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TRIBOLOGICAL CHARACTERISTICS OF STAMPING DIES WITH COATINGS

A variety of cast iron and steel grades are used for manufacturing dies in stamping industry. The costs of these materials may vary considerably. However, with appropriate surface treatments, coatings and lubricants, a cost-effective die material may outperform the expensive ones. Therefore, in selecting die materials, a systematic evaluation of tool materials, coatings and heat treatments are required, considering the cost and tool life as parameters. In the contribution the plasma sprayed ceramic coatings Cr_20_3 and Al_2O_3 were investigated in sliding contact with steel in both, the block-on-ring arrangement (tester T 05) and deep drawing process. The friction coefficient and wear of these coatings were measured at dry friction conditions and with lubricant at utilization of tester T 05. 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 $A1_20_3$ and Cr_20_3 coatings on dies contact surfaces in comparison with dies made of tool steel may be the increase of life-time and wear resistance, the increase of the cup surface quality, savings of deficient elements by replacement of expensive tool steels by common constructional steels.

Keywords: deep drawing, stamping die, ceramic coatings, friction coefficient

1. Introduction

The result of deep drawing process depends on the one hand on steel sheets properties (mechanical and technological, chemical composition, surface microgeometry, size of grain, homogeneity of structure, uniformity of mechanical

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properties, steel sheet thickness along coil etc.), and on the other hand on used type of press, die geometry, microgeometry of die contact surfaces and applied lubricant [1]. The friction conditions on the contact surfaces have the great influence on the final quality of deep-drawing process (life-time of die, quality of drawn part surface, production costs, etc.) and technological formability [2-6]. Friction on contact surfaces depends on the properties of tribological pair and applied lubricant. In consequence of load of contact surfaces (temperature 20°÷100°C, pressure 0÷20 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 drawn part of the surface. Therefore, the sticked material must be laboriously removed from the die contact surfaces. The more is 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.

The fundamental understanding of galling can be obtained in the microscopic and nanoscopic scales (Fig. 1). At a microscopic scale, the tool-workpiece interface has numerous minute asperities and valleys. The magnitude, spacing and directionality of the surface topography in these mating surfaces play important roles not only in creating friction but also in sustaining or breaking a lubricant film designed to mitigate friction and wear. The better performance of the coated tools may be attributed to their ability to minimize, or postpone, the occurrence of galling; an ability that was verified as an absence of particles adhered to the tool surface and the absence of additional peaks and valleys in the roughness profile. It is not possible to make a direct comparison of the results obtained in this work with those of the tests presented in the literature [7, 8], since most of the elements of the tribosystem were different, including

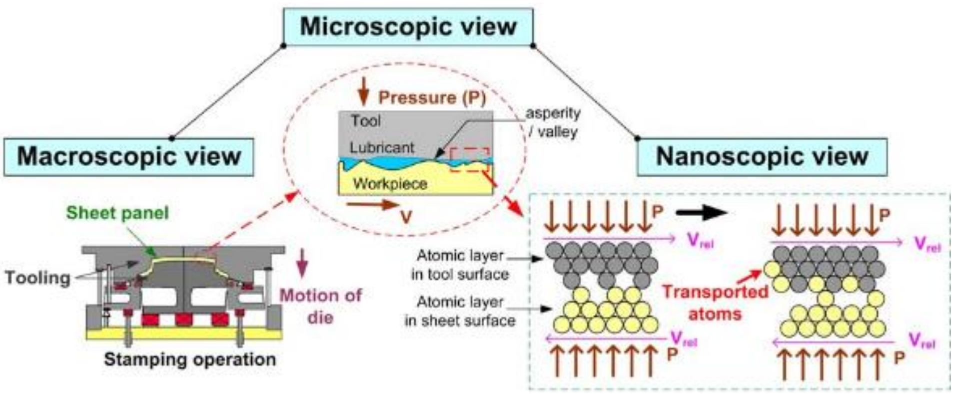

Fig. 1. Macroscopic / microscopic / nanoscopic scale views of galling (material transfer) in metal forming process

materials, geometries, loads and lubrication condition. Based on the results reported in the literature, it can be assumed that the applied test indicates that the lower threshold galling pressures for the uncoated tools than the coated ones. However, in addition to the questionings on the concepts of, literature [7, 8] data also indicates that the preparation of these tests must be careful in order to provide good alignment between the contacting surfaces, even if some of the alternatives to the original standard are selected. The simplicity and quickness of tests with line or point contact may be advantageous. However, taking the example of the test T 05 (Fig. 2), it is possible to state that the use of the outputs of this test to study forming operations is based on the assumptions that: galling is associated with an increase in friction coefficient and galling is the predominant mechanism in forming operations. The first of these assumptions may seem intuitively correct and a direct correlation between friction and galling has been observed in some cases [9].

