DETERMINATION OF COEFFICIENT OF FRICTION DURING COLD RING UPSETTING PROCESS WITH DIFFERENT LUBRICANTS

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ABSTRACT

Contact friction during plastic deformation is always variable and it is highly dependent on the used lubricants. This paper presents the results of determining the coefficient of friction when cold plastic deformation by the method of cold ring upsetting with different lubricants. The ring upsetting process is performed with varying degrees of deformation with three lubricants used: industrial oil, cooking oil, and zinc sulfate powder. Based on the deformation and dimension change of the samples after the upsetting, the coefficient of friction was determined by correlation comparison with the friction calibration curve performed by Male and Cockcroft. A process of verifying the experimental results is carried out on Deform 2D numerical simulation software. Simulation of the ring upsetting process with the same experimental conditions and with the coefficients of friction determined. The dimension of the samples after the deformation simulation is compared with the sample dimension after the weasel to confirm that the results of determining the coefficient of friction are reliable.

XÁC ĐỊNH HỆ SỐ MA SÁT KHI CHỒN NGUỘI PHÔI ỐNG VỚI CÁC CHẤT BÔI TRƠN KHÁC NHAU

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TỪ KHÓA

Hệ số ma sát
Chồn nguội phôi ống
Chất bôi trơn
Đường cong hiệu chuẩn ma sát
Sự biến dạng

TÓM TẮT

Ma sát tiếp xúc trong quá trình biến dạng dẻo luôn thay đổi và phụ thuộc rất nhiều vào việc sử dụng các chất bôi trơn. Bài báo trình bày kết quả khảo sát hệ số ma sát khi biến dạng dẻo nguội bằng phương pháp chồn phôi ống với các chất bôi trơn khác nhau. Quá trình chồn phôi ống được thực hiện với nhiều mức độ biến dạng khác nhau với ba chất bôi trơn được sử dụng bao gồm: dầu công nghiệp, dầu ăn và bột sunfat kẽm. Căn cứ vào sự biến dạng và sự thay đổi kích thước của các mẫu sau chồn, xác định được hệ số ma sát bằng việc so sánh tương quan với đường cong hiệu chuẩn ma sát được thực hiện bởi Male và Cockcroft. Một quá trình kiểm chứng các kết quả thực nghiệm được thực hiện trên phần mềm mô phỏng số Deform 2D. Mô phỏng số quá trình chồn phôi ống với các điều kiện tương tự khi thực nghiệm và với các hệ số ma sát đã xác định được. Kích thước phôi sau mô phỏng biến dạng được đối chiếu với kích thước mẫu sau chồn để khẳng định các kết quả xác định hệ số ma sát có tính tin cậy.

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1. Introduction

During plastic deformation, there is always contact between the deformed material and the tool. This is what causes the resistance against relative sliding on the contact surface. Therefore, the formation of a pair of contact friction impedes the displacement of the metal elements. The contact surfaces can be full surface or partial contact and always change during deformation. Therefore, contact friction during plastic deformation is very different from contact friction in machine parts or in general engineering [1], [2]. Contact friction during plastic deformation is generally harmful. The contact friction between the workpiece and the tool leads to increase resistance to deformation and work of material deformation. It increase wear of the die and contact temperature thereby reducing the life of the die. At the same time, the increasing stress associated with the increased strain force affects the surface state of the products and increases the unevenness of the microstructure and the physical and mechanical properties of the products. Besides, the complexity of the process increases as well as the production cost due to the need to lubricate during deformation [3] - [5]. Therefore, it is extremely important to research to minimize harmful friction during plastic deformation. To do this, the determination of the coefficient of friction for plastic deformation processes must be performed reliably.

