

Research Article

Numerical and Experimental Investigation of Deep Drawing Process of Square Cross-Section Cups Made of St37 Without Blank Holder

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ABSTRACT

Conical dies without blank holders are an interesting subject for metal-forming applications because of their structural simplicity and reduced tooling complexity. However, reduced control of material flow and the increase likelihood of defects, such as excessive thinning and shrinkage, are the main limitations of this process. Therefore, proposing an optimum angle to mitigate this limitation is essential. In this study, the effects of the die half-cone angle and drawing ratio on the thickness distribution and equivalent plastic strain during the deep drawing of a square cup were investigated numerically and experimentally. A statistical study using a full factorial design was employed to examine various combinations of die half-cone angles and drawing ratios. Using this method, the combined effect of the die angle and yield drawing ratio on the thickness distribution and plastic strain was investigated. Despite previous studies suggesting a die with an 18° angle, the results showed that reducing the angle to 16° led to a more uniform thickness distribution and a lower maximum equivalent plastic strain. Specifically, at a drawing ratio of 1.87, the use of a 16° die angle resulted in a 28% reduction in thinning and a 14% reduction in thickening compared with the 18° die angle.

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1. Introduction

Deep drawing is one of the most widely used sheet metal forming processes. In this technique, a flat sheet metal blank is plastically deformed under combined tensile and compressive stresses to produce a hollow, cup-shaped or

box-shaped component [1]. This method is widely employed in the automotive industry, aircraft components, and cookware manufacturing [2]. The applications of deep drawing are increasing daily. The use of tailor-welded blanks [3] and ultrasonic-aided deep

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drawing processes [4] are among the innovations that have been developed in this field. Despite the advantages of this method, there are still some limitations. In this process, defects such as thinning, wrinkling, tearing, and rupture can perhaps may occur because of the sheet's inherent characteristics [3]. The correct design of the die and its components can considerably reduce defects. Among the die components, the blank holder plays an important role in controlling the flow of the material [6]. Despite its advantage of using the blank holder in controlling the flow of materials to prevent wrinkling, using it increases the forming force, the possibility of tearing, and the complexity of the die. Controlling the material flow using an alternative way reduces the production cost by eliminating the disadvantages of using a blank holder [4]. Sheykholeslami et al. [7] proposed the idea of using a rubber matrix and applying ultrasonic vibration to the die simultaneously. In this method, the pressure of the rubber on the sheet and the presence of ultrasonic vibrations applied to the punch allow for controlling the material flow without the need for a blank holder. However, due to the lack of formability of rubber, it is not possible to produce parts with a high stretch ratio. Different studies have focused on eliminating blank holders in the deep drawing process using different die cross sections. Yunus et al. [8] proposed a curved Tractrix matrix to control thinning and shrinkage of the conical part of the die. There is no blank holder in the proposed die. The results of the study showed that it provides better material flow control and fewer defects than conventional conical dies. Hassan et al. [5] introduced a conical die to produce and enhance the durability of square cups without blank holders. The results of this study showed that the highest DR value was obtained when the half-cone angle was 18° . Using the proposed die geometry, the DR values were obtained as 2.92 and 2.74 for the square brass and aluminum cups, respectively. Hassan et al. [6] showed that by appropriately selecting the corner radii of the punch and matrix, a clearance-to-thickness ratio of 1.2, and a half-cone angle of 18° , the drawing ratio in the deep drawing of a square cup with a conical die without a sheet clamp can be increased. Dhaiban et al. [11] showed that

increasing the clearance-to-thickness ratio in the deep drawing of an oval section with a conical die without a sheet clamp reduces the forming force and increases the tensile strength ratio. Dhaiban et al. [7] presented a method for producing elliptical brass cups without blank holders. In this study, optimization using the finite element method for geometric parameters was performed to achieve the highest drawing ratio. The results showed that the maximum strain in the thickness direction was inversely related to the punch corner radius, and an angle of 18° with a sheet thickness of 3 mm produced the highest stretch ratio. In addition, the maximum strain occurred at the end of the large diameter of the elliptic cup.

Fazeli and Arezo [7] predicted the limit of the tensile ratio using the slab method while considering the anisotropy coefficient. In this study, they investigated the effects of friction, work hardening power, and geometric dimensions of the punch, matrix, and sheet metal holder on the limit of the tensile ratio. They showed that the limit of the tensile ratio decreased with increasing work hardening power. Hassan et al. [8] studied deep drawing of a non-circular part made of pure aluminum (AL99.5w) and brass (Cu-Zn67.33) with an 18° angle conical die without a blank holder. They demonstrated that an increase in the initial thickness of the blank results in increased cup height and the limiting drawing ratio. Ameen et al. [15] introduced a mechanism to produce elliptical cups using conventional die without a blank holder from thin circular brass plates with different clearances and without blank holders. The results showed that a clearance of 0.9 mm between the punch and die yielded the best results. Saleh and Ali [9] proposed a blank holder-free conical die to produce circular cups from thin plates using deep drawing. They conducted a two-dimensional finite element method using the DEFORM software. They showed that with a half-cone angle of 30° and a clearance-to-thickness ratio of 0.9, no wrinkling occurred, and a higher drawing ratio could be achieved in the case of a thick brass sheet. Shewakh et al. [10] investigated deep drawing of a square cup made with a conical die. The initial plates are brass alloy (Cu-Zn37) and annealed aluminum