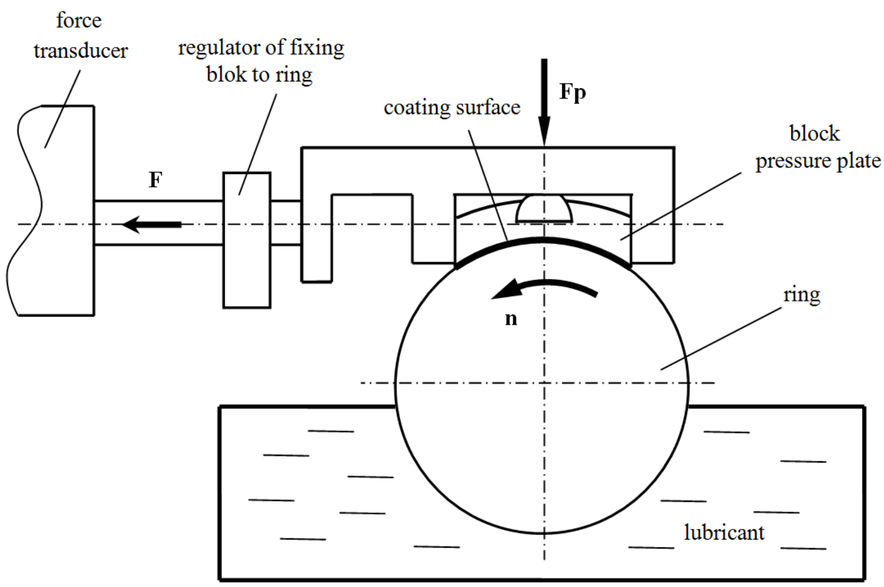

Fig. 2. Principal scheme of tester T 05

2. Experimental procedure

In the first phase of this research the properties of these tested tribological pairs were investigated by tester T 05: Al_2O_3 – constructional steel, Cr_20_3 – constructional steel, $WC_{12}Co$ – constructional steel, tool steel – constructional steel (degree 11 600). Tester T 05 corresponds with US standard ASTM 2714. Its principal scheme is shown in Fig. 2. By plasma spraying the ceramic coatings on the basis of $A1_2O_3$, Cr_20_3 and $WC_{12}Co$ were applied on samples (in the shape of rings) made of steel 11 600. Parameters at spraying were as follows:

- spraying distance – 150 mm,
- current intensity – 60 A,
- voltage – 60 V.

Thicknesses of sprayed coatings were approximately 0.3 mm. Each sample was polished. The friction pressure plates were made of constructional steel (degree 11 600) on the basis of tester requirements. For the purpose of obtaining the characteristics (friction coefficient p, wear Z, index of seizure PV) the tribological pairs (testing ring – pressure plate) were periodically loaded in conditions of dry friction and used lubricant J-4 with kinematic viscosity 35 mm^2/s at temperature 50°C. Rotations were changed four times at single loads (n_1 = 44 rpm, n_2 = 88 rpm, n_3 = 132 rpm, n_4 = 176 rpm) after every 60 s.

Pressure force *Fp* was changed from 300 N to 2100 N by step 300 N – procedure I (Table 1 and 2 and Fig. 3). By using a computer following parameters were obtained:

- friction force – F_F,
- temperature of pressure plate – *Tp*,
- temperature of lubricant – T_L.

Friction coefficient was calculated by the Coulomb law. Mean values of investigated parameters were evaluated from three measurements. Due to the fact that at tribological pair $WC_{12}Co$/steel the seizure occurred very quickly, only coatings on the basis of Cr_20_3 and $A1_20_3$ were applied on die contact surfaces under the same conditions as at testing rings:

Procedure I. Rotations (n_1 = 44 rpm, n_2 = 88 rpm, n_3 = 132 rpm, n_4 =176 rpm were changed every 60 s at single load, pressure forces *Fp* were changed from 300 to 2100 N by step 300 N. Lower values were obtained at load 300 N, rotations 44 rpm. Higher values are connected with higher load before the seizure.