In recently published studies, many methods have been designed and developed for the quantitative assessment of friction during metal forming. Masatoshi Sawamura et al. [6] have proposed a new method to determine the coefficient of contact friction during plastic deformation. The high-pressure backward extrusion method is used to determine the coefficient of friction. During the forming process, the punch press rotates at a very slow speed. Loads and torques during the forming process are determined. From there, it is possible to determine the coefficient of friction in the forming process. In addition, this study also allows us to determine the coefficient of friction when using different types of lubricant compounds. Q. Zhang et al. [7] used combined compression and cylindrical extrusion between the flat punch and the V-groove die to investigate the coefficient of contact friction between the workpiece and the tool. The research method is carried out by experiment and numerical simulation with two commercial software, Forge 3D and Abaqus. The Coulomb friction coefficient μ and Tresca friction factor m are determined through the experimental process and the calibration by numerical simulation of the T-shape compression test. Da-Wei Zhang et al. [8] studied to determine the coefficient of friction of the forming process of titanium alloy TA15. The forming process is performed by ring compression test at high temperatures from 950°C to 970°C. At the same time, the friction correction curves were built by the finite element method with the application of Deform software to simulate the deformation process. The parameter of the loading speed is selected to study its influence on the frictional condition of the forming process. Chengliang Hu et al. [9] have published evaluations of the use of dry lubricants in cold forging. Isothermal compression tests are performed with ranges of strain rate and strain temperature. The optimization process is based on the FE simulation results to obtain the friction calibration curve. On the basis of the obtained optimal simulation results, conduct experiments and determine the coefficients of friction. The effectiveness of dry lubricants is evaluated and useful recommendations are made for lubrication during forging.

Among the techniques for determining the coefficient of contact friction during plastic deformation, the ring upsetting method is widely used because of its obvious advantages. It has a process that is easily accomplished and saves time and money with the use of standard ring patterns and flat tools [10] – [14]. The determination of the coefficient of friction is carried out by assessing the change in the inner diameter of the ring during the upsetting process with different degrees of deformation. The friction calibration curves were generated by Male and Cockcroft [15] relating the percentage reduction in the internal diameter of the test specimen to its reduction in height for varying degrees of the coefficient of friction as shown in Figure 1. Therefore, this method is applied to investigate the coefficient of friction for most metal forming processes. However, as with other methods, the determination of the coefficient of contact friction between the workpiece and the tool is actually significant under different lubrication conditions.

This paper presents the results of determining the coefficient of friction in cold plastic deformation process by the method of cold ring upsetting with different lubricants. The ring upsetting process is performed with varying degrees of deformation with three lubricants used: industrial oil, cooking oil, and zinc sulfate powder. Based on the deformation and dimension change of the samples after the upsetting, the coefficient of friction was determined by correlation comparison with the friction calibration curve performed by Male and Cockcroft. A process of verifying the experimental results is carried out on Deform 2D numerical simulation software. Simulation of the ring upsetting process with the same experimental conditions and with the coefficients of friction is determined. The dimension of the samples after the deformation simulation is compared with the sample dimension after the weasel to confirm that the results of determining the coefficient of friction are reliable.

2. Research method

2.1. Material, tools and equipment for experimentation

The tools have a rectangular cross-section which is used for ring upsetting tests made from 45 steel according to GOST 8731-87 standard. The chemical composition of elements (in %wt.) consists of (0.42-0.50)% C, (0.17-0.37)% Si, (0.50-0.80)% Mn, (≤ 0.3)% Ni, (≤ 0.04)% S, (≤ 0.035)% P, (≤ 0.25)% Cr, and (≤ 0.3)% Cu. The ring samples (D_o:d_o:h_o) are machined to meet the experimental requirements, where D_o, d_o, and h_o are the initial outer diameter, inner diameter and height of ring samples, respectively. Technical drawings and test samples are shown in Figure 2. The top and bottom surfaces of the samples are turned to a surface roughness of about 1.25 μm. Commercial lubricants used in the ring upsetting process include industrial oils, cooking oils, and zinc sulfate powder.