(AL99.5w) with different thicknesses and clearances between the die and punch. They examined the effect of friction at the interface of the punch and the die, the interface of the sheet, and the die on failure caused by thinning and LDR. Choubey et al. [11] showed that using a conical die with a half-cone angle of 18° reduced the forming force by 42% compared to the conventional method. The microstructural study also revealed that the maximum stresses were concentrated in the cup wall area instead of the bottom and corner parts of the cup. Saleh et al. [12] investigated a finite element method to study the effect of clearance ratio on forming force, stress, and thickness in reverse deep drawing of brass elliptical cups without blank holders. The elliptical sheet was drawn to the final product by a hollow elliptical punch through an elliptical die. Their proposed die was an inverted one with a two-piece matrix and a hollow punch for forming oval cups without a blank holder. In this die, the blank holder is eliminated; however, the complexity of the matrix is increased compared to that of the conventional die. Abdel-Magied et al. [13] conducted an experimental investigation of the limiting drawing ratio (LDR) in the deep drawing process without a blank holder. Key parameters considered were the type of lubricant, the use of a knurled punch, and the speed of the ram. The results revealed that a mixture of oil and powder graphite with a ratio of 25 to 75, combined with a knurled punch, achieved a high LDR of 2.275. Xin et al. [14] conducted a numerical and experimental study on the effect of die angle and initial sheet thickness on the formability of cylindrical cups with a conical die. They demonstrated that the highest and the lowest LDR occur at the die with a 60° cone angle and the die with a 30° angle, respectively. Their results indicated that wrinkling and rupturing increase in thinner sheets. Saleh et al. [15] used reverse drawing without a blank holder, they formed a square cup of brass. They used the concept of a hollow punch to control the flow of the material. Parts produced using this method have suitable geometric dimensions. However, owing to the lack of a sheet holder, the parts produced have a large amount of excess material, and

trimming operations are required. Shewakh and Hassab-Allah [23] proposed a two-stage deep drawing process for producing square cups. In the proposed die, a conical punch first forms the sheet into a cone, and then a square punch from inside the conical punch forms the sheet into a square cup. At this stage, the conical punch acts as a blank holder for the square punch. This method provides greater control over the material flow and increases the drawing ratio of the material. The amount of thinning was also improved. The complexity of the die design is a limitation of the proposed method in their study. Ozek et al. [24] proposed a deep drawing die with a conical blank holder. Their results showed that by tapering the blank holder, the drawing ratio and thinning limit were improved. Dwivedi et al. [25] showed that the use of a lubricant in a conical die without a blank holder increased the drawing ratio. Dwivedi et al. [26] formed a 1 mm thick aluminum blank into circular cups using a conical die with a half-cone angle of 18° , and without a blank holder. Abd-Eltwab et al. [27] showed that the use of a knurled punch transfers stress concentration from the punch corner to the cup walls in deep drawing with a conical die without a blank holder. In square cross-section cups, material flow control is more challenging than in components with circular cross sections due to the presence of corners. Therefore, the presented study was focused on the deep drawing process without using a blank holder for a square cross-section cup made of St37. In conical dies without a blank holder, it is essential to select the appropriate dimensions for the die to control the material flow. Therefore, in this article, a set of simulations using finite element and experimental tests were performed to investigate the effects of the angle of the half-cone of the die and the drawing ratio on the thickness distribution. In the literature, a half-cone angle of 18° has been suggested. However, the studies conducted in this paper showed that a die with an angle of 18° can produce cups without defects. By selecting a half-cone angle of 16° instead of 18° , a more appropriate thickness distribution can be obtained, while also producing defectless parts.

2. Simulation Procedure

2.1. Modeling

The finite element method was employed using Abaqus 2024 software to simulate the deep drawing process using the dynamic explicit solver. Due to symmetry, a quarter model was sufficient in the simulation. Table 1 presents the dimensions of the tool and sheet, and the assembly of the model components is demonstrated in Fig. 1.

2.2. Material properties

The mechanical properties of the blank were obtained through a uniaxial tensile test. The sheet material was St37. A tensile test was performed according to the ASTM E8/E8M standard. Table 2 presents the mechanical and physical properties of St37 derived from the tensile test. In this table, n represents the strain hardening exponent, K is the strength coefficient, σ_Y is the yield stress, and ρ , ν , and E are the density, Poisson's ratio, and Young's modulus, respectively. The values for n and K were obtained by fitting the power-law relationship $\sigma = K(\epsilon_p + 0.001785)^n$ to the true stress-true plastic strain curve obtained from tensile tests.

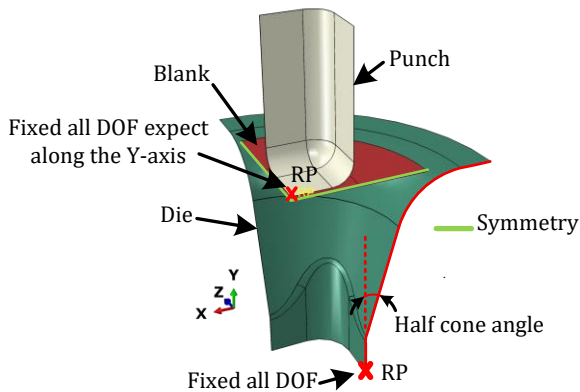


Fig. 1. Assembled model and boundary conditions in the numerical simulation.

