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DRY SLIDING WEAR BEHAVIOUR OF PVD TiN COATINGS FOR COLD FORMING TOOLS

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ABSTRACT

TiN coatings are very common theme of scientific works and are largely used in metal cutting industry and cold forming processes. This work on quantitative way represents improvement, in terms of wear resistance, which is obtained by depositing of PVD TiN coating on substrate material. Wear testing is done on tribometer with block-on-disc contact geometry at sliding contact samples coated by TiN coating with steel disc. Testing was performed in dry sliding condition at variable value of contact parameters (normal load, sliding speed). PVD TiN coatings in all contact conditions show smaller values of wear degree.

Keywords: TiN coating, surface roughness, dry sliding, wear.

AIMS AND BACKGROUND

Intensive developing of complex physicochemical processes in surface layer represents main cause of losing work capabilities of technical systems, energy and material wasting. Optimum choice is surface layer of high quality on basic material, of lower value and price, which directly refers to coating technology. Since 70s of the last century, when intensive development of this kind of surface modification has begun, a large number of coatings have been developed, as well as technologies for their application. Thin hard coating applied on soft substrate proved as tribological very suitable. First commercial tribological TiN coatings are applied by CVD technology on the tools. In 1980s, with PVD technology de-

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velopment, their commercial growth begins. They were primarily used for cutting tools of high speed steel[1–4], but were soon used in other tribological applications, such as the case of drilling tools[5], drawing tools, milling cutters[6], mold punches[7], bearing, seals, as well as protection layer of erosive wear combination materials.

Tribological characteristic studies of TiN coatings are the subject of numerous studies both before and today. Number of papers containing 'TiN coating' in its title is over 35 000 and it grows intensively, which only tells about scientific and technological potential of these coatings.

In this way, suitable mechanical, physical, and chemical properties can be obtained, using thin and hard one-layer or more-layers coatings over conventional constructional material[8]. One of the biggest advantages of PVD method is relatively low temperatures necessary for TiN coating. That makes this method suitable for materials whose hardness can be affected by uncontrolled annealing in the coating chamber such as reinforced and high speed steels[9].

Numerous factors affect tribological coating characteristics, staring with substrate material on which the coating is being applied, the way of final processing, chosen way of deposition, while these factors directly affect the next one, also very important factor, adhesion between substrate material and the coating itself.

The primary objective of TiN coating is to reduce wear and extend the tools lifetime, therefore, great number of papers refer to wear in different exploitation conditions. A large number of parameters have influence on both wear mechanism, and quantitive wear value. Influence of certain coating deposition process and their parameters on tribological characteristics, especially on wear, is the subject of numerous studies[10–15].

Very influential factor, both on mechanical and tribological characteristics, is the material on which the coating is being deposited, as the way of its previous preparation[16]. Harlin has presented the influence of surface roughness of TiN coating on tribological characteristics[17].

Having a constant distribution of titanium interlayer thickness is not necessarily the best solution to achieve maximum performance in terms of wear resistance and hardness. The residual stress distribution along the thickness is unlikely to be constant with the inner layers being more stressed due to a greater amount of thermal differential strain. Influence of thickness on tribological characteristics is shown by Bemporad et al.[18], who concluded that thick coatings (i.e. >10 μm) were achieved by alternate multi-layering of TiN with Ti inter-layers, leading to a tougher and less-stressed film.

Material of counter-bodies has huge influence on wear resistance[19,20], primarily on wear mechanism, that is to say, on tribo-chemical processes which are occurring in the contact zone of two materials.

The aim of this paper is to present the benefit in the sense of reducing tool wear in metal forming processes using PVD TiN coatings. Therefore, when choosing contact parameters such as sliding speed and normal load it should be taken into account to match real exploitation conditions of these tools. The steel X165CrMoV12 is taken as the substrate on which the coating is being deposited and it is often used as a tool material in metal forming process. The paper presents the influence of PVD TiN coating on reducing wear values in comparison to substrate material in dry sliding conditions, as well as the influence of contact parameter change (normal load and sliding speed) on the value of wear degree.

