

Simulation Study On Effect Of Die Corner Radius In Single Stage Deep Drawing Process

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ABSTRACT

This study investigates the effect of die corner radius on the single-stage deep drawing process of an AA6061 aluminium alloy cylindrical cup. Deep drawing is a critical sheet metal forming operation in which process parameters strongly influence material flow, thinning, wrinkling, and damage formation. In this work, the component and tooling were modelled using Uni-graphics NX-8.5, and the deep drawing process was simulated using ADEX/AFDEX metal forming software. The die corner radius was varied from 4 mm to 9 mm, while the blank thickness, punch radius, drawing speed, friction coefficient, material, and other key process conditions were kept constant. Blank holder forces of 700 N, 800 N, 900 N, and 1000 N were considered to evaluate their influence on damage value. The simulation results show that die corner radius has a significant effect on formability and that a decreased die corner radius increases the tendency for wrinkling, earing, and damage. Among the simulated cases, the thesis results identify a blank holder force of 900 N and a die corner radius of 8 mm as the optimum condition, giving the minimum damage value and reducing wrinkling. The study supports the selection of suitable tooling parameters for defect-free deep drawn cylindrical components.

Keywords – Deep Drawing, Die Corner Radius, AA6061 Aluminium Alloy, ADEX Simulation, Blank Holder Force

1. INTRODUCTION

Metal forming is a metalworking process in which a work piece is reshaped through mechanical deformation without adding or removing material. In forming processes, the shape and size of the metal piece change under mechanical forces, while the mass remains unchanged. Sheet metal forming applies force to a sheet to modify its geometry by plastic deformation, and typical operations include bending, roll forming, spinning, deep drawing, and stretch forming.

Deep drawing is widely used to transform flat sheet metal blanks into cup-like or box-like components. It is used for manufacturing pots, pans, containers, sinks, automobile panels, gas tanks, cylindrical cups, cans, household goods, and other closed cylindrical or rectangular parts. The process uses a punch and die, while a blank holder controls the blank flow to avoid excessive wrinkling during forming.

During deep drawing, die corner radius and punch corner radius are important because they influence the force distribution and determine whether the sheet material flows smoothly into the die cavity. Small radii may produce stretching, tearing, wrinkling, and earing defects, while larger radii can reduce damage but may also influence wrinkling limits. For this reason, die corner radius is an important tooling parameter for achieving a defect-free deep drawn component.

The present work focuses on a single-stage deep drawing process for an AA6061 aluminium alloy cylindrical cup. The simulation-based investigation varies the die corner radius from 4 mm to 9 mm and evaluates the damage value under different blank holder forces. The objective is to identify an optimum die corner radius and blank holder force combination that reduces damage and improves component quality.

2. LITERATURE SURVEY

Previous studies reviewed in the thesis indicate that die corner radius, blank holder force, punch radius, friction, and material properties strongly affect the quality of deep drawn components. Kondapalli Siva Prasad and Chalamalasetti Srinivasa Rao studied die corner radius in deep drawing and observed that lower die radii increase drawing force and may lead to stretching and earing defects, whereas larger radii may produce wrinkling marks.

Koppanathi Gowtham, K.V.N.S. Srikanth and K.L.N. Murthy examined the simulation effect of die radius on the deep drawing process using Al 6061 material, constant punch radius, friction, and blank thickness, and reported that a die radius of 7 mm produced an optimum deformation level with minimum damage [1]. R. Venkat Reddy and co-authors investigated die corner radius and punch corner radius in relation to wrinkling and fracture limits and found that blank holding force and tooling radii affect the formation of wrinkles and fractures [3].

Other studies reviewed in the thesis used experimental and computer-aided analysis, fast forming software, LS-DYNA, DEFORM-3D, and Abaqus to analyze wrinkling, fracture, deformation, punch reaction force, and equivalent plastic strain [2], [4], [5], [6]. The reviewed works support the need for simulation-based optimization of die radius and blank holder force. The present study therefore uses ADEX/AFDEX simulation to reduce design trial time and identify a suitable die corner radius for the selected cylindrical cup.