Table 2. Mechanical and physical properties of St37

E (GPa)	ν	ρ ($\frac{kg}{m^3}$)	σ_Y (MPa)	K (MPa)	n
200	0.3	7800	357.8	775.95	0.154

2.3. Boundary conditions

Applied boundary conditions are depicted in Fig. 1. All degrees of freedom for the die were fixed. The sheet was constrained with symmetry boundary conditions. The friction coefficient between the die and the blank was 0.05, and between the punch and the blank was 0.075 [16]. The punch was fixed in all directions except the Y-axis, where a displacement amplitude of 70 mm was applied. Contact between the blank upper surface and the punch bottom surface and between the blank lower surface and the die inner surface was defined as surface-to-surface interaction.

2.4. Meshing

The die and punch were considered discrete rigid bodies and meshed with the R3D4 element. Also, the blank was defined as a shell and meshed with the S4R element. The selected element types are linear and have four nodes. The simulation results were independent of the mesh size.

A reduced integration method was used in the simulations. The number of integration points through the thickness was set to five to obtain a more accurate thickness distribution. Hourglass control was used to prevent such defects. Due to hourglass deformation in the finite element simulation, excessive nonphysical deformation may occur, leading to element distortion, negative Jacobians, and inaccurate evaluation of strain energy. This issue can be effectively mitigated by activating appropriate hourglass control schemes. For this purpose, simulations were repeated by considering

Table 1. Dimensions of the tool and sheet

Die			Punch			
Square section dimensions (mm)	Half-cone angle (degree)	The radius of the corner (mm)	Dimensions (mm)	The radius of the corner (mm)	Clearance (mm)	Diameter of initial blank (mm)
35×35	14°, 16°, 18°	8	29×29	5	1	55, 65, 75

the strain energy for different numbers of elements. In each simulation step, the number of elements was increased by a specific ratio, and ultimately, the number of elements was chosen such that the change in strain energy compared to the previous step was less than 5%. Table 3 and Fig. 2 present the specifications of the elements and the method of partitioning the components, respectively.

3. Design of Experiments (DOE)

It is first necessary to identify the effective process parameters and define their applicable ranges to statistically design experiments. Accordingly, after a comprehensive review of the relevant literature, some preliminary numerical simulations were performed. The results indicated that when the die half-cone angle was smaller than 14° or larger than 18° , adequate control of the sheet material was not achieved. Under these conditions, defects such as severe wrinkling during deformation and premature tearing occurred before the onset of the main forming stage.

In addition, other influential parameters were identified, including the punch corner radius, the die corner radius at the transition from the large diameter region to the conical zone, and the corner radius in the

round-to-square transition. Variations in the punch corner radius significantly affected the deformation of the final product; therefore, this radius was selected to ensure complete forming, with a minimum value of 5 mm. Similarly, a trial-and-error investigation of the die corner radius revealed that radii smaller than 8 mm prevented proper forming. Since further modification of these corner radii was not geometrically justified, only the die half-cone angle and the drawing ratio were selected as the primary factors for investigation, as summarized in Table 4.

The drawing ratio in a square cross section is calculated using Eq. (1). In this equation, D_0 is the initial blank diameter. Eq. (2) shows the D_{ave} calculation method [24]. Fig. 3 shows how the parameters used in Eq. (2) are defined.

$$DR = \frac{D_0}{D_{ave}} \quad (1)$$

$$D_{ave} = \frac{D_{max}}{D_{min}} \quad (2)$$

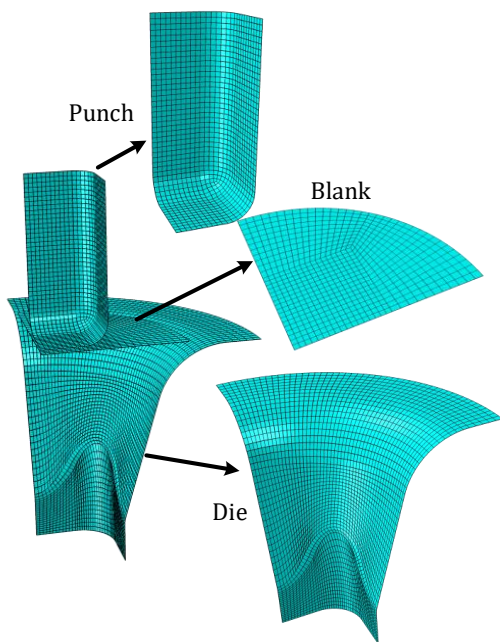


Fig. 2. Meshing of the components.

