Increasing the Durability of Agricultural Working Bodies by Creating Nanostructured Coatings Using Plasma Jet Spraying

Corneliu Munteanu[1], Iurie Melnic[2*], Bogdan Istrate[1], Fabian Cezar Lupu, Vitali Vișanu[2], Constantin Zîrnescu[2], Vladimir Badiul[2]

[1] "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania
[2] Technical University of Moldova, 168, Ștefan cel Mare Blvd., Chișinău, Republic of Moldova
*iurie.melnic@im.utm.md

Abstract: *The article reveals a new method that relates to the treatment of active surfaces of agricultural working bodies, in particular harrow discs, by applying nanostructured coatings using atmospheric plasma jet spraying (APS). The process consists of preparing the surface by corundum blasting at a pressure of 5.5 bar, followed by preheating to 150°C and depositing a nanostructured powder of the WC-Co 88/12 type.*

The technical novelty lies in the synergetic optimization of the deposition parameters: current intensity of 550 A, hydrogen flow rate of 9 L/min, spraying distance of 100 mm and a high scanning speed of 500 mm/s, under forced post-deposition cooling.

The technical result obtained by applying this process consists of creating a protective layer with porosity below 1.2%, adhesion of over 65 MPa and a hardness of 1150-1250 HV0.3, ensuring an increase in the durability of the working element of up to 2.8 times under conditions of severe abrasive wear.

Keywords: *DURABILITY, WEAR PERFORMANCE, AGRICULTURAL WORKING TOOLS, PLASMA-JET SPRAYING.*

Introduction

Agricultural machinery production is constantly evolving. At the same time, methods and techniques for producing the best parts and working components for performing various mechanized technological operations under challenging conditions are also being refined.

Increasing the durability of agricultural working tools of farming machines, such as plows, harrows, cultivators, seeders, etc. is one of the main problem areas in production of agricultural machinery. As a result of soil cultivation these machines are subject to severe abrasive wear.

Analysis of plasma-jet spraying on the active part of working tools of agricultural machines allows to evaluate the resistance to abrasion and corrosion. So, the use of such working bodies increases productivity, reduces costs and ensures the main good results in modern agriculture [1, 2].

Formulation of the problem

To ensure efficient soil cultivation and improve the quality of technological processes, the working parts of agricultural tillage machines must be highly wear-resistant. However, during soil cultivation, the active elements of all tillage machines (including disc harrows) are often subject to significant wear due to abrasive soil particles.

It should be noted that these working elements must have significant impact resistance [3, 4].

A known process for hardening the working parts of agricultural machinery is the use of traditional material heat treatments (quenching and tempering) applied to 65G steel or boron-alloyed steels, achieving a hardness of approximately 48-52 HRC [5].

The proposed technical solution for hardening the agricultural working parts has several drawbacks:

1) limited resistance to severe abrasive wear in heterogeneous soils;

2) rapid changes in the geometry of the harrow disc cutting edge;

3) the need for frequent replacement of parts, which increases operating costs.

During 2024-2026 it was conducted tests of disc harrows in accordance with the current standards for testing agricultural machinery and their working parts [6, 7, 8]. It means also using of efficient methods to improve needed parameters.

Analysis of recent research and publications

All agricultural working bodies wear out faster as the amount of sand particles in the soil increases, which requires improving the mechanical properties of the surfaces of the processed working elements [3, 4].

That assumes a relationship between the wear of the active area of the working parts of the machine, the size of the sand particles and the optimization of their mechanical properties to increase the wear resistance of the working bodies of agricultural machinery which is crucial for increasing the service life of the active areas [5, 6].

Therefore, the active area of the working bodies, especialy of tillage machines must have significant impact resistance [1, 4, 6]. It means using effective methods to improve the parameters of the active surface of the working bodies of agricultural machinery, and subsequently conducting tests of these machines in accordance with current standards for testing.

Plasma-jet thermal spray deposition is one of the effective methods for improving the main parameters of the working elements material of machines for farming, considered an advanced method capable to achieve high-quality surface depositions [5, 7].

