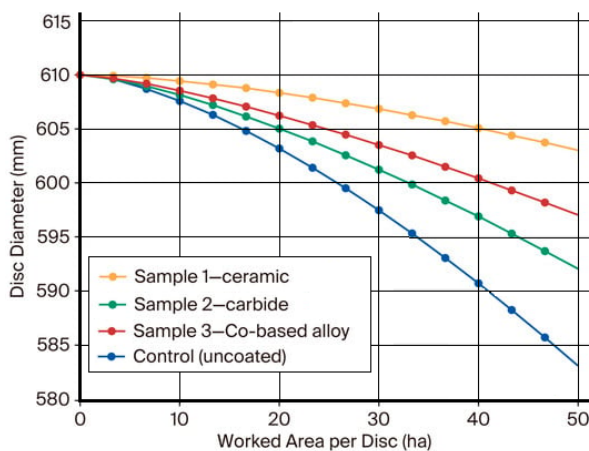


Figure 5. Variation of disc diameter as a function of the worked area per disc

The curve shows the most pronounced acceleration, confirming the susceptibility of untreated carbon steel to abrasive action in quartz-rich soils. This rapid wear in the later stages is consistent with previous studies reporting that unprotected agricultural harrow disc blades lose their geometry more quickly after the cutting edge becomes dull.

Sample 1 exhibits the smallest disc diameter loss after 50 hectares of work per disc and maintains the largest diameter throughout the entire test period. Sample 1 demonstrates the best results, with a final diameter loss of 7 mm. Its curve has the flattest slope, indicating that the ceramic coating effectively slows edge rounding and maintains the harrow disc's geometry significantly longer than discs with other processing methods.

Sample 3 demonstrates intermediate results, with a final diameter loss of 14 mm. The curve lies between the values for the ceramic and carbide coatings, reflecting the balance between strength and moderate hardness characteristic of cobalt alloys. The results of Sample 2 were better than those of the uncoated disc, but worse than those of the ceramic-coated (Sample 1) and alloy-coated (Sample 3) discs.

Compared to the uncoated (control) disc, the tested coated variants demonstrated significantly different wear reductions. The ceramic-coated disc (Sample 1) reduced overall weight loss from approximately 700 g to 390 g after 50 ha, representing a weight loss reduction of approximately 44%. The cobalt-based alloy coating (Sample 3) provided a more modest reduction of approximately 16%, while the carbide-coated disc (Sample 2) showed only a slight improvement of approximately 7%.

Similar trends were observed for disc diameter wear. The uncoated disc (Sample 1) lost about 26 mm in diameter, while the ceramic coating limited the diameter loss to approximately 10 mm (a 62% reduction). The Co-based alloy (Sample 3) and carbide coatings of Sample 2 reduced diameter loss by 46% and 31%, respectively.

Based on these trends, the ceramic coating provides approximately 1.8 times the wear life of an uncoated disc in field testing conditions ranging from 0 to 50 hectares per disc, while the cobalt-based alloy and carbide coatings increase wear life by approximately 1.2 and 1.1 times, respectively.

The minimum working diameter of a worn harrow disc depends on its initial size, but typically discs with a diameter of 620–660 mm should be replaced when they wear down to 500–520 mm. If the diameter is critically reduced more than 100–150 mm from the initial diameter, the disc no longer penetrates effectively and processes the soil efficiently.

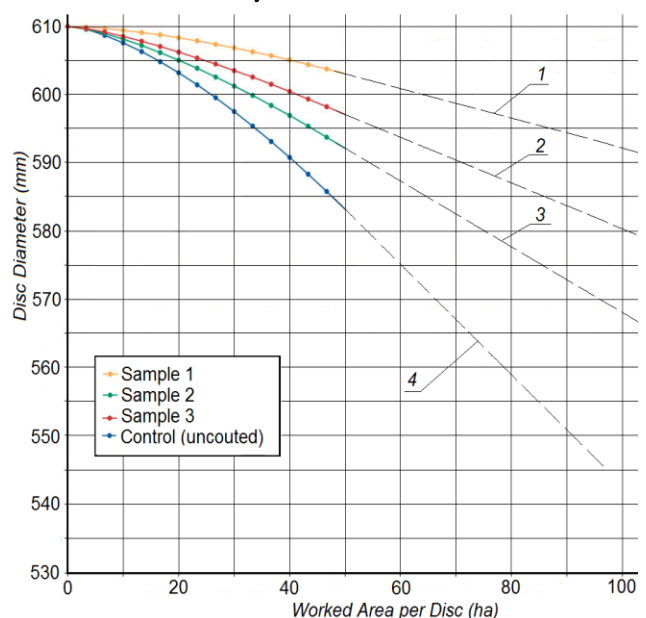


Figure 6. Experimental and theoretical method for expanding the variation of disc diameter as a function of the worked area per disc: 1 - Sample 1; 2 - Sample 3; 3 - Sample 2; 4 - uncoated disc.

