DETERMINATION OF COEFFICIENT UNDER CONDITIONS OF DEEP-DRAWING PROCESS

Prof. Ing. Emil Evin, PhD. 1
prof. dr hab. inż. Bogdan Antoszewski 2

1 Technical University of Košice
Faculty of Mechanical Engineering
Mäsiarska 74, 040 01 Košice, Slovakia
e-mail: emil.evin@tuke.sk
2 Kielce University of Technology
Faculty of Mechatronics and Mechanical Engineering, Laser Processing Research Centre,
Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

Abstract

The conventional and innovative surface technologies are applied to sheet metal stamping dies in order to produce a composite material with properties unattainable in either the base or surface material. To select proper materials for forming dies the systematic evaluation of dies materials, their heat treatment and coatings are required. This paper deals with evaluation of plasma sprayed coatings Cr2O3, Al2O3 and WC12Co by pressure plate-ring test (tester T 05) and deep drawing process. Friction coefficients and seizure of these coatings were studied under dry and wet friction conditions. For different types of die rings (with and without ceramic coatings) the punching forces were measured during deep-drawing process. The results show that the main advantage of application of plasma sprayed coatings on the die contact surfaces under wet friction conditions compare to dies made of the tool steel may be the increase of seizure resistance of stamped part surface. The more significant difference in the friction coefficient values was not observed.

Key words: evaluation, stamping die, tribological properties, coating, friction coefficient, seizure

Introduction

Coating technologies on the one hand improve existing materials and/or products; on the other hand, they are necessary for the implementation of innovative products based on specific properties of layers and coatings. The surface of stamping dies interacts with the environment and stamped material. It determines the chemical, physical, and mechanical behavior of the entire system and the corresponding performance parameters. Functional layers and coatings allow the optimization of e.g. corrosion and wetting properties, friction and wear characteristics according to requirements and practically independent from the substrate material. Often cheaper materials are applied as substrates and rare or strategically important (often expensive) materials as coatings.

Friction on contact surfaces at sheet metal stamping processes depends on the properties of tribological pair and applied lubricant. Factors influencing the forming properties of sheet metals are shown in Fig. 1.

In consequence of load of contact surfaces (temperature in the range approximately from 20° up to 100°C), pressure is in the range approximately from 1 up to 30 MPa. In the area under blankholder the pressure is approximately 2 MPa and on die drawing edge the pressure is in the range from 10 to 30 MPa. At drawing-in of blank into the die, the sticking of softer blank material occurs on the die contact surface. The result is the occurrence of scratches on the surface of drawn part. Therefore, the stuck material must be laboriously removed from the die contact surfaces. The more is the material of the blank similar to material of die contact surfaces, the greater is danger of material sticking. Required quality of the drawn part, reliability and effectiveness of drawn parts production by deep drawing is possible to obtain by application of suitable lubricant, chemical composition of die contact surfaces and their microgeometry.

![Fig. 1 Factors influencing the forming properties of sheet metals](image-url)
In consequence of load of contact surfaces (temperature in the range approximately from 20°C up to 100°C), pressure is in the range approximately from 1 up to 30 MPa. In the area under blankholder the pressure is approximately 2 MPa and on die drawing edge the pressure is in the range from 10 to 30 MPa. At drawing-in of blank into the die, the sticking of softer blank material occurs on the die contact surface. The result is the occurrence of scratches on the surface of drawn part. Therefore, the stuck material must be laboriously removed from the die contact surfaces. The more is the material of the blank similar to material of die contact surfaces, the greater is danger of material sticking. Required quality of the drawn part, reliability and effectiveness of drawn parts production by deep drawing is possible to obtain by application of suitable lubricant, chemical composition of die contact surfaces and their microgeometry. Understanding of the mechanisms of wear and galling can be obtained by studying the stamping processes the macroscopic, microscopic and nanoscopic level (Fig. 2). In macrotribology, the interaction between two surfaces in contact is governed by Amontons’ laws. In microtribology, the contact between two surfaces takes into consideration the real microscopic roughness through the interaction of asperities. In nanotribology, the contact between two surfaces considers the interaction at atomic scale [2]. Recent developments in the field of sheet metal stamping processes are directed to the use of lightweight materials such as Ti, Al and Mg for stamped parts. For many years it has been known that chromium nitride CrN or coatings based on titanium as titanium nitride TiN, TiCN or TiB2 deposited by PVD or CVD techniques can greatly improve the die lifetime [4,5]. Modern coating systems for stamping dies tend to apply multilayer composites [6].

