APPLICATION OF PVD COATINGS IN METAL FORMING
APLIKÁCIA PVD POVLAKOV V TVÁRNENÍ

Ing. Jana Tkáčová, PhD.
Technical University of Košice
Faculty of Mechanical Engineering
Mäsiarska 74, 040 01 Košice, Slovakia
e-mail: jana.tkacova@tuke.sk

Abstract

Thin PVD coatings deposited on sheet metal stamping dies are used to optimize the stamping process and to increase the lifetime of the dies. The aim of the investigation was to optimize the tribological behaviour of stamping process with application of TiCN PVD coating. Experimental results indicate that application of TiCN PVD coating will lead to an improved wear resistance and longer lifetime of the stamping die.

Key words: Tribology, stamping die, PVD coatings, adhesion, wear, friction.

Abstrakt

Tenké PVD povlaky deponované na lisovacích nástrojoch pracujúcich v podmienkach za studena sa používajú na optimalizáciu procesu lisovania a zvýšenie životnosti nástrojov. Cieľom štúdie bolo optimalizovať tribologické správanie procesu lisovania plechu s aplikáciou TiCN PVD povlaku. Experimentálne výsledky ukazujú, že použitie TiCN PVD povlaku povedie k zlepšeniu odolnosti proti opotrebeniu a zvýšenej životnosti lisovacieho nástroja.

Kľúčové slová: Tribológia, lisovací nástroj, PVD povlaky, adhézia, opotrebenie, trenie.

INTRODUCTION

There are several ways to increase the stamping dies lifetime [1] e.g .:

- selection of proper material, production parameters, optimum heat treatment for dies, application of coatings;
- development of new wear resistant dies materials;
- development of lubricants with more effective properties to protect dies material;
- redesign of dies to reduce heat and mechanical load.

Based on the above it can be concluded that, it is e.g. very difficult to carry out redesign of dies as well as the development of new dies materials. Therefore, the coating on the stamping dies for the improvement of the wear resistance is the most viable option to extend their lifetime and to reduce the maintenance costs, downtime and labour costs.

For sheet metal stamping dies is an attempt to deposit thin coatings especially from two reasons: one is to increase the dies lifetime (wear resistant coatings), second to improve the stamping process (e.g. self-lubricating coatings).

Characteristic requirements on material for forming dies are in Tab. 1 [2].

Optimized coating system “architecture” for a forming dies, whatever the type of process (e.g. casting, glass or plastic moulding, metal stamping, forging, or other forming techniques) should meet the following attributes [1],[3]:

- chemical inertness (non-wettability) with the material being processed;
- to meet the specific mechanical, chemical and physical properties defined by the forming process;
- ability to eliminate stress incurred in the process of material processing cycle;
- dispose with adhesion and compatibility with the dies material (substrate);
- to improve the dies material properties.

Tab. 1 Characteristic requirements on material of forming dies [2]

Characteristics of process	**Conditions of application**	**Desired properties of substrate material**
for hot forming dies		
High contact temperatures (300–1100°C), chemically reactive work material, often including abrasive particles, thermal cycling due to water cooling, presence of antisticking agent.	High Young’s modulus, yield stress, and hot hardness to resist macroscopic deformation, high resistance to thermal fatigue, and chemical reactions.	High chemical and thermal resistance, including resistance to thermal fatigue (heat checking) and low tendency to stick to the work material (low chemical potential between coating and work material); low friction, high hot hardness and toughness to resist abrasive wear.
for cold forming dies		
High contact pressure, presence of abrasive particles, high shear stresses, often presence of lubricant.	High Young’s modulus and yield stress to resist macroscopic deformation, high fracture toughness, and high hardness to support the coating.	Low chemical potential between coating and work material give low friction and avoids work material pick up; high hardness and toughness to resist abrasive wear.

