EXPERIMENTAL AND SIMULATION DETERMINATION OF FRICTION COEFFICIENT BY USING THE RING COMPRESSION TEST

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Abstract:

One of the main problems in the plastic deformation of materials is the determination of the coefficient of friction as well as the subsequent application of the simulation for comparative analysis. However forecasting process and matching between simulation and experimental data is still a problem. Causes of this are factors such as roughness, mechanical properties of the material, chemical composition, etc. which strongly influence the behavior of the material in the simulation of the process.

In this study, an approach is proposed to determine the changeable coefficient of friction in the deformation process experimentally, taking into account implicitly the influence of surface roughness on the friction curves. For the comparative analysis between experiment and simulation of the process, the experimental data for objective assessment was introduced. Nevertheless, there are differences between experiment and simulation, which is most evident in high loads, using lubricants differing from more than 12 units for graphite lubricant, with more than 6 units with oil and with dry friction with 8 units.

Keywords: FRICTION, RING, COMPRESSION, SIMULATION, PLASTIC DEFORMATION

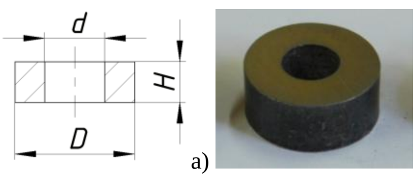
1. Introduction

Forecasting the coefficient of friction of plastic deformation of metals by means of software products is still a problem [1-4]. As is well known, it depends on a number of factors, such as the type of lubricant used and the roughness of the friction surfaces of the tool and the workpiece [5, 6]. Different software products are used to investigate the problem by introducing a set of experimental data for the purpose of adequate simulation and forecasting. For the majority of software products, the surface roughness parameter is not included as an input parameter, but it is part of a complex friction factor index - friction coefficient μ or friction factor m [7]. Both indicators friction usually introduced as constants in the models to simulate until they change the process of deformation. In such case interpretation of the results may lead to incorrect conclusions and significant deviations of the results of experiment and simulation. To obtain an objective solution to the problem, multiple repetition of simulation with different values of μ and m can be performed.

The aim of the present study is to establish the possibility of simulating the process of deformation of pressure rings (DPR) by applying experimentally established equations for the change of coefficient of friction.

2. Materials for Production of Prototype Parts *Грешка! Източникът на препратката не е намерен.*

For the purposes of the experimental study by the process DPR used steel bar material 10 sp. With a chemical composition in% (C - 0.9, Si - 0.26, Mn - 0.43, P – 0.08, S =0.03). The nominal dimensions of the rings with an outer diameter D = 16 mm, the inside diameter d = 6.5 mm and height H = 7 mm (Figure 1).

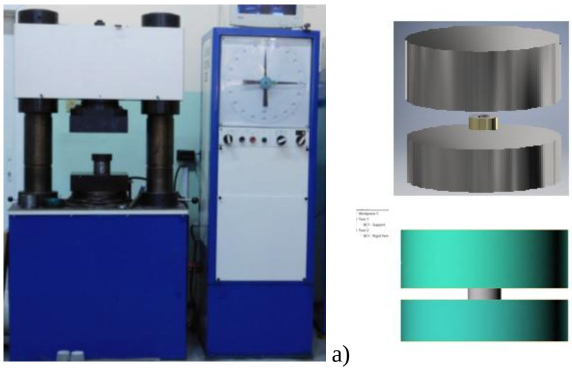


a) b)

Fig. 1. *Test bodies for the experimental determination of the coefficient of friction: (a) the dimensions of the test piece (b) the test piece*

The contact surfaces of the test specimens have a roughness Ra = 2.5 ÷ 1.25 μm, and the working surfaces of the tool are of Ra = 0.63 μm..