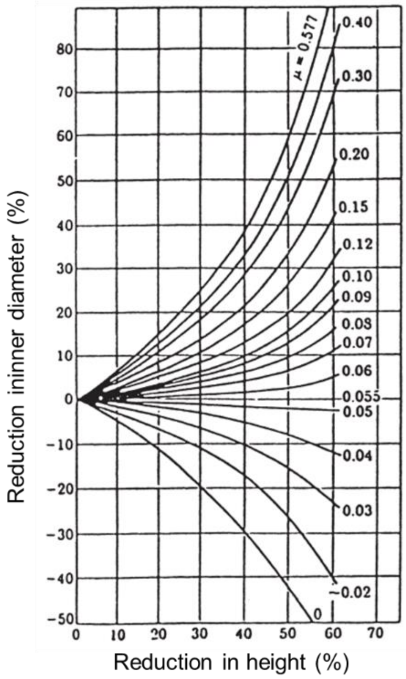

Figure 1. *Friction calibration curves in terms of μ* [15]

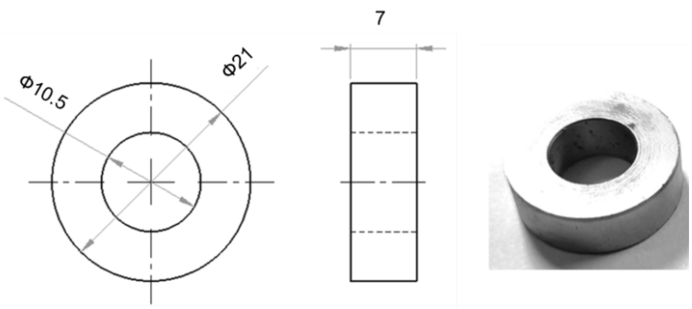

Figure 2. *Geometry of the initial ring sample*

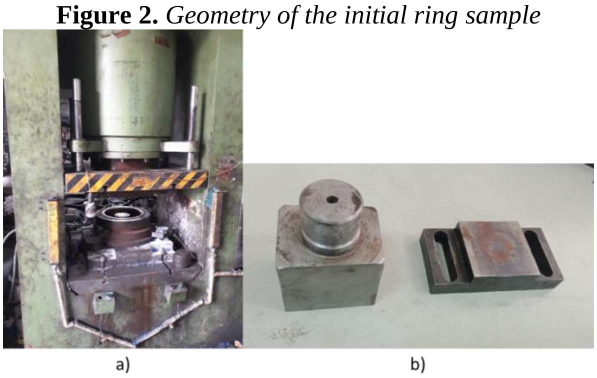

Figure 3. *Pressing device (a) and deformation tools (b) of the ring upsetting process*

Chemical composition testing was performed on the LAB LAVM11 emission spectrometer at the General Department of Military Industries and Manufacture. After that, they were annealed in the LH120/13 Nabthem induction furnace at Metal Forming Department, Le Quy Don Technical University. The ring upsetting process is carried out on a hydraulic press YH32, with a maximum pressing force of 100 tons, a press speed range from 5 mm/s to 50 mm/s. The force of each press is determined through the pressure value applied to the hydraulic cylinder spindle displayed on the pressure gauges. Deformation tools and pressing equipment and deformed samples are shown in Figure 3.

2.2. Experimental process

The ring upsetting process is performed with varying degrees of deformation with three lubricants. The degree of deformation of the upsetting process is selected between 10% and 60% to fit the friction correction curve performed by Male and Cockcroft [14]. The degree of deformation is determined through the amount of reduction in the height of the deformed samples. The experimental steps of the process of ring upsetting with different lubricants are presented in Figure 4.

