Journal of
Engineering Sciences
Faculty of Engineering
Assiut University

مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط

journal homepage: http://jesaun.journals.ekb.eg

Experimental study and Numerical simulation of stress concentration in deep drawing process without blank holder

Received 27 January 2025; Revised 17 May 2025; Accepted 17 May 2025

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Keywords
Deep Drawing Process; Stresses Concentrations; Blank holder; Drawing ratio and Mode failure

Abstract: Deep drawing without blank holder is an important process for producing circular cups which used in many applications. In this process, the blank is subjected to various loads and stresses concentrations which can lead to cup failure. This research presents a Numerical simulation and experimental study on the effects of stresses concentrations in the deep drawing without blank holder. A simulation model was constructed with the Dynamic Simulation Software DEFORM software to study the appropriate values for the variables. Practical experiments were conducted on universal testing machine configured for the process. Aluminum blanks were used as specimens with a thickness of 3 mm and various diameters. The process is carried out by placing the blank on the die and balancing it, then moving the punch downward to complete the drawing process. During process, the specimen is subjected to loads pulling it downward. To avoid this, several suggestions were made to disperse stress and reduce the impact of stress concentration. The experiments were conducted at a speed of 9 mm per minute. For all experiments, the forming loads were measured during the process. The results showed that avoiding stress concentration in the deep drawing process without blank holder had a significant effect in reducing the forming forces, minimizing the tearing of the samples, demonstrates how knurled punches redirect stress, reducing tearing by 33%. and the drawing ratio reached 2.46, which is a high percentage compared to the traditional condition, also there was a convergence between the Numerical simulated and experimental results.

1. **Introduction**

Industry uses the deep-drawing process widely due to its productivity and efficiency. The automotive and aerospace industries are two global sectors that use sheet-metal shaping. Cup-shaped, box shaped, and other complex curved and concave parts can be produced by utilizing the deep drawing. To maximize output, attain greater forming ratios, and get rid of product defects. Many researchers execute analytical and experimental investigations of the deep

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https://doi.org/ 10.21608/jesaun.2025.355849.1413

drawing process parameters [1-3]. Punch force, blank holder force, blank dimensions, die geometry, punch geometry, forming temperature, and coefficient of friction values are some of these characteristics. In order to promote good flow of metal, it is necessary to radius the lead-in of the die and nose of the punch, ensure that the diameter of the punch is within an appropriate size range for the material, and meticulously control the clearances between the punch and die. Highly severe clearance will cause the part to acquire wrinkles. Too little, and the component will rupture. Numerous deep draw configurations incorporate a blank holder and pressure pad in order to reduce flaws and enable more detailed drawings. Typically, a blank holder is needed to keep the blank flat against the die. Kumar [1] used mathematical formulations in the hydroforming deep drawing process with castor oil medium to investigate the impact of blank radius on radial stresses. The punch force delivered to the blank causes radial stress, while the viscous fluid acting on both sides of the blank causes shear stresses. Kumar evolved to the conclusion that while the radial stresses were linearly proportional to the radius of the blanks, they were inversely related to the blank's radial distance from the work axis. The formability of DP590 steel sheets was examined by Reddy et al. [2] in relation to various deep drawing process parameters. They realized that the punch force was inversely proportional to the die angle and directly related to the blank holding forces for all die angles. In order to establish a relation between the friction that results from the deep drawing process and the fracture that happens during the process, M. Mullar et al. [3] look into a mathematical model. Friction between the sheet metal and the deep drawing tools efficiently influences the stress-strain state; as a result, it functions as a lever that may be used to modify the component's damage state. Different constant friction coefficients are introduced for the straight sides and the tool corners in a friction ratio. This model predicts that the greatest damage was generated at the bottom corner area, where the greatest plastic strain was attained. H. Wang et. al. [4] studied the effect of die cavity pressure and forming temperature on the formability behavior of AA2198 in worm sheet hydroforming. At greater pressures and temperatures during the forming process, the formability improved, according to both numerical and experimental study. Room temperature produces the brittle fracture mode, while higher temperatures create the ductile fracture mode. According to Morovvati et al.'s [5] investigation into the effects of the drawing ratio, the forming force, and the blank holder force on the final blank shape, larger punch and blank holder forces are necessary when dealing with high strength materials in order to prevent wrinkling. A larger starting blank diameter results in a smaller drawing ratio, which raises the needed forming force. An analysis is conducted on the impact of punch and die radii on the deep drawing process's stress situation. The impact of die radius on the wrinkling of deep-drawn cups is presented in Reference [6]. [7-9] There is a noticeable difference between the initial stress values without radius and the stress values with radius in the punch and the die. The drawn products have wrinkles as a result of the reduced blank holding force. The stronger the sheet material, the more blank holding strength required to keep it from wrinkling during the deep drawing process. The tearing effect can be prevented by leaving sufficient space between the punch and the dice. By using the right lubricant, the surface scratches will disappear. Phanitwong and Thiram’s [8] enhanced the low carbon steel sheet's formability with a multi-draw radius die. As the sheet plane was positioned 90 degrees in the rolling direction, the drawing ratio utilizing the multi-draw radius die was 2.75, resulting in a 22.22% increase in the LDR (Limit

