Numerical and Experimental Study on Deep Drawing Process for AA2024-T4Sheet

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Abstract

Deep drawing is an important process for forming sheet metal parts. It depends on many parameters regarding the tool design, process conditions and material parameters. In this work, a series of simulations to determine the effect of punch nose radius on maximum drawing height, thickness distribution and drawing force during deep drawing process of a cylindrical cup are using finite element based DEFORM-2D software. The validity occurred through the comparison between simulation and experimental results. The increasing in the punch nose radius could improve the sheet formability was found, and forming the limited formability of the 2024-T4 aluminum sheets.
Keywords: deep drawing, sheet forming, DEFORM-2D, punch nose radius**).**

1-Introduction

Sheet metal forming is a manufacturing process used to produce large amount of products with lightweight and versatile shapes. In sheet metal forming, the sheet plate is cutting into pieces by shearing, slitting, cutting, or sawing and then subjected to plastic deformation using forming tools to get the desired shape.

Deep drawing is a widely used industrial sheet metal forming processes in which a flat sheet of metal is form into a specific shape or geometry at a very high production rate. Deep drawing is a very complicated process, it is affected by several factors such as punch radius, die radius, clearance between punch and die, punch nose radius, die throat radius, press speed, lubrication type and the material characteristics.

Finite elements method (FEM) is a numerical method used to simulate the deep drawing process with accurate prediction of the deformation behavior. The numerical simulations include the evaluation of the influence of various factors on the drawing process, the analysis of various test geometry, as well as the evaluation of applied loads.

Many researches on the deep drawing process have been carried out. The simulation of the deep drawing of cylindrical cups by using the finite-element code DEFORM-3D was reported by **[3]**to determine the factors influencing the drawing process and analyzing the process by varying the Die radius and keeping the Friction, Punch radius and Blank Thickness as constant. They found that reducing in the die radius leads to increasing the required force amount to draw the material. DEFORM-3D was used **[2]** to study the deformation behavior of a cylindrical deep drawing of magnesium alloy sheets at elevated temperatures.

DEFORM-2D was used to study the influence of process parameters on cup drawing of aluminum sheet [**5,8**]. ABAQUS/EXPLICIT was also used **[1,9,10]** to simulate the influence of material and die design parameters on drawing process.

the earing behaviors of AA 2024-T4 aluminum alloy sheets were studied by deep drawing cylindrical parts of the alloys **[4]**, while **[6]** studied the influence of die shoulder radius, blank holder force and punch nose radius on the thickness distribution of the deep draw cup of AA 6061 sheet.

In this work, DEFORM-2D, finite element analysis software is using to perform simulation of deep drawing process for AA2024-T4 alloy sheets **[7]**. The influences of punch nose radius on maximum drawing depth, thickness distribution and drawing force will be investigate numerically and experimentally.

2. FE model

DEFORM-2D software is using to simulate the deep drawing process for AA2024-T4 alloy sheets in this work. Punch, blank holder and die were modeled as rigid parts while the blank was modeled as a plastic part with Holloman flow stress expressed as in equation 1:

$$\boldsymbol{\sigma = 790(\varepsilon)^{0.166}} \text{........ (1)}$$

Where: σ is the true stress and ε is the true strain

The symmetric boundary conditions leads to reduce computational time, so a half of the geometry is using as a model that shown in Figure (1). The placed blank or work piece over the opening of the die is pressing by punch into the die cavity. The pressure is applying to the outer section of the blank during the forming process by using the blank holder.

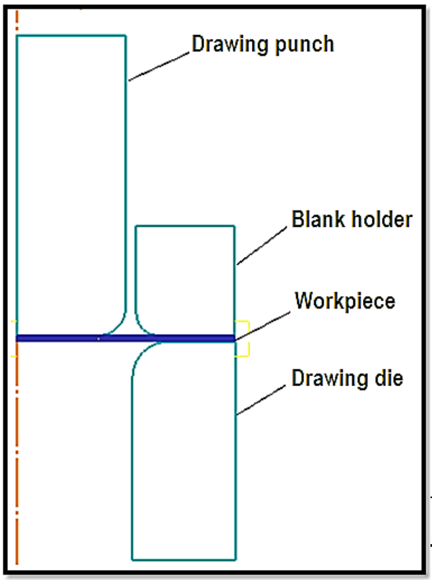

Fig. 1, basic layout for deep drawing.