Procedure II. Load 600 N, rotations 180 rpm, duration of load 300 min.

Table 1. Measured values of tribological pairs

Type of coating applied on testing ring	**Procedure I**	**Procedure II**		
	coefficient of friction with lubricant μ	wear *Z* [mg/h]	index of seizure *PV* [Nm/s]	without lubricant – dry friction μ [M]
Cr_20_3	0.08÷0.22	0.0044	580	0.22*
$A1_20_3$	0.08÷0.19	0.0031	450	0.20*
$WC_{12}Co$	0.10÷0.18	-	198	0.18*
Steel 19 436	0.20÷0.30	-	135	0.32*

* values measured immediately after the seizure

Table 2. Measured values of tribological pairs – procedure I

Pressure force Fp/ /rotations *n* [N]	**Coefficient of friction μ of applied on testing ring**			
	Cr_20_3	$A1_20_3$	$WC_{12}C$	Fe-Fe
300/44	0.15	0.15	0.16	0.16
600/44	0.12	0.12	0.13	0.13
900/44	0.10	0.10	0.11	0.12
1200/44	0.10	0.10	0.11	0.12
1500/44	0.10	0.10	0.11	0.12
1800/44	0.09	0.09	0.10	0.10
2100/44	0.08	0.08	0.11	0.12

The influence of changes of contact surfaces properties on the change of both friction and quality of the drawn part was tested in the deep drawing process of cylindrical cups in the universal deep-drawing die (die inside diameter d_2 = 80 mm, blank diameter D_0 = 148 mm). The material of drawn cups was the steel sheet of extra deep-drawing quality DC 05. Its surface roughness was in the range Ra = 0.8÷1.2 µm. The die ring was made of tool steel degree 19 436 and its roughness was Ra = 0.4 µm. Die rings for coating of contact surfaces were made of steel degree 11 600 and after application of coatings they were polished to Ra = 0.8 µm. Material of drawn cups was the steel sheet of extra deep-drawing quality DC 05. Its surface roughness was in the range Ra = 0.8÷1.2 µm.

For evaluation of the influence of changes of die contact surfaces properties on the change of friction at deep drawing the index of formability i_F was introduced. The index of formability is given by ratio of forces required for drawing of cylindrical cups as follows:

$$i_F = \frac{F_{te}}{F_{ti}} \tag{1}$$

where: F_{te} – punching force obtained at ethalon (lubricant J-4, die ring made of steel degree 19 436, die inside diameter d_2 = 80 mm, die corner radius r_t = 10 mm, punch comer radius r_p = 10 mm),

F_{ti} – force obtained at compared die contact surfaces (lubricant J-4, die ring with coating Al_20_3-$F_{tAl\text{-}Fe}$, Cr_20_3-$F_{tCr\text{-}Fe}$ and $WC_{12}C$ $_3$-F_t WC12C-$F_{tWC12C\text{-}Fe}$ die inside diameter d_2 = 80 mm, die corner radius r_t = 10 mm and punch corner radius r_p = 10 mm).

For recording of forces the dynamometer with the tensometer resistance pickup was used. Measurement and evaluation of recorded signals was carried out by a computer. The mean values were calculated based on five measurements (Table 3).

Table 3. Results of punching forces and formability index for different friction pairs

Punching force F_t [N]				**i_F index**		
Fe-Fe	Cr_20_3-Fe	$A1_20_3$-Fe	$WC_{12}C$-Fe	Cr_20_3-Fe	$A1_20_3$-Fe	$WC_{12}C$-Fe
73 959	69 521	68 782	72 480	0.94	0.93	0.98

