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Forming limit of sheet metal in cylindrical deep drawing with a conical die

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Abstract: It is well-known that the use of a conical die in cylindrical deep drawing can enhance the formability compared with conventional process. The most commonly observed failure mode in the process is fracture near the punch corner or wrinkling in the flange region. In order to obtain the limiting drawing ratio (LDR), a cylindrical deep drawing including only the conical die and flat punch is discussed based on numerical simulation in the paper. A finite element model for the deep drawing with a conical die is developed, and the accuracy of the model is verified by experiments results. The investigation shows that in the cylindrical deep drawing with a conical die, the types of failure above , which can obtain for thinner sheet materials, are obviously related to the sheet thickness and the conical angle, and the optimum conical angle is also found.

1. Introduction

Thin-walled cylindrical deep drawing is one of the most widely used process in sheet forming technology. The main method for producing thin-walled cylindrical cups is conventional deep drawing with a blank holder. In this case, the limit coefficient of drawing, according to Ref [1], does not exceed 2.0. By using a conical die without blank holder for stamping, the maximum drawing ratio can be slightly increased. Hence, the process is carried out without a blank holder, which greatly simplifies the structure of forming tools. The most commonly observed failure mode in the process is fracture near the punch corner or wrinkling in the flange region when drawing cylindrical cup through a conical die. But the deformation mechanism and the influence of processing parameters on the limit drawing ratio of this process have been little studied.

Soweby et al. [2] described an experimental study of deep drawing through conical dies without blankholder. Four common sheet metals with three different thicknesses are used and the wrinkling modes which developed during the different stages of deep drawing are explained. Narayanasamy et al [3] discussed an experimental study of deep-drawing of three different steels through a conical die using flat-bottomed and hemispherical-ended punches and obtained an relation between the limit drawing ratio and a non-dimensional parameter index involving the punch diameter, the blank thickness and the average plastic strain ratio. However, in all the two experimental studies only observed a conical die with a constant die angle. The effect of the die angle on the limit drawing ratio is not discussed in these works.

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Mahadwie and Mellor [4] described an experimental study of the deep drawing of ten sheet metals through a conical die. A semi-empirical approach is adopted to demonstrate the relationships between the blank diameter, blank thickness, punch diameter, punch profile radius and anisotropy of the sheet metal. However, the influence of the die angle on the failure just for the same kind of material is not enough investigated.

In the present work, the influences of the die angle and the blank thickness on the formability of cylindrical cups through a conical die is studied based on numerical simulation. For varication of the finite element (FE) predictions, experiments for similar operation conditions are carried out. Finally, the types of failure of blanks and the optimum conical angle are found.

2 Experimental Procedure and Numerical Simulation

In this research, circular blanks of steel 08F (Russian standard) with 1 mm of thickness were used. The chemical compositions are given in table 1. The engineering stress-strain curve is obtained based on uniaxial tension test. The elastic-plastic material properties and the yield function are listed in table 2.

The forming test was performed on circular blanks of different diameters with a ram speed 1mm/s using a vertical press. The diameter of the punch is 36 mm and the diameter of the die is 40 mm. In Figure 1, the photo of the dies with 30°, 60° and 70° respectively used for forming test are shown. It is considered to be successful if a workpiece without any fractures and wrinkles was obtained during the forming process.

Figure 2 shows the geometries of the tools and a full FE-model in Software Dynaform. The forming tools consisting of punch and die were modelled as rigid bodies and the blank was modelled as deformable. Process was modelled with shell elements with average element sizes 0.3 mm ,0.5 mm and 0.7 mm. By comparing the result of simulation and the experiment (forming accuracy and time of simulation), 0.5 mm were used to discrete the blank in the simulation. According to Ref [5], anisotropy of the blank has little influence on wrinkling in process of deep drawing through a conical die, so during the simulation, the anisotropy of the blank was not considered.

The friction coefficient between the tools and the blank was obtained by comparison of experimental and FE simulation results about the maximum drawing force and the deformation work In this regard, initially approximate value (0.25, without lubricant) of the friction coefficient was determined by the data reported by [6]. The different values of friction coefficient around 0.25 were used in the FE simulations. The drawing load under the die angle of 60° and the blank diameter of 90 mm with different friction coefficients is shown in figure 3. According to figure 3, 0.23 were used as the friction coefficient between die and blank for the simulation.

