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Application of hard coatings for blanking and piercing tools

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ABSTRACT

The aim of the present investigation was to examine the possibility of reducing lubrication and replacing expensive tungsten carbide material in blanking/piercing through introduction of hard tool coatings. Results show that hard PVD coatings can be successfully used in blanking/piercing applications, even on softer tool steels, thus leading to reduced friction and wear as well as to lower costs of the tool. However, preparation of the substrate material and good coating to substrate adhesion are crucial. On the other hand, even with the use of low friction coating (DLC) stamping force exceeds critical value under dry friction conditions and leads to tool failure. Therefore, at present oxidation and temperature resistant hard coatings can give improved wear resistance of stamping tools, but elimination of lubricants in blanking and piercing processes is still not feasible.

1. Introduction

Blanking and piercing operations are widely used for mass production of precision engineering components. The quantity and quality of the stamped components, assessed by the profile of the formed surface and the deviation from the nominal dimensions of the blank and stock, depends on many factors such as tool design, tool material properties, stamping conditions and especially tool wear [1]. In punching and blanking operations, especially the punch is exposed to high dynamic loads, to sliding motion against work material and high contact temperatures [2], which lead to high friction and wear of the tool [3]. The severe tribological conditions between the punch stem and the exposed, virgin work-piece material causes pick-up of work-piece material on the tool and increase in stamping force as well as extraction force [4–6], while tool wear directly affects the part formability and surface quality, and causes production loss, cost increase and delays [7]. In order to reduce friction and wear of the punch different lubricants such as environmentally hazardous chlorinated paraffin oils and/or tool materials made from tungsten carbide are used. Use of tungsten carbide implies high tool costs, while lubricants are not preferred due to environmental issues and subsequent cleaning requirements. Reduction of lubricating oil in machining and forming becomes a critical issue to improve the environmental friendliness in practical operations [8–10]. In particular, once lubricants are used in stamping complete removal of oils is difficult or nearly impossible even by using cleansing agents. Recycling of cleansing agents as well as disposal of waste also becomes an issue for safety and protection against pollution [11].

In order to reduce/eliminate the need for lubrication and to introduce less expensive tool materials surface engineering techniques providing low friction and wear resistant surface are required. One way of modifying the surface, already effectively used in the forming industry, is thermo-chemical surface treatment of the tool [12,13]. In the last decades hard PVD and CVD coatings have started to successfully compete with the traditional thermo-chemical treatments, especially in terms of abrasive wear resistance [14]. However, although hard and corrosion-resistant coatings show high hardness and are frequently used to protect and enhance the lifetime of cutting tools, the majority of forming tools is still uncoated [15]. Beside a complex shape that often makes the forming tool difficult to coat, the traditional hard coatings such as TiN, TiC and CrN cannot meet blanking or piercing tool requirements, including good adhesion to the base material to withstand high loads and shearing forces without chipping or peeling, high toughness and low friction against stamped material [1,16,17]. However, in the last couple of years, tremendous progress has been seen in the field of coating deposition and design, leading to greatly improved tribological properties of contact surfaces [18,19]. Especially carbon-based and multicomponent and multilayered coatings are the promising candidates to put the concept of "cheap" and reliable coated tools for dry or near-dry stamping into practice [20].

Therefore, the aim of this investigation was to examine the possibility of eliminating/reducing lubrication and replacing expensive

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Table 1
Chemical composition and hardness of high speed steel substrates and reference tungsten carbide.

Substrate material		Chemical composition (wt.%)					Hardness	Roughness, R_a (μm)
		C	Cr	Mo	W	V		
A	ASP 2023	1.28	4.2	5.0	6.4	3.1	62 HRC	0.10 ± 0.02
B	S390 MC	1.63	4.9	2.3	10.1	5.1	61 HRC	0.09 ± 0.02
C	AISI M2	0.90	4.1	5.0	1.9	6.4	61 HRC	0.10 ± 0.02

Substrate material		Chemical composition (wt.%)					Hardness	Roughness, R_a (μm)
		Co	TiC	Ta(Nc)C	WC	Grain size (μm)		
D	WC H40S	12	0.2	0.4	87.4	1–2	1400 $HV_{0.1}$	0.09 ± 0.01

tungsten carbide material in blanking/piercing through introduction of hard tool coatings. The investigation included three commercial PVD/PACVD hard coatings (AlCrN, TiCN, Me-DLC), which were deposited on different tool steel substrates, and compared to tungsten carbide. Coatings were evaluated in terms of coating to substrate adhesion, load carrying capacity, wear resistance under dry and lubricated sliding, performance of coated punch and evolution and magnitude of stamping force.