For the flattening of the test bodies was used a hydraulic press MC 2000 with mounted flat parallel boilers (fig.2). The study was performed under three friction conditions - dry, with oil MHL-34 and graphite powder.



a) b)

Fig. 2. *Used Testing Equipment (a) Testing Machine MS-2000; b) a digital simulation model*

The experimental test rings are flattened into three transitions with a loading force (F) of 100, 200 and 300 kN with a set load speed of 0.5 mm / min at room temperature. Upon reaching the specified load the sample is ejected, wherein using a load cell is recorded the maximum thrust force (T) - the criterion for the maximum friction. Before each deformation, the samples are cleaned, measured, and the test rings are lubricated by their working heads at a specific dose. Prior to each test, the working surfaces of the top and bottom lugs are also cleaned and lubricated with the lubricant for the lubricant tests. The dimensions of the rings before and after deformation are measured with an electronic caliper with an accuracy of 0.01 mm (Table 1, 2 and 3). From the obtained measurement data are calculated: the degree of deflection ε (1), the relative change of the inner diameter Δd / d, the force of ejection T between the ring sample and the two flat cylinders, the coefficient of friction μ (2) [8] are constructed experimental curves for the change of the coefficient of friction μ' (Fig.3). The calculated μ values for the different strain rates determine the coefficient of variation curve.

$$\varepsilon = (H_0 - H)/H_0 \times 100 \quad (1)$$

$$\mu = (2 \times T)/F \quad (2)$$

For the comparative analysis of the experimental data and simulation, the software product "QForm 3D" v.7.1 was used, in which the necessary data from the experiment was introduced, instead of introducing a constant coefficient of friction using the experimental curve for the change of the coefficient of friction, the presumed recovery curve from the material pressure test, the chemical composition, the type of lubricant, etc.

Data collection from the simulation was performed at a loading step of 100 kN. The study process continues until the maximum force of the hydraulic press 400 kN has been reached. The results of the simulation are presented in tables (tables 4, 5 and 6) and graphical dependencies are built (fig. 4).

3. Results and discussions

Figure 3 illustrates graphically the change of the experimentally established coefficient of friction for the three cases. At the initial deformation stage, the lowest internal diameter variation values are present for the non-lubricated sample. In fact the initial inner diameter under load of 100 kN is not altered (Table 1), while increasing only the outer diameter. Probably this is due to the fact that the roughness of the sample is greater than that of the tool, resulting in friction being associated with breaking the peaks of the roughness during the loading process.

Table 1. *No lubrication - Experimental data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0	7	6.55	0.00	0	0.00	
1	100	6.33	6.55	18.53	0	9.57	0.3705
2	200	4.43	6.4	26.70	2.29	36.71	0.2670
3	300	3.35	5.76	34.60	12.06	52.14	0.2307

Table 2. *With Oil - Experimental Data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0	7	6.55	0.00	0	0.00	
1	100	6.51	6.8	18.58	-3.82	7.00	0.3716
2	200	4.45	6.92	24.58	-5.65	36.43	0.2458
3	300	3.36	6.7	33.92	-2.29	52.00	0.2261

Table 3. *With graphite lubricant - Experimental data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0	7	6.55	0.00	0	0.00	
1	100	6.38	6.6	18.87	-0.76	8.86	0.3774
2	200	4.36	6.87	27.63	-4.89	37.71	0.2763
3	300	3.22	7.22	35.83	-10.23	54.00	0.2388

As a consequence of this effect the neutral surface has a radius less than the inner radius of the sample, which is typical of cases with a lubricant. The increase in load leads to a leveling of the micro-roughness and consequently increase the contact area with which the friction increases, the neutral surface radius increases its rn to values exceeding the inner radius of the sample (r <rn) and intensive reduction in the inner diameter. The application of lubricant to the other two samples, as well as expected, resulted in the arrangement of the curves in the lower quadrant (Figure 4). Due to reduced friction, the inner diameter (d) increases μ', as in the case of oil in the initial stage and in comparison with the graphite lubricant is lower. This difference may be explained by the complex influence of the lubricant and roughness in the friction zone.

Due to the fact that the roughness in the initial stage is high, friction occurs with a smaller contact area, which state can be said to correspond approximately to a case of border friction. As a result, the increase in the inner diameter is the greatest in comparison with the dry friction and the use of a graphite lubricant. With the increase of load d slightly changed until reaching a deformation of 36%, which is associated with the closure of the micro-volumes of oil between the roughness and thereby providing an increased contribution of the oil in the process of friction.