In figure 4 and table 3, the comparison between experimental results and simulations are shown. The results of the simulation and experiment have a good consistency. The maximum error obtained from the die angle of 60° was 3.3 %. Therefore, the actuary of the simulation is verified.

Table 1. Chemical compositions of steel 08F.

C	Si	Mn	Ni	S	P	Cr	Cu	Ti
0.06	0.056	0.31	0.03	0.015	0.014	0.05	0.05	0.002

Table 2. Mechanical properties and work hardening equation.

Material	Mechanical properties				Work hardening equation (yield function) $\sigma = \sigma_s + k\varepsilon^n$	
	Yield stress $\sigma_s(MPa)$	Tensile strength $\sigma_b(MPa)$	Maximum plastic strain ε_{max}	Young's module $E(G\mathrm{Pa})$	k	n
steel 08F	196.6	365	0.28	186	550	0.512

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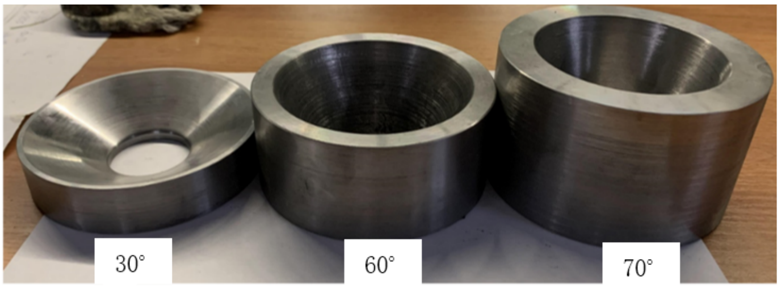

Figure 1 Dies with different die angles in deep drawing test.

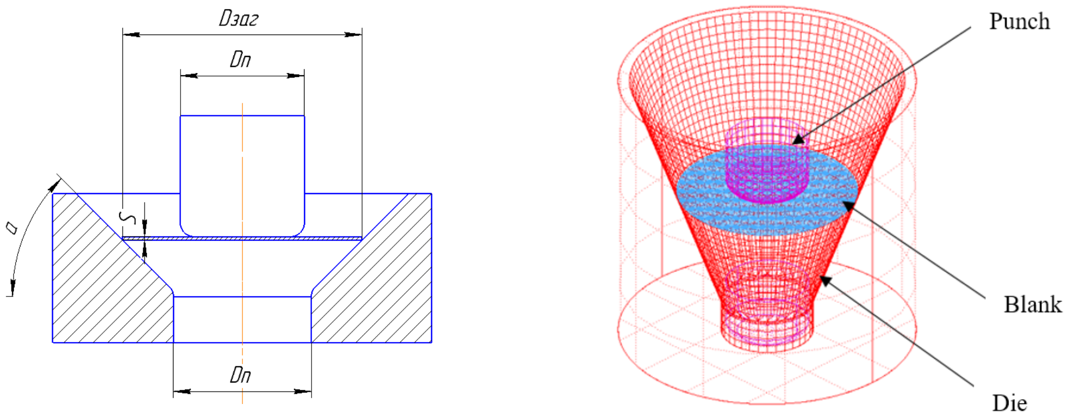

Figure 2 Tool geometry and FE-model in Dynaform.

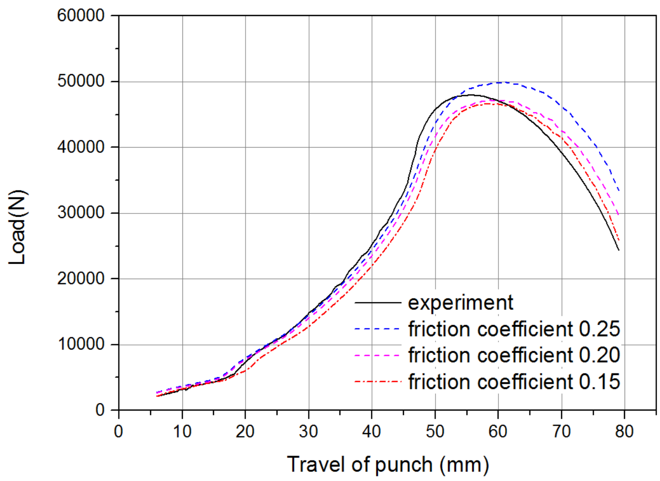

Figure 3. The drawing load under the die angle of 60° and the blank diameter of 90 mm with different friction coefficients