2. Experimental

2.1. Substrate material

Three different high speed steels were included in the investigation as substrate material and compared to reference H40S tungsten carbide. Selected high speed steels comprise P/M high alloy high speed steel ASP 2023, P/M S390 Micro Clean high speed steel from Böhler and ESR high speed steel AISI M2. Chemical composition and hardness after quenching from 1160 °C and triple tempering (560/560/540 °C) are given in Table 1. After Wire Electrical Discharge Machining (WEDM) samples in the shape of discs (ϕ 24 mm × 8 mm) and punches (ϕ 2 mm × 50 mm) were surface ground and polished in order to obtain smooth surfaces suitable for hard coating deposition. Average surface roughness of punches and discs after polishing was in the range of 0.10 μm.

2.2. Hard coatings

Three commercial PVD/PACVD hard coatings were deposited by Oerlikon Balzers on all four substrates, including AlCrN, TiCN and low-friction DLC coating (Table 2). Monolayer AlCrN and gradient TiCN coatings were deposited by PVD process at a substrate temperature of 450 °C and use of a thin (∼0.1 μm) interlayer of Ti for improved coating to substrate adhesion. AlCrN coating with a thickness of 1.4 μm had a hardness of 3200 ± 24 $HV_{0.1}$, whereas TiCN coating of 2 μm thickness had a hardness of 2980 ± 17 $HV_{0.1}$. Commercial W-doped DLC coating (a-C:H:W) with a thickness of 2 μm and hardness of 1495 ± $HV_{0.1}$ was deposited by PACVD on ∼2 μm thick TiAlN support layer (PVD at 450 °C; ∼3000 HV) and had a multilayer structure of WC and C (a-C:H).

2.3. Coatings evaluation

Coated specimens in the as-deposited condition were evaluated in terms of coating to substrate adhesion, load carrying capacity and wear resistance under dry and lubricated sliding. Coating to substrate adhesion was determined according to Rockwell-C indentation adhesion test [21]. Rockwell-C adhesion test distinguishes between 6 levels of adhesion, ranging from excellent adhesion (HF-1) with only minor radial cracks observed around the indentation mark to unacceptable adhesion (HF-6) where coating completely peels off the substrate.

Load carrying capacity of coating-substrate system exposed to severe sliding contact was obtained through dry reciprocating sliding test [22], where Al_2O_3 ball (ϕ 6.34 mm) was loaded against a coated disc at a gradually increasing load. Test at a sliding speed of 0.02 m/s (s = 2.4 mm, f = 5 Hz) was started with a normal load of 10 N (p_H = 1.650 GPa). After 2 min of reciprocating sliding the test was stopped, a new ball was mounted and the test continued at increased load. The load was increased in 10 N steps until failure of the coating indicated by sudden increase in coefficient of friction occurred. For each coating/substrate system test was repeated at least 3 times on three different samples.

Wear resistance of the coated specimens was determined under reciprocating sliding motion using 99.7% Al_2O_3 ball (ϕ 6.34 mm; ∼1750 HV) as a counter-material in order to concentrate this investigation on coating wear. The aim of the tribological testing was to compare friction and wear properties of investigated coatings under the most severe contact conditions. Therefore, all coated specimens were exposed to severe abrasive wear using a sliding speed of 0.02 m/s and a normal load of 30 N, which corresponds to a Hertz nominal contact pressure of 2.38 GPa. In lubricated sliding commercial 5% water emulsion was applied at the coated surface before each test. During testing coefficient of friction was monitored as a function of number of cycles and wear after 9000 sliding cycles determined by the profilometric technique.

2.4. Field test

The piercing field tests were conducted using PMB EPK32 eccentric press with 150 strokes per minute. Two identical as-coated punches with a diameter of 2 mm and matching die, which provides 0.015 mm punch-die clearance, were applied. The test material

Table 2
Coated samples denotation and corresponding surface roughness values (R_a).

Coating	R_a (μm)	Substrate material			
		ASP 023	S390 MC	AISI M2	WC H40S
AlCrN	0.15 ± 0.01	A1	B1	C1	D1
TiCN	0.17 ± 0.02	A2	B2	C2	D2
TiAlN + a-C:H:W (DLC)	0.36 ± 0.01	A3	B3	C3	D3