

Study of harrow discs coated by plasma-thermal method

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Abstract: This study presents a comparative analysis of three types of coatings taken from the active area of the coated harrow discs using atmospheric plasma spray deposition method (APS). The resulting coatings increase the durability of the harrow discs and the inclusion in the composition of coatings of carbides and powdered ceramic compounds will enhance the mechanical characteristics. This study focused on scanning electron microscopy of the coated samples from the harrow discs and their tribological properties. SEM imaging and EDS analysis have been carried out to clarify the morphological characteristics and study of disc cross-section. Tribological tests were carried out to determine the following main parameters: adhesion to the substrate, coefficient of friction (COF), modulus of elasticity and hardness of the material.

The development and implementation of modern technologies for improving the mechanical and chemical properties of materials for coated harrow discs will increase resistance to abrasive wear in modern agricultural conditions.

KEY WORDS: PLASMA SPRAY, HARROW DISC, TRIBOLOGICAL PROPERTIES, COATING.

Introduction

Agricultural machinery increases productivity, reduces farming costs and ensures optimal results. Thus, increasing the durability of soil-cultivating machine components, in particular harrow discs, is one of the key areas in the design of agricultural machinery.

Evaluation of plasma jet thermal deposition on harrow discs allows evaluating their resistance to abrasion and corrosion. Due to the impact of soil cultivation methods, harrow discs are subject to abrasive wear. So, optimization of their mechanical properties for increasing disc wear resistance is crucial for extending the service life of the harrow working parts [1, 2, 3]. Research shows that tillage equipment wears out faster as sand particle size increases, requiring stronger mechanical properties. It is well known that as tillage depth decreases, farm implements require less traction.

Formulation of the problem

The working bodies of tillage machines, such as harrow discs, must have high abrasion resistance to ensure effective soil cultivation and increase crop yields. During soil processing, the blades of harrow discs are often subject to significant wear due to abrasive soil particles such as sand, stones and other similar materials, and at the same time, these working elements must also have significant impact resistance [4, 5]. Therefore, it is necessary to conduct tests of disc harrows in accordance with the current standards for testing agricultural machinery and their working parts [6]. It means also using of efficient methods to improve needed parameters.

Analysis of recent research and publications

One of the methods is plasma thermal deposition, which is an advanced method capable to generate high quality surface layers, but its use is usually limited to coatings with a maximum thickness of around 100 μm. To address the challenges associated with severe wear conditions, tungsten carbide (WC) coatings are typically used due to their exceptional hardness and durability.

These wear-resistant coatings consist of WC particles as a tough hard phase for wear protection, embedded in a metal matrix, which acts as a plastic binder, effectively bonding and supporting the carbide grains under severe operating conditions [6, 7].

Factors such as carbide breakdown, particle ejection, debris removal and subsurface crack formation played a significant role in the wear behavior. The study of erosive and abrasive wear of WC12Co and WC10Co4Cr coatings deposited by the HVOF method highlights that the wear processes are influenced by the coating microstructure and testing conditions [8, 9].

However scientists found that Cr₂O₃-based coatings with higher TiO₂ concentrations prepared using the APS method exhibited a denser microstructure and improved corrosion resistance in three different solutions such as HCl, NaCl, and NaOH. Pure Cr₂O₃ ceramic coatings, due to their brittleness, may suffer from

poor adhesion, delamination, and porosity caused by insufficient particle melting [10, 11]. At the same time, titanium oxide TiO₂, known for its moderate hardness and good strength, improves the coating characteristics when combined with other metal oxides [12, 13]. Dense titanium oxide TiO₂, included into Cr₂O₃, refines the grain size and fills intergranular voids, increasing the internal density of the composite coating [14].

After applying three types of coatings to the working surface of the harrow discs, a comparative analysis will be presented with an emphasis on their microstructural and tribological properties.

Materials and Methods

The deposition facility used for experimental coatings Sulzer Metco 9MCE operated with Ar (5.3 bar, 45 NLPM) and H₂ (3.5 bar, 7.0 NLPM). Disc harrow samples were mechanically ground and intensively sandblasted immediately prior to deposition.

The experimental setup consists of a rotating support, an automated spray arm connected to a Sulzer 9MB gun, and a sample holder [15, 16].

The surface analysis of the coated samples were carried out using scanning electron microscopy (FEG Thermo Fisher - Quattro C, 2024), energy-dispersive X-ray spectroscopy (EDX - Bruker, X-Flash detector) and analytical equipment X-ray diffraction (XRD - Analytical equipment). The samples tested included:

Sample 1 - W₂C/WC12Co - Metco71NS;

Sample 2 - Cr₂O₃-4SiO₂-3TiO - Metco136F;

Sample 3 - Co25.5Cr10.5Ni7.5W0.5C - Metco45C-NS.

Three harrow discs were coated using the atmospheric plasma spray deposition method (APS) (Fig. 1).

