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Wear performance of PVD coated tool steels

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Abstract. The paper describes the performance of high alloy tool steels coated by PVD techniques. Performance evaluation was based on the wear resistance in the conditions of prevalence of adhesion and on tool wear (durability) in the conditions of blanking of electrotechnical sheet steel. Hardmetal (WC-15% Co) was used as a primary standard material. It is shown that adhesive wear resistance depends both on the composition of the PVD coating and on that of the tool material to be coated – steels with higher adhesive wear resistance ensure also a higher strengthening effect of the surface. Sharpening of specimens (cutting tools) – removal of coating at the face zone of the tool by grinding – revealed the difference in the efficiency of the coating in different zones of the tool. In terms of durability, thin PVD coatings do not enable improvement of the performance of sheet metal blanking tools (dies, punches). No correlation between durability in blanking and adhesive wear resistance was revealed. In terms of durability prognostication, alloys' (tool steels, hardmetals, cermets) adhesive wear resistance enables tool life assessment only when materials of similar nature (steels, carbide composites) are compared.

Key words: PVD coatings, wear, adhesive wear, blanking, tool steel, hardmetal.

1. INTRODUCTION

Tool life can be prolonged by application of high performance high-alloy tool steels or ceramic-metal composites (hardmetals, cermets). Application of ceramic-metal composites is limited by the size of the parts and the cost. For these reasons, tools from high-alloy steels, particularly these with coatings, are used. Thin but hard single or multilayer coatings like TiN, TiCN, (Al,Ti)N are widely used to protect tools against wear and corrosion. Use of thin coatings enables abrasion, adhesion and diffusion wear, and friction to be reduced and heat resistance to be enhanced [[1–3]].

Coating processes like chemical vapour deposition (CVD) and physical vapour deposition (PVD) are used to increase tool life. The reason that PVD has become increasingly favourable over CVD when coating high-alloy steels is the fact that the coating process occurs under much lower deposition temperatures (400–600 °C). Another advantage of the PVD technique is the ability to deposit much thinner films [4]. Due to advanced characteristics, PVD coatings are employed in various machining and abrasion applications [5–8].

Research, concerning prospects of coatings, in particular PVD coatings, for metalforming tools, working in prevailing adhesion wear conditions (in particular, sheet metal blanking tools), is comparatively restricted [7–10]. Therefore, the present study is focused on the performance of tool steels, strengthened by PVD coatings, working in adhesion wear conditions (testing of adhesive wear, metalforming, particularly blanking of electrotechnical steel). The high-alloy steels (high-speed steels), widely used in metalworking, were studied as tool materials. WC-Co hardmetal grade, widely used as a metalforming tool material, was used as the reference material. One of the aims was to investigate possibilities to forecast blanking tool durability by simple testing of wear resistance in the prevailing adhesion conditions.

2. EXPERIMENTAL DETAILS

2.1. Materials

High-performance tool steels were chosen as tool materials. Chemical composition and mechanical characteristics (hardness, transverse rupture strength R_{TZ}) of steels as well as the primary standard material (WC-Co hardmetal grade C13) are presented in Table 1.

Electrical sheet steel M700-50A was used as a work material in the functional testing (blanking) of tool performance. Band steel of a thickness of 0.5 mm and a width of 53.1 mm was used. Steel M700-50A is cold-rolled non-grain oriented steel (see chemical composition and mechanical properties in Table 2).

Coatings (TiN, (Ti, Al)N, TiCN) were deposited using Platit π-80 arc-ion plating PVD unit. The unit had two rotating ARC cathodes. The deposition temperature was 450 °C and coating thickness was set to 3.4 μm. Nanohardness of TiN, (Ti, Al)N and TiCN coatings was 25.0, 30.2 and 31.0 GPa, respectively.