The development of coatings for use in cold forming operations depends on the following boundary conditions [4]:

- Macroscopic adhesion which leads to die damage only occurs when there is no longer any coating on the tool surface.
- The main requirement of the coatings is that they need to be able to withstand the mechanical loads of the metal forming process. As long as the coating on the die surface is intact, no adhesive wear is to be expected. This demands especially a high degree of hardness at the lowest possible Young's modulus, as well as the greatest possible bond between coating and substrate.
- The mechanical load of the coating can be reduced by using lubricants as well as through optimizing geometry and surfaces.

In order to be able to develop coatings which can withstand the loads in metal forming processes, it is necessary to clarify under which conditions coatings on dies surfaces fail [1].

In general, dies and moulds are designed for mass production. Although there are different types of forming processes including sheet metal forming, injection moulding, forging, vacuum forming, etc., the main types of defects that lead to damage and failure of the die can be generalized as follows: heat checking, also known as thermal cracking, wear, plastic deformation, sticking and corrosion, major failure [5].

An important benefit of PVD and CVD processes is the high flexibility of composition and structure of the coatings. These coatings are today successfully utilized for deposition of a large variety of mechanical components (Fig. 1). Most of today's PVD and CVD coating materials consist of nitrides (TiN, CrN, etc.), carbides (TiC, CrC, W_2C, WC/C, etc.), oxides (e.g., alumina), or combinations of these. Important exceptions are molybdenum disulfide (MoS_2), diamond-like carbon (DLC), and diamond. MoS2, WC/C, and DLC can be classified as low-friction coatings because they often display friction coefficients ranging from 0.05 to 0.25 in dry sliding (Holmberg and Matthews, 1994; Hirvonen et al., 1996). Their wear resistance is generally inferior to that of nitrides, carbides, and oxides. On the other hand, nitrides, carbides, and oxides normally give friction values between 0.4 and 0.9 in dry sliding. In this context, they are referred to as wear-resistant coatings. A very important exception to this simple classification is the CVD diamond coating, which in many applications combines an ultralow friction with very high wear resistance. Friction values below 0.05 have been recorded for diamond in nonconformal dry sliding. A further reduction in friction down to 0.02 can be obtained by water lubrication. This makes diamond a very strong coating candidate, in particular when environmental considerations have to be met (Hogmark et al., 1996) [2].

Substrate material high deposition temperatures can cause undesired phase transformations, softening, or shape changes of the coated component [2],[7].

Coatings for tribological applications may require the deposition in the range from room temperature up to over 1000 ° C. Typical thickness values are in the range from micrometers to several millimeters. Thinnest films are produced on the atomic level.

In the near future for the forming dies is expected to apply the coatings based on multilayer composites. The substrate material, e.g. hardened steel is a typical "particle" composite, substrate material plus the coating constitutes coating composite and finally the coating of sandwich type with one or more layers of varying substructure.

The deposition of suitable self-lubricating coating on the stamping dies may result in the forming process without the application of lubricant. Forming processes without lubrication have economic and environmental advantages compared to the forming process with the application of lubricants. Diamond like carbon (DLC) coatings are proving suitable self-lubricating coating for protection of stamping dies (under moderate load) when forming process without lubricant [7].

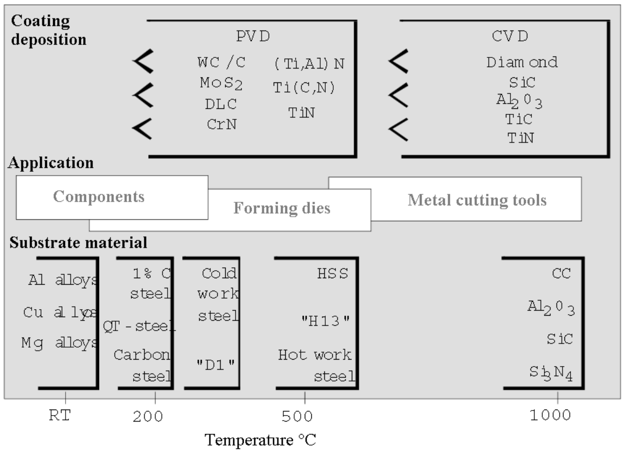

Fig.1 Typical temperature limits of potential substrate materials compared with typical working temperatures of applications and deposition temperatures of PVD and CVD coating processes [2].