**Experimental procedure, results and their discussion**

The aim of this study was to evaluate the tribological characteristics (friction coefficient and seizure) of plasma sprayed coatings (Cr2O3, Al2O3 and WC12Co) under dry and wet friction conditions using the tester T 05 and deep drawing cup test.

The tester T 05 corresponds with US standard ASTM 2714. Its principal scheme is shown in Fig. 3.
The study of tribological characteristics is based on the assumptions that galling is associated with an increase in friction coefficient and galling is the predominant mechanism of wear of dies and drawn part. The direct correlation between friction and galling has been observed in some cases [6].

The properties of tested tribological pairs were investigated in the following combinations: Al2O3 – tool steel (Slovak standard 19 436; X210Cr12), Cr2O3 – tool steel, WC12Co – tool steel, structural steel (Slovak standard 11 373; S235JRG1) – tool steel. Ring was made of tool steel (Slovak standard 19 436; X210Cr12), quenched on hardness HRC = 60±2. Dimensions of samples were: diameter of ring = 35 mm, concave block length = 15.75 mm, concave block width = 6.35 mm).

By plasma spraying the Al2O3, Cr2O3 and WC12Co ceramic coatings were applied on samples (block pressure plate) made from structural steel. Parameters of spraying were as follows: spraying distance – 150 mm, current intensity – 60 A, voltage – 60 V.

Table 1 Measured values of tribological pairs

<table>
<thead>
<tr>
<th>Type of coating applied on block pressure plate</th>
<th>Procedure I – with lubricant J</th>
<th>Procedure II – without lubricant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr2O3</td>
<td>Friction coefficient µ</td>
<td>Friction resistance to seizure PV</td>
</tr>
<tr>
<td>Fp/p 300</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Fp/p 600</td>
<td>0.12</td>
<td>0.1</td>
</tr>
<tr>
<td>Fp/p 900</td>
<td>0.1</td>
<td>0.11</td>
</tr>
<tr>
<td>Fp/p 1200</td>
<td>0.1</td>
<td>0.11</td>
</tr>
</tbody>
</table>

*Values measured immediately after seizure, Fp – loading force [N], p- pressure [MPa], n- rotation per minute

The thickness of sprayed coatings was approximately 0.3 mm. Each sample before spraying was polished. To obtain friction coefficient µ and index of seizure PV, the tribological pairs (testing ring – pressure plate) were periodically loaded with and without lubrication. As lubricant, the oil J-4 with kinematic viscosity of 35 mm2/s was applied. At procedure I (with lubrication) the rotations were n1 = 44 rpm and load was changed in the range from 300 N (1.8 MPa) to 2100 N (12.5 MPa) by step 300 N after every 60 s. At procedure II (dry friction) the test conditions were as follows: load 600 N, rotations 180 rpm (Table 1). At the time when a greater dispersion of the frictional force was recorded the seizure was observed and the test was interrupted.

By using a computer; the friction force – FF, temperature of pressure plate – Tp, temperature of lubricant – TL were measured. Friction coefficient was calculated by the Coulomb law. Mean values of investigated parameters were evaluated from three measurements.

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Obtained results showed that tribological pairs Al2O3/Tool Steel, Cr2O3/Tool Steel, WC12Co/Tool Steel and Structural Steel/Tool Steel.

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The results of friction tests for single tribological pairs in dry friction conditions and with lubricant J-4 are presented in Table 1. The index of seizure PV was calculated as follows:

\[ PV = F_p * \text{Nosc} \]  

where: Fp – loading force [N], Nosc = path length of block pressure plate under given time [m/s].

Values of seizure resistance are shown in Table 1. For tribological pair WC12Co/Tool Steel the seizure occurred sooner when compare with other coatings. The highest values of the PV index were obtained at tribological pair Cr2O3/Tool Steel.