Table 1. Composition and mechanical properties of the investigated tool materials

Tool material grade	Composition, wt%						Properties	
	C	Cr	Mo	V	W	Co	*HRA*	R_{TZ}, MPa
S390	1.6	4.8	2.0	5.0	10.5	8.0	83	4500
S690	1.33	4.3	4.6	4.1	5.9	–	83	4000
C13					85 WC	15	89	3100

Table 2. Composition and mechanical properties of the work material – steel M700-50A

Composition, wt%						Properties			
C	Al	Mn	P	S	Si	*HV*	R_{po2}, MPa	R_m, MPa	*A*, %
0.05	0.75	0.75	0.25	0.05	2.0	140	240	372	23

For the determination of adhesion of the coatings an experimental procedure, based on the CEN/TS 1071-8:2004 adhesion test was used [11]. Tests were performed on a Zwick/ZHR 8150 hardness tester. According to CEN/TS 1071-8, adhesion is divided into 4 categories: Class 0 – high quality, Class 1, Class 2 and Class 3 – poor quality. Coating adhesion was found to be sufficient (Class I – cracking without adhesive delamination of the coating) for TiN and (Ti, Al)N coatings – no delamination was observed. Adhesion of the TiCN coating was lower than in the other two coatings.

2.2. Testing conditions

Adhesive wear tests were performed by a cutting method, consisting of turning mild steel ($HV \sim 150$) at low speed ($V < 12$ m/min). Such testing conditions simulate mainly adhesive nature of wear in blanking of soft steel (Fig. 1) [12]. In previous studies an excellent correlation between the adhesive wear resistance and the wear of blanking dies was revealed [12,13]. The wear resistance was determined as the length of the cutting path $L_{0.3}$ when the height of the wear land at the specimen (cutting tool) nose achieved 0.3 mm.

Durability (blanking performance) test resembled that in service, i.e., blanking of grooves into electrical sheet steel (Fig. 2) by a 3-row die, reinforced with high-alloy tool steel S390 with and without coating (Table 3). Steel grade S390 was chosen for functional testing as a tool material with the highest adhesive wear resistance (see Section 3.1. of the present paper).

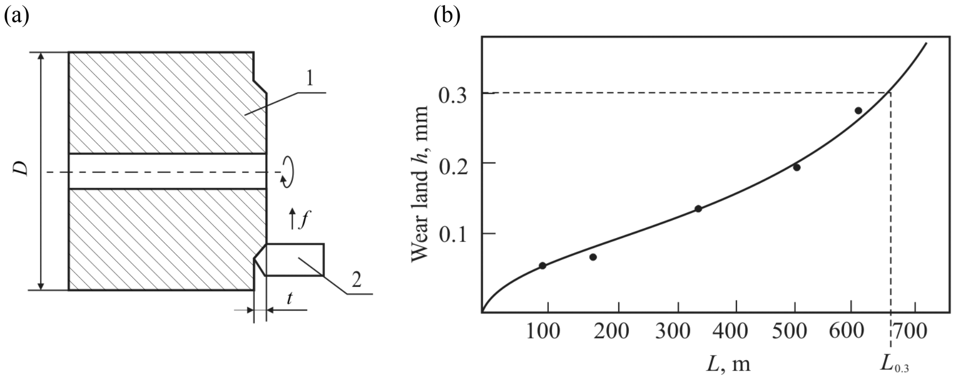

Fig. 1. The scheme of adhesive wear testing: (a) scheme of testing (1 – mild steel to be turned, 2 – specimen); (b) kinetics of wear ($L_{0.3}$ – adhesive wear resistance, L – cutting path).

