



RESEARCH ON THE INFLUENCE OF LUBRICATION ON THE RESULTS OF THE MICRO-DEEP DRAWING PROCESS USING A FINITE ELEMENT MODEL ON QFORM 10 CLOUD SOFTWARE

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ABSTRACT

In the process of material forming, the selection of friction conditions (lubrication) belongs to one of the important tasks affecting, for instance, the value of deformation force. The article deals with the impact of friction factor calculated based on the A.N. Levanov's friction law on the deformation forces during the micro-drawing process of a cup made from aluminum alloy AD33 with the help of the finite element modeling in the QForm 10 Cloud. The forming process was simulated for two cases, with and without lubrication, whereby several scaling factors for toolset and blank were under study. It was found that the maximal force obtained for tools without lubrication, and the influence intensity decreased with a reduction of the dimensions of the workpiece and toolset.

Keywords: *micro-drawing process, friction, Qform 10 cloud, finite element modeling, deformation forces.*

1. Introduction

The major difference between the micro-deep drawing process and conventional deep drawing lies in the geometric dimensions and the surface contact area between the tools and the workpiece. Reducing the geometric size of the tooling and the initial blank from several millimeters to a few micrometers leads to difficulties in selecting appropriate technological parameters for the micro-deep drawing process. Therefore, the theoretical foundations of conventional deep drawing cannot be directly applied to micro-deep drawing [3, 4].

When the geometric dimensions of the part decrease, the actual contact area between the tool and the blank becomes smaller, while the overall shape characteristics

and surface roughness remain unchanged. During the deep drawing process, when the tools are closed, lubricant fills the surface roughness valleys, forming both open and closed lubricant pockets. As a result, the ratio between the number of lubricant pockets and the contact area decreases significantly, and the external load is redistributed among fewer pockets (Fig. 1) [6–8].

When a force F is applied to the contact surface, a normal stress (σ_n) is generated. The surface roughness asperities begin to deform plastically, and due to the low compressive resistance of the lubricant, the lubricant pressure inside the pockets increases and acts on the side walls of the roughness valleys.

The roughness valleys that connect to the outer edges of the surface cannot retain the

lubricant, forming open lubricant pockets. As the pressure increases, the lubricant is squeezed out and cannot support or transmit the deformation load. In contrast, closed lubricant pockets, which are not connected to the surface edges, trap the lubricant inside and maintain pressure during micro-deep drawing. Significant plastic deformation is observed on surfaces with closed pockets, leading to higher contact stresses and better smoothing of the blank surface roughness when harder and stronger tools are used. Consequently, the actual contact area

increases, resulting in higher friction [5].

The development of hydrostatic pressure within the lubricant pocket absorbs part of the external load, thereby reducing the normal pressure acting on the asperities and lowering friction. Thus, closed lubricant pockets reduce friction. When the specimen size decreases, the number of closed pockets decreases as well, leading to an increase in the friction coefficient. The behavior and influence of open and closed lubricant pocket models have been studied and presented in the literature [1–2].

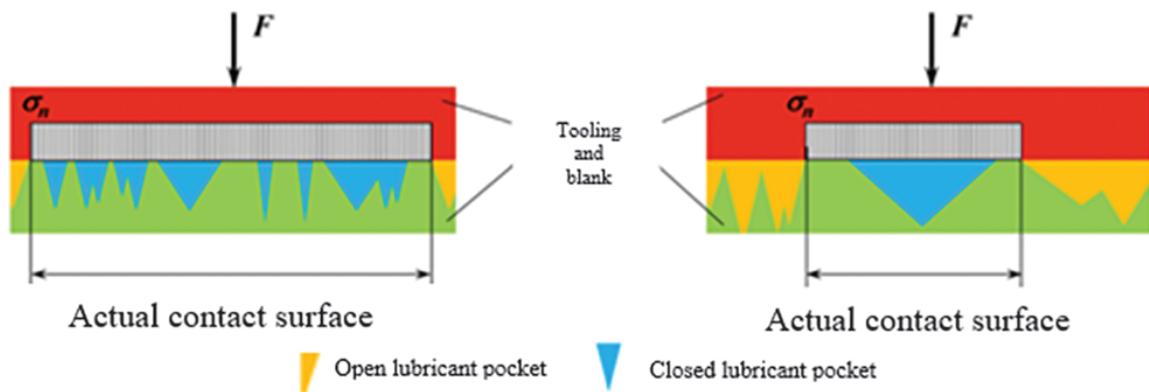


Figure 1. Comparison of the contact surface size in conventional deep drawing (left) and micro deep drawing (right).