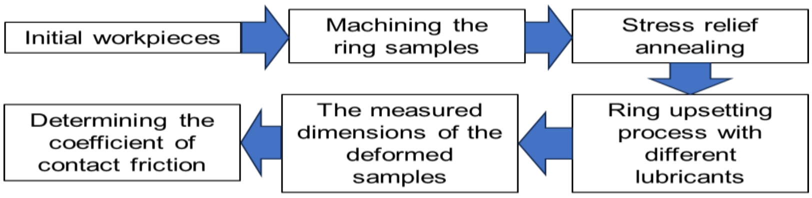

Figure 4. *The experimental steps of the process of ring upsetting*

Various lubricants were selected for the experiments including industrial oils, cooking oils, and zinc sulfate powder. The lubricants selected are common lubricants, relatively inexpensive, and easy to use. For each lubricant compound used, there will be six tests with a degree of deformation. Thus in total, there are eighteen test samples corresponding to three lubricants. The height *h* (mm) and inner diameter *d* (mm) of the deformed samples are determined. Dimension A is defined as the dimensions at the smallest position and is measured at 4 points equally spaced around the circumference. Then, the values of the aggregated dimensions in the study are the average values. Then a reduction in height δh (%) and a reduction in inner diameter δd (%) could then be predicted by using Equation (1) and Equation (2).

$$\delta h = \frac{h_o - h}{h_o}.100\% \tag{1}$$

$$\delta d = \frac{d_o - d}{d_o}.100\% \tag{2}$$

On the basis of the changes in the dimensions of the samples after upsetting, determine the relationship between δd and δh. From this will determine the coefficient close to the friction calibration curve created by Male and Cockcroft [14] and developed and normalized by Wanheim-Bay's [10].

2.3. Numerical simulation of the ring upsetting process

Commercial software Deform 2D was used to numerically simulate ring upsetting processes. This leads to the friction conditions in the simulation problem on the software that will be set up corresponding to the coefficients of friction determined from the experimental process. Based on the relationship between height reduction and inner diameter reduction, this paper will evaluate the deviation of the friction calibration curve between experimental and simulation results.

The geometric model of the upsetting process is built on the software and is shown in Figure 5a. The material model used in simulations that hardening plastic material of 45 steel are shown in Figure 5b and Equation (3) [10]. For the initial meshes, the number of mesh elements to be constructed is 3000 elements. The initial element size is less than 0.1 mm for the ring (Figure 5a is based on the two-dimensional model). The coefficient of friction between the tool and the sample is taken by experimentally determined values. The speed of the punch is 15 mm/s. Corresponding to the strain rate of the deformation process is less than 5 (1/s).

$$\sigma = K.\varepsilon^{n} = 1000.\varepsilon^{0.167} \tag{3}$$

where σ is the effective flow stress (MPa), K is the strain hardening coefficient (MPa), ε is the effective strain, n is the strain hardening exponent.