Drawing Ratio) as compared to the value when the traditional die was utilized. The material flow into the die is facilitated and accelerated by using the multi-draw radius die. In Reference [9], the effects of angles and die/blank radius were examined experimentally. The results showed that the limiting drawing ratio and punch force were increased as the die/blank angles increased and the LDR reached to the maximum value (β=2.3) at α=12.5°. The optimal drawing ratio was obtained at the die/blank angles of 12.5° then the maximum punch force reached their maximum value at the punch/die radius of 10 mm. Using material behavior under the influence of complex loads during the deep drawing process, yield criteria are used to forecast the fracture of the steel cups. [10]. Without the use of a blank holder, FE analysis and experimental research on the square cup drawing through conical die have been conducted [11] and with blank holder [12]. FE analysis and simulation of the hydroforming deep drawing process was carried out to predict the wrinkling behavior when conical tools were used [13]. The results demonstrated a strong correlation between the FE model's failure prediction and the experimental results. If the thinning at the punch nose failure is suppressed, then the LDR can be extended. Reducing friction at the die-blank interface surfaces and raising friction at the punch-cup interface will accomplish this. Reference [14] and Ragab K. et.al. [15] shows how process design and machine learning are utilized to predict the high drawing ratios of aluminum cups, examine how the type of lubricant and the knurled punch affect the deep drawing process's LDR in the absence of a blank holder. In deep drawing [16], Circumferential compressive stress in thin-walled dome components is the primary cause of wrinkles. The two main objectives are to reduce friction between the blank and blank holder and to make it easier for the material to align and flow among the coils of the spring. The blank holder is constructed from a sturdy flat steel plate with a tightly coiled spiral spring mounted on it. In addition, a new practical approach to blank setup and installation has been shown. The cup walls have a uniform thickness distribution, better material flow, and more efficient long-term lubrication, according to test results [17]. When the thickness-diameter ratio falls from 13.3% to 3.3‰, the maximum radial strain increases by 50%. Reducing hoop compressive stress and preventing wrinkling flaws can be achieved by increasing blank-holder force and decreasing temperature gradient [18]. The blank holding plate was constructed from two concentric rings of varying materials with equal or uneven widths in order to acquire the structural solutions of the new tools [19]. Average errors of 0.12 mm (or 0.25 %) in predicting the outer radius and 0.015 mm predictions for the sheet metal blank were compared with experimental data [20]. The maximum drawing ratio of 2.275 was obtained when knurled punch and the lubricant mixing of oil and graphite powder with 25% wt. and 75% wt. respectively were used. In general, in studying the variables of manufacturing processes of a raw material or product, Mahmoud Hashem et al. used the ANOVA package for this purpose [21-23], Other references have provided methods for selecting experimental/operational parameters, composite properties, dynamic parameters, finite element analysis, numerical simulation, etc. [24]. Abdelaal, Osama et al. and Astakhov, Viktor P et al. used experiment methods in manufacturing Design of experiment methods in manufacturing: Basics and practical applications on the effect of water-silica slurry impacts on 3D-Printed polylactic acid [24, 25]. While most studies focus on deep drawing with blank holders (e.g., [5, 12]), few address stress concentration mechanisms in blank-holder-free processes. This work bridges this gap by analyzing how punch geometry and friction control can mitigate tearing. Condensed literature review (removed redundant citations) and highlighted key findings recent work by [14] demonstrated that knurled punches improve formability, but their impact on stress redistribution remains unquantified. Similarly, [6] studied die radii effects but omitted punch-surface interactions. In addition, the research objectives to (1) Quantify stress concentration effects via FEA and experiments, (2) Evaluate knurled punches' role in load redistribution, and (3) Establish process windows for defect-free cups.

As presented in previous literature, many attempts are drawn to simulate and predict the effects of various parameters that influence the deep drawing process especially when a blank holder was used. A few articles are concerned about the effects of deep drawing parameters when a blank holder is not used as well as the effects of the friction forces between the cup wall and the die surface and the analysis of reaction forces isn't well studied. However, the present work concerned on studying (analytically & experimentally) the effect of punch force, friction forces and reaction forces on the stress state and the behavior of cup wall material and shape in the case of the deep drawing process without blank holder.

2. Finite Element Analysis and Simulation Setting

In this section, draw forming is studied mainly using finite element analysis. Simulations are performed to predict sheet necking and rupture behavior by replacing the Coulomb friction coefficient. The conditions affecting forming in deep drawing forming are studied by finite element analysis to find the optimal forming parameters. SOLIDWORKS was used to draw the molds under different parameter conditions. DEFORM 3D was then used for the finite element analysis simulation. The forming coefficients were changed according to the final product part. The obtained optimal geometric parameters of the mold were used for mold unloading. A test mold is drawing to verify the predictability of the analysis software. The mold and cup drawing simulation mold are shown in Figure 1. Finite Element Analysis Before performing a wired element analysis, it is necessary to draw an analysis model in SOLIDWORKS drawing software and import the STL file of the model. In this case, the material properties of the workpiece were set to plasticity. The calculations were predicated on the following hypotheses and assumptions: (i) It is possible to ignore the strain hardening fluctuation throughout the forming process. (ii) It is possible to ignore the spring-back effect. (iii) The spinning substance possesses homogeneity, isotropy, and incompressibility. (iv) During the deformation, the effects of temperature can be ignored. The mesh setting values are appropriate. If the analysis value does not change when the number of meshes is increased, the analysis time will increase as the number of meshes continues to increase. Here,75,500 meshes are used. Material properties other than the workpiece are rigid. The punch blessing curve setting is a function that uses paths, and custom coordinate functions. The friction setting uses Coulomb friction with a value of 0.03, while constant shear friction is suitable for the analysis of drawing operations. After the part is defined, the simulation setup is run. It is designed to define the total number of steps for the analysis according to the number of steps. The set value is 1600 steps, each 0.01secondis1step, stop setting the definition of time used, when the set value is 6secondsit stops. The mold temperature set point is 25°C to complete the simulation setting.

3. Materials and Method

In this section, the details and specifications of the experimental setup will be presented, including the measuring devices, materials, and raw materials used along with their specifications. The specifications are illustrated in Figure 1, which shows a solid drawing, outlining the deep drawing process without blank holder. The drawing die is placed in such a way that it has three areas: the first is the entry and convergence area, the second is the neck area of the die, and the third is the exit area for the formed cup. Figure 2 represents the experimental setup for conducting deep drawing experiments without blank holder. In the setup, a universal testing machine is used to replace the sample forming machine. The upper part of the testing machine is utilized to move the ram downward, securing the punch to the upper part of the testing machine. The deep drawing die is positioned below it, perfectly aligned with the punch's axis. A base is placed under the die to ensure there is sufficient space for the formed cup to exist. Additionally, the forming machine (testing machine) is equipped with an operating and control unit and is connected to a computer for data recording during the experiment. Figure 3 illustrates the parts and components of the deep drawing process used, such as the drawing die, the blank holder, and a set of punches used, along with a scale to adjust the position of the blank before the drawing process, ensuring it is perfectly balanced and horizontal. Figure 3 shows the set of punches used in the drawing process according to the experimental work, which was designed to feature punches of different shapes to allow for the concentration of stress at various locations on the formed blank. To conduct experiments in the deep drawing process without the use of a blank holder, aiming to determine the effect of stress concentration and its position relative to the formed blank. A die was used with a convergence angle of approximately 36 degrees, a neck diameter of 46 mm, and a die height of about 120 mm. A set of punches with diameters ranging from 40 mm to 45 mm with a 1 mm step was used. "When using a blank with a thickness of 3 mm, a punch with a diameter of 40 mm is perfectly suitable to produce a cup where the wall thickness is equal to the base thickness, which will be around 3 mm. However, when using a punch with a diameter larger than 40 mm with a 3 mm thick blank, the thinning value of the cup wall will be equal to the difference between the neck diameter of the die minus the punch diameter, divided by two. For example, when using a punch with a diameter of 44 mm, the thinning value for the wall thickness will be 2 mm, resulting in a wall thickness of 1 mm. It should be noted that stress concentration values are affected by the type of punch used and the clearance between the formed blank and the neck opening of the die. In this research, the main objective of these experiments is to determine the effect of stress concentration on the deep drawing process without using a blank holder. The punches used have a rough section (Knurled) at the bottom, which increases the surface roughness coefficient and frictional resistance between the punch and the blank. This transfers the effect of stress concentration from the base to the wall of the cup, thus reducing the chances of the sample tearing, experiment conditions and cases listed in table 1.