Table 3. Type and number of elements of the components

Part	Element type	Number of elements
Die	Discrete rigid-R3D4-linear	2856
Punch	Discrete rigid-R3D4-linear	463
Blank	Shell-S4R-linear	684

Table 4. DOE table

No. of experiment	Die angle (degree)	Diameter of blank (mm)	Drawing ratio (DR)
1	14	55	1.37
2	16	55	1.62
3	18	55	1.87
4	14	65	1.37
5	16	65	1.62
6	18	65	1.87
7	14	75	1.37
8	16	75	1.62
9	18	75	1.87

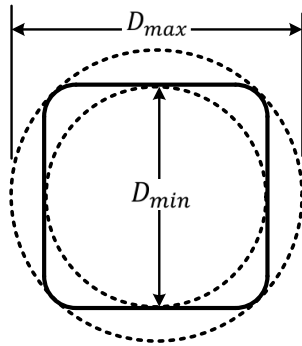


Fig. 3. Definition of drawing ratio parameters.

4. Experimental Procedure

Ten blanks with a diameter of 75 mm (DR = 1.87), four blanks with a diameter of 65 mm (DR = 1.62), and four blanks with a diameter of 55 mm (DR = 1.37) made of St37 with a thickness of 2 mm were prepared using a laser cutting machine. 16-degree half angle conical die and punch made of AISI 1045 were manufactured using a CNC milling machine. The manufactured punch and die and the positioning of the blank on the die are depicted in Figs. 4 and 5, respectively. The oil used for lubrication was SAE 5W-30. After pressing the punch against the blank and pulling it into the die, due to the movement of the punch by the press, the sheets take the shape shown in Fig. 6.

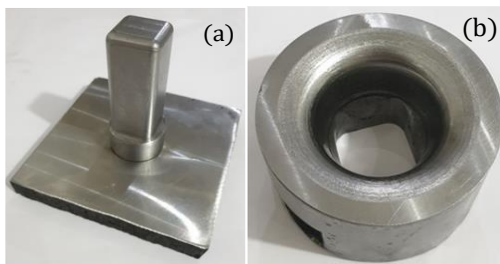


Fig. 4. Manufactured tools: (a) punch, shoe, and (b) die.

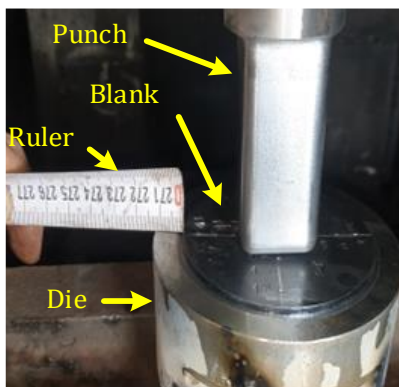


Fig. 5. Assembly of the punch and die and positioning of the blank.



Fig. 6. Cups formed by experimental tests from blank with diameters of (a) 75 mm, (b) 65 mm, and (c) 55 mm.

For a more accurate comparison of the thickness distribution results between the experimental and simulation results, the blank was numbered, as shown in Fig. 7. Initially, the thickness of the desired points was measured before forming. After completing the deep drawing process, the cups were cut along a path close to the marked points to enable more accurate measurements with a micrometer (Fig. 8). The thickness of the cut pieces at the numbered points was remeasured. The thickness before and after deformation can be compared by following the described measurement procedure.

5. Results and Discussion

In this section, numerical and experimental results of the process are presented, compared, and discussed. A measurement path and three deformation zones are defined to compare the experimental and simulation



Fig. 7. Samples of cut pieces by wire cut blank with diameters of (a) 75 mm, (b) 65 mm, and (c) 55 mm.



Fig. 8. The numbered sheet for measurement.

results. The agreement between the values and trends of the thickness change in the results indicates the reliability of the numerical model. The impact of the die angle and drawing ratio on thinning and equivalent plastic strain was studied, and an example of the simulation performed in this study is shown in Fig. 9. As can be seen, the blank was drawn into the die by the punch, resulting in a shaped piece at the end. As shown in Fig. 9(a), the punch comes into contact with the blank at this stage. On the other hand, the edge of the sheet is in contact with the curvature of the die, due to the force applied by the punch to the blank and by the die to the edge of the blank. The blank bends as shown in Fig. 9(b). At this stage, the radius of the die and the opening of the die, which depends on the half-cone angle of the die, play a significant role in the correct flow of the blank. The results of the initial simulations showed that at angle of more than 18° , the sheet does not form correctly at this stage. Fig. 10 shows an example of a die simulation with a half-cone angle of 25° . As can be seen, tearing and wrinkling occurred in the blank due to improper material flow.

In this section, a path in the FE model is defined for comparing the simulation results with the experimental results, as shown in Fig. 11. Additionally, for analysis, the deformed zones are divided into three areas.

