EFFECT OF BULK CURRENT DENSITY ON TRIBOLOGICAL PROPERTIES OF FE-W, CO-W AND NI-W COATINGS

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Abstract: Evaluation of tribological behaviour of Fe-W, Ni-W and Co-W coatings produced by electrodeposition at various bulk current densities (BCD) was under investigation in the given study. BCD does not have essential effect on the microhardness and wear characteristics of Fe-W and Co-W coatings. But the scratch tests reveal the presence of such influence. These tests showed superior wear resistance for the coatings obtained at low BCD. It was found that BCD has influence on wear resistance of Ni-W coatings under dry friction conditions. The BCD also has an influence on the coefficient of friction of Fe-W and Ni-W coatings at dry friction conditions. However, such an effect is opposite to that, observed at the scratch test.

Keywords: Fe-W, Ni-W and Co-W coatings, bulk current density, friction, wear, scratch

1. INTRODUCTION

Coatings produced from the alloys of iron group metals with tungsten are finding increasing use for numerous technical applications, including their use as strengthening and anticorrosion coatings, electrocatalysts, materials having magnetic properties [1]. One of the widely used and available methods for their manufacturing is the electrochemical method [1-3]. The electrochemical method for producing such kind of coatings is based on the electrodeposition from the solutions containing complex ions of iron group metals and tungsten [1-3]. The electrodeposition of tungsten from aqueous solutions of its complexes do not occurs [1-4], however the introduction of iron group metals salts leads to the formation of tungsten alloys with the metal. Therefore such electrodeposition was named "induced codeposition" [1 - 3, 5]. The induced codeposition of tungsten with cobalt and obtaining of Co-W coatings has been described in [6], where size effect of microhardness of such coatings was observed. The mentioned study demonstrates that the microhardness values of the coatings obtained from the citrate and gluconate electrolytes are highly influenced by the bulk current density (BCD) and are less determined by electrodeposition parameters (current density, potential, temperature and hydrodynamic conditions). The meaning of such effect is related to dependence of the microhardness of the coatings produced at a certain current density (A/dm²) on the surface deposition area (for a fixed volume of the bath) or on the volume of the bath, when surface area is fixed. In [6] it was shown that the composition of the coatings (content of cobalt and tungsten) is independent from the BCD. Therefore, the authors assume that the microstructure of the obtained coatings should be responsible for changes in the mechanical properties. The subject of the present research is related to the investigation of the BCD effect on the tribological properties of the coatings based on the iron group metals alloys with tungsten, and namely Co-W, Ni-W and Fe-W coatings were under investigation.

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2. EXPERIMENTAL

Steel S45 having hardness of 800 ± 10 kg/mm² was used as a substrate. The samples were isolated with adhesive tape, than a window having given area was cut (Figure 1). The areas of S1 = 4.7 cm² and S2 = 7.6 cm² were available for deposition. The surfaces were rinsed with acetone, activated in sulfuric acid (10 wt. %) and then a nickel sublayer was deposited. Solution for nickel deposition was of the following composition: NiCl₂ • 7H₂O - 240 g/l and HCl - 80 g/l. Electrodeposition was carried out for 1 minute at a current density of 30 mA/cm².

The alloys electrodeposition was carried out from electrolytes having composition (g/l) given below, and under the following deposition conditions:

- **Co-W electrodeposition**: CoSO₄ • 7H₂O -14.9, Na₂WO₄ • 2H₂O - 16.5, C₆H₁₁NaO₇ 120; H₂BO₃ - 40.3, NaCl - 29.8, temperature 80 °C, i - 2 A/dm², pH 6.7, [6-8];
- **Ni-W electrodeposition**: NiSO₄ • 7H₂O - 16.9, Na₂WO₄ • 2H₂O - 46.2, Na₃C₆H₅O₇ • 2H₂O - 147, NaBr - 15.5, NH₄Cl - 26.5, temperature 75 °C, i - 5 A/dm², [9];
- **Fe-W electrodeposition alloy**: FeSO₄ • 7H₂O - 55.6, Na₂WO₄ • 2H₂O - 132, Na₃C₆H₅O₇ • 2H₂O - 97, C₆H₈O₇ - 32.6, temperature 70 °C, i - 2 A/dm² [10].

![Figure 1](attachment:image.png)

**Figure 1.** Sample drawing representing different surface areas for alloys deposition S1 and S2.

The variation of the BCD values was made by changing the area of electrodeposition and the electrolyte volume from 0.5 to 1 litter (Table 1).