Table 1 Experiment conditions

<table>
<tr><th colspan="2" rowspan="2">set of experiments</th><th rowspan="2">d_p(mm)</th><th rowspan="2">D_b(mm)</th><th colspan="2">Thickness (mm)</th><th rowspan="2">Value of corrective thinning</th><th rowspan="2">Knurled</th></tr>
<tr><th>Before process</th><th>After process</th></tr>
<tr><td rowspan="7">drawing process cases</td><td>Case 1</td><td rowspan="3">40</td><td rowspan="7">ranging from 94 mm to 104 mm</td><td>3</td><td>3</td><td>0</td><td>No</td></tr>
<tr><td>Case 2</td><td>3</td><td>3</td><td>0</td><td>semi-spherical</td></tr>
<tr><td>Case 3</td><td>3</td><td>3</td><td>0</td><td>yes</td></tr>
<tr><td>Case 4</td><td>41</td><td>3</td><td>2.5</td><td>0.5</td><td>yes</td></tr>
<tr><td>Case 5</td><td>42</td><td>3</td><td>2</td><td>1</td><td>yes</td></tr>
<tr><td>Case 6</td><td>43</td><td>3</td><td>1.5</td><td>1.5</td><td>yes</td></tr>
<tr><td>Case 7</td><td>44</td><td>3</td><td>1</td><td>2</td><td>yes</td></tr>
<tr><td colspan="2">Process Parameters</td><td colspan="6">Punch speed 9 mm/min in UTM</td></tr>
</table>

In the experimental program used, the values of the deep drawing process variables were selected in two cases: with and without wall thinning of the produced cup, using punches with and without serration (surface roughening of the punch). Punches with different diameters and base radii were also used, including one punch with a spherical section at the base to allow for transferring stress concentration to areas far from the formed blank. All experiments were conducted at a punch linear speed of 9 mm per minute, with lubrication applied between the blank and the die only to prevent and reduce friction between them. Aluminum blanks with specific specifications were used in deep drawing to produce cylindrical cups with a circular cross-section. The table shows the specifications of the aluminum sample used in the work, with diameters ranging from 94 mm to 104 mm. The blanks were cut into circles with specific diameters according to the experimental program. A laser cutting machine was used in the cutting process. After cutting the blanks to specified diameters, all the blanks undergo annealing by placing them in a dedicated furnace for two hours at a temperature of 450°C [15]. They are then left for 24 hours to cool down to room temperature, making the blanks ready for the deep drawing process, chemical composition of test specimens illustrated in table 2. The results of the tensile test for the aluminum sample before annealing, after annealing, and after the deep drawing process. It is clear from the figure the importance of the annealing process in removing the residual stress caused by previous machining operations. Additionally, the stress-strain curve after annealing shows a decrease compared to the results before annealing, which reduces the forces required for the drawing process and decreases the number of samples that tear during the drawing process, plastic behavior of the tested material listed in table 3.

Table 2 Chemical composition of tested Aluminum blanks (AL1055).

Element	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**
Percent	96.7	0.1844	0.071	2.54	0.0288	0.08046	0.094	0.1266
Element	**Be**	**Ca**	**Pb**	**Sn**	**Sr**	**V**	**Bi**	**Ni**
Percent	0.001	0.005	0.00288	0.00243	0.001	0.00203	0.00997	0.01
Element	**Cd**	**Co**	**Ag**	**In**	**Ga**	**Ti**	**B**	**Zi**
Percent	0.0042	0.0643	0.0137	0.0213	0.0139	0.0172	0.004	0.00183

Table 3 Measured plastic behaviour of the tested material.

	Strength Coefficient, (k)	Strain Hardening Exponent, (n)
Before annealing	K = 137 MPa	n=0.142
After annealing	K = 83 MPa	n=0.215

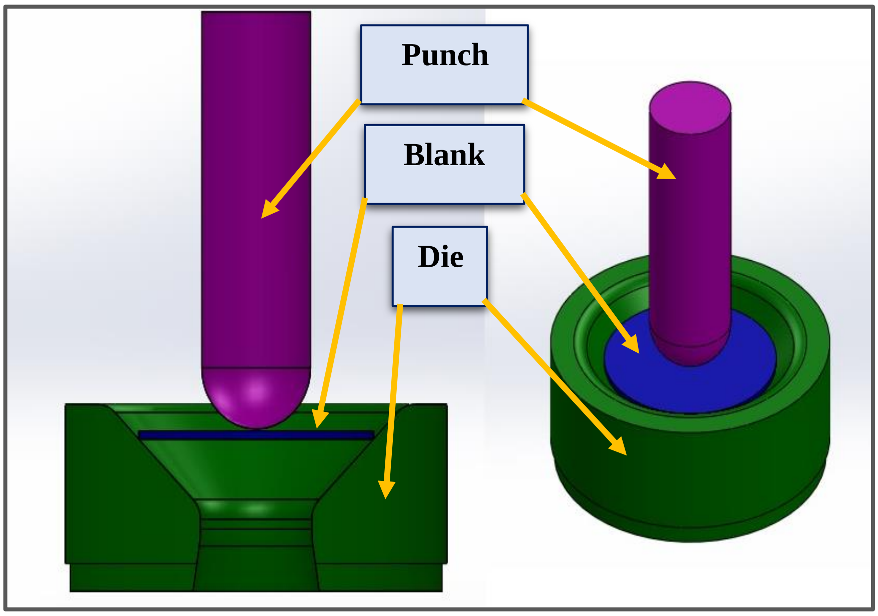

Figure 1 sketch for the deep drawing process without a blank holder.