3. Boundary Condition

The element type selected for meshing the work piece is a high order, 8-node 2D rectangular element 0.24 mm edge length was found to be appropriate with mesh number 1500, Figure (2).

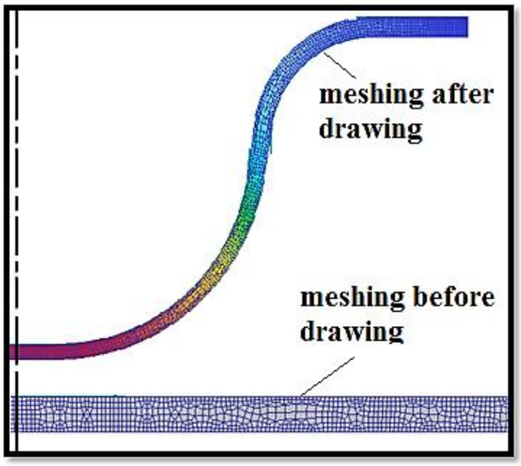

Fig. 2, mesh before and after drawing

In the FE model, there are only displacement boundary conditions and the symmetric condition applied to lines and nodes. In all freedom degrees, the lines representing the die walls are fixed. The restrained punch lines from rotating and moving are along the *x*-axis.

The contact of Master – Slave is create between punch-blank, blank holder-blank and die-blank pairs. For these contact surfaces, the chosen Coulomb's friction law with 0.13 coefficient of friction, which is obtained from ring compression test. To simulate the blank holder force, a uniform pressure 0.8 MPa is applied on the upper surface of the blank holder as shown in figure (3). The movement of the blank is constrained in the x-direction so that it is allowed to move along the y-direction inside the die cavity as shown in figure (4). Four different values for punch nose radius (5, 7, 9.5 and 12) mm were chosen to perform the simulation. Parameters used for simulations are 6.5mm die corner radius and 1.4mm clearance between punch and die.

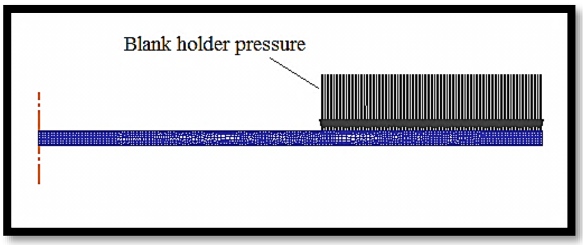

Fig. 3, Simulation of blank holder pressure on the blank.

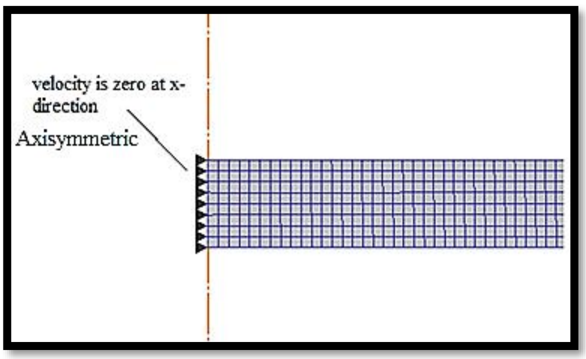

Fig. 4, Work piece with applied velocity boundary condition.

4. Experimental works

4.1 Material

The blank material used in this work is AA2024-T4 aluminum alloy sheets with 1.2mm thickness and 80 mm blank diameter.

The chemical composition and the mechanical properties are listed in tables1 and 2 respectively.

The deep drawing die consists of six different assembled parts designed and fabricated as shown in figure (5). 40mm punch diameter, 42.8mm die cavity diameter, and 4mm blank holder corner radius are the used dimensions.