2. Materials and Research Method

The blank material is aluminum alloy AD33, whose chemical composition is known and provided in reference [9]. **Numerical modeling.** The 3D models of the blank and tooling (Figure 2) were created using Autodesk Inventor. Circular blanks were cut from sheets and then placed into the die to form a cup in a single drawing stroke of the punch. A clamping force was applied using a spring-loaded tool to prevent the formation of wrinkles in the flange area. To investigate the size effect, the similarity coefficient λ and geometric scaling were used. The similarity coefficient (KD) or scaling factor λ (KM) in this study ranged from 1 to 0.125, with a multiplier of 0.5 used to reduce the geometric

parameters of both the blank and the tooling. The blanks used in the study therefore had thicknesses ranging from 0.8 mm to 0.1 mm, corresponding to λ -scaled cases. The clearance between the punch and die was $1.5s$, the punch radius was $3s$, and the die radius was $2s$. The dimensions of the tooling configurations used in the simulations are shown in Table 1.

The numerical simulation process was carried out using the finite element method (FEM) in the QForm 10 Cloud software. QForm was first introduced in 1991 by the company “QuantorForm”, Russian Federation (QForm 2D). It is a numerical simulation program for metal forming processes with automatic mesh

generation based on FEM algorithms, intended for use on specialized computers [11]. QForm 10, released in 2022, meets modern requirements for compatibility and performance, enhancing online computation capabilities, offering more flexible licensing options, and improving both accuracy and calculation speed. The software has been further optimized for detailed technological design, enabling efficient simulation of

complex deformation processes, reducing the number of manufacturing steps, and ensuring reliable calculation of process parameters [12]. The similarity coefficient or scale ratio (λ) is determined according to Equation (1).

$$l = \frac{D_{Ch}}{D_C} \tag{1}$$

Where, DCh - Diameter of the punch; DC - Reference punch diameter, selected as 8 mm.

Table 1. KD values and geometric dimensions of the tooling

Similarity coefficient KD (λ)	1	0.5	0.25	0.125
Punch diameter (DCh)	8	4	2	1
Die diameter (Dc)	10.4	5.2	2.6	1.3
Blank diameter (DP)	16	8	4	2
Punch radius (R1)	2.4	1.2	0.6	0.3
Die radius (R2)	1.6	0.8	0.4	0.2
Punch–die clearance (c)	1.2	0.6	0.3	0.15
Blank thickness (s)	0.8	0.4	0.2	0.1