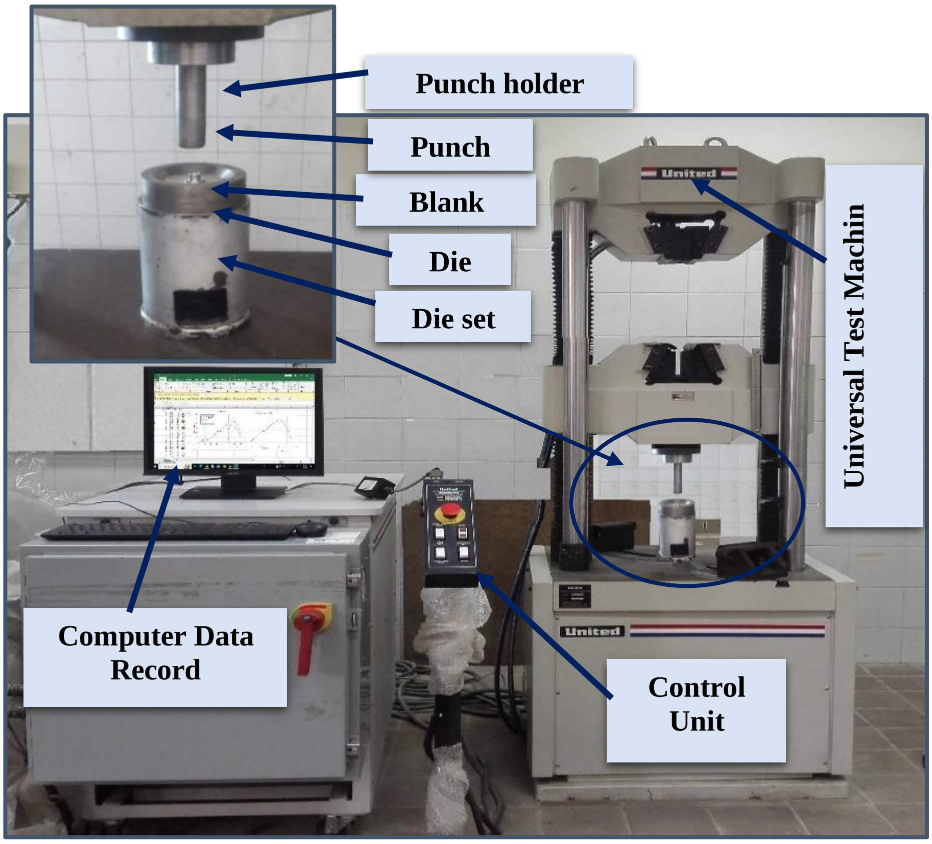

Figure 2 Experimental setup for deep drawing without blank holder.

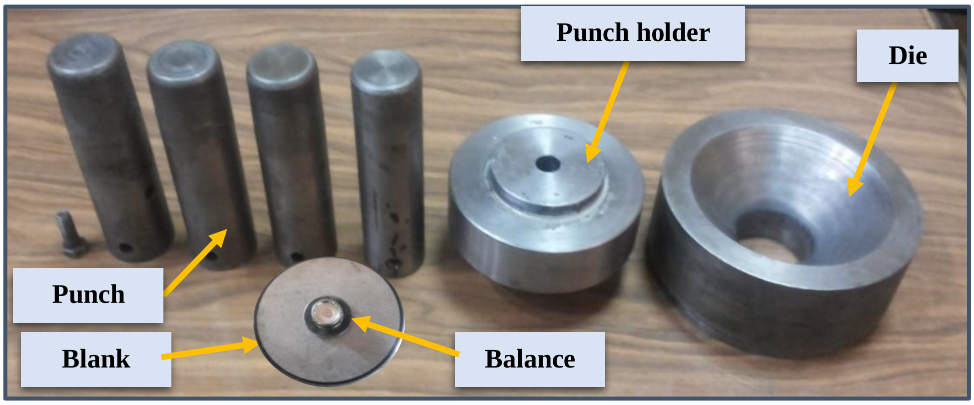

Figure 3 Components of the deep drawing process.

4. Results: analysis and discussion

4.1. successful produced cups

Figure 4 shows the produced cups formed by a deep drawing process in the middle Figure 4b, two cups of different heights after the drawing process and partial section of the aluminum cup, as shown in Figure 4c and blank before the drawing process illustrated in Figure 4a. The partial section shows a section of the drawn cups, highlighting the roughness of the inner surface of the cup. Figure 5 shows samples that were cut during the experiment, with the sample cuts made at various locations according to stress concentration. Some samples had their cuts occurred at the upper wall, while others were cut from the bottom due to the blank being subjected to a set of loads during the drawing process. These include the forming loads acting downward and the reaction loads of the blank against the punch, which resist the drawing process and act upward. At the base of the punch, in contact with the blank, concentrated loads are located around the radius of the punch base. As a result, the combination of all these loads affects the drawing process. A balance between the loads and their reactions can lead to the sample tearing, as the blank is subjected to tensile loads. Conversely, when the blank's resistance to the drawing process decreases, the resistance values during drawing do not result in tearing of the formed sample. Figure 6 illustrates an array of cups produced through deep drawing without a blank holder, in various cases according to the experimental conditions, and with different lengths based on the drawing ratio, all in good condition without any tearing. Additionally, Figure 7 shows a collection of aluminum cups after the deep drawing process. Figure 8 shows the stress-strain curve for the deep drawing process in several different cases, from Case 1 to Case 7. In Cases 1, 2, and 3, a punch diameter of 40 mm is used, meaning there is no corrective thinning of the wall of the drawn cup. In these cases, the thickness of the base of the cup is approximately equal to the wall thickness. In Case 1, the punch diameter is 40 mm without any surface roughening. In Case 2, the base of the punch is semi-spherical, where the edge rounding radius is large enough to match the punch radius, which reduces stress concentration at the punch edge. In Case 3, surface roughness is applied to the punch, resulting in higher resistance values during drawing and further decreasing the effect of stress concentration. The resistance forces during drawing are transferred from the base to the walls of the drawn cup. In Cases 4, 5, 6, and 7, there is a corrective thinning of the wall of the cup. When using a 41 mm punch, the wall thickness is 2.5 mm; with a 42 mm punch, the thickness is 2 mm; and with a 43 mm punch, the thickness is 1.5 mm, which corresponds to Case 6. In Case 7, with a 44 mm punch, the wall thickness is reduced to 1 mm, meaning the wall thickness has decreased by approximately 2 mm, representing a reduction of about 66% from the original thickness of the blank before drawing. It is evident that the longest wall of the drawn cup occurred at the highest thickness reduction, which is Case 7, where the height of the wall increases while the thickness decreases.