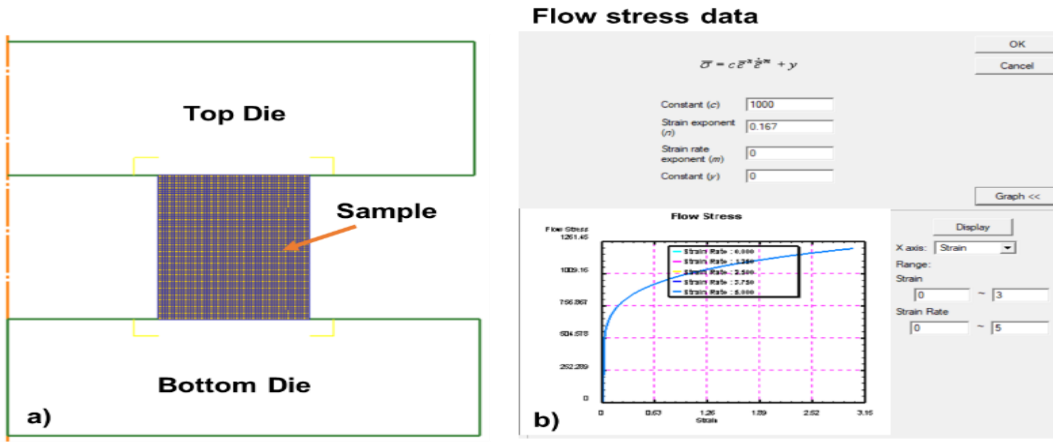

Figure 5. *The geometry model (a), the material model (b)*

3. Results and discussion

3.1. Experimental determination of coefficient of friction

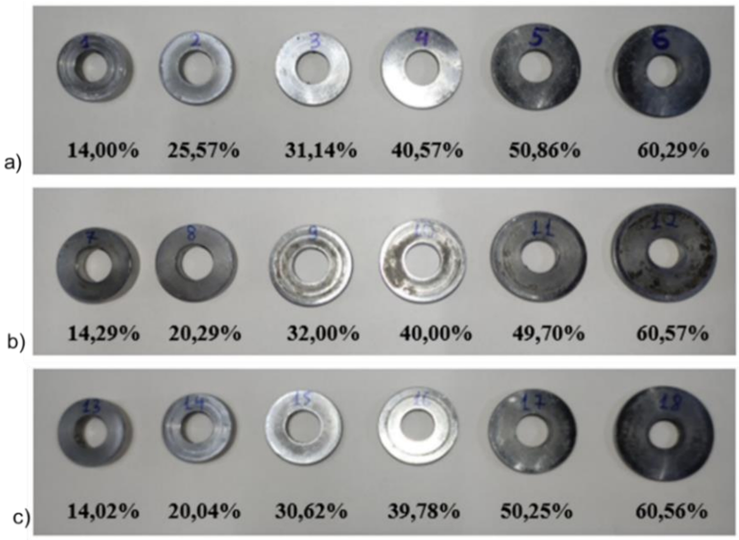

Figure 6. *The deformed ring samples*

A total of eighteen upsetting tests were conducted and the resulting shapes of the compressed ring samples after different reductions in height are shown in Figure 6. The results of the dimension survey of the samples after upsetting are summarized in Table 1. Figure 7 shows the test calibration curve results. These curves are compared with the friction calibration curve

(Figure 1) to determine the coefficient of friction. Through experimental results, the coefficient of friction of cooking oil, industrial oil, and zinc sulfate powder is 0.07, 0.08, and 0.09, respectively. Thereby, it is found that the friction coefficient of cooking oil is the smallest. This confirms that the lubricating ability of cooking oil is the best among the three selected lubricants in the study. That means, with the increase of the degree of deformation (reduction in the height), the reduction in the inner diameter of the test samples is small. The dimensions of the samples after deformation meet the technical requirements of the forming process. However, because cooking oil has a higher cost, the choice of lubricant in many cases must be based on economics to ensure the cost of shaping products.

Table 1. *Geometric parameters of the sample after deformation*

Samples	Lubricants	Height (mm)	Inner diameter (mm)	δh (%)	δd_{Exp} (%)
1	Cooking Oil	6.02	10.44	14.00	0.57
2		5.22	10.32	25.57	1.62
3		4.82	10.26	31.14	2.21
4		4.16	10.22	40.57	2.67
5		3.44	10.08	50.86	4.00
6		2.78	9.98	60.29	4.95
7	Zinc Sulfate Powder	6.00	10.46	14.29	0.38
8		5.58	10.36	20.29	1.33
9		4.76	10.16	32.00	3.23
10		4.20	9.98	40.00	4.95
11		3.52	9.52	49.70	9.33
12		2.76	8.90	60.57	15.23
13	Industrial oil	6.02	10.48	14.02	0.19
14		5.60	10.40	20.04	0.95
15		4.86	10.22	30.62	2.67
16		4.22	10.02	39.78	4.60
17		3.48	9.76	50.25	7.04
18		2.76	9.32	60.56	11.20