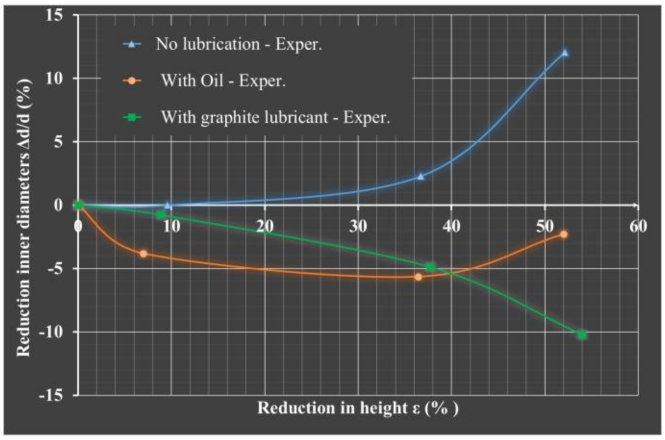


Fig. 3. *Friction curves μ' from experimental data*

The reduction of d in deformations of more than 38% is in accordance with the known regularity of increasing the coefficient of friction at high loads associated with the increase of the contact area and a significant increase of the inhomogeneity of distribution of the oil, accompanied by its displacement.

Table 4. *No lubrication - Simulation data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0.00	6.80	10.00	0.00	0.00		
1	96.34	6.80	9.88	23.44	1.20	0.00	0.4865
2	122.42	6.30	9.81	25.42	1.90	7.35	0.4152
3	153.38	5.89	9.74	27.52	2.60	13.38	0.3588
4	181.31	5.51	9.68	29.56	3.20	18.97	0.3260
5	210.39	5.15	9.54	31.56	4.60	24.26	0.3000
6	243.26	4.81	9.39	34.08	6.10	29.26	0.2802
7	278.49	4.48	9.18	36.83	8.20	34.12	0.2645
8	316.23	4.18	8.96	39.31	10.40	38.53	0.2486
9	360.26	3.91	8.63	42.11	13.70	42.50	0.2338

Table 5. *With Oil - Simulation Data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0.00	6.80	10.00	0.00	0.00	0.00	
1	88.12	6.80	9.86	23.34	1.40	0.00	0.5298
2	110.49	6.30	10.01	25.36	-0.10	7.35	0.4591
3	142.83	5.80	10.20	28.95	-2.00	14.71	0.4054
4	175.10	5.30	10.38	30.04	-3.80	22.06	0.3431
5	210.92	4.83	10.54	33.04	-5.40	28.97	0.3133
6	250.53	4.40	10.64	36.35	-6.40	35.29	0.2902
7	294.24	4.01	10.92	40.19	-9.20	41.03	0.2732
8	342.07	3.67	10.93	43.59	-9.30	46.03	0.2548
9	395.87	3.38	10.97	47.93	-9.70	50.29	0.2422

Table 6 *With graphite lubricant - Simulation data*

Measurement number	Load force	Height	Inner diameter	Strength of pushing	Relative amendment	Relative deformation	Coefficient of friction
	Fn (kN)	H (mm)	d (mm)	T (κN)	Δ d/do (%)	ε (%)	μ
0	0.00	6.80	10.00	0.00	0.00	0.00	
1	92.40	6.80	9.87	23.67	1.30	0.00	0.5124
2	116.52	6.30	9.80	25.46	2.00	7.35	0.4371
3	150.54	5.81	9.90	27.80	1.00	14.56	0.3694
4	181.01	5.37	9.92	30.22	0.80	21.03	0.3339
5	213.05	4.97	9.86	32.69	1.40	26.91	0.3069
6	247.77	4.60	9.88	35.63	1.20	32.35	0.2876
7	286.38	4.25	9.71	38.48	2.90	37.50	0.2687
8	325.62	3.96	9.60	41.46	4.00	41.76	0.2546
9	370.96	3.69	9.48	44.66	5.20	45.74	0.2408

Typical for lubrication with graphite lubricant is the increase of the internal diameter continuous from the beginning of the load. Compared to the effect of the oil, it is obvious that the graphite grease eliminates the influence of roughness, which can be explained by better adhesion to them. In addition, the results of the experiment once again confirm the well-known fact for the good lubricating effect of graphite at high loads [9].