Figure 4 Aluminum Specimen before and after forming process:
Fig.4a test specimen, Fig. 4b produced cup and Fig. 4c Partial section.

Figure 5 Successful and unsuccessful cups were produced by deep drawing process.

Figure 6 Array of successful cups at various cases.

Figure 7 Collection of successful aluminum cups after the deep drawing process.

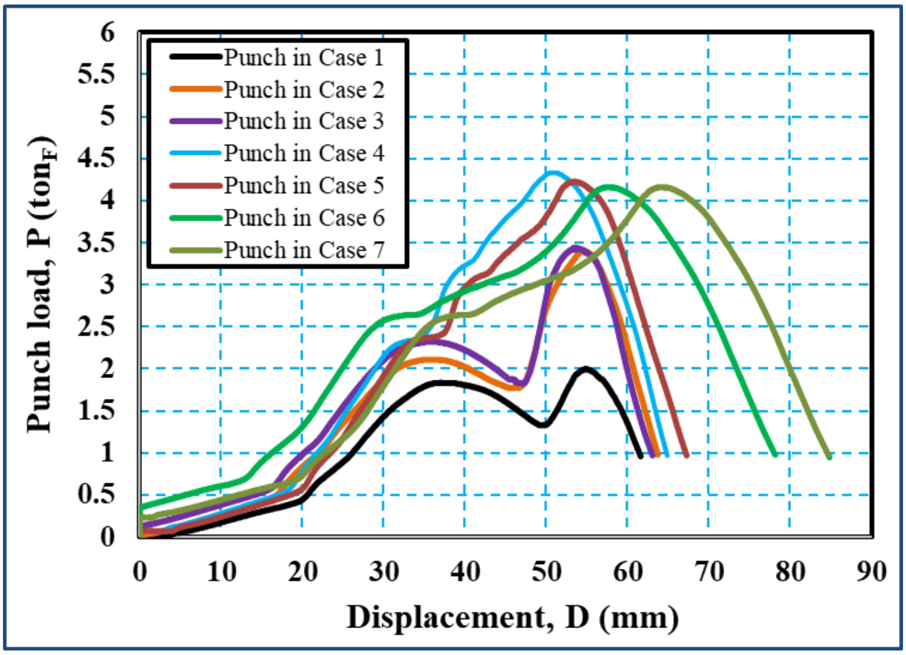

Figure 8 Punch load – displacement curve for the deep drawing process in different cases, from Case 1 to Case 7.

4.2. Deep drawing simulation results

Figure 9 presents a series of simulation results of the deep drawing process without a blank holder at various locations in the die interface and at the neck of the die, illustrating the formation of the cup. The figure shows the effect of stress concentration in the overlap area, where the highest stress values occur at the base of the cup. If the resistance to drawing of the blank is less than the forming values, no tearing of the sample occurs, and the process proceeds smoothly. However, if the drawing resistance is high enough to cause tearing at the base of the punch, it will lead to cup failure. Therefore, using surface roughness on the punch helps reduce sample tearing. The simulation results also show a similar trend to the actual stress-strain curve during the drawing process, as there is a significant resemblance between the curves, as shown in Figure 9, specifically for the cup with reduced wall thickness.

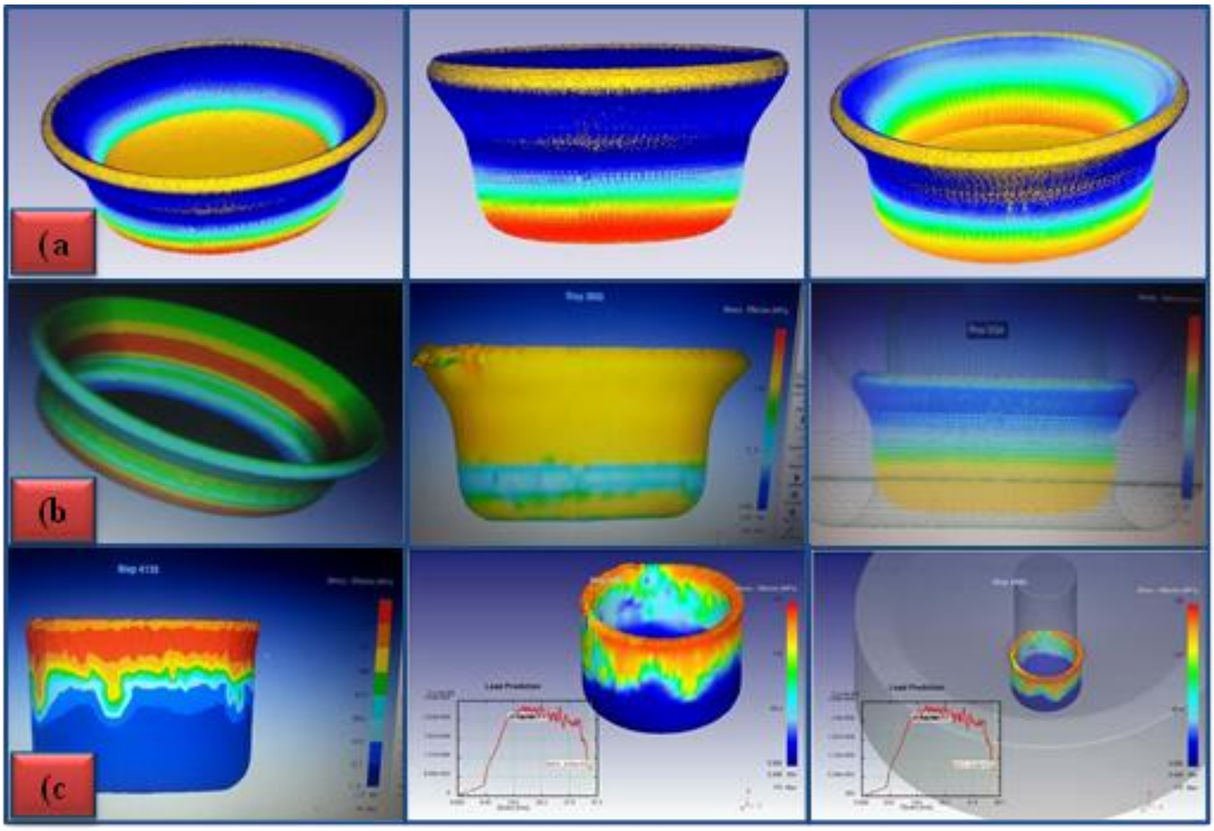

Figure 9 Simulation to stresses concentrations during deformation process.

