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RESEARCH

Triboanalysis in Industry for PVD-coated Stamping Dies

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A B S T R A C T

The application of hard wear-resistant coatings is expanding into various sectors of industry to protect tools and other components from failure caused by wear and corrosion. However, in forming industry it is still rather an exception than a rule to find coated forming dies. This study has objectives to investigate wear behaviour of P/M Vanadis 6 ledeburitic steel with PVD-TiN and TiCN coatings. The tests were carried out in the laboratory and industrial process conditions. The obtained results under operating conditions show that the application of PVD coatings appears as a very effective method for increasing the lifetime and wear resistance of cold stamping dies.

1. INTRODUCTION

In the manufacturing industry, e.g. in the automotive industry the on-line production is steadily shortened. Stamping dies are often very expensive, therefore it is necessary to reduce their production costs and alternatively to increase their durability. Forming processes are linked to tribological contact conditions that occur between the materials and dies. In many cases the die lifetime can be increased by deposition of thin and hard coatings on die but mechanical and tribological behavior of the coated die must be optimized [1-4].

The application of hard wear-resistant coatings is expanding into various sectors of industry to protect tools and other components from failure caused by wear and corrosion. However, in cold stamping industry it is still rather an exception than a rule to find coated forming dies. The improvements include coating by a ceramic thin film, which is produced by physical vapour deposition (PVD). Several PVD coatings are now available to increase the tool wear performance in boundary conditions that are usually encountered during stamping. The basic requirements are good adhesion to the base steel in order to counteract the shearing stresses without microcracking or delaminating and high hardness in order to induce low wear rates and a low friction coefficient [5-7].

The traditional single layer hard coatings such as titanium nitride, titanium carbide and chromium nitride, deposited by physical vapour deposition

(PVD) or chemical vapour deposition (CVD), cannot meet these requirements in many applications, such as blanking of carbon-steel, because of their insufficient hardness or high friction coefficient.

Among advanced coatings the multilayer concept seems to be the most versatile and promising with respect to properties and performance in almost all fields of application.

Due to different contact conditions at dies-blank interfaces, and the wide range of applied contact pressures, the selection of the correct coating is very important and also complex problem. To select the suitable coating the results of experimental tests can be helpful. But we must consider fact, that methods for wear investigations like the pin-on-disk tribometer and the calotest cannot fully reflect the real conditions of cold forming processes [8,9]. There are a number of publications on comparative die wear studies, however, they do not give quantitative information regarding die life under practical conditions [10-12]. Wear is caused by sliding and may be characterized by adhesion, abrasion, transfer phenomena and also by brittle surface microcracking. Such damage impairs the quality of the stamped production.

The presented investigations are obtained from the production of mechanical parts for heating units. The stamping dies are made of powder metallurgy the P/M Vanadis 6 steel, a very popular tool steel used for different cold work applications [13]. The stamping operation takes place under constant lubrication. Our investigation is divided into two stages. In the first stage, both PVD-TiCN and TiN coatings were deposited onto Vanadis 6 steel.

The laboratory tests give the basic investigations on the tribological behaviour of coatings. In the second stage, considering the results of experimental tests it was decided to coat the stamping die segments with PVD-TiCN coating and to analyse under operating conditions by optical microscopy and SEM analysis.

The aim of this study was to show the improvement to increase the lifetime of cold stamping die.

2. EXPERIMENTAL PROCEDURE

The objective of the investigation was the optimization of the lifetime of stamping die in the production of stamped parts for heating units. In manufacturing industry the problems with failure of stamping die occurred after 0.5 x 10^6 strokes.

2.1 Investigated materials for stamping dies

The P/M Vanadis 6 steel is taken as the substrate on which the coating is deposited and applied for cold stamping die. 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 as delivered state is approximately HB 255 (HRC 23), and after heat treatment a hardness of HV 750 (HRC 62) can be easily achieved. Material of stamped parts is cold rolled steel sheet according to Slovak Standard STN 41 1321 (EN DC01, 1.0330), thickness of 2.2 mm.

Cold stamping die is shown in Fig.1. Dimensions of stamping die segment are given in Fig. 2.a. Fatigue failure of die segment is shown in Fig. 2b (after 5 x 10^3 strokes). Microstructure of die segment is shown in Fig. 3.