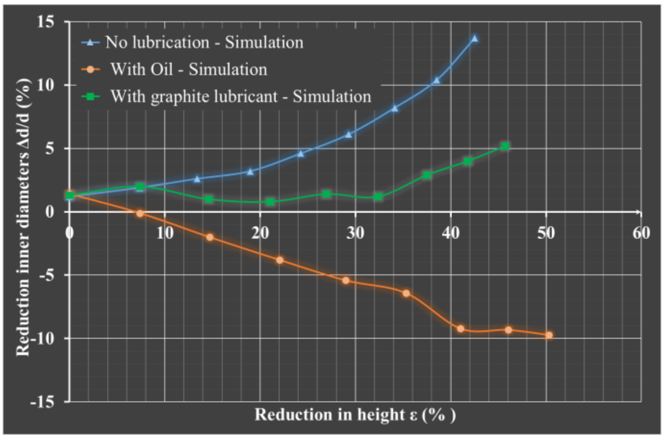


Fig. 4. *Friction curves μ" from simulation data*

The comparative analysis of the height variation for the three friction cases shows that for the small deformation rates, the strongest change occurs in dry friction, which can be explained by the influence of the roughness as mentioned above. Furthermore, the dry friction deformation is at the expense only of a change in the outer diameter D, whereas when using a lubricant, deformation occurs at the expense of the outer and inner diameters.

The simulation results show deviations in comparison with the experimental results obtained. The biggest deviation is obtained using a graphite lubricant. The simulation gives a curve to change the friction coefficient (μ") located above the zero line and up to 32% of the deformation degree, the internal diameter is almost unchanged, indicating that the deformation is largely at the expense of the outer diameter. The character of the curve shows that the software does not take into account the influence of surface roughness, although the input data from the experiment contain implicitly the roughness of the wells and samples. Moreover, in the area of large loads (over 32% deformation), the software provides a change in the direction opposite to the experimentally established. However, the deformation deflection of 46% represents a total of 12 units in the variation of d. These large deviations can not be explained except that graphite in the software is treated as solid particles leading to dry friction when the load is increased.

And when simulating the oil process in the initial stage, the curve of μ" indicates that the effect of roughness is not taken into account. And when simulating the curve shows that the inner diameter is amended practically linear law until a degree of deformation of 35%. In this range there is some coincidence with experimental curves, then there is a sharp decline in contrast to experiment. This means that the software treats friction at high loads, as if the oil is not thrusting but continues to lubricate, as with low loads.

Regarding dry friction, the simulation gives a comparatively satisfactory result, the curve being similar in character to the experimental but located above it. As the degree of deformation increases, the deviation increases, with 40% of the deformation reaching nearly 8 units. For the difference of lubricant cases, the results of the simulation are more reliable as the lubricant factor is eliminated.

These differences in friction variation also led to a difference in the flattening heights between experiment and simulation, most notably at high deformation rates. Highest values are achieved with dry friction - 9.64%, followed by graphite lubricant - 9% and the smallest with oil reaching 2%.

4.Conclusion

The simulation of the ring flattening process in the case of dry friction gives reliable results regardless of the established deviations. In the presence of a lubricant, the differences between the friction curves from the experiment and the simulation are significant, with the largest change being observed for the graphite lubricant. This is due to the incorrect reading of the influence of lubricants on the changes in roughness in the deformation process. By using oil, it is also accepted that friction continues to decrease with a deformation increase of over 40%, which results in contradiction to experimental data and unrecognized change in contact area. In order to correctly simulate the process of flattening of the underlying rings it is necessary to introduce the change of roughness in the process of deformation.

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