Figure 10 illustrates the shape of the drawn cup using simulation at various positions or specific steps as the punch advances toward the blank for shaping. In Figure 11, nine positions are shown, from the start of the drawing process to the end of the drawing stroke, along with the stress-strain curve during the drawing process at each position. It is noted that the effects of stress concentration were initially at the bottom and then shifted to the wall of the cup, increasing until the end of the wall. In this figure, the stress distribution is shown from the beginning of the drawing process to its end, and this is at several locations. Regardless of the stress values, it is clear from the figures that stress concentration is transferred from the base of the formed cup to the walls, especially with the presence of a knurled. This reduces the effect of stress concentration, which leads to the success of the process despite the increase in the drawing percentage see Figure 9 and Figure 11.

Table 4 Steps with Forming load from the start to the end of stroke nine positions

Positions	Stroke, (mm)	Forming Load, (N)	Step
(a)	20	8.1e+03	200
(b)	20.8	8.81e+03	208
(c)	35.4	5.67e+04	354
(d)	40.6	1.07e+05	406
(e)	50	1.03e+05	500
(f)	100	1.25e+05	1000
(g)	109	1.27e+05	1092
(h)	131	1.51e+05	1310
(i)	160	9.05e+04	1600

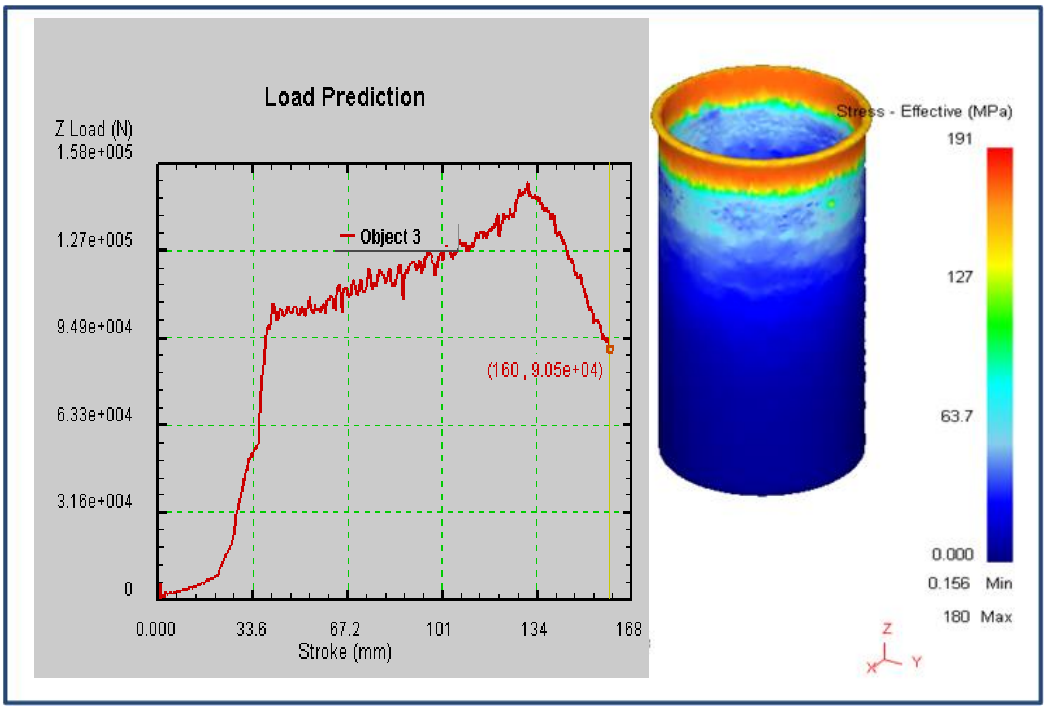

Figure 10 Stresses concentrations on the deformed cup during process

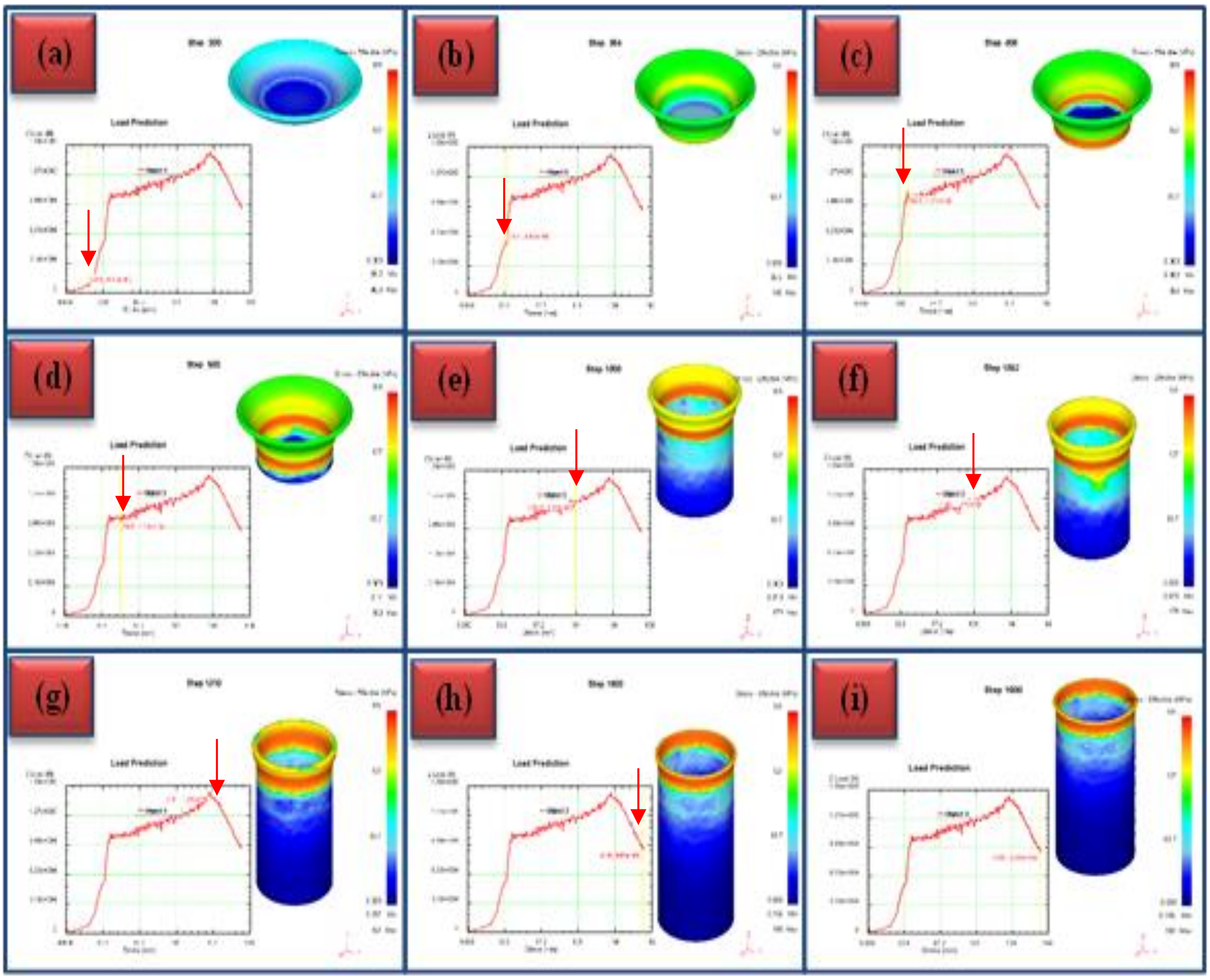

Figure 11 Various positions from start to end of the drawing stroke.

5. CONCLUSIONS

In this study, we investigated the production of parts using the deep drawing process without blank holder. The results were analyzed conceptually, leading to several important conclusions. Below are key insights derived from the discussion of these results. The position of stress concentration in the deep drawing process has a significant impact on the successful formation and drawing of the cup without tearing. When using a punch with a rough surface, the drawing resistance shifts from the base to the wall of the cup, reducing the sample tearing and slightly increasing the drawing force values. Demonstrates how knurled punches redirect stress, reducing tearing by 33%. With a reduction in the wall thickness of the drawn cup, the drawing forces increase, and the length of the drawn cup wall also increases. The convergence of the simulation results with the actual process results. Analysis of the sample results revealed a predicted modulation load that closely aligns with the experimental findings

Author Contributions:

The contribution of the authors is as follows; Ayman Ali Abd-Eltwab and Gomaa, A.A. designs the main idea. Eman S. M. Abd-Elhalim, Hammad T. Elmetwally and Ayman Ali Abd-Eltwab are prepared the test-rig component and made experimental works. Eman S. M. Abd-Elhalim Gomaa, A.A., Hammad T. Elmetwally and Ayman Ali Abd-Eltwab, wrote a draft copy, collected the data and analyzed it. Gomaa, A.A and Ayman Ali Abd-Eltwab review and revised the manuscript.