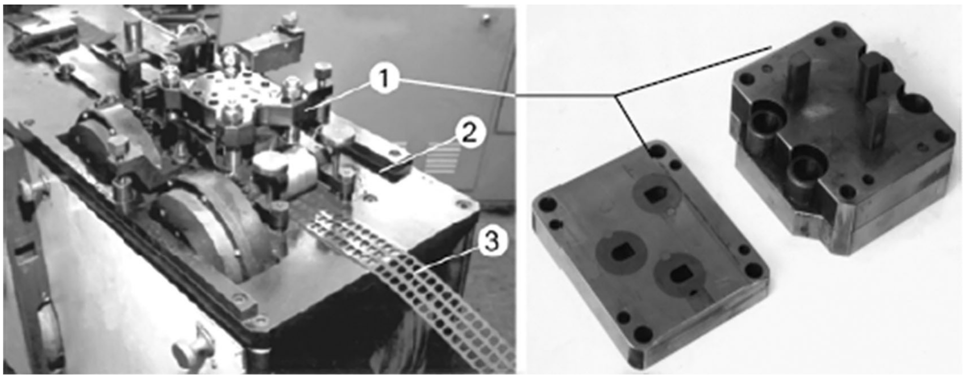

Fig. 2. Durability testing in the blanking of grooves into a steel sheet using three-row die, reinforced with alloys under investigation (1 – die, 2 – mechanical press, 3 – sheet steel band).

Table 3. Composition of a 3-position tool (die and punch) for functional testing

Position of die	Die and punch material grade	Coating
1	S390	–
2	S390	TiN
3	S390	(Ti, Al)N

The wear resistance (durability) was evaluated as the side wear of the die ΔD (increase in diameter) after an intermediate service time $N = 0.4 \times 10^6$ strokes (as $N/\Delta D$) [14]. The side wear was measured by the Mitutoyo STRATO 9-166 measuring machine in fixed environmental conditions (constant room temperature of 20 ± 2 °C and humidity of 40%) as an average of five measurements.

Hardmetal grade C13 (WC-15Co) was used as a primary standard tool material both in functional testing (tested at $N = 0.5 \times 10^6$ strokes) and in the testing of adhesive wear resistance.

3. RESULTS AND DISCUSSION

3.1. Adhesive wear resistance

Wear curves "*h–L*" of steels, coated by different PVD coatings, are presented in Figs 3 and 4. The performance (wear resistance $L_{0.3}$) of coated steels exceeds that of the uncoated ones. The results refer to a slight superiority of a TiN coating over the (Ti, Al)N one.

The results, presented in Figs 3, 4 and 5, show that the effect of PVD coatings depends both on the composition of a coating and on that of the steel substrate to be coated. Steel grade S390 with higher adhesive wear resistance ensures also a higher strengthening effect.

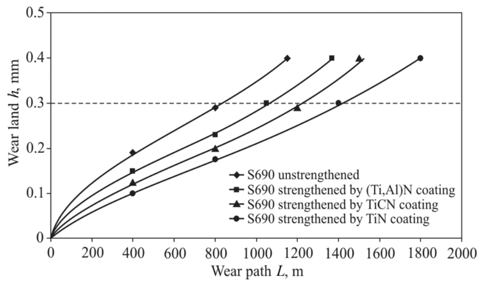

Fig. 3. Adhesive wear curves of steel S690, coated with PVD technique.

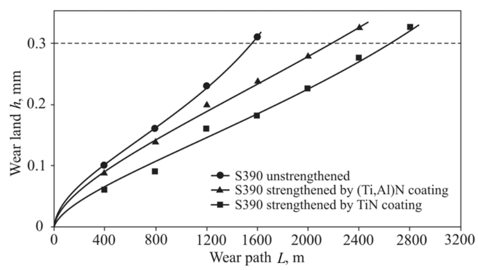

Fig. 4. Adhesive wear curves of steel S390, coated with PVD technique.

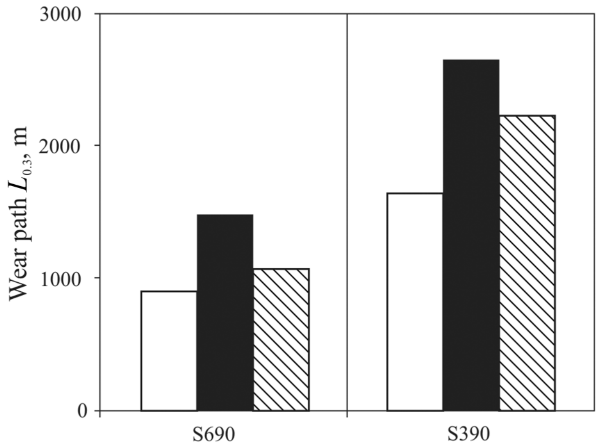

Fig. 5. Wear performance of tool steels (grades S690 and S390) coated by different depositions: □ uncoated, ■ TiN coating, ▧ (Ti, Al)N coating.