A disc is considered worn out when its diameter decreases by 15-20% of the original, which critically affects the angle of attack and the depth of soil cultivation [8, 9].

The use of heavily worn discs leads to a decrease in the quality of stubble processing and increased fuel consumption.

If we continue the curves shown in Figure 5, we see that the minimum operating period of uncoated harrow disc is 0-150 hectares of processed area per disc or more precisely less than 110 ha/disc (Figure 6, curve 4). The uncoated disc will reach its maximum permissible wear at a minimum diameter of 530 mm. In Figure 6, we see that the minimum operating period of a ceramic-coated disc (Sample 1) is more than 0-150 ha/disc (Figure 6, curve 1) and it will also reach the maximum permissible wear at a minimum diameter of 530 mm.

However, it remains unclear how ceramic-coated discs Sample 1 and other Samples will perform in the future due to blade rounding as a result of wear, and changing of disc diameter (Figure 5, curve 1, 2, 3).

In this study, the APS ceramic coating provided an estimated increase in service life of approximately 1.8 times based on the mass loss factor and approximately 2.6 times based on the diameter retention factor, indicating that, depending on the functional failure criterion, thin APS ceramic coatings can approach the lower and mid-range performance reported for conventional hardfacings while providing improved thickness control and reduced geometric variations.

The wear assessment in this study was based primarily on quantitative measurements of mass and diameter loss, supplemented by previously performed microstructural analysis of the applied coatings using a scanning electron microscope.

Further research could be expanded to include field experiments until the discs coated by plasma-jet thermal deposition method are completely worn out.

Conclusions

1. This study examined the wear performance and behaviour of harrow discs coated by plasma-jet thermal deposition method with three different thermal spray systems:

- 1) Sample 1 - Cr₂O₃-SiO₂-TiO₂ ceramic;
- 2) Sample 2 - WC/W₂C-Co carbide;
- 3) Sample 3 - Co-Cr-Ni-W-C alloy.

Their performance was compared with an uncoated (control) disc under field operating conditions.

2. Compared to the uncoated (control) disc, the tested coated variants demonstrated significantly different wear reductions. The ceramic-coated disc (Sample 1) reduced the overall weight loss by approximately 44%, the cobalt-based alloy-coated disc (Sample 3) had a reduction of approximately 16%, and the carbide-coated disc (Sample 2) only showed an improvement of approximately 7%. The results obtained in the field confirm that the microstructural stability of the coating determines the long-term wear resistance of harrow discs, and not only its density or nominal hardness.

3. Based on these trends, the ceramic harrow disc coating provides approximately 1.8 times longer disc life than the uncoated disc in field trials covering 0 to 50 hectares per disc, while cobalt-based alloy and carbide coatings increase disc life by approximately 1.2 and 1.1 times, respectively.

4. The research results clearly show that applying coatings to the surface of harrow discs can significantly reduce mass loss and extend their service life, and the degree of improvement largely depends on the coating materials.

5. The research results show that Cr₂O₃-SiO₂-TiO₂ ceramic coatings (Sample 1) represent a very perspective solution for increasing the durability of disc harrows operating in abrasive soil environments and significantly reducing wear of the discs coated by plasma-jet thermal deposition.

6. This study highlights the value of combining laboratory research with long-term field trials. The integration of scanning electron microscopy analysis, chemical profiling, and long-term performance data allows for more accurate predictions of coating performance than any laboratory test alone.

7. Further research could be expanded to include field experiments until the discs coated by plasma-jet thermal deposition method are completely worn out. Future research should expand field tests to study how ceramic-coated discs Sample 1 and other Samples will perform in the future due to blade rounding as a result of wear, and changing of disc diameter (Figure 5, curve 1, 2, 3).

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