EXPERIMENTAL

Material. Contact pairs are made of alloy tool steel with great toughness and hardness, label X165CrMoV12. This steel is wear resistant and scheduled to work on cold. Hardening in oil and loosening were done before mechanical grind processing. Mechanical characteristics are given in Table 1, and chemical composition in Table 2.

Table 1. Mechanical characteristics of alloy tool steel X165CrMoV12

Hardness after soft annealing (HB) max	Tensile strenght after soft annealing (MPa) max	Hardness after hardening in oil and loosening (HRC)	Measured hardness on the used tool (HRC)
250	830	57–65	58–63

Table 2. Chemical composition of alloy tool steel X165CrMoV12 (in mass %)

C	Si	Mn	P max	S max	Cr	Ni max	Mo	V	W
~1.65	~0.30	~0.30	0.035	0.035	~12.0	0.25	~0.60	~0.10	~0.50

In order to test them, the samples were coated with hard coating of titan-nitride (TiN). It should be pointed out that the substrate was heat-treated alloy tool steel X165CrMoV12.

TiN coating is done by RTB Bor PVD (Physical Vapour Deposition) technique – high-vacuum plasma deposition technology of hard layers depositing on contact surfaces.

Characteristics and conditions of applying TiN coating are as follows:

- microhardness: ≈ 2000 HV,
- layer thickness: 3–4 mm,
- adhesive force: over 50 N,
- application speed: 6–7 min/mm,
- time of application: 21 min,
- application temperature: 450°C,
- gold coating.

Tribological test. The specimens were tested using a block-on-disc sliding wear testing machine with the contact pair geometry in accordance with ASTM G 77-83. A schematic configuration of the test machine is shown in Fig. 1. More detailed description of the tribometer is available elsewhere[21]. The wear behaviour of the block was monitored in terms of the wear scar width – *h* (Fig. 2). Using the wear scar width and geometry of the contact pair the wear volume (in accordance with ASTM G77-05) and wear rate (expressed in mm^3) were calculated. The repeatability of the results for replicate tests was found as satisfactory (variation of wear scar width was under 5%). The test block was loaded against the rotating steel disc. This provides a nominal line contact Hertzian geometry for the contact pair.

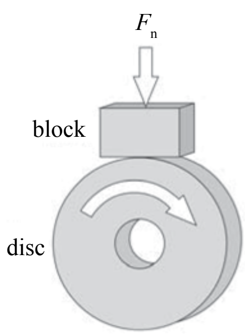


Fig. 1. Scheme of contact pair geometry

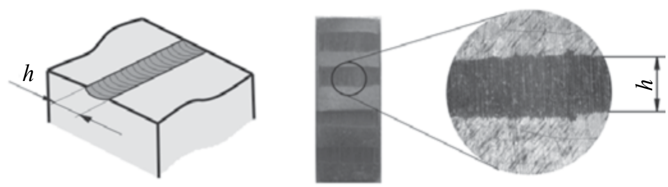


Fig. 2. Wear scar

The test blocks (6.35×15.75×10.16 mm) were prepared from tool steel X165CrMoV12, while one part of the samples is TiN coated. The values of surface roughness were measured on the prepared samples before and after depositing

