Study of wear intensity of solid nanocoatings deposited on steel 1.2080 (X12)

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The wear resistance of hard nanocoatings - TiN, TiCN and nc-TiAlN/a-Si_3N_4 - deposited on tool steel 1.2080 (X12) was studied. One-factor experimental tests on specific wear intensity resulting from the load were performed. The research methodology is based on the volume of the removed material. Correlation dependences of the specific wear intensity on the load were found. A comparative assessment of the individual coatings was made and practical guidelines for their application were proposed.

Keywords: multilayer coating, wear intensity, PVD method

INTRODUCTION

Tool steel 1.2080 (X12) is widely used for the manufacture of cutting and forming tools for plastic deformation. The increase of the service life of these tools is achieved primarily by increasing the wear resistance of the cutting and forming elements [1, 2]. The chemical-thermal methods for coating [3-5] do not always meet the tribological requirements toward the forming tools made of X12 tool steel. Under certain operating conditions (high process temperatures) these tools are not sufficiently effective from a tribological point of view, which limits their wide application. This type of coating is further developed by adding different amounts of other elements during the process of laying in order to improve the physical, mechanical and tribological properties of the coating. For example, by adding carbon, TiCN is obtained which combines both the high hardness and the low friction coefficient of TiC with the high strength of TiN [6-8]. Adding aluminum and boron produces TiAlN, TiBN or TiB_2, respectively [9-14]. These additives improve the tribological characteristics of the friction surfaces [15-19], which leads to improvement of the dynamic behavior of the technological processes [9, 20, 21].

An important requirement is to apply coatings with small thickness (about 1-3 μm), which is achieved by the nanotechnologies of the vacuum deposition methods (PVD, CVD). These methods provide high purity, very good adhesion to the substrate, good uniformity and density of the layers, small residual stresses and microdefects in the structure, possibility for deposition of ultra-thin layers, very good possibilities for controlling the thickness, structure, mechanical stresses and other parameters of the layers, all listed leading to high quality of the obtained coatings [9, 22].

The results from numerous studies of various types of coatings deposited on a particular material reveal their tribological characteristics. However, no studies have been performed of the different hard-alloy coatings on the same material and no comparative analysis of them has been made. Such an analysis is important for the practical application of the coatings.

EXPERIMENTAL

This work aims at studying the specific wear intensity of TiN and TiCN hard coatings and of the nanocomposite coating nc-TiAlN/a-Si_3N_4 deposited on tool steel 1.2080 (X12), as well as at making a comparative analysis of these coatings and giving recommendations for their practical application.

- Samples of tool steel were made, with the following characteristics (Table 1):

Table 1.

Notation	EN	DIN	Böhler	DS
	1.2080	*X210Cr12*	*K100*	*X12*
Composition	C 2%; Si 0.1-0.4%; Mn 0.15-0.45%; Ni ≤0.4%; S ≤0.03%; P≤0.03%;Cr 11.5-13%			

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- The samples were subjected to heat treatment in the sequence: annealing, hardening and tempering with the following characteristics of the modes:
- Annealing - heating to a temperature of 800 - 850 °C, holding for 1 (one) hour and cooling with the furnace. Hardness after annealing - 230-250 HB;
- Hardening - heating in a vacuum furnace to a temperature of 1000-1050°C, holding for 35 minutes and cooling in a stream of nitrogen under pressure. Hardness after hardening - 64-65 HRC;
- Low-temperature tempering - heating to a temperature of 180-200°C for a minimum of 2 (two) hours after reaching the pre-set temperature and cooling in calm air. Hardness after tempering - 59-60 HRC.
- The samples were divided into three groups:
- group A: unhardened, ground to roughness Ra = 0.11 μm;
- group B: hardened to hardness HRC=59-60 and ground to roughness Ra = 0.11 μm;
- group C: hardened to hardness HRC=59-60 and polished to roughness Ra = 0.02 μm;
- Both the TiN and TiCN hard coatings and the nanocomposite coating nc-TiAlN/a-Si_3N_4 were applied by the electric arc PVD method in a vacuum chamber: coating thickness - 2 μm; temperature of coating - 300 ºC; hardness - (30-31) GP.
- Measurement of the parameters of the wear trace was performed with TESA microscope, magnification 100×.
- The specific wear intensity I_w was determined by the volume method, using the dependence [23, 24]:

$$I_w = \frac{V}{F.L}, \text{ mm}^3/\text{N.m}, \qquad (1)$$

where V is the volume of the amount of removed material (the trace), mm^3;

F is the normal load, N; L is the distance or the run of the sample relative to the counter-body, m.

- For more convenient, fast and acurate calculation of the parameters from the formula above, a program was generated in MS Excel [2].

RESULTS AND DISCUSSION

The experimental studies were conducted by the method "Ball on Flat Sliding Wear Test" with horizontal orientation of the tested surface (Fig. 1) on a SIIP-1 stand (Fig. 2) [23].