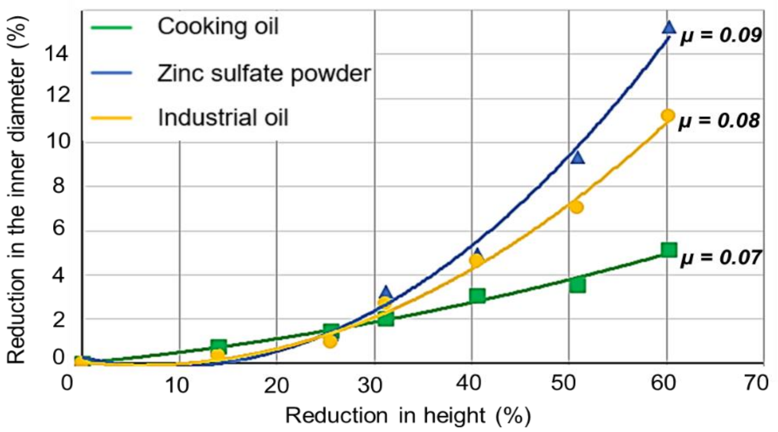

Figure 7. *Experimental results and correlation with the friction calibration curve*

3.2. Numerical simulation results

The change in sample geometry during the cold ring upsetting process is shown in Figure 8. Figure 8a is the first step of the simulation problem, where the sample has meshed and boundary conditions are set up corresponding to the experimental process. Figure 8b and Figure 8c show the next and final steps of the upsetting process. As shown in Figure 8, when compressing the ring sample between the top die and bottom die, the contact friction between the sample surfaces and the tools increases. As a result, the material flows in unequal directions affecting the shape and dimension of the samples after deformation. Both the inner diameter and outer diameter of the test samples change with the compression deformation. Both the inside diameter and outside diameter of the test piece change with the mink deformation compression deformation The outer diameter of the test piece usually increases during deformation smallest. If the inner diameter of the sample increases during the ring upsetting process, the contact friction has a low value. If the inner diameter of the sample decreases during the ring upsetting process, the contact friction has a high value [15]. The dimensions of the samples are easily measured directly on the Deform 2D software.

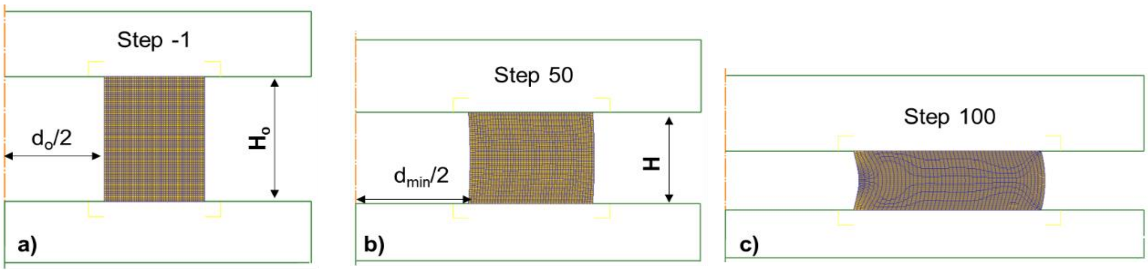

Figure 8. *Geometry of ring sample in upsetting process*

The dimension of the samples after upsetting processes is shown in Table 2. The deviation between the reduction in the inner diameter of the test samples between the experimental and simulation processes is also evaluated in Table 2 and Figure 9. This deviation has a small value, not exceeding 1% indicating that the coefficient of friction is determined by the cold ring upsetting method with high reliability. It was found that, when setting up the problem of simulating the upsetting process with the coefficient of friction of 0.07 (corresponding to the lubricant being cooking oil), the deviation of the reduction in inner diameter of the test samples compared with the experiment is smallest. It shows that using lubricants with good properties will ensure the results of determining the coefficient of friction including experimental and simulation results.