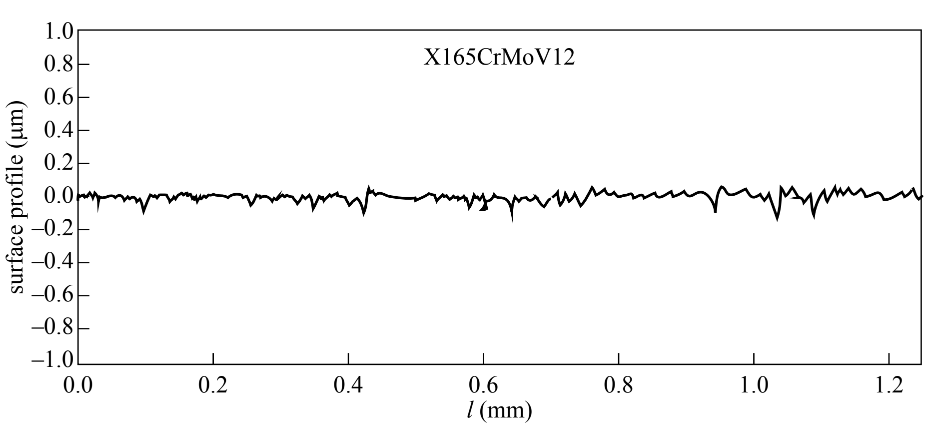


Fig. 3. Surface profilometer X165CrMoV12

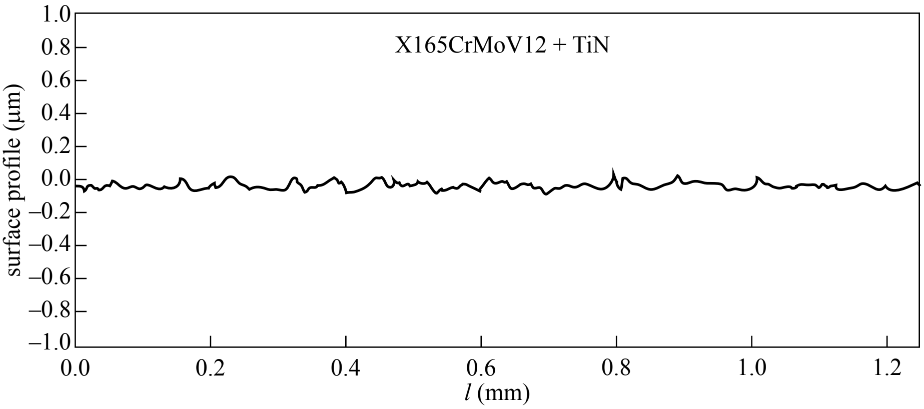


Fig. 4. Surface profilometer X165CrMoV12 + TiN

of coating. Measuring of surface roughness was done on Talysurf 6 device and appearance of material layout in surface layer on referent length $l = 1.2$ mm, is shown in Figs 3 and 4.

Surface roughness of sample, without coating was $R_a = 0.01$ μm, and with TiN coating was $R_a = 0.02$ μm, which suggests that after deposition there was no serious change of surface roughness.

The counter face (disc of 35 mm diameter and 6.35 mm thickness) was made of EN: HS 18-1-1-5 tool steel of 62HRC hardness. The roughness of the ground contact surfaces was $R_a = 0.45$ μm. The tests were performed in dry sliding conditions at sliding speeds (0.25–1 m/s) and applied loads (10–50 N). Each experiment was repeated five times. Sliding distance for all tested samples was 200 m. All tests were carried out at a temperature 23±2°C and relative humidity 65–70%.

RESULTS AND DISCUSSION

In the paper steel samples are tested with and without coating in order to quantify the improvement of coating to wear resistance in relation to substrate material. Prepared samples are tested in dry sliding condition, with varying values of sliding speed and normal load. Sliding speed in contact was taking three values 0.25, 0.5 and 1 m s^{-1}.

The normal load value also had three values 10, 30 and 50 N during the tests. The normal load values are selected to avoid coating perforation during the testing, which was achieved.