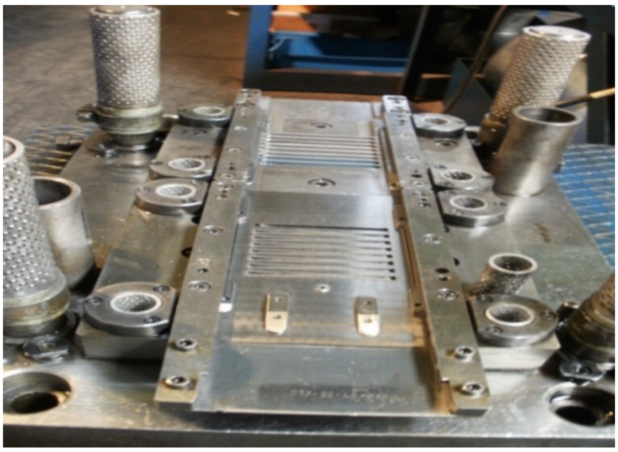

Fig. 1. View on stamping die.

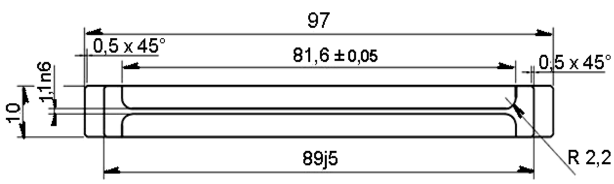

Fig. 2a. Stamping die segment.

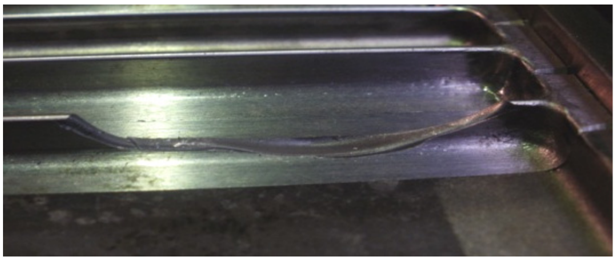

Fig. 2b. Failure of die segment.

Fig. 3. Microstructure of die segment.

2.2 Characteristics of the coatings

PVD coatings have a greater potential to reduce wear, crack extension and improve the lifetime of cold stamping die. The study was to investigate the wear mechanisms of PVD cathodic arc system TiN and TiCN coated die materials under laboratory conditions and to discuss comparative wear properties.

Analysis of both TiN monolayer and TiCN multilayer coatings (hardness and thickness) was carried out. The thickness was determined using calotest (CSM ball with diameter 10 mm). The mechanical properties of PVD TiCN coating were determined by depth-sensing nano-indentation under the load of 30 mN, loading rate 20 mN/min, indentor of Berkowich type– Fig. 4.

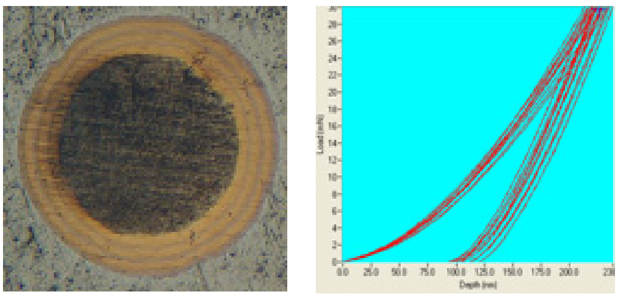

Fig. 4. Calotest of TiCN and nanohardness load-depth graph.

The primary tribological tests were performed on modified Amsler wear machine with the contact pair geometry blocks – on – disc (Fig. 5). The test block was loaded against the rotating steel disc. This provides a normal force 700N for the contact pair, under 5 x 10^3 strokes and sliding speed 100 mm/min. Normal load and friction moment were measured continuously using the measuring system by MATLAB/Simulink (Fig. 6) [14]. The test blocks (20 x 30 x 6 mm) were made of tool steel Vanadis 6 coated with PVD TiN and TiCN coatings. The counterpart cylindrical discs (50 x 10 mm) in contact pair geometry of block-on-disc test were made of steel EN ISO 21MnCr5 (1.7147) heat hardened, tempered and carburized of 800 HV (62HRC).