Table 2. *Geometric parameters of the sample after deformation simulation*

Samples	The coefficient of friction	Height (mm)	Inner diameter of the experimental processes, d_{Exp} (mm)	Inner diameter of the simulation processes, d_S (mm)	δh (%)	δd_S (%)	$\left\|\delta d_{Exp} - \delta d_S\right\|$ (%)
1	0.07	6.02	10.44	10.42	14.00	0.73	0.16
2		5.22	10.32	10.32	25.57	1.75	0.13
3		4.82	10.26	10.27	31.14	2.20	0.01
4		4.16	10.22	10.15	40.57	3.38	0.71
5		3.44	10.08	10.11	50.86	3.70	0.30
6		2.78	9.98	9.94	60.29	5.36	0.41
7	0.09	6.00	10.46	10.42	14.29	0.75	0.37
8		5.58	10.36	10.38	20.29	1.15	0.18
9		4.76	10.16	10.20	32.00	2.88	0.35
10		4.20	9.98	9.93	40.00	5.42	0.47
11		3.52	9.52	9.48	49.70	9.75	0.42
12		2.76	8.90	8.87	60.57	15.5	0.27
13	0.08	6.02	10.48	10.46	14.02	0.40	0.21
14		5.60	10.40	10.38	20.04	1.13	0.18
15		4.86	10.22	10.26	30.62	2.30	0.37
16		4.22	10.02	10.06	39.78	4.23	0.37
17		3.48	9.76	9.70	50.25	7.65	0.61
18		2.76	9.32	9.38	60.56	10.7	0.50

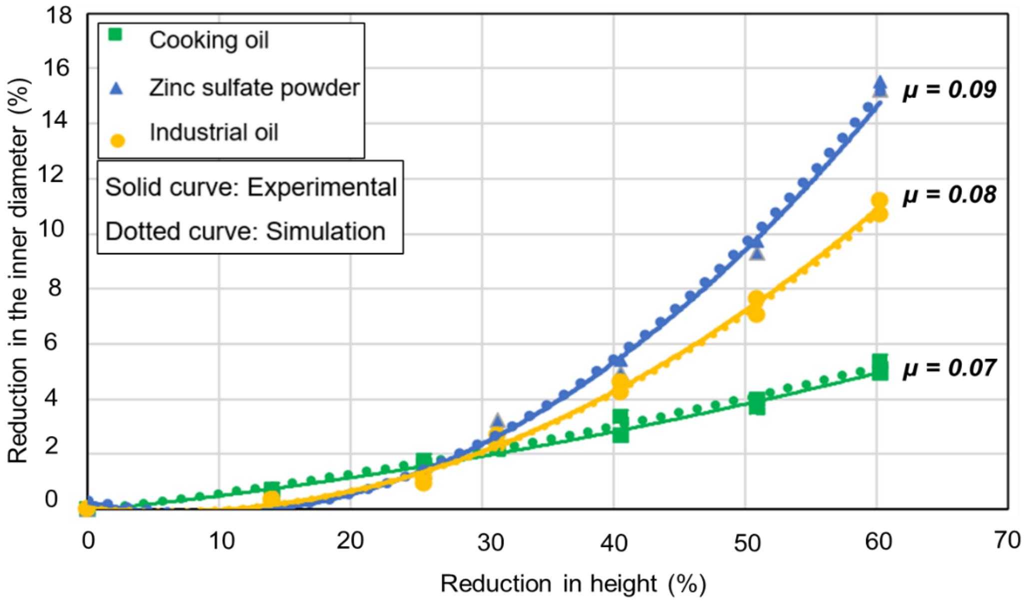

Figure 9. *Deviation between the friction calibration curve of the simulation and the experimental process*

4. Conclusion

This paper has achieved the following specific results:

- The ring upsetting method was chosen to determine the coefficient of friction with different used lubricant compounds. This is a suitable method for estimating the coefficient of friction of bulk-forming processes.

- The relationship curve between the reduction in inner diameter and the reduction in height was built from the experimental results. By comparison with the friction calibration curve according to Male and Cockcroft, the coefficient of friction is determined when ring upsetting with lubricants including cooking oil, zinc sulfate powder, and Industrial oil. The results show that cooking oil has the best lubricating effect (corresponding to a coefficient of friction of 0.07). The reduction in inner diameter in upsetting processes with different degrees of strain is of small value.