2.1 Problem Statement

The thesis identifies that many previous deep drawing simulations were carried out using DEFORM-3D or ANSYS, but optimization of die corner radius, blank holder force, and load can be time-consuming in conventional finite element environments. The thesis further states that DEFORM-3D consumes large time for optimizing design defects and may not identify certain design defects of the component. Hence, ADEX software is selected for simulation and analysis of deep drawing process parameters because it is easier to operate, consumes less time, and can be used to solve design defects of the component.

2.2 Objective

The objective of this project is to study the effect of die corner radius in the deep drawing process using ADEX software and to determine the factors influencing the deep drawing process by varying die corner radius while keeping blank thickness, punch radius, drawing speed, and coefficient of friction constant. CAD modelling using Uni-graphics NX-8.5 is combined with process simulation to analyze the deep drawing process and find the optimum die corner radius with minimum damage value.

3. METHODOLOGY

The study follows a simulation-based methodology. First, the cylindrical cup component was selected and modelled using Uni-graphics NX-8.5. The die, punch, blank holder, blank thickness, die diameter, cup height, die corner radius, and punch corner radius were designed in the software and converted into STL extension files for simulation. ADEX simulation software was then used to analyze the deep drawing process for different die corner radii and blank holder forces.

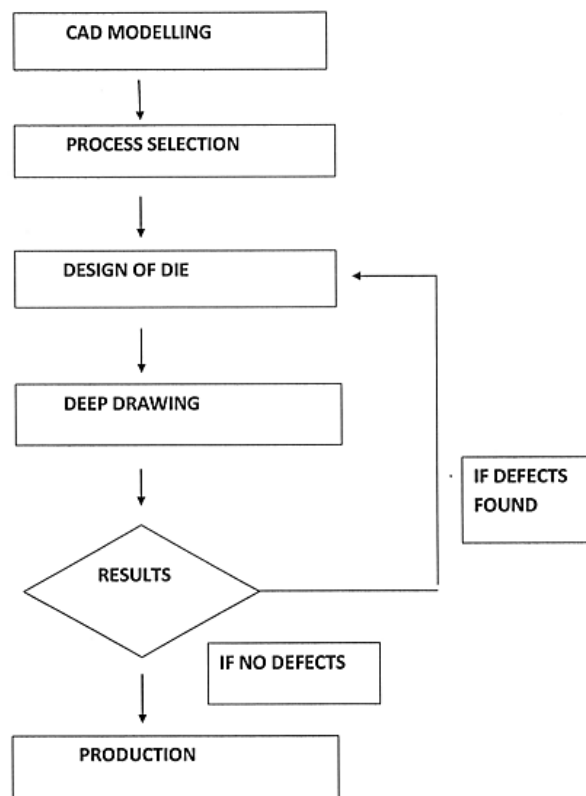


Fig. 1. Methodology flow chart used for the simulation study.

The component considered in the thesis is a cylindrical cup. For blank and die design, the blank diameter relationship used is $D = (d^2 + 4dh)^{0.5}$, where h is cup height, d is cup diameter, and D is blank diameter. Drawing ratio and reduction are expressed as $DR = D_b/D_p$ and $r = (D_b - D_p)/D_b$, respectively. The die diameter is calculated as punch diameter + $(2 \times \text{clearance})$; in the thesis calculation, die diameter = $38 + 2 \times 1 = 40$ mm.

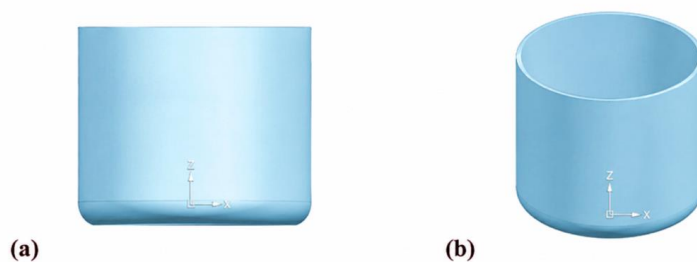


Fig. 2. CAD modelling views of the cylindrical cup.