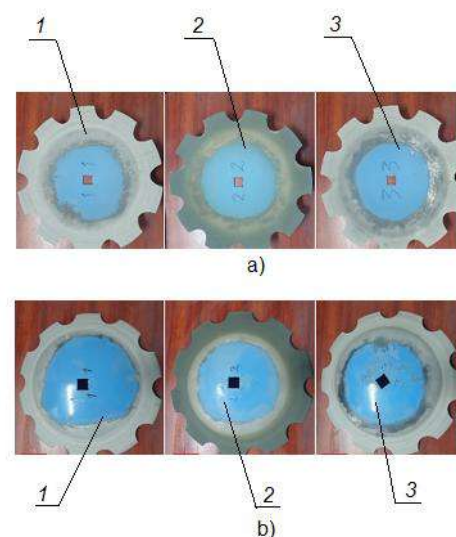


Figure 1. Experimental harrow discs with coatings: a) concave part; b) convex part; 1 - Sample 1; 2 - Sample 2; 3 - Sample 3.

Standard microhardness and scratch tests were performed using the microtribometers CETR-UMT-2 with the microindentation method to determine the mechanical properties of studied coated samples [17].

Powders for spraying the working areas of the harrow discs were produced by Oerlikon Metco and have the following three designations: $W_2C/WC12Co$ (Metco71NS), $Cr_2O_3-4SiO_2-3TiO$ (Metco136F) and $Co25.5Cr10.5Ni7.5W0.5C$ (Metco45C-NS). The nominal particle size ranges were $-62+176\ \mu m$ for Metco71NS, $-63+5\ \mu m$ for Metco136F, and $-95+12\ \mu m$ for Metco45C-NS. The harrow discs had different microstructures of the base material [16].

Microstructural analysis of the base material for interior area of the harrow disc and exterior (working area) shows that in the working area (Area 2), a heat-treated and rapidly cooled structure results in a Widmanstätten microstructure [16].

Results and discussions

To clarify the morphological characteristics, *microstructural analysis* was performed. Application of metallic and ceramic coatings on sandblasted samples using the APS method resulted in the formation of compact coatings with a uniform thickness, which generally depends linearly on the number of passes. SEM analysis of the surface morphology of studied samples and SEM imaging of sample cross-section show the morphological characteristics of the applied layers (Fig. 2).

The conducted EDS analysis of the surface of studied samples show microstructural peculiarities and EDS - chemical composition of coating [16]. EDS - Chemical composition of coating for Sample 1 is: C - 5.8%; Co - 12.7%; W - 81.5%. The errors are 0.3, 0.8 and 3.7 respectively.

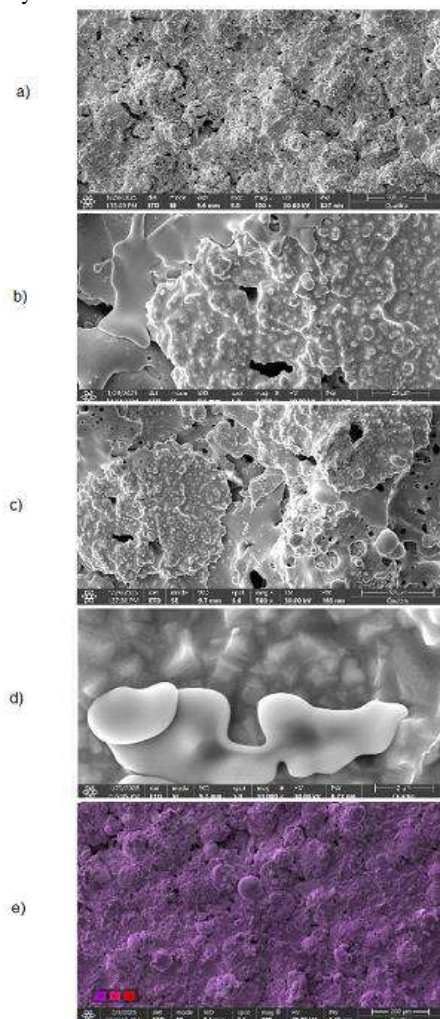


Figure 2. SEM and EDS analysis of the surface morphology of the surface of Sample 1 - $W_2C/WC12Co$ (Metco71NS); a, b, c, d - SEM analysis; e - EDS analysis: a)100X; b)500X; c)1000X; d)10000X.

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Research shows that Metco 45C-NS coating is more effective in improving wear resistance, Metco71NS enhances compressive strength, and Metco136F improves corrosion hardness and resistance.

Although the APS deposition method produces uniform layers, it also results in the presence of unmelted particles, micropores and cracks.

Changes in the composition of the deposited layers were obtained, as well as a relatively uniform distribution of chemical elements (Figure 3,e) [16]. EDS - Chemical composition of coating for Sample 2 is: O - 33.8%; Si - 1.4%; Ti - 3.7% and Cr - 61.1%. The errors for Sample 2 are 0.4, 0.1, 0.1 and 0.7 respectively. EDS - Chemical composition of coating for 3 is: C - 4.2%; Ni - 10.7%; Co - 48.4%, Cr - 29.9% and W - 6.8%. The errors for Sample 3 are 0.3, 0.6, 1.2, 0.6 and 1.4 respectively.

