Comparative analysis of wear resistance of thermodiffusion coatings obtained using the HFC melting method

Yuri Rozhkov1*

1Federal Scientific Agroengineering Centre "VIM", Moscow, Russia

Abstract. When using HFC welding, an important problem is the selection of a suitable surfacing material. The main criterion for this selection is the wear resistance of the resulting coating. The higher the wear resistance, the longer the working element will last. To achieve good wear resistance, higher hardness materials are often used for surfacing. However, it is important to find a balance so that the hardness of the coating does not increase to the point where it becomes brittle. Among the coatings studied, coatings that contain boron carbide and are additionally mixed with P-0.66 powders in 10% volume and FeSi in 90% volume have the highest wear resistance. These coatings proved themselves by showing wear rates that are 18 times less than those of 65G steel in the tests. However, despite their outstanding hardness, they are very brittle and are impractical for practical applications. However, coatings consisting of boron carbide mixed with P-0.66 powders in 10% volume and FeSi in 50% volume also have excellent wear resistance. Compared to 65G steel, they have 4 times less wear, are not as brittle and can be used for hardening coatings.

1 Introduction

Wear and tear of the working elements of agricultural machines is a common problem for all modern tillage and sowing machines. Considering that these machines can operate over an area of up to 10,000 hectares per season, the question of extending the service life of the working elements becomes very important.

To reduce wear, replacement plates made of wear-resistant materials are often used. However, this can significantly increase the cost of the tool, and the use of such inserts in Russian conditions does not always justify the cost. Therefore, an important task is to create a new hardening coating, which would combine the positive properties of hardening the edge of the carbide insert with strengthening the rest of the surface using modern high-tech methods.

There are several methods for restoration and hardening of working elements of agricultural machines. When choosing the appropriate method, it is important to consider how thick a coating can be applied and how much harder it can be made [1]. The HFC-melting method is characterised by the fact that it allows the creation of coatings with

* Corresponding author: dozor.06@mail.ru
Significant thicknesses that have increased wear resistance, while providing high performance during operation [2, 3, 4].

The HFC-melting method produces a coating that can be characterised as a composite material with metal and ceramic elements. It includes two main layers: a steel sublayer modified by chemical composition and a strengthening layer. The strengthening layer is represented by a matrix consisting of iron boride eutectic in which cementite particles, iron borides, iron carborides and additional steel elements are distributed to provide additional strengthening [5]. These components provide additional uniform strengthening of the coating. There is a diffusion boundary between the two layers that separates them. This method is sometimes used in combination with electrospark alloying to provide a more uniform structure. There are known cases where this combination of methods is used and the result is coatings whose wear resistance level exceeds that of 65G steel after quenching by a factor of 5.5 [6].

The main problem associated with the use of HFC melting is the difficulty in selecting a suitable material to create new coatings. This difficulty is partly due to the limited range of available synthesised materials, especially when there is a shortage of available and cost-effective eutectic materials in powder form. This can increase the cost of the final products [7, 8]. To address this problem, the method of using exothermic mixtures of self-propagating temperature synthesis (STS) has been applied. This method allows the cladding process to be carried out using exothermic reactions that occur when the mixtures are heated to a temperature of 850 °C. However, depending on the required characteristics of the coatings, different mixture compositions may be required.

2 Methods and Materials

The service life of machine components and operating elements depends to a large extent on the wear resistance of the materials used in their manufacture. Wear resistance is defined as the inverse of the rate or intensity of wear of materials.

The most rational way to assess the wear resistance of materials is the results of field tests of parts made of the materials under study, or parts with inserts made of these materials. However, field tests are limited and cover only a limited number of materials. In addition, the variability of wear caused by differences in soil conditions often makes the results of such tests difficult to be consistent and comparable.

In order to assess the wear resistance of materials used in the working elements of soil tillage machines, it is sufficient to carry out laboratory tests that can accurately reproduce wear conditions similar to those occurring in the soil [8, 9].

To apply this methodology, the authors of the article have created a simple device that allows testing of specimens without the need to pre-treat them by grinding [10].

