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WEAR RESISTANCE OF THE MODIFIED SURFACE OF THE CUTTING TOOL

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ABSTRACT. A way to improve cutting tools is a new kind of multilayered coatings that combine wear resistance and antifriction properties to be developed. The objective of the present work is to study effects of antifrictional sublayer composition on the life of cutters with these engineered coatings and to finding scientific basis for developing multilayered coatings with programmable change of properties, providing each layer of the coating to fulfill a given function at a certain stage of wear. The 'triplex' multilayered coatings are studied. The coating was deposited using three units. Used as the base, the high-speed steel (HSS) was previously nitrided in the glow discharge. Then the tool surface was modified by ion doping prior to applying the hard coating. Finally, the modified layer was deposited with the (Ti, Cr)N □ coating by the PVD method. Researches show that the mixing of antifrictional alloys, that is widely used to improve conditions of sliding friction, allows to increase the tool life not more than two times. This way of the tool life increase, reduces the shear strength of adhesion bonds developed between the tool and the workpiece does not seem to be the most efficient one for the multilayered coating under analysis. For almost all studied antifrictional materials, the adhesion of the coating to the modified surface was rather low. This precludes their practical application due to technological reasons. Implanting the chemical elements makes possible better results to be obtained. Such elements as indium, silver and nitrogen enhance the tool life by 2 – 3 times under different cutting conditions (with and without cooling). The obtained results can be regarded as regular. Indium and silver are the least interactive ones with ferrum, and they can be used as metal lubricants. They promote a crushed chip forming at cutting using coating under the study. Ion modification of the tool surface with other studied elements exhibits unstable or negative effects, i.e. reduction of tool life and failure to provide high adhesion between the hard coating and the substrate.

ИЗНОСОУСТОЙЧИВОСТ НА МОДИФИЦИРАНАТА ПОВЪРХНОСТ НА РЕЖЕЩИЯ ИНСТРУМЕНТ

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РЕЗЮМЕ. Начин за подобряване на режещите инструменти е разработването на многослойни покрития, които комбинират износоустойчивост и антифрикционни свойства. Цел на настоящата работа е изследването на влиянието на антифрикционния подслой върху експлоатационния срок на инструментите с такива покрития и да създаде научна основа за разработване на многослойни покрития с програмирана смяна на свойствата така, че всеки слой от покритието да изпълнява определена функция на даден етап на износването. Изследвани са „триплексовите” многослойни покрития. Полагането на покритието се извършва на три етапа. Използваната за основа бързорежеща стомана (HSS) предварително се азотира с тлеещ разряд. След това, преди нанасянето на твърдото покритие, повърхността на инструмента се модифицира чрез добавяне на йони. Накрая, върху модифицираната повърхност по PVD метод се отлага (Ti, Cr)N покритието. Изследванията показват, че комбинирането на антифрикционни сплави, широко използвано за подобряване на условията на триене, позволяват удължаване на експлоатационния срок на инструмента с не повече от два пъти. Този начин на удължаване на експлоатационния срок намалява якостта на срязване на адхезионните връзки между инструмента и заготовката и не е най-ефективния при анализираноте многослойно покритие. При почти всички изследвани антифрикционни материали, адхезията на покритието към модифицираната повърхност е доста малка, което практически прави приложението им невъзможно по технологични причини. Внедряването на химически елементи позволява постигането на по-добри резултати. Елементи като индий, сребро и азот удължават експлоатационният срок 2-3 пъти, при различни условия на рязане (с и без охлаждане). Получените резултати могат да се разглеждат като стабилни. Индият и среброто взаимодействат най-слабо с желязото и могат да бъдат използвани като метални лубриканти. Чрез използването им в изследваните покрития, те спомагат за образуването на елементообразна стружка в процеса нарязане. Йонното модифициране на повърхността на инструмента с други елементи показва нестабилни или отрицателни резултати, т. е. намаляване на експлоатационния срок и невъзможност да се осигури адхезия между твърдото покритие и основния материал.

1. Introduction

One way to improve cutting tools is it to develop a new kind of multilayered coatings that combine wear resistance and antifriction properties (Such coatings appeared quite recently. The reason of keen interest in such coatings is well grounded. It is known that high wear resistance of hard coating tools is determined by their acting as a shield to contact surfaces of a tool, thus, protecting them from external effects at cutting. Mostly this happens during the stationary stage of wear (phase of normal wear). Yet the inevitable wear of a coating leads to the exposure of a base material whose frictional properties are considerably worse than those of a coating. Consequently, tool wear quickly enters its catastrophic stage. Prolongation the stage of normal friction, however, is quite feasible. This is achieved by applying an additional sublayer in the multilayered coatings onto the surface of tool base. The layer can combine antifrictional properties and ability to generate the protective secondary structures at the coating substrate interface.