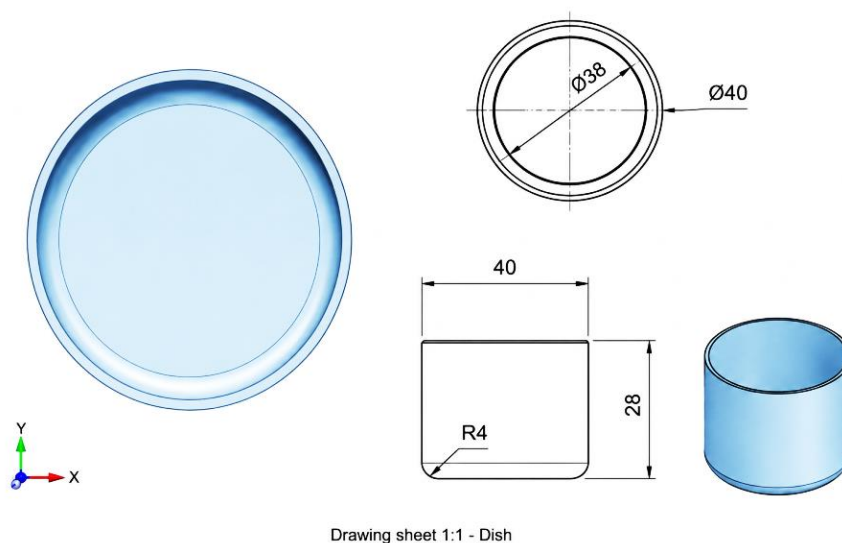


Fig. 3. Top view and drafting representation of the cylindrical cup.

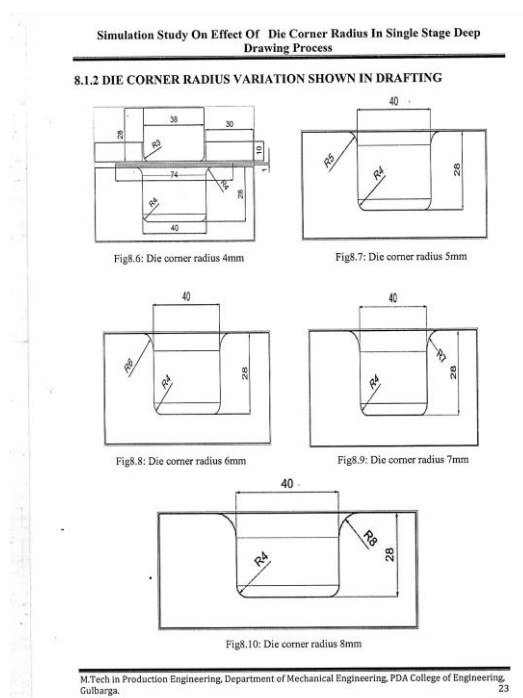


Fig. 4. Die corner radius variation shown in drafting for an 8 mm radius.

3.1 Material Properties

The material selected for the deep drawing simulation is AA6061 aluminium alloy. The chemical composition and material properties used in the thesis are retained in Tables 1 and 2.

Table 1. Chemical composition of AA6061 material.

Component	Composition by weight percentage (%)
Al	98.6
Mg	1.2
Si	0.8
Cu	0.4
Fe	0.7
Zn	0.25
Mn	0.15
Ti	0.15
Cr	0.35

Table 2. Material properties of AA6061.

Property	Value
Ultimate tensile strength	310 Mpa
Modulus of elasticity	68.9 Gpa
Poisson's ratio	0.33
Yield tensile strength	276 Mpa
Hardness, vickers	120
Density	2.7 /gcc

3.2 Simulation Conditions

The thesis considers hot deep drawing and varies the die corner radius while maintaining the selected drawing speed, material, friction coefficient, and other process conditions. The initial diameter is stated as 74 mm, the drawing speed is 0.9 m/sec, and the coefficient of friction between blank and die is 0.125. Blank holder forces of 700 N, 800 N, 900 N, and 1000 N are evaluated.