4.2 Conducting experiments

Table (1): The chemical composition of AA2024-T4

	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ni %	Zn %	Ti %	Pb %	V %	Al %
Standard	Max 0.5	Max 0.5	4.9	0.6	1.8	Max 0.1	Max 0.05	Max 0.25	Max 0.15	Max 0.05	Max 0.05	94.7
Actual	0.113	0.352	4.6	0.534	1.6	0.0024	0.014	0.049	0.022	0.008	0.01	92.7

Table (2): The mechanical properties of AA2024-T4

Properties	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation %	Hardness BHN	Strength Coefficient(K) (Mpa)	Hardening Exponent (n)
Standard	470	325	20	120	720	0.21
Actual	462	328	18	120	790	0.166

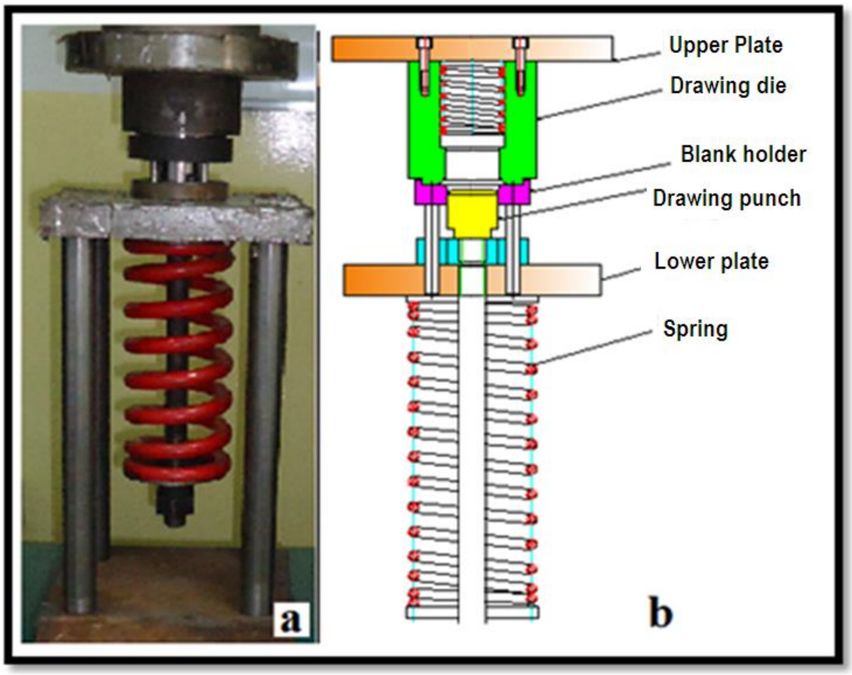

Fig. 5, Deep Drawing die . (a) assembled die, (b) Sectional view

The deep drawing process was performed using a 10-Ton universal testing machine under dry and cold conditions. Figure (6) shows the experimental setup of drawing process, were the drawn cups is sectioning at the middle and the thickness distribution along the cup profile is measure at six locations as shown in Figure (7)

Fig. 6, Universal testing machine with drawing die

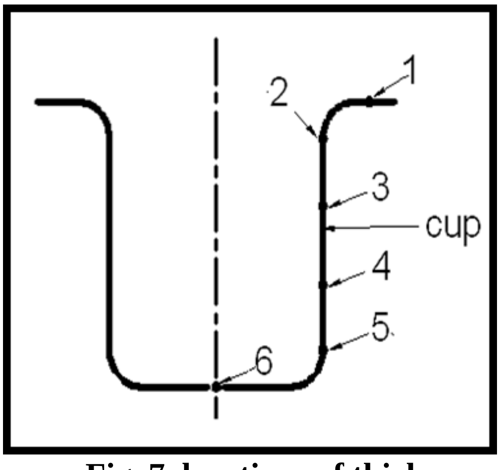

Fig. 7, locations of thickness distribution measurement

5. Results and Discussion

5.1 Thickness distribution

Thickness is an important quality characteristic in formed sheet metal part. The thickness distribution is unevenly after deep drawing of the part.

Figure (8) shows the typical shape characteristics and thickness variation of a partially drawn cup.