The removal of a coating (by sharpening) from the face zone of a specimen does not result in the decrease of wear resistance (Fig. 6). It means that there are differences in the effectiveness of a coating strengthening in different tool zones – it is remarkable in the flank zone (side wear) and uncertain at the face zone. It can be explained by the difference in the wear mechanism and in the state of stress at the face and flank surfaces of the tool and high brittleness of the coating deposited. It means that abrasive and adhesive wear takes place mainly on the side zone of a tool. Therefore, applying the coating to the face zone does not have marked influence on the tool life.

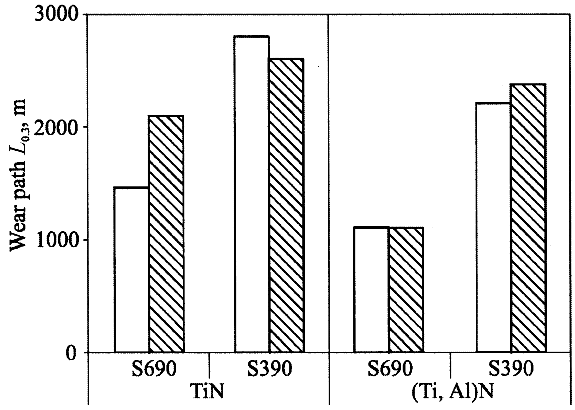

Fig. 6. Wear performance $L_{0.3}$ of the tool steels (grades S690 and S390), coated by PVD technique: □ all sides (flanks, faces) of the tool/specimen coated, ▧ the face zone of the die is sharpened (coating is removed by grinding).

3.2. Performance in the blanking of sheet steel

The functional performance (testing in blanking conditions) of the tool steel S390 (the best grade in adhesive wear tests) with thin PVD coatings was studied in the same conditions as the blanking performance of carbide composites in our previous research [12,13]. The results of functional tests are presented in Figs 7 and 8 as wear contours (side wear on the depth H from the cutting edge of a tool) after service time $N = 0.4 \times 10^6$ strokes.

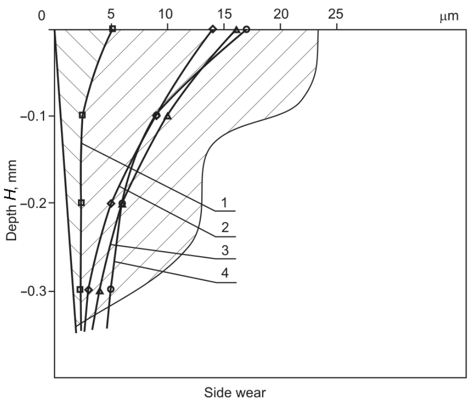

Fig. 7. Wear contours of blanking dies: 1 – hardmetal WC-Co grade C13 ($N = 0.5 \times 10^6$ strokes), 2 – uncoated steel S390, 3 – steel S 390 coated by (Ti, Al)N, 4 – steel S390 coated by TiN.

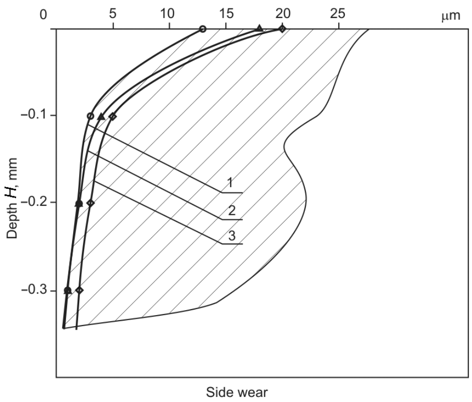

Fig. 8. Wear contours of blanking punches: 1 – steel S390 coated by TiN, 2 – steel S390 coated by (Ti, Al)N, 3 – uncoated steel S390.