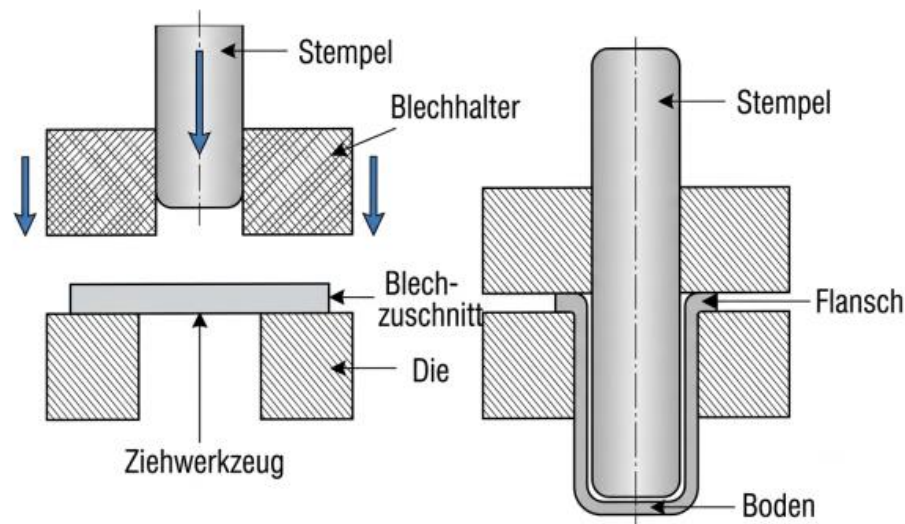


Fig. 5. Principle of the deep drawing process.

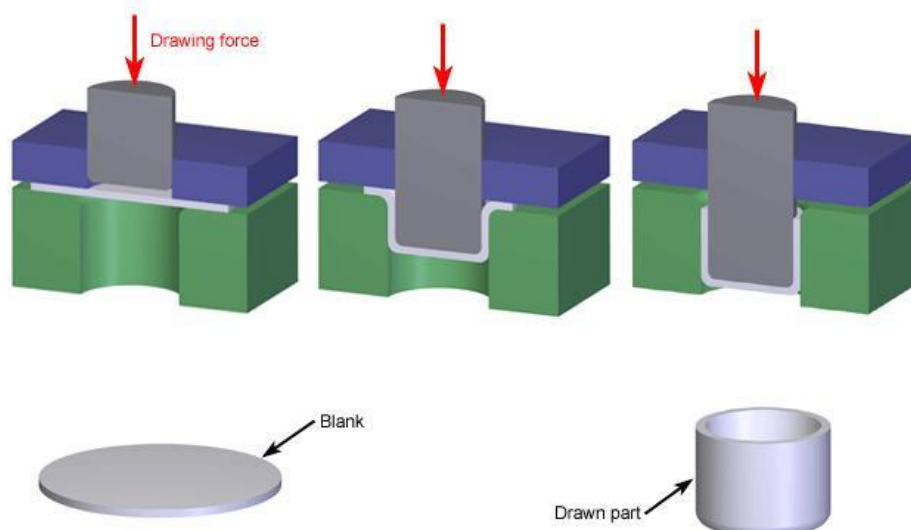


Fig. 6. Sequence of operation for deep drawing.

Table 3. Simulation parameters.

Parameter	Value
Material	AA6061
Drawing speed	0.9 m/sec
Friction coefficient	0.125
Blank holder force	700, 800, 900, 1000N
Temperature	260-600

Table 4. Parameters considered for deep drawing simulation.

S/No	Die corner radius (mm)	Blank holder force (N)	Drawing speed (mm/s)
1	4	700, 800, 900, 1000	0.9
2	5	700, 800, 900, 1000	0.9
3	6	700, 800, 900, 1000	0.9
4	7	700, 800, 900, 1000	0.9
5	8	700, 800, 900, 1000	0.9
6	9	700, 800, 900, 1000	0.9

4. RESULTS AND DISCUSSION

The simulation output was analyzed by varying the die corner radius from 4 mm to 9 mm and considering blank holder forces of 700 N, 800 N, 900 N, and 1000 N. The damage values reported in the thesis are retained exactly in Tables 5 to 8. These values form the core evidence for identifying the optimum die corner radius and blank holder force.

Table 5. Damage values for blank holder force = 700 N.

S/No	Die Corner Radius (mm)	Blank Holder Force (N)	Damage Value (mm)
1	4	700	3.34666E-001
2	5	700	2.72764E-001
3	6	700	2.65790E-001
4	7	700	2.50205E-001
5	8	700	2.41134E-001
6	9	700	2.14115E-001

Table 6. Damage values for blank holder force = 800 N.

S/No	Die Corner Radius (mm)	Blank Holder Force (N)	Damage Value (mm)
1	4	800	3.47310E-001
2	5	800	2.50839E-001

3	6	800	2.87036E-001
4	7	800	2.42355E-001
5	8	800	2.29880E-001
6	9	800	2.30667E-001

Table 7. Damage values for blank holder force = 900 N.