The application of thin abrasion-resistant coatings and/or coatings with low friction on soft material requires the support of the intermediate layer in order to ensure sufficient capacity to transfer load. Electroless nickel, hard chrome plating, laser cladding and thermal spraying of hard coatings; nitrided and carburized layers can be candidates to ensure this property. The primary design parameters are the thickness of the intermediate layer and the Young's modulus, and the aim is to prevent plastic deformation, and minimize the elastic deflection of the substrate.

Many different types of coatings are used for dies in the forming process with varying levels of success. The basic philosophy is specifically designed optimum coating system or a range of systems to ensure each material application for the forming dies, rather than one coating or coatings range was suited to the specific application.

In the future, the often discussed issue will be the dies and tools lifetime and reducing the environmental burden also in the sheet metal forming. Therefore, new surface treatments environmentally friendly will play an important role, increase the importance of new environmental coatings industry, modifications such as multi function pre-treatment as deposition of thin organic coatings on metal coated steel. Attention will be focused on cost-effective environmentally friendly products with optimized multifunctional properties. Subsequently, further work on optimization of forming properties and corrosion properties of thin organic coating is required.

The aim of the investigation was to optimize the tribological behaviour of stamping process with application of TiCN PVD coating.

APPLICATION OF PVD COATINGS

For tests the steel Vanadis 6 (31CrMoV9) was selected. VANADIS 6 is a powder metallurgical cold work tool steel offering a combination of very high wear resistance and good toughness. VANADIS 6 is suitable for long run tooling of work materials where mixed (abrasive–adhesive) or abrasive wear and/or chipping/cracking and/or plastic deformation are dominating failure mechanisms e.g. blanking and fine blanking of harder work materials, forming operations where a high compressive strength is essential, powder pressing, substrate steel for surface coating, plastic moulds and toolings subjected to abrasive wear conditions, knives.

For the Vanadis 6 (16MnCr5 EN 10084-94, EN 84-70) steel with chemical composition: 2.1% C, 1.0% Si, 0.4% Mn, 6.8% Cr, 1.5% Mo, 5.4% V and the residual of Fe, the hardness in delivered state is about HB 255 (HRC 23), and after heat treatment a hardness of HV 750 (HRC 62) can be easily achieved. All the specimens made of the low-alloyed steel (31CrMoV9) were heat treated (hardened + tempered) and they were prepared for TiCN PVD coatings.

The mechanical properties of TiCN PVD coating were determined by depth-sensing nano-indentation under the load of 30 mN. The thickness of the hard coating was determined using calotest (CSM with diameter 10 mm).

The coefficient of friction was monitored on the tribotester Amsler (normal force Fn=700 N, sliding speed 100 mm/s, temperature 22 °C, boundary friction). The principle and detailed view on the test is shown in Fig. 2. The friction pair consists of flat sample made of VANADIS 6 (coated by PVD/TiCN) in tribocontact with counterpart discs (Disc-on-Plate test) made of steel 14 220 (1.7131 (16MnCr5), heat hardened, tempered and carburized to 62HRC - 800HV) with 50 mm in diameter and 10 mm width. The hardened steel disc was used as counterpart to initiate wear of the investigated materials and coatings. Analysis of worn surfaces was performed by light microscopy and SEM.