The objective of the present work is to study effects of antifrictional sublayer composition on the tool life of cutters with these engineered coatings and to finding scientific basis for developing multilayered coatings with programmable change of properties, providing to each layer of the coating fulfilling a given function at a certain stage of wear.

2. Experimental materials and techniques

In this work, we have studied 'triplex' multilayered coatings. The coating was deposited using three units. Used as the base, the high-speed steel (HSS) was previously nitrided in the glow discharge [1]. Then the tool surface was modified by ion doping prior to applying the hard coating. Finally, the modified layer was deposited with the (Ti, Cr)N □ coating by the PVD method.

Ion nitriding of the HSS substrate was produced in a special ion nitriding unit with combined heating. The technological parameters were as follows: glow discharge current density, 3 A/m2; time of nitriding, 0.5 h; gas pressure 266 Pa; gas composition, 25% N2 + 75% H2 (dissociated ammonia); temperature, 500°C.

Hard coating was deposited by the cathode arc plasma deposition process (CAPDP). Parameters of deposition were as follows: gas-reagent (nitrogen) pressure, 3·10-1 Pa; arc current, 100 A; bias voltage, 200 V; focusing coil current, 0.2 A; deposition temperature, 500°C.

Before applying the PVD coating, the common set of the samples was implanted with ions of 16 various elements by using a high-energy ion implanter with energy of approximately 60 keV at the room temperature. Typical doses to be used were 4·1017 ions per cm2. Prior to ion implantation of the studied elements surface etching by argon ions was performed. To minimize surface contamination, a cold trap was used during implantation to maintain a low background pressure of about 2·106 Torr. The base HSS was of M2 type (AISI) and it contained 0.8-0.88% C; 5.0-5.5% W; 5.0-5.5% Mo; 3.8-4.2% Cr; 1.7-2.1 % V; Fe-balance, wt.%.

The atomic concentration of the implanted elements was analyzed by the X-ray microanalysis using the scanning electron microscope JSM-U3 equipped with a double crystal wave dispersive spectrometer. These concentrations were about 1.0-1.5 at.%.

Chemical composition of secondary phases emerging on the tool surface at cutting was studied by means of secondary ion mass spectroscopy (SIMS). This was carried out with the aid of an ESCALAB MK2 (VG) electron spectrometer equipped with an SQ300 ion analyzer of quadrupole type and AG-61 scanning ion gun, which allows the flow of argon primary ions with energy up to 5 keV to be focused on a spot up to 0.5 □m in diameter on the surface of a sample. Ion etching speed was in the order of 0.2 monolayer per min; the analysis was carried out in the static mode. We studied the average chemical composition of the wear zone of the coating out of the build-up.

The 16 chemical elements preselected for this work were applied for ion modification of the surface. The elements can be grouped as follows:

1. high oxidizing capacity elements creating dynamic stable protective surface films at friction, e.g. O, N, J and Cl;

2. nonmetals able to create compounds of high tribotechnical properties (B, C, Si) when interacting with base materials and environment elements;

3. metals including:

3.1 low-melting ones (in particular In, Mg, Sn, Ga) used as lubricants or antifriction materials;

3.2 Co-type metals with a hexagonal lattice and antifrictional properties [3, 4];

3.3 metals (Al, Cr) able to form oxide-like films, stable at cutting, with good antifrictional properties, and a low coefficient of thermal conductivity;

3.4 metals with a low coefficient of friction when in contact with principle machined materials (steel, nickel and titanium alloys), those are Ag and Cu.

Selecting metal materials, we took into account the well-known research on tribological compatibility of contacting elements. The chosen for analysis were elements least compatible in tribocouples with ferrum, nickel, and titanium, i.e. with metals found in the composition of low alloyed, heat-resistant and non-corrosive steels as well as titanium alloys widely used in machining. Moreover, the surface was subjected to mixing with four types of antifriction alloys often used to improve conditions of sliding friction, in particular the zinc-based alloy Zn + Al (9%) + Cu (2%); the copper-based alloy Cu + Pb (12%) + Sn (8%); the lead-based alloy Pb + Sn (1%) + Cu (3%); and the aluminum-based alloy Al + Sn (20%) + Cu (1%) + Si (0.5%).