Currently, the application of this method is generally limited to coatings up to 100 μm [8, 9].

Another process of thermal spraying deposition in atmospheric plasma jet (APS) of tungsten carbide (WC-Co) or ceramic mixtures (Cr2O3-SiO2-TiO2) powders is known, using standard operating parameters according to the technical data sheets of powder manufacturers, [1, 7, 10].

To improve the microstructural and tribological properties of coatings on the active areas of studied harrow discs and the quality of the agricultural working bodies, three types of coatings were applied to the active areas of the discs [7, 8]:

- W_2C/WC12Co (Metco71NS);
- Cr_2O_3-4SiO_2-3TiO (Metco136F);
- Co25.5Cr10.5Ni7.5W0.5C (Metco45CNS).



Figure 1. Atmospheric plasma jet thermal spraying coating process

Experimental coatings on harrow discs were applied using a Sulzer Metco 9MCE deposition system operating on Ar (5.3 bar, 45 Nl/min) and H_2 (3.5 bar, 7.0 Nl/min).

After mechanical grinding and intensive sandblasting, samples with thermally applied APS were tested on the active areas of the harrow discs of the working parts of agricultural disc harrows.

The experimental setup for the study included a rotating support, an automated arm connected to a Sulzer 9MB sprayer, and a sample holder (Fig. 1).

In order to to determine the main parameters of the material of the studied coatings obtained by thermal spraying with an atmospheric plasma jet, such as adhesion to the substrate, coefficient of friction (COF), Young's modulus (modulus of elasticity), rigidity (stiffness) and hardness a tribological analysis was carried out.

Tribological tests were held by a group of researchers from the Technical University of Moldova (Republic of Moldova) and the Technical University "Gheorghe Asachi", Iasi (Romania) in a specialized laboratory of the Technical University "Gheorghe Asachi", Iasi, Romania (Fig. 2).



Figure 2. Conducting tribological tests in the laboratory of Technical University „Gheorghe Asachi", Iasi, Romania

In these conventional solutions, the thermal regime is optimized for general depositions, without taking into account the specifics of abrasive stresses in heterogeneous agricultural soils.

The technical solution presented has the disadvantage that standard sputtering processes (characterized by low scanning speeds of 200-300 mm/s and large sputtering distances of over 120 mm) often lead to thermal degradation of carbides through the decarburization phenomenon [5, 7].

During the flight of particles in the plasma jet with temperatures exceeding 10,000 K, the hard WC (tungsten carbide) phase decomposes into more brittle and less hard phases, such as W2C or metallic tungsten. This chemical and structural transformation process results in a layer with high porosity (above 2-3%) and a coarse microstructure.

Excessive porosity allows moisture and acids from the soil to penetrate, leading to corrosion of the interface between the layer and the substrate, which causes premature exfoliation of the coating. Also, structural degradation limits the hardness of the layer below the threshold of 1000 HV, an insufficient value to ensure long-term protection against silica (quartz) fractions present in the soil, which have a comparable or higher hardness.

The purpose of the innovation is to increase the durability and resistance to abrasive wear of agricultural working bodies by creating a coating with a nanometric, dense and ultra-hard structure, without affecting the mechanical properties of the metal substrate.

Rezults and discussion

The stated problem is solved by using plasma-jet spraying to produce a nanostructured coating, which involves strict heat transfer control using a current of 550 A, a hydrogen flow rate of 9 L/min and a high scanning speed of 500 mm/s at a distance of 100 mm. This ensures a particle temperature sufficient to melt the binder phase without degradation of the nanometric carbide cores, resulting in a layer with a porosity of less than 1.2% and a hardness exceeding 1150 HV0.3.

The essence of the innovation consists in solving the problem of increasing durability of active areas of agricultural working bodies by applying a well-studied technological regime that allows preserving the nanometric structure of the WC-Co powder (type Metco 71NS or similar) in the deposited layer.