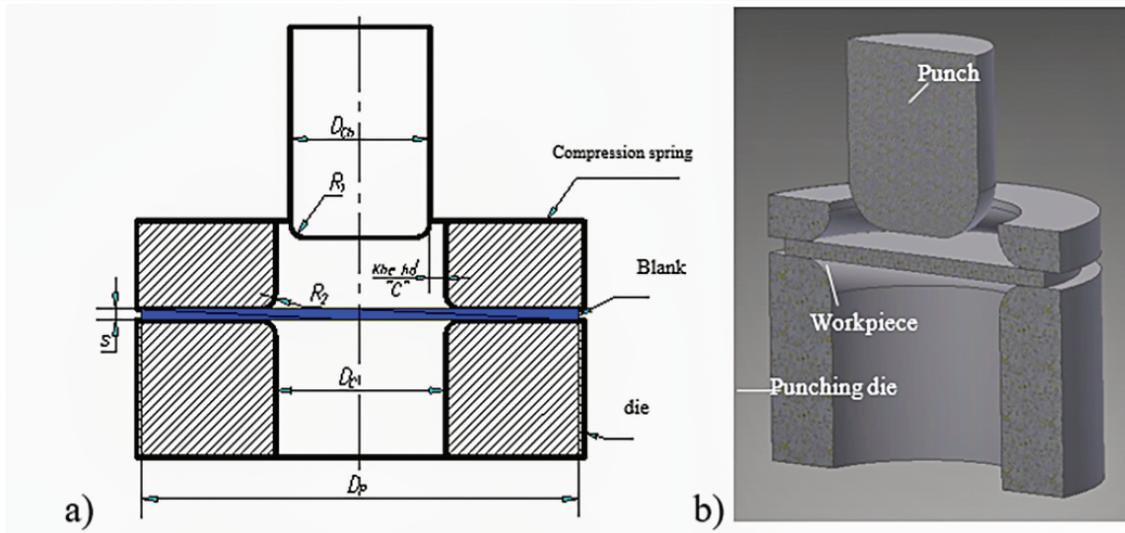


Figure 2. Schematic of the micro deep drawing process (a) and the 3D model (b).

The deformation rate, number of tool passes, and clamping force are presented in Table 2. The influence of the lubricant on the maximum forming force was determined according to Equation (2). The micro deep drawing process was simulated under two friction conditions: with lubrication and without lubrication.

$$H = \frac{F_{M1} - F_{M2}}{F_{M1}} * 100\% \tag{2}$$

Where, H – Influence of the lubricant on the maximum forming force; FM1 – Maximum forming force without lubrication; FM2 – Maximum forming force with lubrication.

Table 2. Process parameters used in the micro deep drawing simulation in QForm 10 Cloud.

Similarity coefficient, λ [-]	Punch speed, V [mm/s]	Punch stroke, h [mm]	Clamping force, Fk [N]
1	1	8	100
0.5	0.5	4	50
0.25	0.25	2	25
0.125	0.125	1	12.5

The effect of friction was calculated using Levanov’s friction model, which has been applied for the study of hot bulk forming [10]. However, this friction model has not yet been tested in micro deep drawing and may not have been applied at the theoretical microscale level, where the stress and strain

states of the material coincide with those in all other pressure-based forming processes. The coefficient values corresponding to the selected friction conditions were taken from the lubricant library of QForm 10 Cloud and are presented in Table 3.

Table 3. Levanov friction model parameters selected from the lubricant library of QForm 10 Cloud

Lubricant	Friction, [-]	Levanov coefficient, [-]	Heat transfer coefficient, [W/m ² ·K]	Stopping coefficient, [-]
Mineral oil	0.15	1.25	75000	0.05
No lubrication	0.5	1.25	30000	0.05

3. Research Results and Discussion

The main results from the computer modeling of the micro deep drawing process for cup-shaped parts made from aluminum alloy AD33 under both lubricated and non-lubricated conditions are presented in Figure

3 and Table 4. The simulation results allow for evaluating the influence of lubrication on the maximum forming force in micro deep drawing, as well as the dependence of the forming force on the similarity coefficient λ of the tooling.

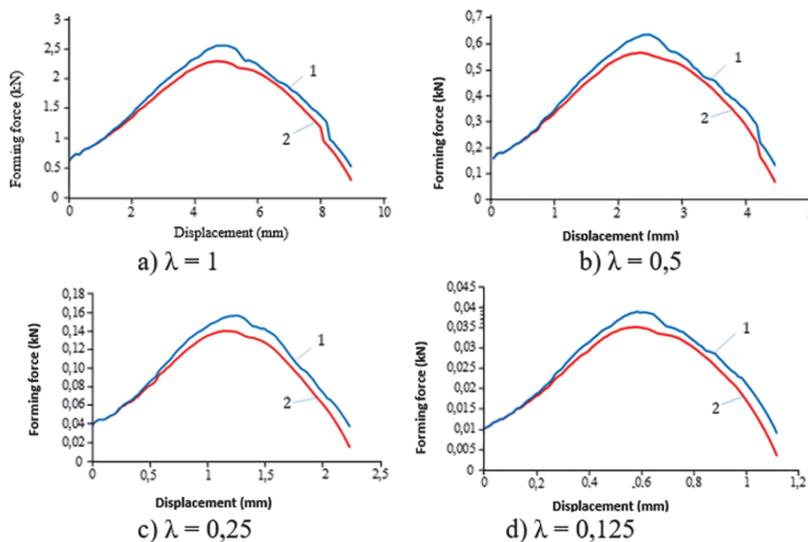


Figure 3. Dependence of the forming force on the punch stroke
1 – Without lubrication; 2 – With lubrication.