The coating thicknesses vary from a few tens of microns (Sample 2) to over 200 microns (Samples 1 and 3). The layers have a typical splat shape, where the powder component particles are flattened during the deposition process. At the same time, several small pores are sporadically present in Sample 1 due to differences in the melting temperatures of cobalt and tungsten carbide.

Figure 13 shows the X-ray diffraction pattern compared with the base material, showing the compositional changes in the range of $15-90^\circ$ (2θ). The major compound of Sample 1 is WC (ICDD file: 96-591-0042) at $\theta=39.66^\circ$, showing a hexagonal crystal structure.

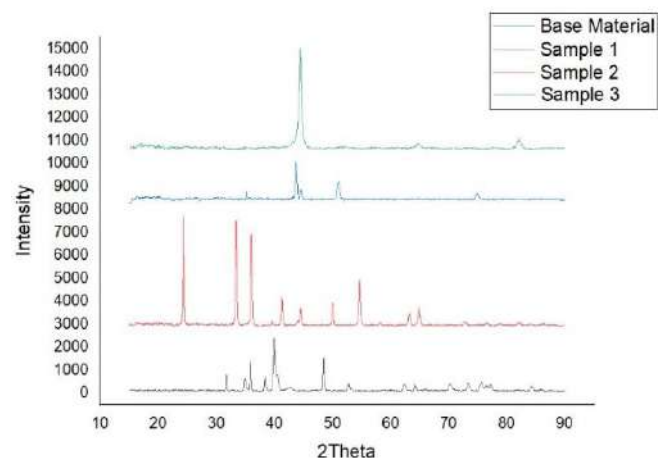


Figure 3. X-ray analysis of coated samples

The main and dominant compounds of Sample 2 are chromium(III) oxide Cr_2O_3 (ICDD: 96-900-8085) at $\theta=33.58^\circ$ having a hexagonal crystal structure and TiO_2 (ICDD: 96-900-1682) at $\theta=27.44^\circ$, with a tetragonal crystal structure. The main compound of Sample 3 is nickel-chromium NiCr (ICDD: 96-901-2969) at $\theta=44.57^\circ$, characterized by a cubic crystal structure. The base material is mainly composed of Fe-based compound (ICDD: 96-901-5839) at $\theta=43.82^\circ$, which shows an orthorhombic structure.

Table 1. Mechanical properties determined during tribological tests

	Sample	COF	Young's Modulus (GPa)	Stiffness (N/ μm)	Hardness (GPa)
1	P1 - Metco 71NS	0.4105	23.988	2.482	1.143
2	P2 - Metco 136F	0.5425	53.102	4.478	1.635
3	P3 - Metco 45C NS	0.5059	37.679	3.672	1.255
4	Base Material	0.1394	42.964	4.393	1.131

Tribological tests were conducted to determine such material parameters as substrate adhesion, coefficient of friction (COF), Young's modulus of elasticity and hardness.

To determine the coefficient of friction, which was calculated as the ratio of the horizontal force F_x (N) to the applied load force of 10 N, F_z (N), a micro-scratch test was performed. The average width of scratch marks was: 227 μm for Sample 1, 124 μm for Sample 2 and 232 μm for Sample 3.

The numerical values obtained as a result of scratch analysis for all three layers are presented in Table 1. An analysis of the results presented in Table 1 of all three tested samples and the base material shows that the coating of Sample 2, containing ceramic compounds of chromium oxide, titanium oxide and silicon oxide, resulted in a higher coefficient of friction, as well as higher hardness, stiffness and Young's modulus of elasticity compared to the other two coatings.

Conclusions

1. Morphological analysis of $\text{W}_2\text{C}/\text{WC12Co}$ (Metco71NS), $\text{Cr}_2\text{O}_3\text{-4SiO}_2\text{-3TiO}$ (Metco136F) and $\text{Co25.5Cr10.5Ni7.5W0.5C}$ (Metco45C-NS) coatings deposited on the working area of the harrow discs using the atmospheric plasma spray deposition method revealed a rough and porous surface with some unmelted particles and small cracks.

2. The harrow discs had distinct microstructures in the base material: in the central region (region 1) the microstructure consists of alpha-ferrite and pearlite, while in the working region (region 2) it is a Widmanstätten microstructure.

3. SEM cross-sectional images of the deposited layers highlighted very good adhesion to the metal substrate, with coating thicknesses varying from a few tens of micrometers in Sample 2 to more than 200 μm in Sample 1 and Sample 3. From a tribological analysis point of view, none of the three coatings allowed substrate exposure, however, microcracks and delamination of the surface layer were observed.

4. Sample 2 showed the highest values among all studied coatings for coefficient of friction, Young's modulus of elasticity and hardness.

Acknowledgments

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