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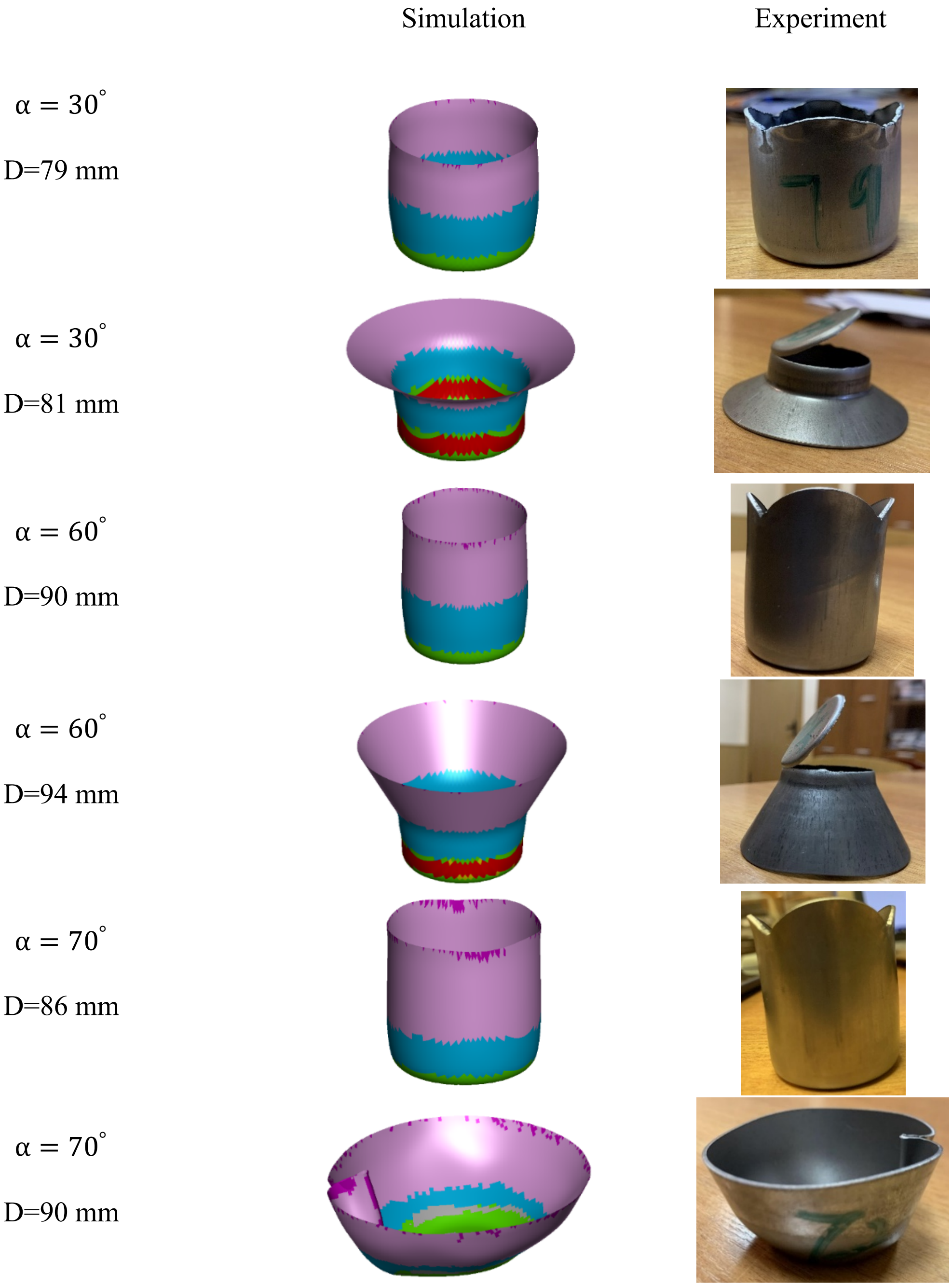

Figure 4. Comparison under different die angles with 1mm thickness of blank

Table 3. Results of experiment and simulation.