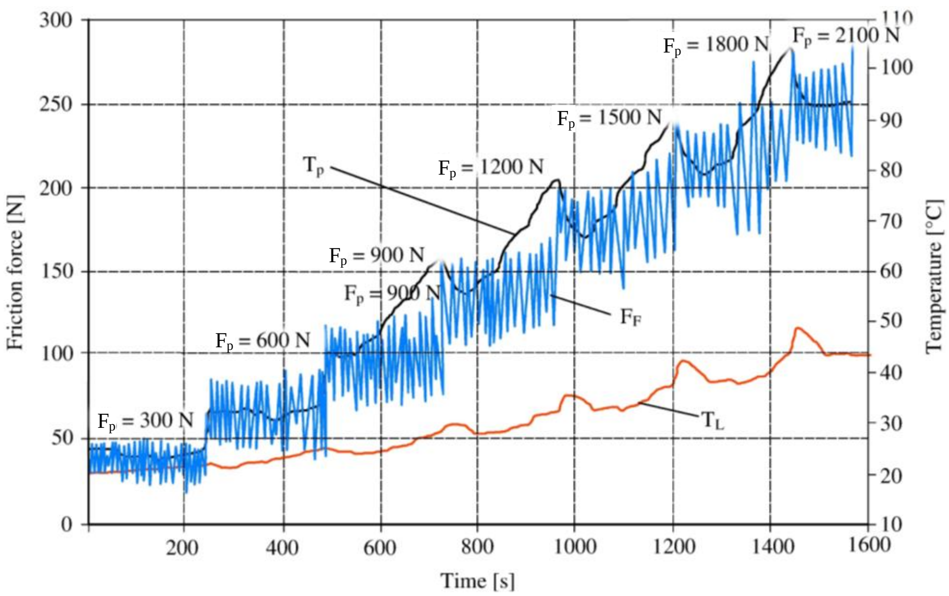

Fig. 3. Typical diagram of procedure I: F_F – friction force, F_p – pressure force, T_p – temperature of pressure plate, T_L – temperature of lubricant

3. Results and discussion

In Table 1 the results of friction tesing for single tribological pairs in dry friction conditions and also with lubricant J-4 were presented. The index of seizure PV was calculated according to the formula

$$PV = F_p \cdot \text{Nosc} \tag{2}$$

Limits of seizure resistance are shown in Table 1. At tribological pair $WC_{12}Co$ - steel the seizure occurred sooner as it was planned. The highest values of the PV index were obtained at combination of tribological pair Cr_20_3-steel.

Values of the friction coefficient in dry friction conditions were different at coated testing rings and non-coated testing rings from tool steel. The course of friction force F_f, as well as temperature of pressure plate T_p and for tribological pair Cr_20_3-steel with lubricant J-4 is shown in Fig. 3. Mutual dependence between the friction coefficient, pressure force and temperature at all tribological pairs had the same character. At modelling loads the seizure did not occur in any case. But diffraction of friction coefficient values at tribological pair tool steel/steel was greater than at tribological pairs Al_2O_3/steel or Cr_20_3/steel.

Process of abrasive wear was analyzed on the basis of measurements obtained at constant load 600 N, 180 rotations per minute during 300 min [10]. It was impossible to keep the intended duration of the test for all tested tribological pairs because at tribological pair $WC_{12}C$/steel the seizure occurred very soon. Obtained results showed that tribological pairs Al_20_3/steel, Cr_20_3/steel are more seizure resistant as tribological pair $WC_{12}Co$/tool steel and tool steel/tool steel.

Steel sheet surface was lubricated with mineral oil J-4 (cca 3-4 g/m^2) and then the cup was produced by deep drawing. From measured values of punching forces at single tribological pairs result that the substantial difference of friction values was not recorded (I_{FAl-Fe} = 0.93, I_{FCr-Fe} = 0.94, $I_{FW12C-Fe}$ = 0.98). During the deep drawing of cylindrical cups in the deep-drawing die with the die ring with ceramic coating the scratches on cups surfaces were not observed. In deep-drawing die with die ring made of tool steel the scratches on cups appeared. Sticking of material was removed by polishing the contact surfaces. Mentioned above was confirmed also by results obtained on tester i.e. coatings on the basis of $A1_20_3$ and Cr_20_3 are more seizure resistant [10, 11].

Conclusions

On the basis of measured results we may state:

1. In dry friction conditions the substantially higher differences of the friction coefficient values were recorded at tribological pairs Al_20_3/steel (μ = 0.20), Cr_20_3/steel (μ = 0.22), $WC_{12}C$/steel (μ = 0.18) than at tribological pair steel/steel (μ = 0.32).
2. During utilization of lubricant the more substantial changes of friction coefficient values were not recorded at single tribological pairs. Dispersion of the friction coefficient values was lower at tribological pairs with ceramic coatings than at tribological pair tool steel/constructional steel.
3. In the deep-drawing process with lubricant the more substantial changes of friction coefficient values were not recorded at tribological pairs coating/steel (I_{FAl-Fe} = 0.93, I_{FCr-Fe} = 0.94, $I_{FW12C-Fe}$ = 0.98) in comparison with tribological pair tool steel/constructional steel.
4. The results show that the main advantage of application of $A1_20_3$ and Cr_20_3 coatings on dies contact surfaces in comparison with dies made of

the tool steel may be the increase of life-time and wear resistance, increasing the cup surface quality, savings of deficient elements by replacement of expensive tool steels by common constructional steels.
5. From the point of view of application of ceramics on die contact surfaces it is needful to evaluate the economical effectiveness.
6. It is suitable to orientate further research on modelling the various values of load (temperatures on contact surfaces) and on investigation of mechanisms of destruction of created adhesion layer on contact surfaces during deep drawing in dry friction conditions, with application of lubricant and with carbon impregnated contact surfaces.