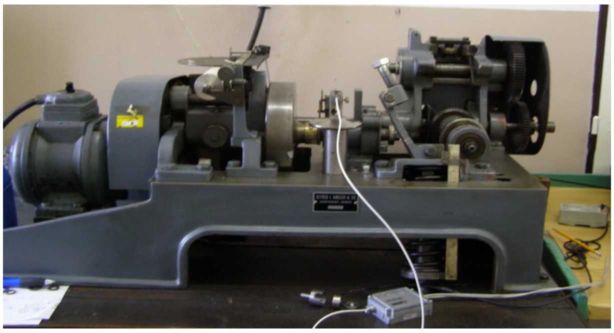

Fig. 5. Modified Amsler wear machine.

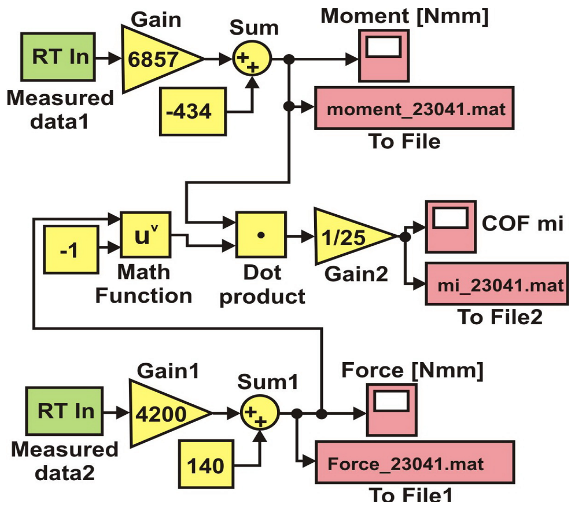

Fig. 6. Processing the data by MATLAB/Simulink

3. RESULTS AND DISCUSION

Thickness of coatings was determined by calotest as follows: TiN in the range 2,0-2,5 µm and TiCN in the range 2,5-3,5 µm. Table 1 summarizes main mechanical properties of tested coatings.

Table 1. Mechanical characteristics of coatings.

Substrate/coating	H_{IT} [GPa]	E_{IT} [GPa]
Vanadis 6/TiN	20.40	216
Vanadis 6/TiCN	32.82	320

When TiCN coated blocks were applied the friction coefficient was reduced to (0.67÷0.73) compare to friction coefficient of the TiN coated blocks (0.81÷0.85). With decrease of friction coefficient value in the contact zone of sliding test specimens the steel transfer (light contrast) was observed as very low.

The occurrence of wear is attributed to the four wear mechanisms adhesion, abrasion, surface fatigue and tribochemical reaction [15]. The peeling of the TiN coating was observed, the wear debris were smeared on the coating surface (Fig. 7). The transfer and back transfer phenomena may occur due to the chemical reactions with the environment, oxidation of the surfaces and the transferred material.

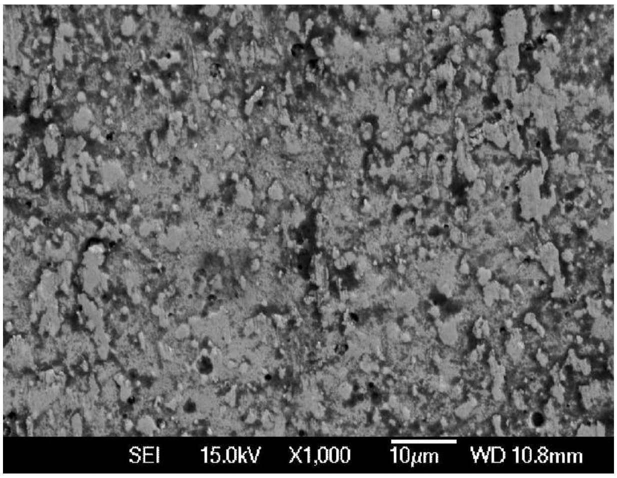

Fig. 7. Wear debris smeared on TiN.

The wear type was predominantly of an abrasive nature for TiN coated blocks. Adhesive wear generate wear debris with TiN microparticles which causes further wear by two or three body abrasion.

The some very fine scratches were found on the TiCN surface (Fig. 8). The polishing of the functional surfaces was the dominant mechanism of wear. It was demonstrated that, the TiCN coating showed a slight degradation. Due to its high hardness, PVD TiCN coating with increased thickness compare to TiN improves the adhesive and abrasive wear resistance of surfaces. Based on results of experimental tests it was recommended to apply PVD-TiCN coating on the stamping die segments. Notably minimal wear performance was observed for all coated blocks with PVD-TiCN under sliding conditions.