Die angle	Limit drawing ratio in the experiment	Limit drawing ratio in the simulation	Error between the experiment and simulation
30°	1.975	2.0	1.2%
60°	2.25	2.325	3.3%
70°	2.15	2.2	2.3%

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3 Results and discussion

The influence of the die angle and blank thickness on the limit drawing angle is obtained through simulation using the verified FE model. Results of prediction of limit drawing ratio are shown in Figure 5 and Figure 6.

From figure 5, it can be observed that for the blank thickness of 0.5 mm, the main type of failure is wrinkling when the blank was drawing into a conical die without blank holder. The optimum conical angle is 40°. When the die angle is below the optimum die angle, with a decrease of conical angle, the process is more like the case of conventional deep drawing without a blank holder, so the limiting drawing ratio falls rapidly. When the angle is higher than the optimal die angle, wrinkles are more likely to occur during the deep drawing process, because the flange of blank will be further deformed without contact with the surface of the die, which contributes to the formation of wrinkles.

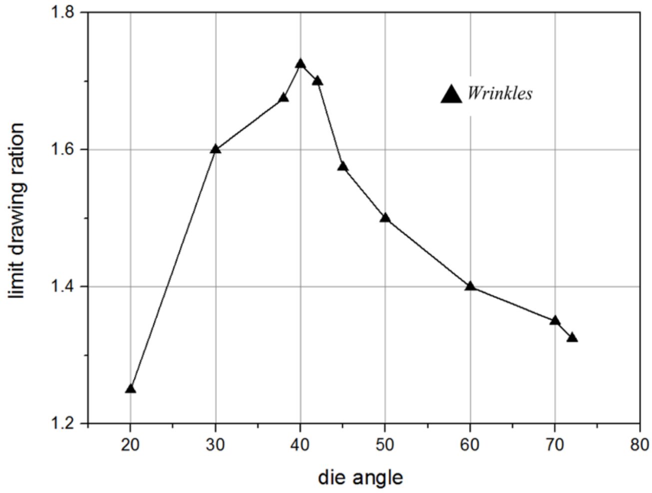

Figure 5. Variation of limiting drawing ratio with die angle for thickness 0.5 mm

Figure 6 show that with small die angels, the main type of failure is facture at the bottom of the cylindrical cup under the blank thicknesses of 1.0 mm and 1.5 mm, respectively. With an increase in the die angle, wrinkling at the edge of the flange becomes a limitation of the drawing process. There is a die angle at which the type of failure changes from factures to wrinkles, and at the same die angle, the maximum limiting drawing ratio is achieved

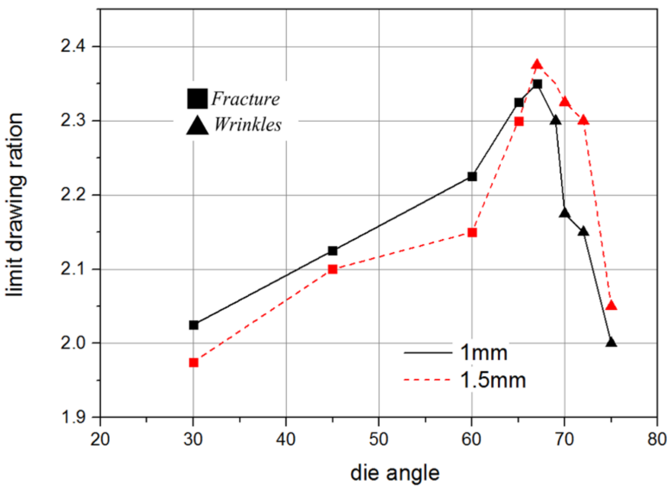

Figure 6. Variation of limiting drawing ratio with die angle for thickness 1.0 mm and 1.5 mm

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The above results are good in agreement with the quoted results of Mahadwie and Mellor [4]. However, in the latter work the limit drawing ratio with several materials with diffident thickness under the same die angle was given. The present work draws attention to the influence of the die angle under the same material with different thickness.

4 Conclusion

The limit drawing ratio was obtained when forming through a conical die without blank holder using simulation method. The type of failure in the forming process depends on the blank thickness. For small blank thickness (blank thickness of 0.5 mm), the wrinkles at the edge of flange are more likely to occur during process. For thicker plates (blank thickness of 1 mm and 1.5 mm), the type of failure changes from factures to wrinkles with increase in die angle, and the maximum limiting drawing ratio is achieved at die angle, at which the change occurs.

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