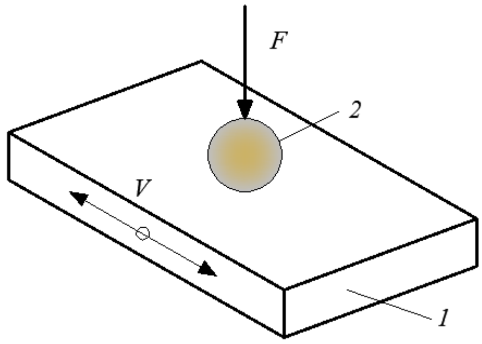

Fig. 1. Friction scheme according to the Ball on Flat Sliding Wear Test

Fig. 2. General view of a SIIP stand for testing wear resistance

The variable factor here is the load F (N), varying from 1 to 5 N. Three experiments were conducted for each value of the load. The constant factors are: the speed V=20 mm/s and the length of the distance L=75 m. The width of the trace is measured in five points and then the average value taken.

Table 2 presents the results for the specific wear intensity of the TiN hard coating, Table 3 gives the results for the specific wear intensity of the TiCN hard coating, and Table 4 shows the results for the specific wear intensity of the nc-TiAlN/a-Si_3N_4 nanocomposite.

Table 2.

TiN

Specific wear intensity as a function of the load I_w=f (N), V=20mm/s = const, L=75m = const

Load F, N	X12_A	X12_B	X12_C
1	4.175	13.547	12.266
2	2.312	14.492	10.161
3	6.121	15.018	13.942
4	19.547	14.561	12.914
5	19.368	13.977	12.657

Table 3.

TiCN

Specific wear intensity as a function of the load I_w=f (N), V=20mm/s = const, L=75m = const

Load F, N	X12_A	X12_B	X12_C
1	11.521	7.068	5.171
2	10.982	7.523	3.315
3	7.643	6.675	2.967
4	8.109	7.419	2.454
5	15.24	7.311	2.255

Table 4.

nc-TiAlN/a-Si_3N_4

Specific wear intensity as a function of the load Iw=f (N), V=20mm/s = const, L=75m = const

Load F, N	X12_A	X12_B	X12_C
1	88.893	79.084	75.547
2	73.956	82.279	80.098
3	71.327	60.414	86.778
4	70.603	62.255	83.009
5	199.839	84.985	121.515

The graphics and the correlation dependences of the wear intensity on the load for the different coatings are given in Figures 3, 4 and 5.

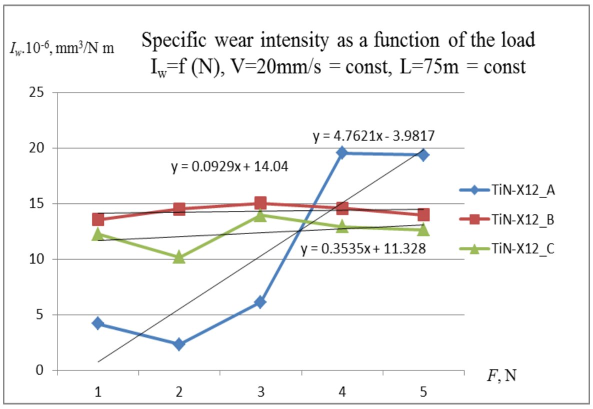

Fig. 3. Specific wear intensity for TiN, depending on the load

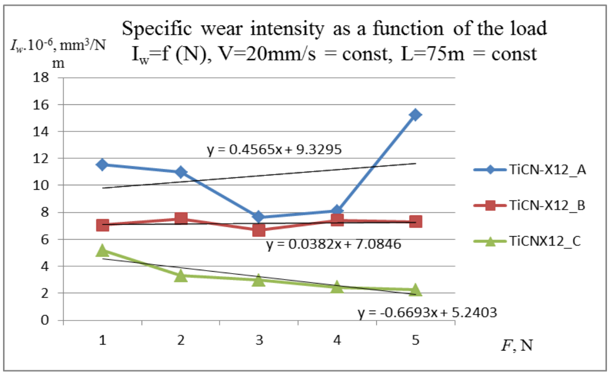

Fig. 4. Specific wear intensity for TiCN, depending on the load

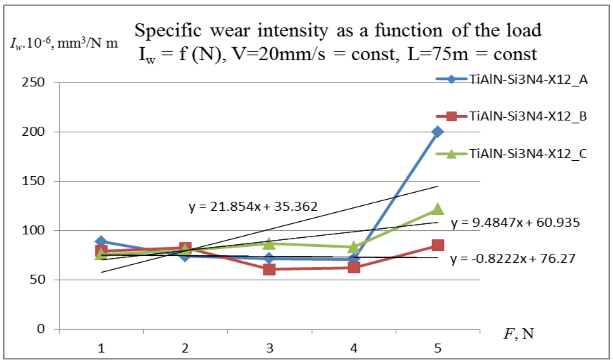

Fig. 5. Specific wear intensity for nc-TiAlN/a- Si_3N_4, depending on the load

A comparative assessment of the uncoated samples and the three types of coatings for the following surfaces was made: unhardened and ground (Table 5); hardened and ground (Table 6) hardened and polished (Table 7).

Table 5.