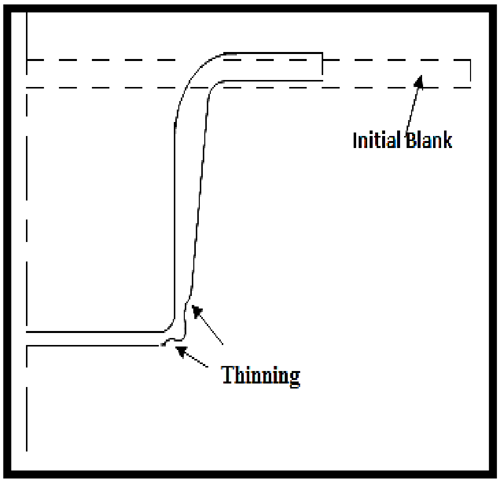

Fig. 8m, Deformation and thinning of work piece[6]

Generally, thickness values are low above punch nose radius whereas it is high at the flange area. The objective of better forming is to reduce thickness difference between thinning and thickening locations of the cup. Tables 3 to 6 show the comparison of the numerical predicted and experimental results of thickness distribution along the cup profile for different punch nose radius. It can be noticed that thickness distribution predicted by simulation matches well with experimental. The minimum thickness value is located above punch nose radius, while the maximum value is located at the flange area (Figures (9 and 10)).

In this work, the punch nose radii (9.5mm and 12mm) give the best thickness distribution for **AA2024-T4** material as shown in Figures 9 and 10. So, as the punch nose radius greater than three times of thickness the sheet thinning is reduced too at the punch nose region (location5 of figure 7). In addition, it reduces the failure caused by thinning that occurs at this region and this indicates a less sheet stretching and better drawing conditions. These results are compatible with **(H. Zein et al., 2013)** that showed "The punch nose radius is recommended to be greater than 3 times sheet thickness"**[9]**.

Table (3) Thickness distribution along the cup profile (punch nose radius= 5mm)

Points		1	2	3	4	5	6
Thickness (mm)	**Simulation**	1.2	1.19	1.129	0.975	1.08	1.035
	Experimental	1.2	1.2	1.1	0.97	1.073	1.05
Error%		0	0.840	2.568	0.512	0.648	1.45

Table (4) Thickness distribution along the cup profile (punch nose radius= 7mm)

Points		1	2	3	4	5	6
Thickness (mm)	**Simulation**	1.205	1.2	1.1423	0.992	1.09	1.084
	Experimental	1.234	1.2	1.122	0.98	1.09	1.084

Error%	2.4	0	1.77	1.209	0	0

Table (5) Thickness distribution along the cup profile (punch nose radius= 9.5mm)

Points		1	2	3	4	5	6
Thickness (mm)	Simulation	1.22	1.2	1.15	1	1.0995	1.148
	Experimental	1.259	1.213	1.146	1	1.095	1.099
Error%		3.196	1.083	0.347	0	0.409	4.268

Table (6) Thickness distribution along the cup profile (punch nose radius= 12mm)

Points		1	2	3	4	5	6
Thickness (mm)	Simulation	1.23	1.2	1.16	1	1.10228	1.153
	Experimental	1.284	1.23	1.15	1	1.099	1.12
Error%		4.39	2.5	0.862	0	0.279	2.86