5.1. Experimental validation

For the experimental work, the half-die angle was 16° , and the blank diameters were 55, 65, and 75 mm, corresponding to drawing ratios (DR) of 1.37, 1.62, and 1.87, respectively. For this purpose, the thickness of the blank was measured at specified points on the experimental samples before and after deformation using a digital caliper with a resolution of 0.02 mm. In the three zones shown in Fig. 11, the average thickness change at the measured points was the criterion for comparing the experimental and simulation data. Fig. 12 shows the distribution of the percentage change in thickness obtained from simulation and cartography for the areas indicated in Fig. 11. In this figure, a positive thickness change indicates an increase in thickness, while a negative thickness change indicates a decrease in

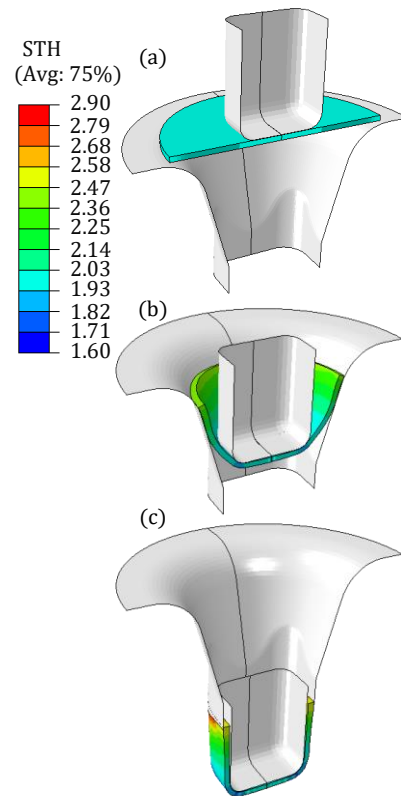


Fig. 9. An example of the thickness distribution at (a) the initial, (b) the intermediate, and (c) the final stages.

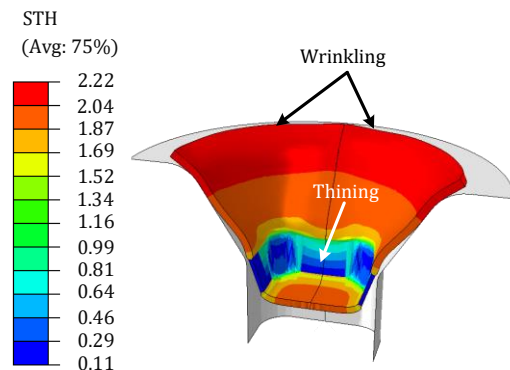


Fig. 10. Example of a simulation with a 25° half-cone angle.

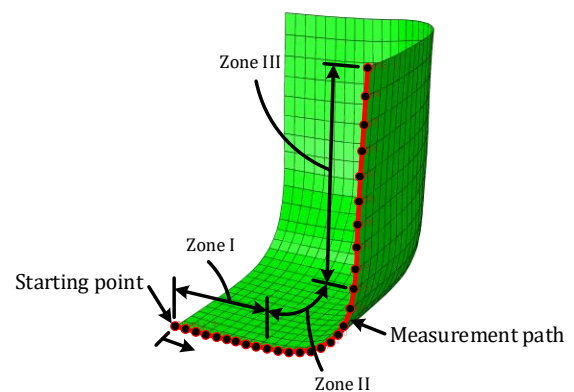


Fig. 11. Measurement path and points in simulation.

thickness. In both the simulation and experimental work, the thickness change in zone I was minimal for all three blank radii. In zone II, which is the punch corner area, a thickness reduction occurred in both cases. In zone III, which is the wall of the part, an increase in thickness occurred in both cases. The comparison of experimental and simulation results in Fig. 12 shows that the values and trends of thickness changes in both the experimental and simulation cases are similar, indicating the accuracy of the simulation results.

For a more accurate comparison, Fig. 13 shows the maximum error between the simulation and experimental results. As can be seen, the maximum difference is 10.6%, which is an acceptable value. The reasons for this difference can be listed as follows. In experiments, the positioning of the initial plate and the centering of the punch are not as accurate as the modeling carried out in the simulation. Also, in the simulation, the thickness of the blank is considered uniform, although this is not the case in reality.

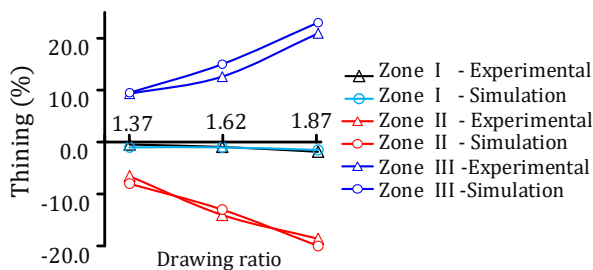


Fig. 12. Thinning versus deep drawing ratio of St37 sheet during deep drawing (numerical and experimental results).

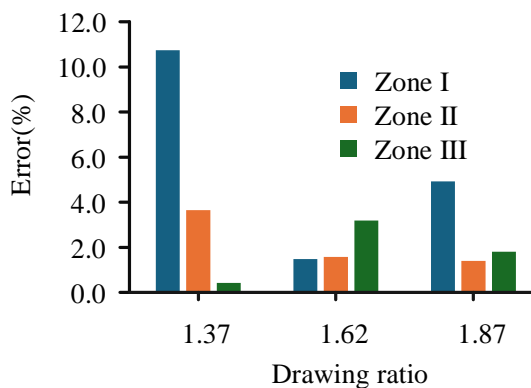


Fig. 13. Error percentage and comparison of experimental and simulation results.