Acknowledgement

The authors would like to extend acknowledgement to their research institutions (Beni-Suef University, South Valley University and Assuit University) that provided support for this work

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Kumar, R.U., *Effect of blank radius on radial stresses in hydroforming deep drawing process.* International Journal of Applied Research in Mechanical Engineering, 2012: p. 231-236. DOI: 10.47893/IJARME.2012.1042.

[2] Reddy, P.V., et al., *Effect of Geometries of Die/Blank Holder and Punch Radii in Angular Deep-Drawing Dies on DP Steel Formability.* Applied Mechanics and Materials, 2015. **813-814**: p. 269-273. DOI: 10.4028/www.scientific.net/AMM.813-814.269.

[3] Müller, M., et al., *Numerical analysis of the dependence of damage on friction during deep drawing of asymmetric geometries.* Advances in Industrial and Manufacturing Engineering, 2024. **8**: p. 100136. https://doi.org/10.1016/j.aime.2024.100136.

[4] Wang, H., et al., *Evaluation of the formability of AA2198-T3 Al-Li alloy in warm sheet hydroforming.* The International Journal of Advanced Manufacturing Technology, 2022. **118**(1): p. 405-416. https://doi.org/10.1007/s00170-021-07961-z.

[5] Morovvati, M.R., A. Fatemi, and M. Sadighi, *Experimental and finite element investigation on* wrinkling *of circular single layer and two-layer sheet metals in deep drawing process.* The International Journal of Advanced Manufacturing Technology, 2011. **54**(1): p. 113-121. https://doi.org/10.1007/s00170-010-2931-9.

[6] Özbek, R. and O. Gül, *Effect Of Radius On Deep Drawing Stress Analysis.* International Conference on Pioneer and Innovative Studies, 2023. **1**: p. 374-378. DOI: 10.59287/icpis.859.

[7] Kapil Dudhatra, S.G., Maulik Khunt, Tushar Kaneriya, Jasmin Hirpara, *EFFECT OF VARIOUS PARAMETER ON WRINKLING IN DEEP DRAWING CYLINDRICAL CUPS WITH DIFFERENT MATERIAL.* International Journal For Technological Research In Engineering 2018. **5**(8): p. 2566-2572. IJETT - Effect of Various Parameters on the Wrinkling In Deep Drawing Cylindrical Cups (ijettjournal.org).

[8] Phanitwong, W. and S. Thipprakmas, *Multi Draw Radius Die Design for Increases in* Limiting *Drawing Ratio.* Metals, 2020. **10**(7): p. 870. **https://doi.org/10.3390/met10070870**.

[9] Özek, C. and M. Bal, *The effect of die/blank holder and punch radiuses on limit drawing ratio in angular deep-drawing dies.* The International Journal of Advanced Manufacturing Technology, 2009. **40**(11): p. 1077-1083. https://doi.org/10.1007/s00170-008-1435-3.

[10] Trieu, Q.-H., et al., *A Study on Yield Criteria Influence on Anisotropic Behavior and* Fracture *Prediction in Deep Drawing SECC Steel Cylindrical Cups.* Materials, 2024. **17**(12): p. 2872. **https://doi.org/10.3390/ma17122872**.