Values of the friction coefficient under dry and wet friction conditions were different for coated testing rings (Table 1). At modelling of wet friction conditions the seizure did not occur in any case.
Table 2 Measured punching forces and friction coefficients depending on blankholder force

<table>
<thead>
<tr>
<th>Fp [kN]/p [MPa]</th>
<th>15/1.4*</th>
<th>25/2.3</th>
<th>35/3.2</th>
<th>55/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ft [kN], lubricant foil (etalon)</td>
<td>67.30±0.5</td>
<td>68.90±0.5</td>
<td>69.90±0.5</td>
<td>70.6±0.5</td>
</tr>
<tr>
<td>Ft [kN], lubricant:J-4, Tool steel-DC05</td>
<td>73.9±0.5</td>
<td>76.4±0.5</td>
<td>78.2±0.5</td>
<td>81.05±0.5</td>
</tr>
<tr>
<td>Ft [kN], lubricant:J-4, Cr2O3- DC05</td>
<td>69.5±0.5</td>
<td>71.8±0.5</td>
<td>73.5±0.5</td>
<td>76.2±0.5</td>
</tr>
<tr>
<td>Ft [kN], lubricant: J-4, Al2O3- DC05</td>
<td>68.8±0.5</td>
<td>71.1±0.5</td>
<td>72.8±0.5</td>
<td>75.4±0.5</td>
</tr>
<tr>
<td>Ft [kN], lubricant: J-4, WC12Co- DC05</td>
<td>74.9±0.5</td>
<td>76.7±0.5</td>
<td>79.4±0.5</td>
<td>-</td>
</tr>
<tr>
<td>µ, lubricant:foil, Tool steel- DC05</td>
<td>-</td>
<td>0.055</td>
<td>0.048</td>
<td>0.041</td>
</tr>
<tr>
<td>µ, lubricant J-4, Tool steel- DC05</td>
<td>-</td>
<td>0.125</td>
<td>0.108</td>
<td>0.095</td>
</tr>
<tr>
<td>µ, lubricant J-4, Cr2O3- DC05</td>
<td>-</td>
<td>0.115</td>
<td>0.10</td>
<td>0.084</td>
</tr>
<tr>
<td>µ, lubricant J-4, Al2O3- DC05</td>
<td>-</td>
<td>0.115</td>
<td>0.10</td>
<td>0.083</td>
</tr>
<tr>
<td>µ, lubricant J-4, WC12Co- DC05</td>
<td>-</td>
<td>0.12</td>
<td>0.11</td>
<td>0.086</td>
</tr>
</tbody>
</table>

* Reference value of blankholder force Fp,etalon = 15 kN

In cup deep drawing with increasing pressure on the contact surfaces between the blank and blankholder a decrease of friction coefficient was recorded similar to the pressure plate-ring test.

We assume that this reduction of friction coefficient values is influenced by application of the J-4 lubricant containing high pressure additives and also as a result of increased pressure. At deep drawing of cups the seizure was not observed on the surface of drawn cups.

Conclusions

Based on measured results we may state:

1. Under dry friction conditions the lower values of the friction coefficient were recorded for tribological pairs Al2O3/Tool Steel (µ = 0.20), Cr2O3/Tool Steel (µ = 0.22), WC12Co/Tool Steel (µ = 0.18) compared to tribological pair Structural Steel/Tool Steel (µ = 0.32).

2. Applying lubricant the more substantial changes of friction coefficients were not recorded at single tribological pairs. The friction coefficient values were lower at tribological pairs with ceramic coatings than for tribological pair Structural Steel/Tool Steel.

3. The results show that the die contact surfaces with application of Al2O3 or Cr2O3 coatings are more seizure resistant compared to dies made from the tool steel, what positively influences the drawn part surface quality. Due to the fact that for tribological pair WC12Co/Tool Steel the seizure occurred very quickly, we recommend from studied coatings to apply for dies for steel sheet metal deep drawing the Cr2O3 and Al2O3 coatings.

4. In the deep-drawing process with lubricant the more substantial changes of friction coefficients were not recorded at tested tribological pairs coating/steel compared to tribological pair tool steel/structural steel.

5. It is suitable to orientate further research to modelling the various values of load on coated die contact surfaces and to investigation of mechanisms of their wear during deep drawing process under dry and wet friction conditions.

References


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