Figures 7 and 8 show that the blanking performance of the tool steel S390 does not depend on the applying of thin PVD coatings. In other words, no advantages of the PVD coated tool over those of uncoated ones were revealed. Performance of a tool steel (coated or not) is approximately three times lower than that of a hardmetal.

Influence of thin PVD coatings on the blanking performance differs from that of PVD coatings on the adhesive wear performance, i.e., an obvious effect of coatings on adhesive wear resistance was found (Figs 3 and 4). It also contradicts to the results of performance in blanking and in adhesive wear conditions of carbide composites (WC-Co hardmetals, TiC-base cermets), demonstrating a good correlation between performance in banking and adhesive wear resistance [12]. Such a result can be explained by differences in the working conditions during adhesive wear tests (constant loading conditions, turning of soft steel at low speed) and sheet metal blanking (cyclic loading fatigue conditions accompanied by adhesive wear as well as by abrasion) [15].

In terms of durability, PVD coatings on tool steels used in the present research seem not to be effective in the strengthening of the surface of thin electrotechnical sheet metal blanking tools (dies, punches). In terms of forecasting durability of tools, made from different alloys (hardmetals, cermets, tool steels), testing of adhesive wear resistance (in the conditions used in this research) permits tool life to be assessed only when materials of similar nature (e.g., carbide composites or tool steels) are compared. Adhesive wear resistance cannot be used for forecasting when durability in the blanking of carbide composites and tool steels (both strengthened or not strengthened by coatings) have to be assessed.

4. CONCLUSIONS

Investigation of the performance of high-alloy tool steels with PVD coatings in thin sheet metal blanking and adhesive wear conditions has revealed the following.

- Adhesive wear performance depends both on the composition of the PVD coating and on that of the tool material to be coated, i.e., steels with higher adhesive wear resistance ensure also a higher effect of surface strengthening.
- Sharpening of the tool (removal by grinding the coating at the face zone of the die) showed a difference in the effectiveness of a coating in different zones of a tool.
- Using of PVD coatings on tool steels does not enable improvement of sheet metal blanking performance of dies and punches (in the conditions used in present research).
- In terms of forecasting possibilities of tool durability, made from different alloys (tool steels, hardmetals, cermets), testing of adhesive wear resistance enables tool life to be assessed only when materials of similar nature (steels or carbide composites) have to be compared.

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Õhukeste PVD-pinnetega tugevdatud tööriistateraste kulumiskindlus

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On käsitletud õhukeste PVD-pinnetega tugevdatud kõrglegeeritud tööriistateraste kulumist. Kulumiskindlust hinnati adhesioonkulumise prevaleerimise tingimustes õhukese elektrotehnilise terase väljalõikestantsimisel. Uuringutes kasutati etalonmaterjalina survega töötlemisel kasutatavat WC-Co kõvasulamit (WC-Co). Uuringud näitasid, et adhesioonkulumiskindlus sõltub nii PVD-pinde kui ka pinnatava tööriistaterase koostisest; suurema adhesioonkulumiskindlusega teraste tugevnemine PVD-pinnetega on suurem. Adhesioonkulumisel kasutatavate proovikehade teritamine (pinde eemaldamine lõiketera esitahult) näitas pinde erinevat mõju kulumisele proovikeha (lõiketera) erinevates piirkondades. PVD-pinded ei võimaldanud suurendada väljalõikestantside osade (matriitsid, templid) püsivust. Samuti puudus korrelatsioon pinnatud stantsiosade püsivuse ja adhesioonkulumiskindluse vahel. Stantside tööosade püsivuse prognoosimine adhesioonkulumiskatsete abil on võimalik vaid juhul, kui võrrelda ühe grupi tööriistamaterjale (näiteks karbiidkomposiidid või tööriistaterased).