- Commercial software Deform 2D is applied to simulate the deformation process. The friction calibration curve is controlled in both experimental and numerical simulations. The results show that the deviation is not significant, thereby showing the reliability of the studied method.

- Subsequent studies focused on key issues including: the determination of the coefficient of friction for the forming process of high-strength alloys; the coefficient of friction during hot forming; effect of forming process parameters on friction and lubricating efficiency.

REFERENCES

[1] M. Sigvant, J. Pilthammar, J. Hol, J. H. Wiebenga, T. Chezan, B. Carleer, and T. van den Boogaard, "Friction in sheet metal forming: influence of surface roughness and strain rate on sheet metal forming simulation results," *Procedia Manufacturing*, vol. 29, pp. 512-519, 2019.

[2] H. U. Vierzigmann, M. Merklein, and U. Engel, "Friction Conditions in Sheet-Bulk Metal Forming," *Procedia Manufacturing*, vol. 19, pp. 377-382, 2011.

[3] L. Figueiredo, A. Ramalho, M.C. Oliveira, and L.F. Menezes, "Experimental study of friction in sheet metal forming," *Wear*, vol. 271, pp. 1651-1657, 2011.

[4] E. Ceretti, A. Fiorentino, and C. Giardini, "Process parameters influence on friction coefficient in sheet forming operations," *International Journal of Material Forming*, vol. 1, pp. 1219-1222, 2008.

[5] P. S. Nielsen, N. A. Paldan, M. Calaon, and N. Bay, "Scale effects in metal-forming friction and lubrication," *Proc. ImechE, Part J: J. Engineering Tribology*, vol. 225, pp. 924-931, 2011.

[6] M. Sawamura, Y. Yogo, M. Kamiyama, and N. Iwata, "Measurement of friction coefficient by backward extrusion with rotating tool under severe forming conditions," *Procedia Engineering*, vol. 81, pp. 1866-1871, 2014.

[7] Q. Zhang, E. Felder, and S. Bruschi, "Evaluation of friction condition in cold forging by using T-shape compression test," *Journal of Materials Processing Technology*, vol. 209, pp. 5720–5729, 2009.

[8] D.-W. Zhang, H. Yang, H.-W. Li, and X.-G. Fan, "Friction factor evaluation by FEM and experiment for TA15 titanium alloy in isothermal forming process," *Int. J. Adv. Manuf. Technol*., vol. 60, pp. 527–536, 2012.

[9] C. Hu, S. Osaki, B. Cai, M. Aoyama, and K. Dohda, "Evaluation of dry-in-place lubricants for cold forging by using an optimal steady combined forward and backward extrusion testing method," *Friction*, vol. 11, 2023, doi: 10.1007/s40544-022-0717-3.

[10] H. Tschaetsch, *Metal Forming Practise: Processes - Machines - Tools*, Springer-Verlag Berlin Heidelberg, Germany, 2020, pp. 373.

[11] Q. Zhang, M. Arentoft, S. Bruschi, L. Dubar, and E. Felder, "Measurement of friction in a cold extrusion operation: Study by numerical simulation of four friction tests," *International Journal of Material Forming*, vol. 1, pp. 1267-1270, 2008.

[12] S. B. Petersen, P. A. F. Martins, and N. Bay, "An alternative ring-test geometry for the evaluation of friction under low normal pressure," *Journal of Materials Processing Technology*, vol. 79, pp. 14-24, 1998.

[13] P. Christiansen, P. A. F. Martins, and N. Bay, "Friction compensation in the upsetting of cylindrical Test Specimens," *Experimental Mechanics*, vol. 56, pp. 1271-1279, 2016.

[14] J. Obiko, "Friction correction of flow stress-strain curve in the upsetting process," *IOP SciNotes*, vol. 2, pp. 1-5, 2021.

[15] H. Sofuoglu and J. Rasty, "On the measurement of friction coefficient utilizing the ring compression test," *Tribology International*, vol. 32, pp. 327-335, 1999.