References

[1] Lange K.: Umformtechnik. Band 3 Blechbearbeitung, Springer-Verlag, Berlin 1990.

[2] Zibulla G.G.: Auftragen des Schmierstoffes beim Tief-ziehen von Blechen, Bänder Bleche Rohre, 10/1982, 286-288.

[3] Jeffery B.: Advanced lubricant technology for high-strenght steel, Stamping Journal, 2004.

[4] Kim H., Altan T., Yan Q.: Evaluation of stamping lubricants in forming advanced high-strength steel (AHSS) using deep drawing and ironing test, J. Mat. Proc. Technol., 209 (2009), 4122-4133.

[5] Kim H., Han S.S., Kim K., Altan T.: Evaluation of die coatings and stamping lubricants using the strip drawing test, CPF Report, CPF 2.3/08/02, 2008.

[6] Trzepieciński T.: Numerical modeling of the drawbead simulator test, Zeszyty Naukowe Politechniki Rzeszowskiej, s. Mechanika, 84 (2012), 69-78.

[7] Hummel S.R.: Development of a galling resistance test method with a uniform stress distribution, Tribol. Int., 41 (2008), 175-180.

[8] Swanson P.A., Ives L.K., Whitenton E.P., Peterson M.B.: A study of the galling of two steels using two test methods, Wear, 122 (1988), 207-223.

[9] Vollertsen F., Zhenyu H.: Determination of size dependent friction functions in sheet metal forming with respect to the distribution of contact pressure, Prod. Eng. – Research Development, 2 (2008) 345-350.

[10] Antoszewski B.: Friction and wear behavior in plasma sprayed coating, Acta Physica Polonica A, 89 (1996), 145-152.

[11] Evin E., Antoszewski B.: Computer aided measurement and evaluation of friction ratios at deep drawing, Zeszyty Naukowe Politechniki Świętokrzyskiej, Kielce 1998.

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CHARAKTERYSTYKA TRIBOLOGICZNA MATRYC DO TŁOCZENIA Z NANIESIONYMI POWŁOKAMI CERAMICZNYMI

Streszczenie

Różnorodne żeliwa oraz stale są stosowane do wykonywania narzędzi do procesów tłoczenia. Koszt tych materiałów może kształtować się na różnym poziomie. Tymczasem, poprzez zastosowanie określonej obróbki powierzchniowej i powłoki oraz smaru, matryce można wytwarzać metodami mniej kosztownymi, zastępując drogie materiały. Dlatego też w doborze materiałów konieczna jest systematyczna analiza materiałów narzędziowych, stosowanych powłok oraz przewidywanej obróbki cieplnej, biorąc pod uwagę jako podstawowe parametry koszty wykonania oraz żywotność narzędzi. W prezentowanym opracowaniu badano naniesione plazmowo powłoki Cr_20_3 oraz Al_2O_3 w kontakcie ze stalą, zarówno za pomocą tribotestera T 05, jak również w procesie wytłaczania. Pomiary współczynnika tarcia oraz zużycia realizowano za pomocą tribotestera w warunkach tarcia na sucho oraz z zastosowaniem smaru. W trakcie procesu wytłaczania dokonywano pomiaru siły kształtowania dla różnych pierścieni matrycowych z powłoką ceramiczną oraz bez powłoki. Wyniki badań zdecydowanie wykazały główne korzyści wynikające ze stosowania narzędzi z powłokami ceramicznymi w porównaniu z narzędziami bez powłoki na powierzchniach kontaktu z kształtowanym materiałem – zwiększenie żywotności poprzez zmniejszenie zużycia ściernego, poprawę jakości wytłoczek oraz oszczędzanie materiałów deficytowych przez zastąpienie drogich stali stopowych stalami konstrukcyjnymi.

Słowa kluczowe: tłoczenie blach, matryce, powłoki ceramiczne, współczynnik tarcia

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