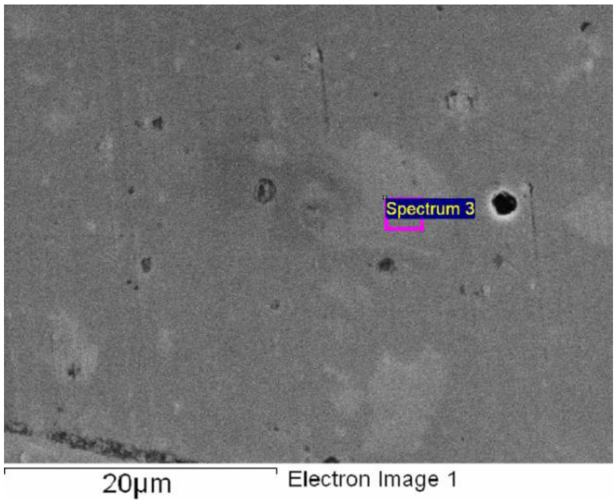

Fig. 8. The worn TiCN surface.

Therefore, in this study an attempt is made to investigate the effect of PVD TiCN coating to industrial application on stamping dies.

In second phase, the surfaces uncoated stamping die segment and coated with PVD-TiCN under operating conditions in industry were explored. In Fig. 9 the surface of uncoated die along the radius after 0.5 x 10^6 strokes is shown. Primarily the adhesive wear occurs under the contact pressure between sliding surfaces. Abrasive wear, however, occurs between two hard sliding surfaces when hard debris particles are indented and make grooves in the sliding surface of the material. In the area of the radius cracks are developing during the stamping operation showing the linear striations visible oriented parallel to sliding direction on the surface.

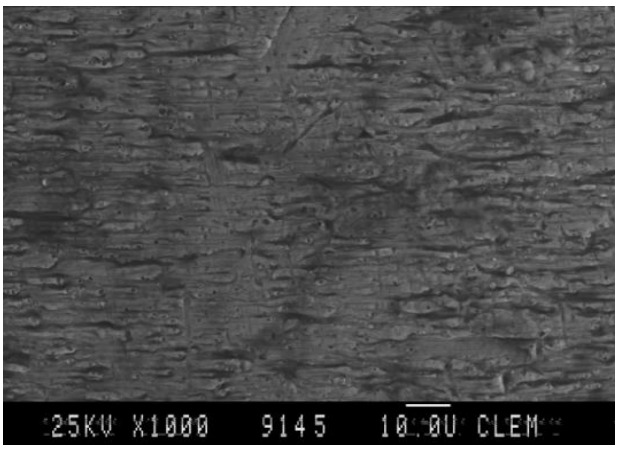

Fig. 9. SEM micrograph of uncoated die segment.

Figure 10 shows carbide particles of the substrate material protruding on the surface of die.

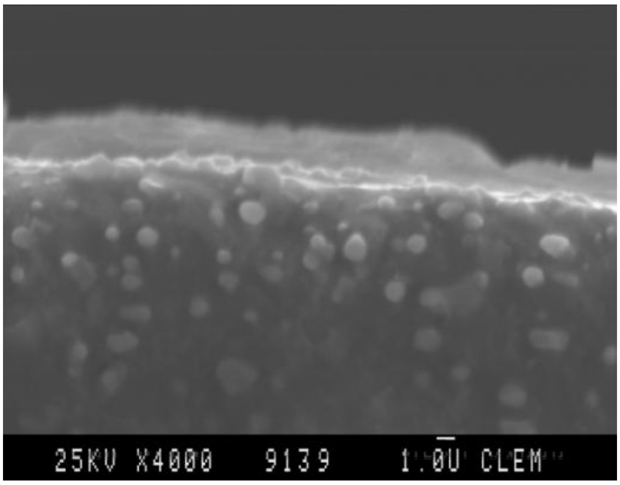

Fig. 10. SEM micrograph of cross-section of worn uncoated die segment.

The TiCN coated die segment surface after 1.8 x 10^6 strokes is shown in Fig. 11.