S/No	Die Corner Radius (mm)	Blank Holder Force (N)	Damage Value (mm)
1	4	900	3.30980E-001
2	5	900	2.48195E-001
3	6	900	2.36407E-001
4	7	900	2.36763E-001
5	8	900	2.08430E-001
6	9	900	2.11486E-001

Table 8. Damage values for blank holder force = 1000 N.

S/No	Die Corner Radius (mm)	Blank Holder Force (N)	Damage Value (mm)
1	4	1000	3.41252E-001
2	5	1000	2.88573E-001
3	6	1000	2.33333E-001
4	7	1000	2.40034E-001
5	8	1000	2.29885E-001
6	9	1000	2.13847E-001

For a blank holder force of 700 N, the damage value decreases from 3.34666E-001 at a die corner radius of 4 mm to 2.14115E-001 at a die corner radius of 9 mm. For 800 N, the lowest reported damage value is 2.29880E-001 at an 8 mm die corner radius, with a close value of 2.30667E-001 at 9 mm. For 900 N, the damage decreases to a minimum of 2.08430E-001 at an 8 mm die corner radius. For 1000 N, the lowest damage value reported is 2.13847E-001 at a 9 mm die corner radius.

The thesis conclusion states that decreased die corner radius creates wrinkling and earing-type problems and that the optimum condition is obtained at a blank holder force of 900 N and a die corner radius of 8 mm. This combination gives the minimum damage value among the reported results and is therefore selected as the recommended parameter setting for the simulated single-stage deep drawing process.

The retained simulation output figures from the thesis result section are provided in Appendix A as supplementary result evidence. The quantitative comparison in Tables 5 to 8 is kept in the main article because it directly supports the objective of determining the optimum die corner radius.

5. CONCLUSION

The effect of die corner radius on the single-stage deep drawing process of an AA6061 aluminium alloy cylindrical cup was studied using ADEX/AFDEX simulation software. Around 24 iterations were carried out by varying die corner radius and blank holder force while keeping important process parameters such as material, drawing speed, and coefficient of friction constant.

The study confirms that die corner radius is an important design parameter in deep drawing simulation. A decreased die corner radius increases wrinkling and earing-type defects, making optimization necessary for producing a defect-free component. Based on the thesis results, a blank holder force of 900 N and a die corner radius of 8 mm provide less wrinkling and the minimum damage value. The developed model can be used to simulate similar deep drawing problems for different materials and component designs.

Declarations

Funding: [Not specified in the thesis]. Conflicts of interest: [Not specified in the thesis]. Data availability: Data values used in this article are retained from the supplied thesis report. Ethics approval: Not applicable to the simulation-based study.

APPENDIX A. SUPPLEMENTARY SIMULATION OUTPUT FIGURES

The following ADEX/AFDEX simulation screenshots are retained from the thesis result section as supplementary visual evidence. The captions are based on the surrounding iteration text and original figure labels where available.