5.2. Effect of die angle and drawing ratio on thinning in conical dies

In deep drawing, the thinning of the blank is a frequent and somewhat unavoidable defect. In traditional dies, blank holders can control wrinkling and material flow. Control of material flow in conical dies without blank holders is considerably more limited than in conventional dies. In such dies, material flow is mainly controlled by the cone angle. In this paper, the effect of the main factors on material flow control in this type of die was investigated using numerical simulation. Fig. 14 shows the thinning results from the simulations for three drawing ratios (1.37, 1.62, and 1.87) and die angles (14°, 16°, and 18°) for the path defined in Fig. 11. Examining zone I in Fig. 14(a, b, and c), it is observed that thinning in this zone is relatively minor, with no significant differences across the three drawing ratios and die angles. This minor thickness change in this zone was reported for other types of blanks [14]. In contrast, zone II, the corner area of the part, exhibits different behavior. This zone is prone to tearing, which is expected to initiate from this area in the deep drawing process. Fig. 15 shows the effect of die angle and drawing ratio on thinning for the drawing ratios. In region 1, where the sheet is in contact with the punch bottom, there is the least change in thickness, and in region 2, due to the blank's contact with the punch corner, the greatest change in thickness occurs. In region 3, which forms the wall of the final part, there has been an increase in thickness. References [22, 28-30] confirm this result.

Fig. 15 shows the thinning results from simulations for three die angles (14°, 16°, and 18°) and three drawing ratios (1.37, 1.62, and 1.87) along the path defined in Fig. 11. As observed, in zone I, there is no significant change in thinning across the different drawing ratios and die angles.

To examine more precisely the effect of the die hemi-conical angle, the maximum thickening and maximum thinning are shown in Figs. 16 and 17, respectively, for the path defined in Fig. 11, for different drawing ratios. As can be seen, in the case in which the die angle is 16° for all three drawing ratios of 1.37, 1.62, and 1.87, the amount of thinning and thickening of the blank is less

compared to other angles. References [10, 11] reported the appropriate angle as 18°, while both experimental and simulation studies show that the 16-degree hemi-conical angle is more appropriate than other angles.

5.3. Effect of die angle and drawing ratio on equivalent plastic strain (PEEQ)

In sheet metal forming, equivalent plastic strain (PEEQ) indicates the deformation in the plastic region. Exceeding the blank's tolerable strain limit causes tearing, and if the strain is too low in the area where deformation should occur, it means a high elastic strain

and significant springback. Conversely, large and sudden variations in equivalent plastic strain in a formed area indicate a potential defect. Fig. 18 shows the effect of the die angle on the distribution of plastic strain along the defined path, according to Fig. 11. In Fig. 18(a), the PEEQ variations for a die angle of 16° vary more uniformly across all three zones compared to the other two angles. Notably, a wider variation range is observed for a die angle of 18°. This observation is also observed in Figs. 18(b) and 18(c), confirming that the forming conditions are more suitable for a die angle of 16° compared to other angles.

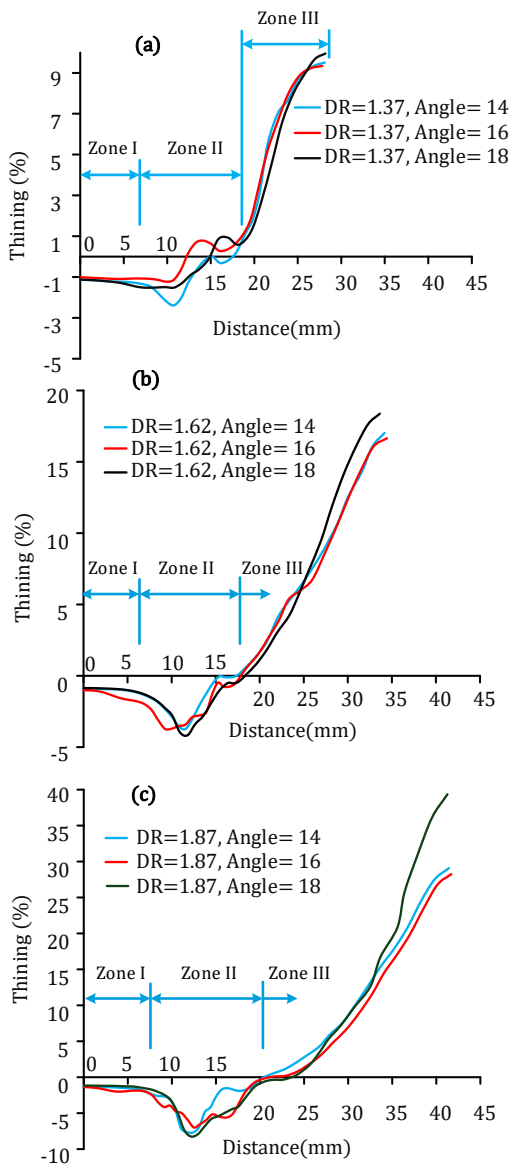


Fig. 14. Effect of die angle and drawing ratio on thinning for drawing ratios (DR) (a) 1.37, (b) 1.62, and (c) 1.87.