[11] Shewakh, W., M.A. Hassan, and I. Hassab-Allah, *Square-Cup Deep Drawing of Relatively Thick Sheet Metals through a Conical Die without Blankholder.* International Journal of Materials Forming and Machining Processes, 2015. **2**: p. 31-46. DOI: 10.4018/IJMFMP.2015070103.

[12] The-Thanh, L., et al., *A study on a deep-drawing process with two shaping states for a fuel-filter cup using combined simulation and experiment.* Advances in Mechanical Engineering, 2019. **11**(8): p. 1687814019872674. https://doi.org/10.1177/168781401987267.

[13] Amini, A., et al., *Hydro-mechanical deep drawing of conical components:* Wrinkling *behavior and process enhancement.* Journal of Engineering Research, 2024. https://doi.org/10.1016/j.jer.2024.04.005.

[14] Hwang, Y.-M., et al., *Formability Prediction Using Machine Learning Combined with Process Design for High-Drawing-Ratio Aluminum Alloy Cups.* Materials, 2024. **17(16): p. 3991. https://doi.org/10.3390/ma17163991.**

[15] Abdel-Magied, R., et al., *An Investigation into Deep Drawing Process without Blank Holder.* 2020. http://sersc.org/journals/index.php/IJAST/article/view/4317.

[16] Sun, W., W. Liu, and S. Yuan, *Suppressing wrinkles in thin-walled dome parts: A* novel *deep drawing method with active stress control.* Journal of Materials Processing Technology, 2024. **324**: p. 118249. https://doi.org/10.1016/j.jmatprotec.2023.118249.

[17] Gavas, M. and M. Izciler, *Design and application of blank holder system with spiral spring in deep drawing of square cups.* Journal of Materials Processing Technology, 2006. **171**(2): p. 274-282. https://doi.org/10.1016/j.jmatprotec.2005.06.082.

[18] Fan, X., X. Chen, and S. Yuan, *Novel forming process for aluminum alloy thin shells at ultra-low temperature gradient.* International Journal of Machine Tools and Manufacture, 2023. **185**: p. 103992. https://doi.org/10.1016/j.ijmachtools.2022.103992.

[19] Brabie, G., B. Chirita, and A. Albut, *Minimization of sheet thickness variation and other* defects *of mini drawn parts using a blank holder plate made from concentric rings.* Precision Engineering, 2015. **42**: p. 311-320. https://doi.org/10.1016/j.precisioneng.2015.03.011.

[20] Lee, S., et al., *Gaussian process regression-driven deep drawing blank design method.* International Journal of Mechanical Sciences, 2024. **265**: p. 108898. https://doi.org/10.1016/j.ijmecsci.2023.108898.

[21] Heshmat, Mahmoud, and Mohamed Adel. "Investigating the effect of hot air polishing parameters on surface roughness of fused deposition modeling PLA products: ANOVA and regression analysis." Progress in Additive Manufacturing 6.4 (2021): 679-687

[22] Heshmat, M., & Abdelrhman, Y. (2020). ANOVA and regression model of slurry erosion parameters of a polymeric spray paint film. International Journal of Materials Engineering Innovation, 11(3), 198-211.

[23] Heshmat, M., Maher, I., & Abdelrhman, Y. (2023). Surface roughness prediction of polylactic acid (PLA) products manufactured by 3D printing and post processed using a slurry impact technique: ANFIS-based modeling. Progress in Additive Manufacturing, 8(2), 87-98.

[24] Astakhov, V. P. (2012). Design of experiment methods in manufacturing: Basics and practical applications. In Statistical and computational techniques in manufacturing (pp. 1-54). Berlin, Heidelberg: Springer Berlin Heidelberg.

[25] Abdelaal, O., Heshmat, M., & Abdelrhman, Y. (2020). Experimental investigation on the effect of water-silica slurry impacts on 3D-Printed polylactic acid. Tribology International, 151, 106410.

الملخص العربي

عملية السحب العميق بدون ساند الاقراص من العمليات الهامة لإنتاج الكؤوس الدائرية المستخدمة في العديد من التطبيقات وفي هذه العملية يتعرض القرص لقوى مختلفة الاتجاهات هى التى تؤدي إلى قطع فى الكأس وعدم اكتمال عملية السحب . يؤدى تركيز الاجهادات الى شكل من أشكال الانهيارات بعملية السحب العميق بدون ساند الاقراص , في هذا البحث دراسة نظرية وعملية لتأثير تركز الاجهادات فى عملية السحب العميق بدون ساند الاقراص ,تم بناء موديل محاكاة باستخدام برنامج الدينافورم بغرض دراسة القيم المناسبة للمتغيرات. وقد اجريت التجارب العملية علي ماكينة الاختبار العامه كماكينة تشكيل لعملية السحب العميق لاقراص الالومنيوم بسمك 3 مم واقطار مختلفة وفق برنامج التجارب وتتم العملية بوضع قرص الالومنيوم علي اسطبة السحب وضبط اتزانها ثم تحريك مكبس لاسفل لتتم عملية السحب العميق ,حيث أنه فى بداية السحب يكون الكأس المشكل معرض لقوى تسحبه لاسفل والقرص نفسه يقاوم هذه القوة ومع وجود احتكاك بين القرص وبين البنش من ناحية وبين القرص والاسطمبة من الناحية المقابله فإن تاثير محصلة جميع هذه القوى يؤدى إلى تمزق فى قاع الكأس ولتفادى ذلك تم تقديم عدة مقترحات لتقليل تأثير تركز الاجهادات بغرض نقل الاجهادات من قاعدة الكؤوس الى الجدار واستخدم بنش قاعدته درائرية لتشتت الاجهادات تمت التجارب عند سرعه 9 مم لكل دقيقة ولكل التجارب تم قياس قوى التشكيل والخصائص الميكانيكية قبل وبعد التشكيل . وقد اظهرت النتائج ان تلافي تركيز الاجهادات في عملية السحب العميق بدون ساند الاقراص المقترح لها تاثير واضح فى تقليل القوي اللازم للتشكيل وتقليل قطع العينات وتحسين الخصائص الميكانيكية للكؤوس , تعمل الترترة على إعادة توجيه الاجهاد، مما يقلل من التمزق بنسبة 33%. وقد وصلت نسبة السحب الى 2.46 وهي نسبة عالية مقارنة بالحالة العادية وقد ظهر تقارب فى النتائج النظرية والمحاكاة مع النتائج العملية.