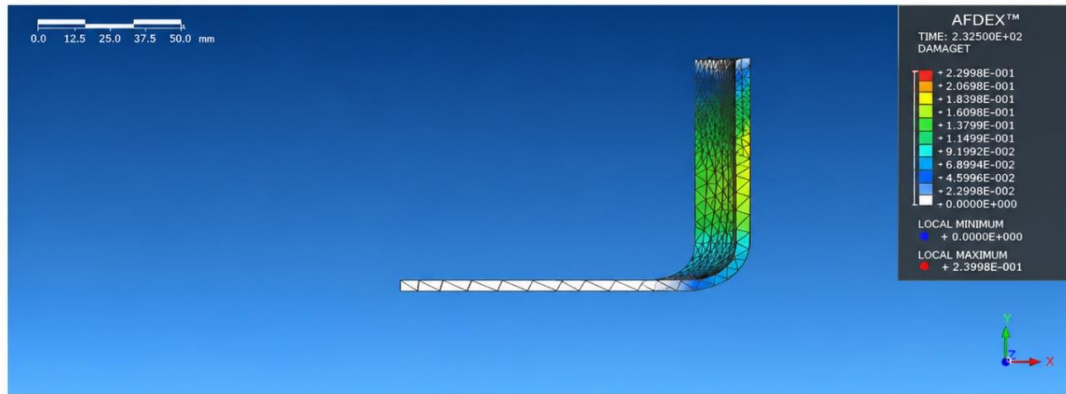


Fig9.1: Blank holder force 700N

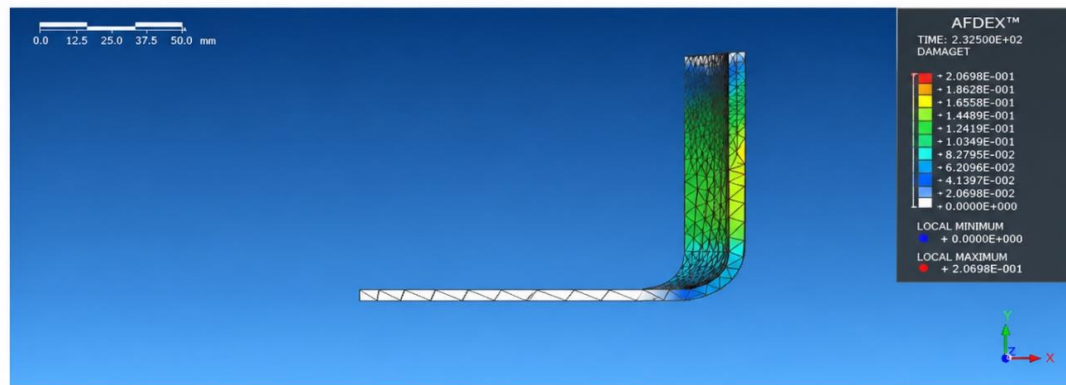


Fig9.2: Blank holder force 800N

Fig. A1. Simulation output retained from Iteration 01 for the 4 mm die corner radius case.

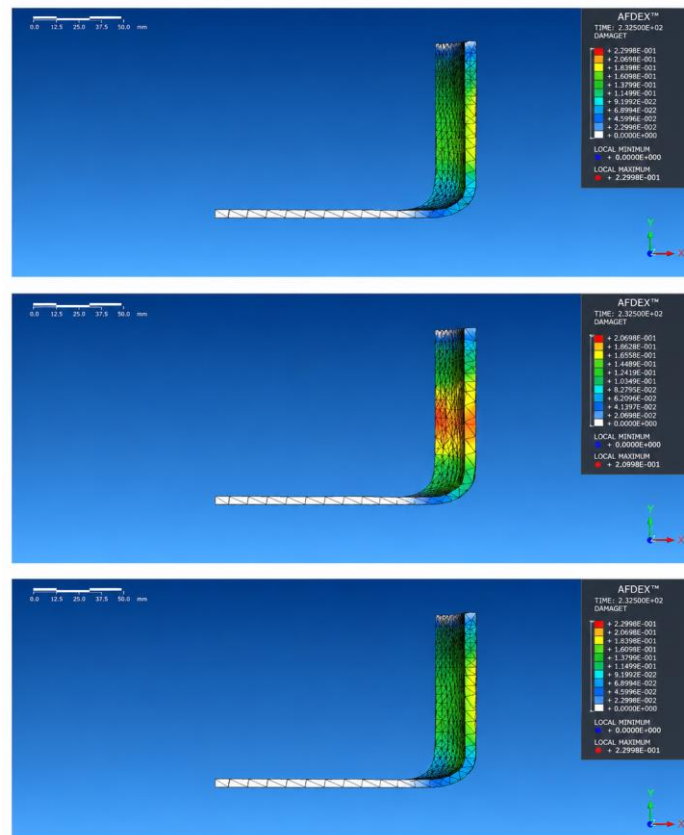


Fig. A2. Simulation output retained from the thesis result section for blank holder force cases.