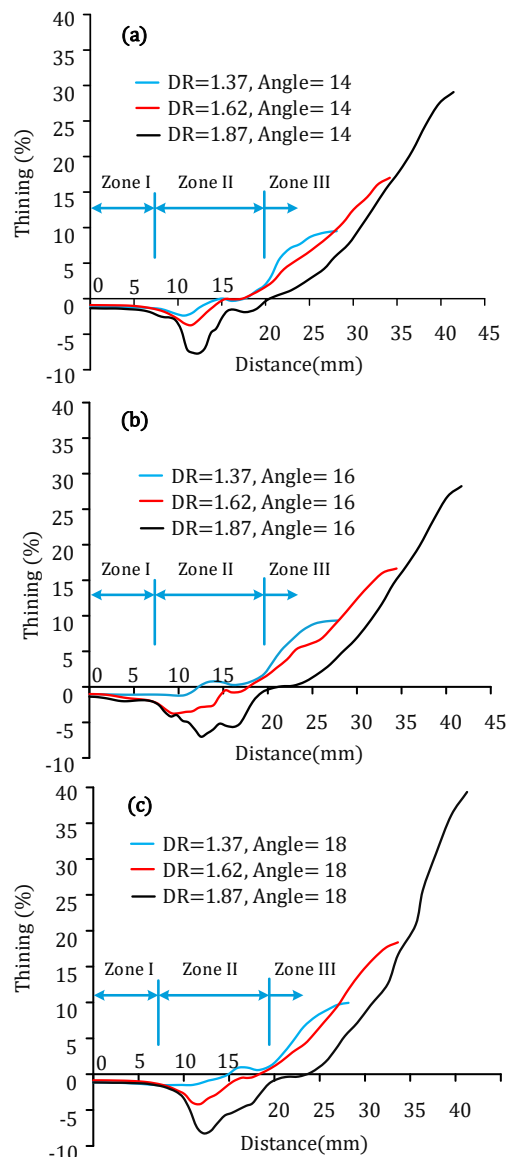


Fig. 15. Impact of die diameter and angle on thinning for die angles (a) 14°, (b) 16°, and (c) 18°.

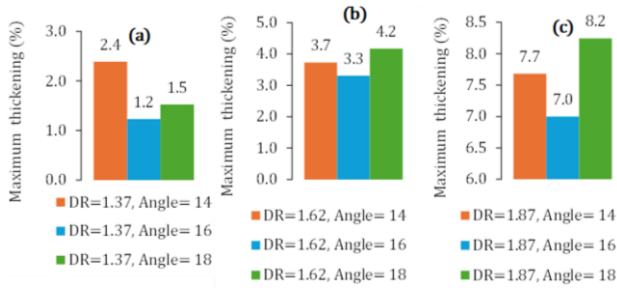


Fig. 16. Maximum thickening at different die angles for a drawing ratio of (a) 1.37, (b) 1.62, and (c) 1.87.

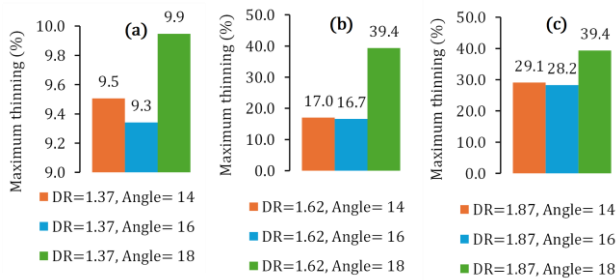


Fig. 17. Maximum thinning at different die angles for a drawing ratio of (a) 1.37, (b) 1.62, and (c) 1.87.

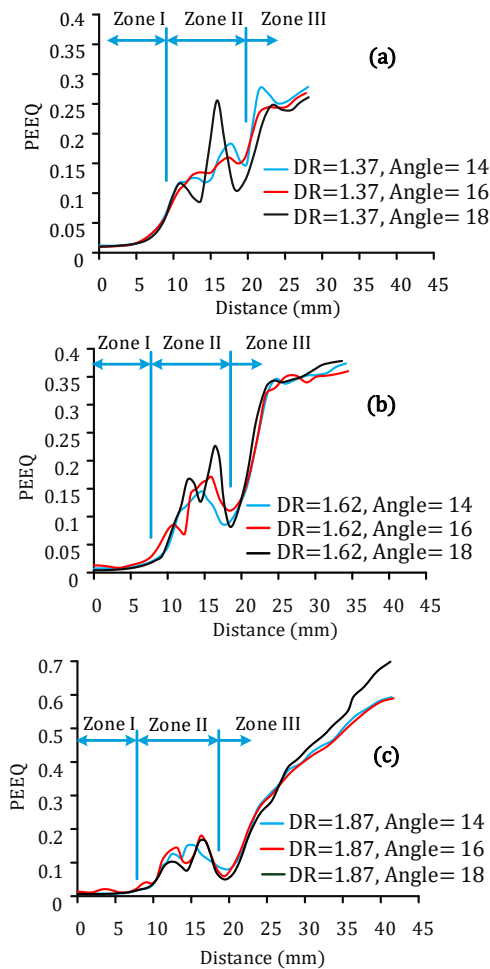


Fig. 18. Effect of die angle on equivalent plastic strain (PEEQ) for drawing ratios (DR) (a) 1.37, (b) 1.62, and (c) 1.87.