The device for conducting accelerated tests of specimen wear resistance has the following components: a rotor with a central axis (1), an abrasive belt for grinding (2), a specimen holder (3), a lever (4) that holds the specimen, an electric motor with adjustable speed (5) and a control unit (6). All these components are mounted on a single platform.

Figures 1 and 2 show a schematic diagram and a view of the device. The samples of materials to be subjected to wear resistance tests are flat plates of size 60x40 and thickness of 3 mm. Table 1 shows the technical characteristics of the device.
Fig. 1. Installation scheme: 1 - rotor with axis; 2 - abrasive belt; 3 - sample holder; 4 - lever; 5 - electric motor, 6 - control unit.

Fig. 2. Installation photo

### Table 1. Technical characteristics of the device.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Abrasive belt R60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressing force, N</td>
<td>17.417</td>
</tr>
<tr>
<td>Circle speed, s&lt;sup&gt;−1&lt;/sup&gt;</td>
<td>2.293×10&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Linear speed, m/s</td>
<td>1.8</td>
</tr>
<tr>
<td>Test time, min</td>
<td>5</td>
</tr>
</tbody>
</table>

Statistical processing of experimental data was performed using Microsoft Office Excel 2003 and Statistica v6.0.437.0.

To estimate the values obtained during measurements we used the mathematical expectation m:

\[
m = \frac{1}{n} \sum_{i=1}^{n} x_i,
\]

(1)
here $x_i$ is the result of $i$-th measurement out of $n$ results.

The standard deviation was used as a characteristic of the scatter of values:

$$
\sigma = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (x_i - m)^2}.
$$

To obtain an idea of the significance of the variation, the coefficient of variation was determined:

$$
v = \frac{\sigma}{m} \cdot 100\%.
$$

Student's criterion was used to exclude gross errors from the experimental data:

$$
t_{op} = \frac{|x_i - m|}{\sigma},
$$

here $x_i$ is the $i$-th measurement result

$m$ is mathematical expectation

If the experimental value of the criterion $t_{op}$ is greater than the tabulated value $t_{0.05}$ at a significance level of 0.05, this value is considered a gross error and is eliminated from the sample. The tabulated value $t_{0.05}=3.182$.

Wear resistance tests have been carried out on chrome-free coatings such as $B_4C$, $B_4C+Fe_2Al_5$, $B_4C+NIAL$, $B_4C+P-0.66$, $T15K6+HFC$, $C+T15K6$, $B_4C+P-0.66+WO_3$, $B_4C+Fe_2Al_5+WO_3$, $B_4C+Ni_2Al_5+WO_3$, $B_4C+P-0.66+FeSi (50\%)$, $B_4C+ P-0.66+FeSi (90\%)$, as well as materials Steel 65G (hardened), Steel 40 as standards.

3 Research results and discussion

Figure 3 shows a histogram with the wear of all tested samples.

![Fig. 3 - sample wear](image-url)

Wear resistance tests revealed that the coating containing boron carbide and additives P-0.66 and FeSi (90%) exhibited a minimum wear rate of 0.04 g. However, in practice it was found that this coating $B_4C+P-0.66+FeSi (90\%)$ also has increased brittleness, which leads to its intensive wear during operation in stony soils. Therefore, the use of such coatings for hardening of working elements of agricultural machines in stony soils is not rational. Instead, as hardening coatings it is recommended to use coatings based on $B_4C+P-0.66$, $T15K6+HFC$...
welding and similar variants, as they demonstrate wear resistance exceeding that of 65G steel after hardening by a factor of 4.

4 Conclusions

a) Coating B₄C+P-0.66+FeSi (90%) has the highest wear resistance, and the wear of this coating is 18 times less than that of hardened 65G steel. However, due to its high brittleness, the use of this coating is not rational.

b) Coating B₄C+P-0.66+FeSi (50%) has a wear resistance that is 4 times higher than that of hardened 65G steel. At the same time, this coating does not have an increased brittleness, which allows it to be used successfully for hardening of working elements of machines.

References

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6. V. F. Aulov, Y. N. Rozhkov // Technics and equipment for rural areas 2(296), 28-32 (2022)