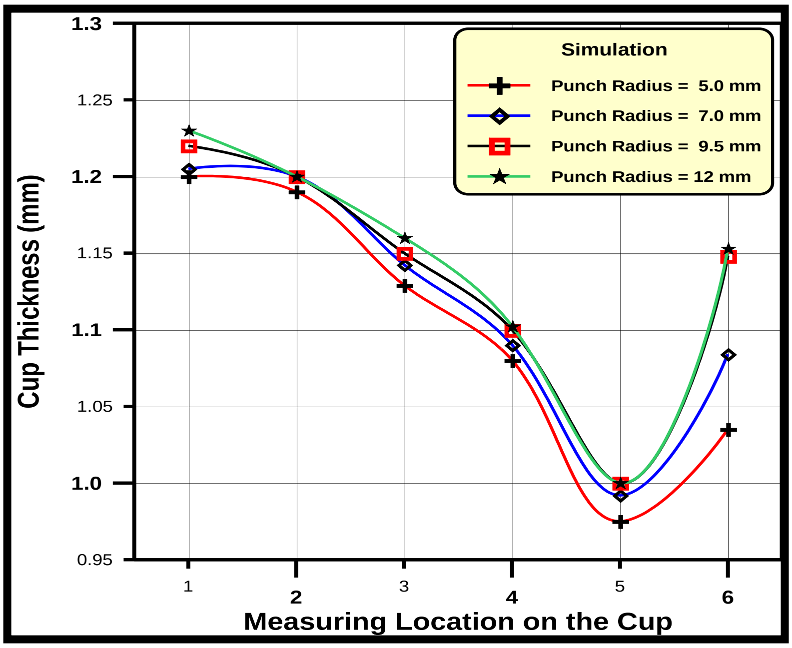

Fig. 9, Effect of punch nose radius on predicted thickness distribution.

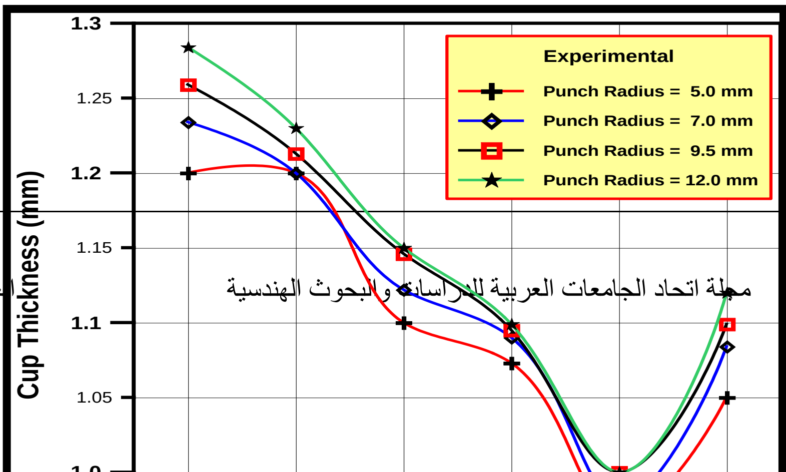

Fig. 10, Effect of punch nose radius on experimental thickness distribution

5.2 Drawing depth

The punch radius is larger than the punch nose radius so the punch is treated as flat-bottomed punch. Figure (11) shows the effect of punch nose radius on the maximum drawing depth. The maximum cup height 20mm obtained from 9.5mm and 12mm punch nose radii, and the maximum error between the predicted cup height during simulation and the experimental one is 13%. The maximum drawing height is proportional to the punch nose radius. The increasing in punch nose radius indicates the improvement in formability of AA2024-T4 under cold and dry forming.

5.3 Drawing force

It has been found that as the punch nose radius is increased, the amount of fore required to draw the material(AA2024-T4) is decreased in simulation and experimental results as shown in figure (12).These results are appears due to the gap between the punch bottom face and inner die surface increases as a result of punch nose radius increasing, so the ability of the blank material to flow in the gap increases during the drawing process and will needs less drawing force to form the blank material. The maximum error between simulation and experimental results is less than 5%