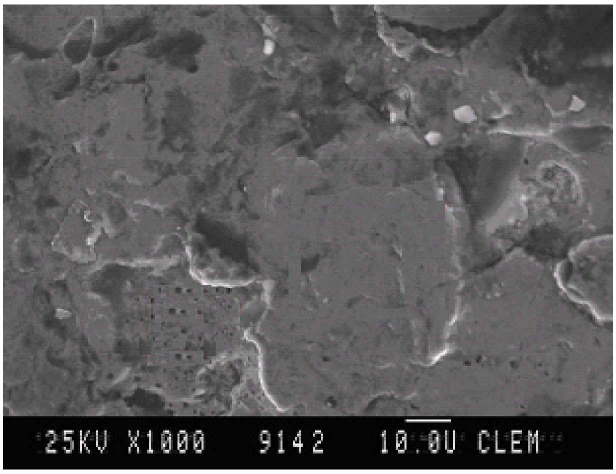

Fig. 11. SEM micrograph of worn TiCN coated die segment.

SEM cross-section analysis (Fig. 12) of worn surface showed good adhesion of the TiCN coating to substrate.

Creating the best die for a stamping operation involves analysing tool steels to find one that provides the proper balance of wear, strength, and toughness characteristics for a particular application. Whatever grade of tool steel is selected must be heat-treated properly to capitalize on those qualities and provide optimal results in production. A variety of surface treatments also are available to increase surface hardness and wear resistance while reducing the coefficient of friction of tool steels, helping to prolong die life. Understanding the available tool steel options is the first step in achieving quality results.

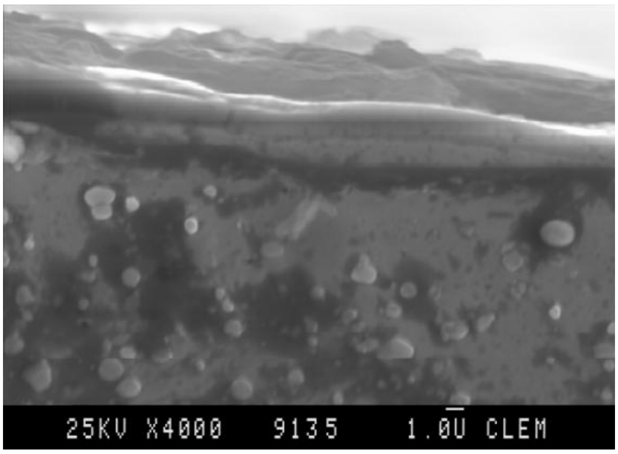

Fig. 12. SEM micrograph of cross-section of worn TiCN coated die segment.

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 forming processes, the final behaviour is determined by the ratios between the stamped material and die.

The average hardness and elastic modulus of the TiCN coating are about 38.82 GPa and 320 GPa, respectively. For the TiN coating, the average hardness and elastic modulus decreased to 20.40 GPa and 216 GPa. The results are consistent with the literature [16]. The higher hardness of the TiCN coating compared to TiN may be partly attributed to the solid solution effect of carbon in the TiN lattice. Due to its high hardness, PVD TiCN coating can improve the adhesive and abrasive wear resistance of metal surfaces.

Obtained results under operating conditions showed that TiCN coating on the surface of stamping die improved the lifetime four-times compare to the uncoated die.

4. CONCLUSION

Considering the results of experimental tests it was decided to coat the stamping die inserts with PVD-TiCN coating and to analyse under operating conditions by optical microscopy and SEM analysis.

TiCN coatings were deposited onto mechanically polished P/M Vanadis 6 substrates by cathodic arc method. The results obtained can be summarized as follows:

- Ceramic coatings like TiCN improve the wear resistance of the system because of high hardness, good friction characteristics, dense coating morphology and improved adhesion properties.
- Wear damage of the TiCN coatings is minimal. Good adhesion between coating and substrate does not allow the coating to be delaminated easily and remaining coating continues the protective function to the last.

The multilayer structure of TiCN provides an effective barrier to fissure propagation caused by dynamic stress, inhibiting surface fractures from propagating to the die and/or to wear of die. Application of PVD TiCN coating on die surface resulted in improved quality of stamping operation, the lifetime of TiCN coated die was increased four-times, wear and sticking problems were reduced and also elimination of long-lasting and expensive production failures.

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