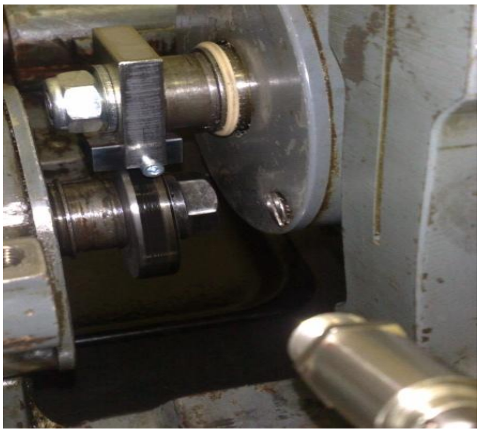

Fig. 2 Friction pair

The mechanical and tribological characteristics of analyzed TiCN coating are summarized in Tab. 2.

We can see that the higher values of hardness and elastic modulus were measured for TiCN. The observation of friction (laboratory tests) shows that, in the case of Vanadis 6 steel the friction coefficient varied between 0.83 and 0.86. The TiCN coating showed the lower values of friction coefficient in the range of 0.67-0.72. The tests in industry show that polishing of the functional surfaces was the dominant mechanism of wear for the PVD TiCN.

Tab. 2 Mechanical and tribological characteristics of TiCN

Material/ property	H_{IT} [GPa]	E_{IT} [GPa]	COF
Vanadis 6 - TiCN	32.82 ± 2.42	319.5 ± 14.3	0.67÷0.72

Based on the results of experimental tests it was decided to deposit the inserts of stamping die with PVD-TiCN coating (Fig. 3) and analyze the influence of surface treatment on the die lifetime in operating conditions. During operational testing the surface of stamping inserts was examined by a digital microscope DigiMicro 2.0. Stamped material was cold rolled steel sheet 11 321 (DC 01, Cr 01).

Damage of uncoated stamping insert was observed after 0.5 x10^6 strokes - Fig. 4(a). The surface of PVD-TiCN treated stamping insert after 1.8×10^6 strokes was observed without damage, the surface was smooth and compact, wear particles were not present on the surface - Fig. (b) [8-11]. The experiments show that the roughness of stamped parts obtained by coated and uncoated dies have been unaltered.

Fig. 3 Segments with TiCN/PVD coating

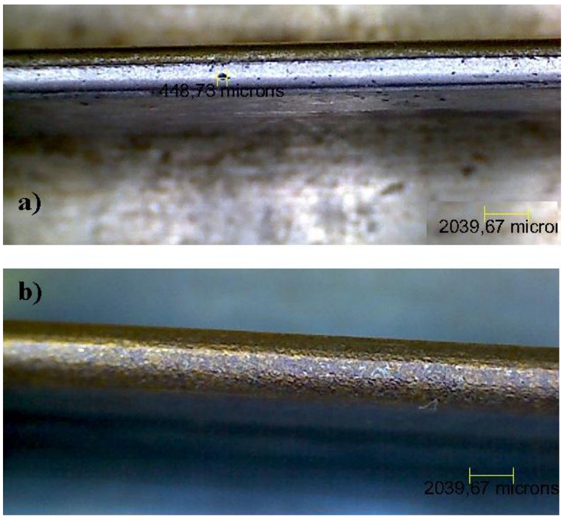

Fig. 4 Detailed view on: (a) uncoated segment with microcracks, (b) TiCN coated segment

CONCLUSION

The tribosystem i.e. the contact of sheet metal and the die is affected by several tribology aspects, including microgeometry and mechanical properties of dies materials. Although the mechanical properties of stamped materials are important for stamping processes, the final behaviour is determined by the ratios between the stamped material and die. The surface of PVD-TiCN treated stamping insert was observed without damage compared to uncoated die inserts.

Application of PVD TiN coating on VANADIS 6 steel increased die lifetime approximately four times, sticking problems were not recorded.

PVD coatings appear to be one of the possible effective ways to enhance the lifetime of the dies and their wear resistance, taking into account that thin coatings represent only one but important factor affecting the lifetime of the dies and tools.

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ACKNOWLEDGMENTS

This work was supported by the Grant Agency of the Ministry of Education of the Slovak Republic through the VEGA project No. 1/0117/15.