Wear of coatings was studied while turning carbon steels containing 0.45% of carbon. The cutting speed being 270 m/min, cutting depth 0.5 mm, feed 0.28 mm/rev. Cutting was made both with and without a coolant. Impact of ion modification of the surface on tool durability was determined by comparing the cutting time for tools with proposed multilayered coatings (surface engineered coatings + ion modification) and for that with surface engineered coatings without additional ion modification. The durability coefficient of a tool was determined from the ratio of the time necessary for cutting to a specified wear value in a multilayered coating tool (surface engineered coatings ion modification) and that in a surface engineered coating tool ((Ti, Cr)N+ ion nitriding) whose durability coefficient was adopted as a unit. Not less than eight cutting tests were performed for each kind of surface modification (two tetragonal inserts were studied). The scatter the of tool life measurements was near 10%.

Friction coefficients were determined with the aid of a special design adhesiometer [2]. Inside the above-mentioned adhesiometer, a rotating sample with coatings under investigation was placed between two polished specimens made of low-alloyed steel containing 0.45% of carbon. To simulate tool friction conditions, the specimens were heated by the electrocontact method in the temperature range from 150 to 550°C. The standard force comprised 2400 N, this providing for plastic strain in the contact zone. To evaluate antifrictional properties of a layer, we used the adhesion component of the friction coefficient. This component is mainly responsible for HSS-tool catastrophic wear stage intensity (when the seizing phenomenon occurs). It was determined as the ratio of the shear strength induced by adhesion bonds between the tool and the work-piece to the normal contact stress developing on the contact surface at the test temperatures (Tnn/Prn).

As it can be seen, ion modification of the cutting tool surface significantly affects the tool life. In our opinion, the increase in tool life is caused by a complex combination of numerous interacting factors. Here, belong the factors, which make it possible:

to form liquid and gaseous phases or low-melting eutectics which act as lubricants;

to develop amorphous oxygen-containing films with low coefficients of friction and thermal conductivity;

to reduce sticking of the tool surface to the processed material and, at the same time, to increase adhesion of the hard PVD-coating to the modified base.

3. Results and discussion

Data from Table 1 show that the mixing of antifrictional alloys, that is widely used to improve conditions of sliding friction [3], allows to increase the tool life not more than by two times. This way of the tool life increasing, reduce the shear strength of adhesion bonds developed between a tool and a workpiece does not seem to be the most efficient one for the multilayered coating under analysis. For the almost all studied antifrictional materials, the adhesion of the coating to the modified surface was rather low. This precludes their practical application due to technological reasons (possibility of coating peeling).

Implanting the chemical elements makes it possible to gain better results. Such elements as indium, silver and nitrogen enhance the tool life by 2 – 3 times (see Table 1) under different cutting conditions (with and without cooling). The obtained results can be regarded as regular. Indium and silver are the least interactive ones with ferrum, and they can be used as metal lubricants. They promote a crushed chip forming at cutting using coating under the study. Ion modification of the tool surface with other studied elements exhibits unstable or negative effects, i.e. reduction of tool life and failure to provide high adhesion between the hard coating and the substrate.

Table 1

Number tables in a consecutive order (10-p., italic)

№	Material (subgroups)	Element compo-sition	Coefficient of PVD-coating adhesion to modified surface base	Durability coefficient at cutting	
				Without coolant	With coolant
Surface modified by ion implantation					
1.	Elements with high oxidation power	O	0.25	0.9	1.25
		N	0.41	2.0	1.83
		I	0.7-0.8	3.2	0.7
		Cl		1.8	
2.	Nonmetals	B	0.6	1.2	0.65
		C	0.6	1.7	0.83
		Si		0.7	0.6
3.	Metals				
a	Low-melting	In	0.6	2.4	2.1
		Mg	0.25	3.0	0.08
		Sn	0.6	0.8	0.7
		Ga		2.0	
b	With hexagonal lattice	Co	0.5	1.8	0.13
c	Forming stable oxides	Al	0.4	0.15	1.3
		Cr	0.6	0.2	1.2
d	With low coefficient of friction	Cu	0.55	1.0	2.5
		Ag	0.4	3.1	2.7
Surface modified by antifriction materials (mixing)					
4	Zn-Al-Cu 9-1.5 GOST 21437-75 (Russia)	Zn + Al (9%) + + Cu (2%)	0.44	1.98	–
	Bronze 8-12	Cu+Pb (11%) + + Sn (9%)	0.4	0.95	–
	Babbitt BK2 GOST 1320-74 (Russia)	Pb +Sn (1.5%)	0.35	0.6	–
	Al-Sn-Cu AO20-1 GOST 14113-69 (Russia)	Al + Sn (20%) + +Cu (1%) + Si (0.5%)	0.3	0.4	–