The simulation results show that during the micro deep drawing of cup-shaped parts made from aluminum alloy AD33, the forming force without lubrication is higher than the forming force when lubrication is applied (Figure 3). This is because the presence of lubricant generates normal forces that reduce the sliding friction between the tool surface and the blank surface [1].

The maximum forming force is defined as the force acting on the blank during the micro deep drawing process. According to the micro deep drawing simulations, the values of the maximum forming force corresponding to different KD (λ) values are presented in Table 4.

Table 4. Maximum forming force values

Similarity coefficient KD, λ [-]	1	0.5	0.25	0.125
Maximum forming force, [kN]	FM1	FM2	FM1	FM2
	2.559	2.27	0.635	0.5648
H value, [%]	11.3	11.1	10.5	9.8

(where H – influence of the lubricant on the maximum forming force, calculated according to Equation (2); FM1 – maximum forming force without lubrication; FM2 – maximum forming force with lubrication).

Based on these results, a plot showing the relationship between the maximum forming force and the influence of lubrication on the maximum forming force (H index) for different KD (λ) values was constructed (Figure 4).

maximum forming force and the similarity coefficient KD in the case without lubrication:

$$y = 2,5622x^{2,0123}; R^2 = 0,99 \quad (3)$$

Dependency equation between the maximum forming force and the similarity coefficient KD in the case with lubrication:

$$y = 2,695x^{2,004}; R^2 = 0,99 \quad (4)$$

Dependency equation between the influence of lubrication on the maximum forming force and the similarity coefficient KD (λ):

$$y = 0,7382 \ln(x) + 11,425; R^2 = 0,95 \quad (5)$$

It can be explained that during the micro deep drawing of parts, the contact area between the tool and the blank is divided into three zones: open lubricant pockets, closed lubricant pockets, and the actual contact area. As the tool size decreases, the contact area becomes smaller, reducing the number of both closed and open lubricant pockets. The normal forces are generated primarily by the open lubricant pockets [6]; therefore, decreasing the tool size reduces the influence of lubrication. Simulation results (Figure 4 – Line 3) show that the influence of lubrication on the maximum forming force decreases as the KD coefficient decreases from 1 to 0.125. Specifically, the lubrication influence index (H) decreases by 11.3% when KD = 1

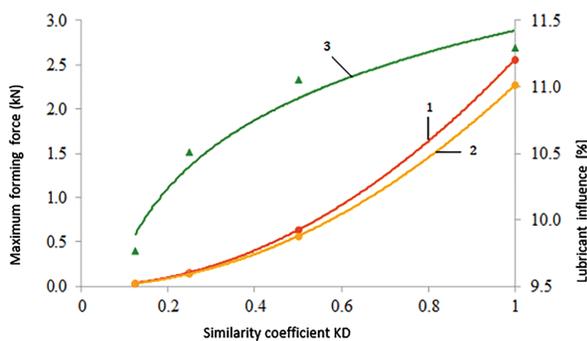


Figure 4. Graph showing the dependence of the maximum forming force on the similarity coefficient KD (λ) (Line 1 – without lubrication; Line 2 – with lubrication) and the influence of lubrication on the maximum forming force (Line 3).

From this graph, the following dependency equations can be derived:

- Dependency equation between the

and by 9.8% when $KD = 0.125$. This is due to the reduction of the similarity coefficient λ , which increases the actual contact area between the working surface of the tool and the blank (enhancing the role of friction). Smaller open and closed pockets reduce the effect of lubrication, indicating the need to develop specialized lubrication methods for micro deep drawing processes.

4. Conclusions and Future Research

The simulation results of micro deep drawing of cup-shaped parts made from aluminum alloy AD33 indicate the influence of the geometric size of the blank and tool, as well as friction conditions, on the process parameters. The key findings are:

The forming force under non-lubricated conditions is higher than under lubricated conditions;

The influence of lubrication on the maximum forming force decreases as the similarity coefficient KD (or scaling factor KM) decreases. In other words, smaller tools reduce the effect of lubrication on the micro deep drawing process.

Future research should focus on developing specialized lubrication methods for micro deep drawing processes (for small-sized parts) and investigating the influence of the similarity coefficient λ on other technological parameters of micro deep drawing.

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