Figure 5 shows diagram of wear rate dependence on change of normal load value with constant sliding speed value in contact zone. The figure clearly shows that, with increase of normal load in contact zone, the wear rate of all tested samples increases. It is also clear that wear rate of TiN coatings in relation to the sam-

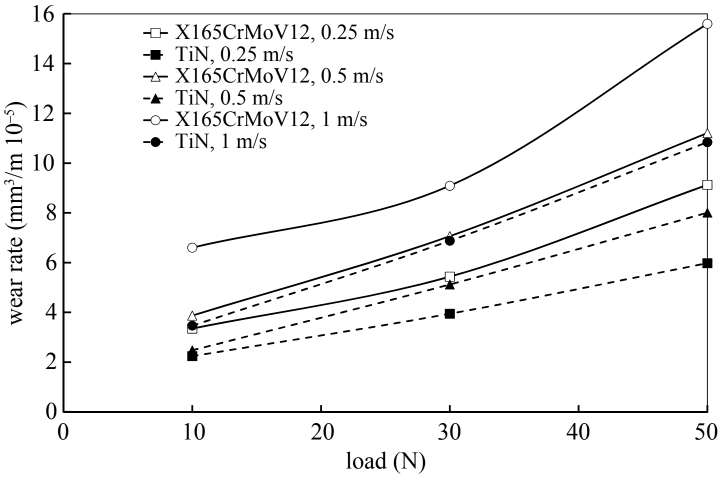


Fig. 5. Wear rate dependence of tested samples on the normal load value (10, 30 and 50 N)

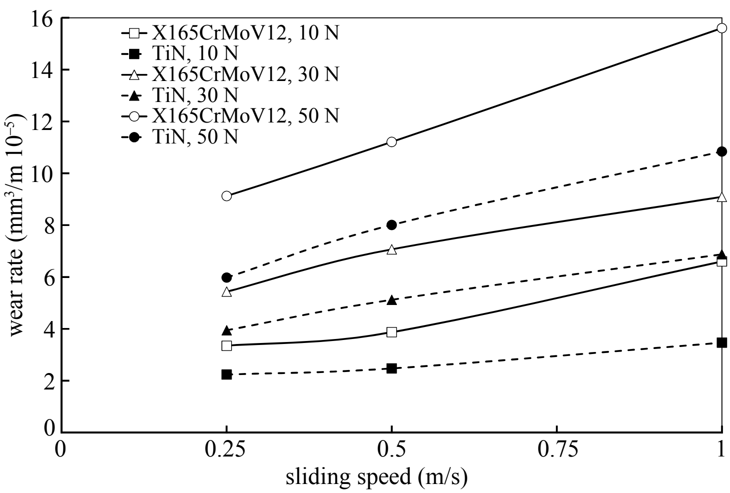


Fig. 6. Wear rate dependence of tested samples on sliding speed (0.25, 0.5 and 1 m s^{-1})

ples without coatings for the same values of tested parameters is always smaller. Wear rate for steel samples at the highest speed of 1 m s^{-1} stands out among the results. At this speed with increase of load it comes to expressive increase of wear rate, based on which we can conclude that further increase of normal load would very quickly cause catastrophic wear of tool material in metal forming application.

Figure 6 shows diagram of wear rate dependence of tested samples on sliding speed change, at constant values of normal load in contact zone. It is obvious that with increase of sliding speed value it comes to slightly increase of wear rate