From our point of view, the most preferable, with regard to the complex of properties, is coating with an implanted layer of In that does allow to increase the tool life up to the maximal one, independently being it with or without a coolant (Table 1). At the same time, adhesion between the coating and the base surface modified with indium is also sufficiently high, this attesting the reliability of the coating as a whole.

Examination of the temperature dependence of the friction coefficient for specimens with the modified surface demonstrated that In improves the frictional properties of HSS (Fig. 1). Acting as a lubricant, In mainly reduces the shear strength (τ_{nn}) of adhesion bonds developed in tribocouples.

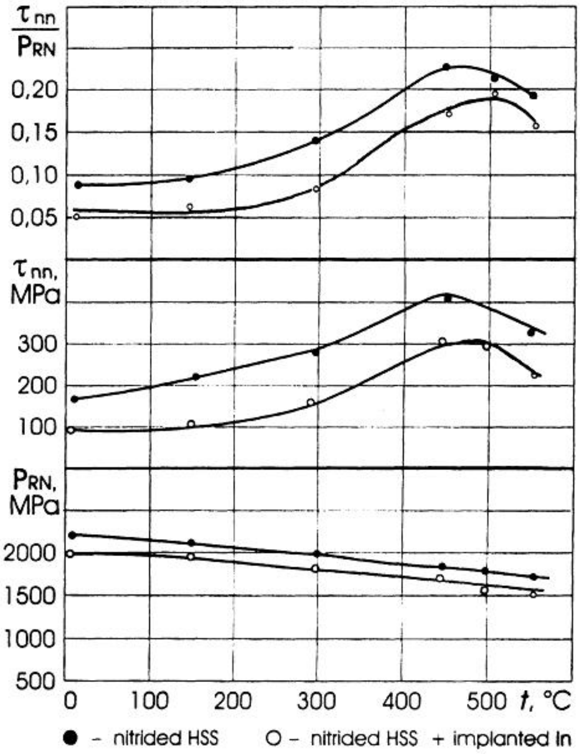

Fig. 1 Impact of test temperature on the frictional properties of the surface modified HSS

This, however, is insufficient to account for more than two-fold growth of tool life in cutters with the In-modified surface. As is shown by the mass-spectrometric analysis of the wear zone, the impact of In is more complicated. Apart from a metal indium, the wear zone reveals the presence of the indium oxide, resulting from both In and In-N dissociated upon heating at friction.

Optimizing the technology of implantation and mixing, we possibly can augment the positive impact of ion modification on tool wear. We also can predict the advisability of combining the ion implantation and the PVD-processing within a unified technological cycle and single multipurpose equipment for application of coatings.

4. Conclusion

This work considered some ways improving the surface engineered coatings developed through double step hardening of the tool surface layer: by diffusion saturation with nitrogen (ion nitriding of HSS) and by applying a wear-resistant coating with complexly alloyed nitrides (Ti, Cr)N using the cathode arc plasma deposition process (CAPDP). The coating includes an additional modified sublayer applied while ion doping the surface of the high-speed steel previously nitrided in the glowing discharge. Such multilayered coating allows to significantly increase the tool life due to the increased stage of normal wear.

Investigated were effects on the HSS tool life of 16 chemical elements implanted into the base surface and those of four antifrictional materials. The optimal combination of high durability and reliability (characterized by a high adhesion of the coating to the base) is exhibited by the multilayered coating with an In-enriched sublayer. This element is present in the sublayer both in metal and bound (In-N) states.

Positive effects of In implantation on tool life was explained by complex processes. Acting as a liquid metal lubricant at cutting temperatures, indium encourages reduction of the friction coefficient. Besides, when a cutting tool is heated under friction, the oxygen-containing phases are developed on wear surface, that protects the tool, delaying the transition from normal to avalanche-like wear. This allows to increase the stage of normal wear and considerably increases the tool life.

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