The technical result is that the process of producing nanostructured coatings by plasma jet spraying to increase the durability of agricultural working elements ensures obtaining a hardness of 1150-1250 HV0.3, 20-30% higher than standard methods, reducing the porosity of the layer below 1.2-1.5%, preventing the infiltration of corrosive agents from the soil and increasing the service life of metal working elements by up to 3 times in abrasive soil conditions.

The peculiarities of the process of making nanostructured coatings are ensured by a researched technological regime and can be applied by selecting as the base material a working element with a metallic surface (disks, cutters, knives, blades) made of boron alloyed steel (27MnCrB5) or spring steel (65G), having a thickness of 4-6 mm.

The actual deposition is performed using an atmospheric plasma spraying installation, fed with a nanostructured powder of the WC-Co 88/12 type (cobalt cemented tungsten carbides), with an average carbide crystallite size below 500 nm.

The working parameters used to obtain the nanometric structure are:

- electric current intensity: 550 A;
- arc voltage: 65-70 V;
- primary plasma gas flow rate (Argon): 45 L/min;
- secondary plasma gas flow rate (Hydrogen): 9 L/min;
- spraying distance: 100 mm;
- torch scanning speed: 500 mm/s.

By applying this process, a protective layer with a thickness of 250-300 μm is obtained, characterized by a porosity of 1.1% and an average microhardness of 1210 HV0.3. Laboratory tests (according to ASTM G65 standard) have demonstrated a reduction in mass loss through abrasive wear of 2.8 times compared to untreated discs and an increase in the adhesion of the layer to the support of up to 68 MPa.

Further research

Further research into ways to increase the durability of agricultural machinery by creating nanostructured coatings using plasma jet spraying relates to substantiating the application modes and parameters for APS coatings and conducting further experiments directly related to the working parts of transplanting machines and seeders [11, 12, 13].

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Conclusions

1. Morphological analysis of the studied coatings W_2C/WC12Co (Metco71NS), Cr_2O_3-4SiO_2-3TiO (Metco136F) and Co25.5Cr10.5Ni7.5W0.5C (Metco45C-NS), applied to the active surface of harrow disks using the atmospheric plasma spraying method, revealed shortcomings that allowed us to draw conclusions regarding the spraying process and methods for improving operating parameters.

2. A study of coated samples followed by tribological analysis of surface scratches on three groups of samples revealed shortcomings and next steps for improving the atmospheric plasma spray (APS) thermal deposition process.

3. The features of the process of manufacturing nanostructured coatings are provided by the studied technological regime and can be implemented by choosing as the main material of the working element with a metal surface (discs, cutting elements, knives) on such agricultural machines as plows, scaricators, disc harrows, seeders, transplanting machines, etc. made of boron-alloyed steel (27MnCrB5) or spring steel (65G) with a thickness of 4-6 mm.

4. Excessive porosity of the coatings obtained using the studied APS modes allows moisture and acids from the soil to penetrate inside, causing corrosion of the interface between the layer and the substrate, which leads to premature delamination of this coating. Also, structural degradation limits the layer hardness below the threshold of 1000 HV, which is insufficient to provide long-term protection against silica fractionspresent in the soil, that have comparable or higher hardness.

5. The innovative proposal involves the actual deposition being carried out using an atmospheric plasma spraying unit, into which nanostructured powder of the WC-Co 88/12 type (tungsten carbides bonded with cobalt) with an average carbide crystallite size of less than 500 nm is fed.

6. The operating parameters and modes of the system used to produce the nanometric structure are as follows:

- Electric current: 550 A;
- Arc voltage: 65-70 V;
- Primary plasma gas flow rate (argon): 45 l/min;
- Secondary plasma gas flow rate (hydrogen): 9 l/min;
- Spray distance: 100 mm and torch scanning speed: 500 mm/s.

7. By applying the proposed process of atmosferic plasma spray termal deposition, a protective layer with a thickness of 250-300 μm is obtained, characterized by a porosity of 1.1% and an average microhardness of 1210 HV0.3.

8. Theoretical studies and laboratory tests (in accordance with the ASTM G65 standard) have shown a reduction in mass loss due to abrasive wear by 2.8 times compared to untreated discs and an increase in layer adhesion to the substrate to 68 MPa.

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