Specific wear intensity as a function of the load I_W = f (N), V=20mm/s = const, L=75m = const

Load N	E_X12_A	TiN-X12_A	TiCN-X12_A	TiAlN/Si_3N_4-X12_A
1	78.189	4.175	11.521	88.893
2	77.602	2.312	10.982	73.956
3	166.609	6.121	7.643	71.327
4	179.268	19.547	8.109	70.603
5	424.063	19.368	15.24	199.839

Table 6.

Specific wear intensity as a function of the load I_W = f (N), V=20mm/s = const, L=75m = const

Load N	E_X12_B	TiN-X12_B	TiCN-X12_B	TiAN/SI3N4-X12_B
1	5.2809	13.547	7.068	79.084
2	49.874	14.492	7.523	82.279
3	43.828	15.018	6.675	60.414
4	91.679	14.561	7.419	62.255
5	128.543	13.977	7.311	84.985

Table 7.

Specific wear intensity as a function of the load
I_w = f (N), V=20mm/s = const, L=75m = const

Load N	E_X12_C	TiN-X12_C	TiCN-X12_C	TiAlN/Si3N4-X12_C
1	62.075	12.266	5.171	75.547
2	87.334	10.161	3.315	80.098
3	90.493	13.942	2.967	86.778
4	146.221	12.914	2.454	83.009
5	287.34	12.657	2.255	121.515

The graphics and the correlation dependences of the wear intensity on the load for the uncoated samples and the three types of coatings, deposited on the different technological surfaces, are given in Figs. 6, 7 and 8.

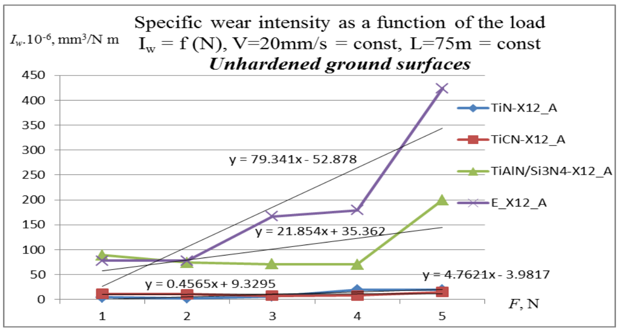

Fig. 6. Specific wear intensity as a function of the load for unhardened ground surfaces

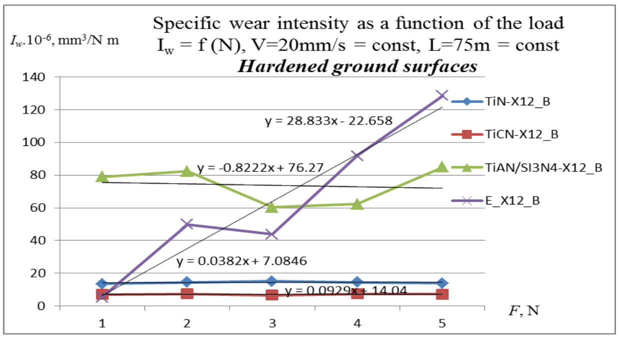

Fig. 7. Specific wear intensity as a function of the load for hardened ground surfaces

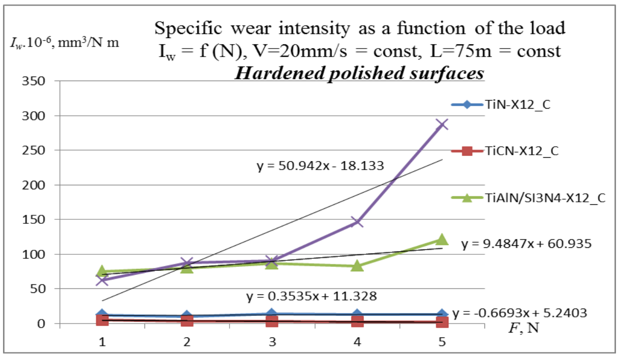

Fig. 8. Specific wear intensity as a function of the load for hardened polished surfaces

CONCLUSIONS

The following conclusions can be drawn from the analysis of the obtained experimental results:

1. TiN and TiCN hard coatings, applied by the PVD method on tool steel 1.2080 (X12), reduce the volume of the trace and the intensity of wear compared to uncoated surfaces.
2. The nc-TiAlN/a-Si_3N_4 nanocomposite, deposited on tool steel 1.2080 (X12), shows only slight improvement in the wear intensity, and with hardened ground surfaces even worsening is observed (Fig. 7), which may be due to the high brittleness of the coating, which cracks under load and forms abrasive micro-particles. This leads to increased abrasive wear. Similar results for this type of coating have been obtained in other studies [25].
3. It is recommended for equipment, made of tool steel 1.2080 (X12), with unhardened ground surfaces, subjected to intensive wear, to be coated with the hard coatings TiN and TiCN, showing the same wear resistance (Fig. 6).
4. It is recommended for equipment, made of tool steel 1.2080 (X12), with hardened ground and hardened polished surfaces, if subjected to intensive wear, to be coated with the TiCN hard coating, showing the best wear resistance (Figs. 7 and 8).

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