**Table 1.** Electrolytes and parameters of electrodeposition.

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Area</th>
<th>Electrolyte volume, l</th>
<th>Current, mA</th>
<th>BCD, mA/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-W, citrate</td>
<td>S1</td>
<td>1</td>
<td>475</td>
<td>475</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0.5</td>
<td>760</td>
<td>1520</td>
</tr>
<tr>
<td>Co-W, gluconate</td>
<td>S1</td>
<td>1</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0.5</td>
<td>152</td>
<td>304</td>
</tr>
<tr>
<td>Fe-W, citrate</td>
<td>S1</td>
<td>1</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>0.5</td>
<td>152</td>
<td>304</td>
</tr>
</tbody>
</table>

The deposition time was estimated based on the current efficiency values of electrodeposition alloys and coatings having 20 μm thickness where produced. The area of graphite anode at electrodeposition was more than 10 times bigger than that of the cathode area.

The microhardness of the coatings as depth function was measured using CSM Mincocombitester (Switzerland) with a Vickers indenter at 500 and 1000 mN and loading time 15 s. The adhesion and wear of the coatings was measured using progressive load scratch method. The scratch starts with the load of 50 mN and finishes at 10000 mN, having loading rate of 10 N/min and scratch length - 4 mm. The equipment for scratch test was CSM Mincocombitester (Switzerland) having Rockwel indenter with tip with radius of 100 μm. The penetration and residual depth was measured along the scratch, as well as critical adhesion load.

Friction and wear tests were conducted in dry sliding friction conditions using ball-on-disc tribometer TRM-500 (Germany). The 6 mm ball, made of bearing steel 100Cr6, was reciprocated against tested
surface with a speed of 5 mm/s. The applied load of 25 N corresponds to 1 GPa maximum pressure in the contact. The displacement was 2 mm. The test duration was 600 fretting cycles. All the tests were performed at the ambient temperature of 20 °C.

Sliding friction was recorded during the test. After the test the wear track profile was measured perpendicularly to the sliding direction. The worn area in the profile is represented as wear rate. The morphology of wear track was investigated with optical metallographic microscope NIKON Eclipse (Japan).

3. RESULTS AND DISCUSSION

Figure 2 shows the measured values (with standard deviations) of coatings microhardness obtained for different materials and different values of BCD. It is clear that the maximum values of microhardness are achieved on the Fe-W coatings. Change in microhardness with the change of BCD is not detected (it is within the measurement error).

![Figure 2](image-url)

**Figure 2.** Microhardness of the obtained Fe-W, Ni-W and Co-W coatings.

While the maximum values of microhardness were obtained for Fe-W coatings, it was interesting to understand tribological behaviour of such coatings. It can be seen, that the scratch penetration depth and the residual depth after the scratch test is slightly less for the coatings obtained at lower BCD (Figure 3).

![Figure 3](image-url)

**Figure 3.** Scratch penetration (a) and residual (b) depths obtained for Fe-W coating for both S1 and S2 areas.

For Fe-W and Co-W coatings was no noticeable effect of BCD on their wear characteristics (Figure 4-6). However, for Ni-W coatings such an impact was detected (Figure 4). It should be noted that in this case the wear is higher for the coatings obtained at lower BCD (Figure 4).
Figure 4. Wear track cross section area depending on the coating surfaces type.

Figure 5. Wear track profiles (top) and optical images of S1 and S2 Ni-W coatings.
The lowest coefficients of friction are observed for Co-W coatings (Figure 7). There was no noticeable effect of BCD in this case. In contrast, a higher difference is observed for the Fe-W and Ni-W coatings. The coefficient of friction for coatings produced at higher BCD, is significantly lower (Figure 7).

Figure 7. Dependence of friction coefficient of investigated coatings from the type of the alloys and deposited surface, where surface S1< S2.

4. CONCLUSIONS

Research on tribological behaviour of Fe-W, Ni-W, and Co-W coatings produced by electrodeposition at various bulk current densities showed different BCD effect on the tribological properties. Thus, the
independence of the microhardness and wear characteristics on BCD for Fe-W and Co-W coatings were revealed. At the same time scratch tests showed the presence of such influence. These tests show greater wear resistance for the coatings obtained at low BCD. It was found that BCD has influence on wear resistance of Ni-W coatings under dry friction conditions. The BCD also has an influence on the coefficient of friction of Fe-W and Ni-W coatings in dry friction conditions. However, such effect is the opposite to that, observed in the scratch test.

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