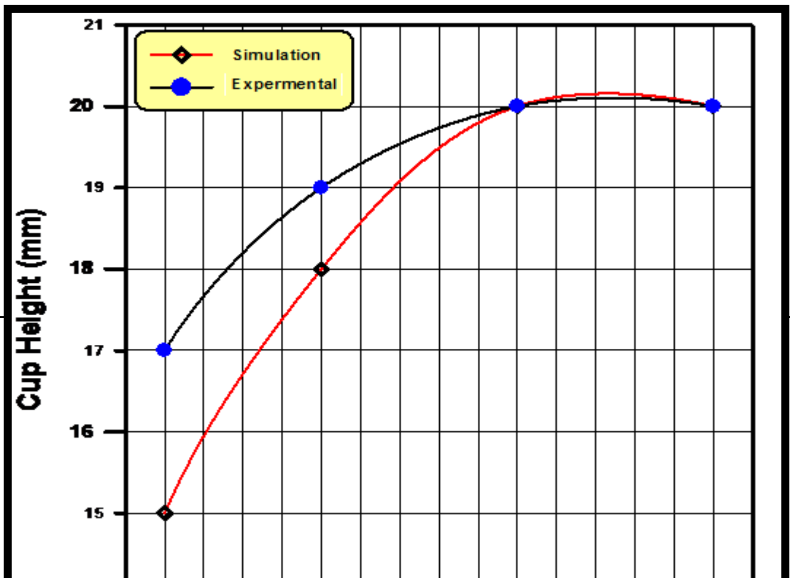

Fig. 11, Effect of punch nose radius on the maximum cup height

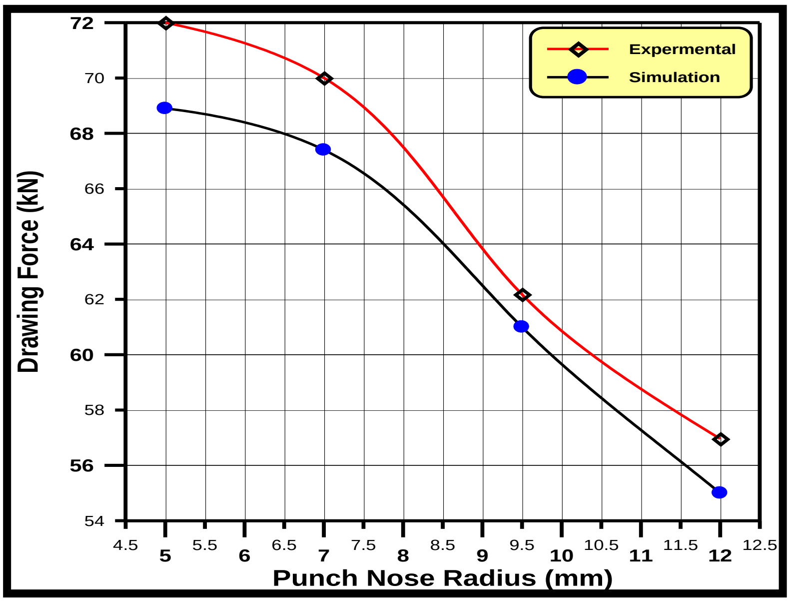

Fig. 12, Effect of punch nose radius on drawing force

6.Conclusions

1. Increasing the punch nose radius reduces the sheet thinning above the punch nose region. In this work ,using punch nose radius greater than three times of thickness to prevent failure due to thinning.
2. Increasing the punch nose radius increases the formability of the sheet. This is figured out by decreasing the amount of force required to draw the material and increasing the maximum drawing depth.

3. There is agreement between simulation results and experimental results.
4. FEM effectively used to simulate the deep drawing process.

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دراسة عددية وعملية على عملية السحب العميق لصفائح سبيكة الألمنيوم 2024-T4

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الخلاصة

السحب العميق هو عملية هامة لتشكيل أجزاء الصفائح المعدنية. تعتمد هذه العملية على العديد من العوامل فيما يتعلق بتصميم الأداة، ظروف عملية السحب والخصائص المعدنية. استخدمت طريقة العناصر المحددة في هذا العمل وبمساعدة برنامج DEFORM-2D لمحاكاة تنفيذ سلسلة من عمليات السحب العميق على صفائح من سبيكة الألمنيوم 2024-T4 لدراسة تأثير نصف قطر قمة أداة السحب على أقصى ارتفاع للسحب، توزيع السمك على طول منطقة السحب وقوة السحب خلال عملية السحب العميق لقدح اسطواني. تم إجراء عملية مقارنة بين نتائج المحاكاة والنتائج التجريبية للتحقق من دقة نموذج المحاكاة. أوضحت النتائج أن زيادة نصف قطر قمة أداة السحب يمكن ان تحسن قابلية تشكيل صفائح الألمنيوم 224-T4 المحدودة التشكيل..