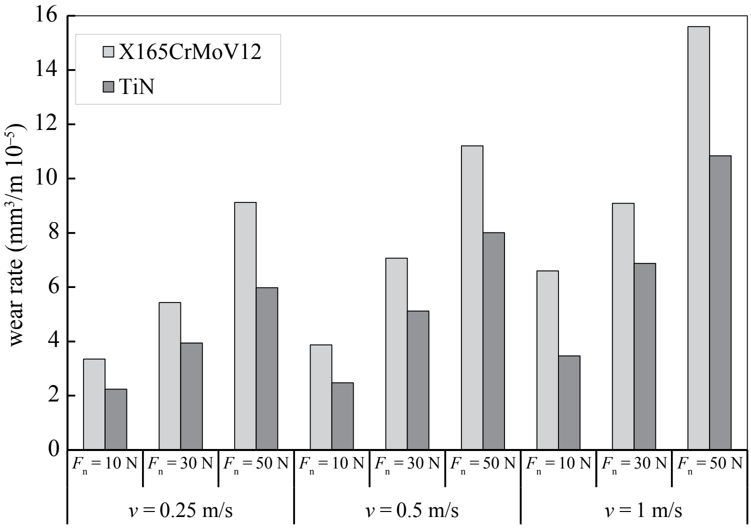
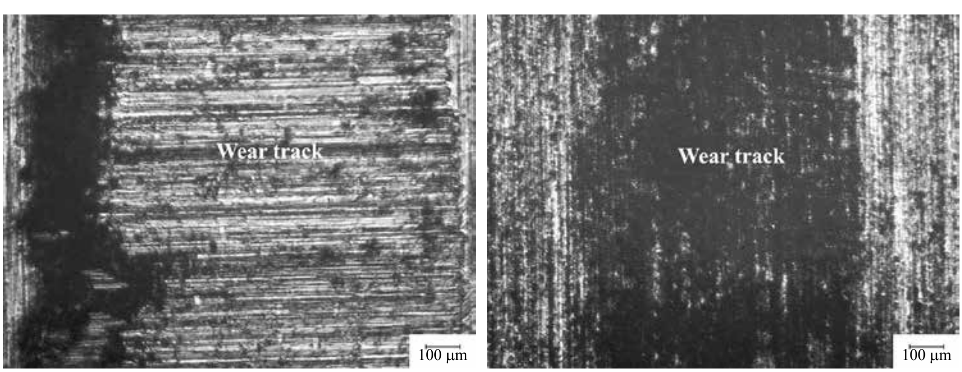


Fig. 7. Histogram display of wear rate value for tested samples

with all tested samples, except in the case of steel samples without coating. Also, it should be noted that wear rate value of the sample with TiN coating is always lower in comparison to the samples without coating for the same values of sliding speed and normal load.

For better quantification of TiN coatings advantage in comparison to the samples without coating, histogram display of wear rate value is shown (Fig. 7). The samples, on which TiN coating is deposited for the same values of contact parameters, show 20–40% less wear rate values.



a *b*

Fig. 8. Display of wear tracks after sliding distance of 200 m, normal load value of 50 N and sliding speed of 1 m s^{-1}
a – without coating; *b* – TiN coating

Figures 8 show typical wear tracks of tested samples in dry sliding conditions. Regardless of the value of contact parameters there was no coating penetration, which can be seen on Fig. 8*b*. Based on the appearance of wear tracks at samples with and without coating we may say that the basic wear mechanism is abrasive wear. At the very beginning of making contact we can talk about adhesive wear, which is the consequence of contact block-on-disc, or high contact pressures which appears when contact is achieved only on the peaks of prominences. With further development, the wear from linear contact gradually transits into contact on surface where the titanium oxides created in contact TiN coating with steel, act as abrasive. Based on that dominant wear mechanism is abrasive wear.

CONCLUSIONS

The results of wear studies, carried out to quantify the influence of TiN coatings on material wear resistance in application of metal forming, showed that in all contact conditions TiN coatings have lesser wear rate values in comparison to the material without coating. Based on the results, we can conclude that advantages of TiN coating in terms of wear resistance, in dry sliding conditions, in comparison to material without coating, have bigger influence at sliding speed values higher than 0.5 m s^{-1} and normal load value higher than 20 N.

These results are consequences of expected, by numerous studies confirmed, mechanical and tribological characteristics of TiN coatings. Based on that we can conclude that by TiN coating of material, the significant increase of tool lifetime in metal forming application is acquired, which is expressed at higher values of contact load and sliding speed.

In the dry sliding conditions, TiN coatings have proven as economically payable which is reflected in decreasing wear degree of tools, in some cases up to 40% in comparison to surfaces without coating.

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