Fig. 19 shows the PEEQ results for the simulation along the defined path in Fig. 11. As observed, with an increase in the drawing ratio, the variations and the peak PEEQ increase in all three die angles. This indicates that the likelihood of defects such as tearing and wrinkling increases with an increase in drawing ratio. By examining the results in Fig. 19, when the die angle is 16°, both the variations and the peak PEEQ are lower compared to the 14° and 18° die angles. It confirms that using a die with an angle of 16° provides better forming conditions than the angles of 14° and 18°.

For a better comparison of the effect of the cone half angle on the equivalent plastic strain, Fig. 20 shows the maximum equivalent plastic strain for three drawing ratios. As can be seen, with a fixed geometry, the maximum strain value in the case where the cone half angle is 16° is lower than that in the case where the cone half angle is 14° and 18°. This indicates that when the

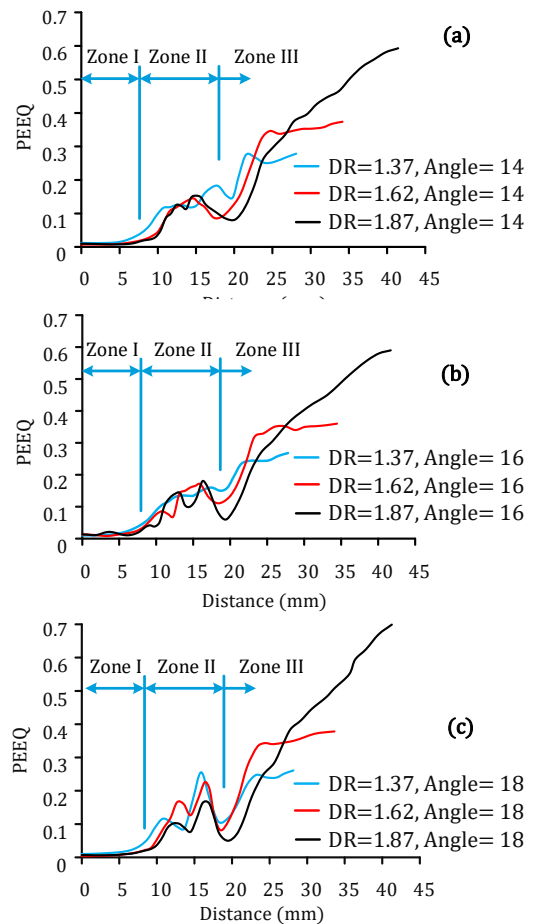


Fig. 19. Effect of drawing ratio on equivalent plastic strain (PEEQ) for die angles of (a) 14°, (b) 16°, and (c) 18°.

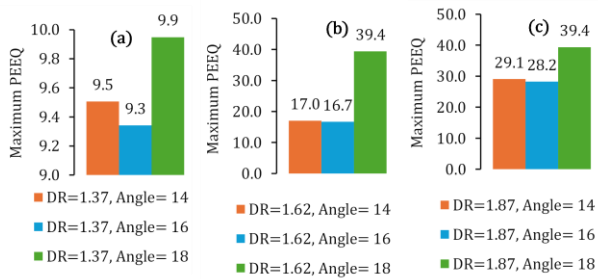


Fig. 20. Maximum equivalent plastic strain (PEEQ) at different mold angles for drawing ratio (a) 1.37, (b) 1.62, and (c) 1.87.

angle is 16° , material flow occurs more smoothly, and the probability of defects such as rupture is reduced.

6. Conclusion

This paper presents a numerical study on the effect of the half-cone angle and drawing ratio of a conical die on operational parameters in the blank holderless deep drawing process. For this purpose, conical dies having half-cone angles of 14, 16, and 18 degrees and drawing ratios of 1.37, 1.62, and 1.87 were used as working parameters in the simulations. An experimental setup consisting of a die with a 16° half-cone angle was developed to experimentally validate this study on a St37 steel blank for the mentioned drawing ratios. The experimental results confirmed the numerical results. In this study, the maximum difference between experimental and simulation results for the thinning distribution was 10.6%. Previous researchers suggested using a die with a half-cone angle of 18° . In this paper, after examining the thickness distribution and equivalent plastic strain, it was shown that using a die with a 16° angle at a drawing ratio of 1.87 improves thinning and thickening by 28% and 14%, respectively, compared with a die with an 18° angle at the same drawing ratio. In addition, the results of the equivalent plastic strain distribution confirmed that using a die with a 16-degree half-cone angle has a lower maximum equivalent plastic strain compared to a die with a half-cone angle of 14° and 18° . This indicates easier material flow in the blank. Therefore, a conical die with a 16° angle is recommended for producing square sections.

Authors' contributions

S. Kashi: Conceptualization, Methodology, Data curation, Formal analysis, Software, Investigation, Writing - review & editing

S. Mazdak: Conceptualization, Methodology, Data curation, Formal analysis, Software, Investigation, Validation, Writing original draft, Writing - review & editing

M. R. Sheykholeslami: Formal analysis, Software, Validation, Writing original draft, Writing - review & editing

M. Shahsanami: Validation, Writing original draft, Writing - review & editing

V. Fartashvand: Validation, Writing original draft, Writing - review & editing

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

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Data availability

The datasets generated and/ or analyzed during the current study are available from the corresponding author on reasonable request.

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