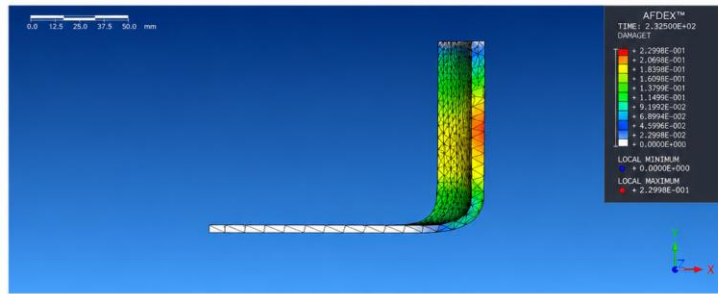


Fig9.6: Blank holder force 800N

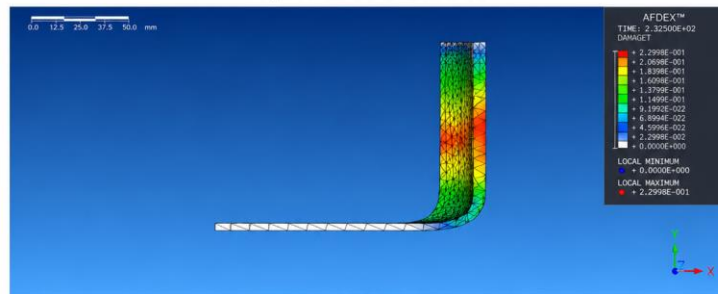


Fig9.7: Blank holder force 900N

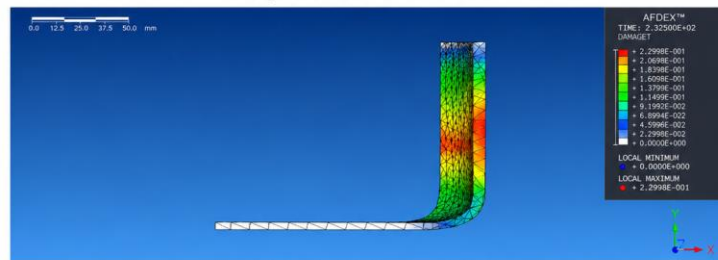


Fig9.8: Blank holder force 1000N

Fig. A3. Simulation output retained from Iteration 02 for the 5 mm die corner radius case.

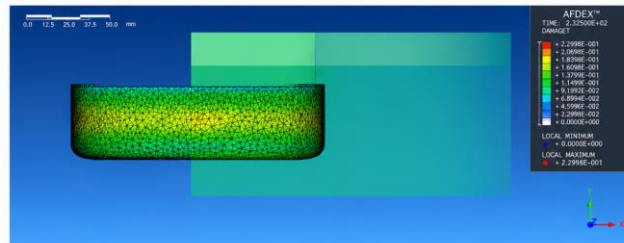


Fig9.9: Blank holder force 700N

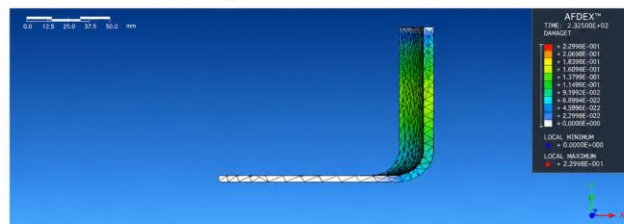


Fig9.10: Blank holder force 800N

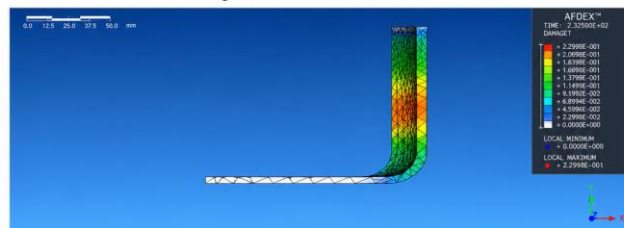


Fig9.11: Blank holder force 900N

Fig. A4. Simulation output retained from Iteration 03 for the 6 mm die corner radius case.

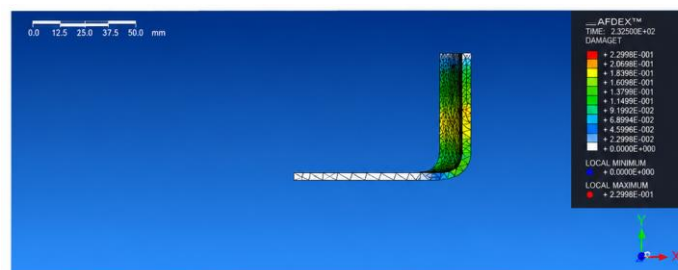


Fig9.12: Blank holder force 1000N

9.1.5 Die corner radius 7mm

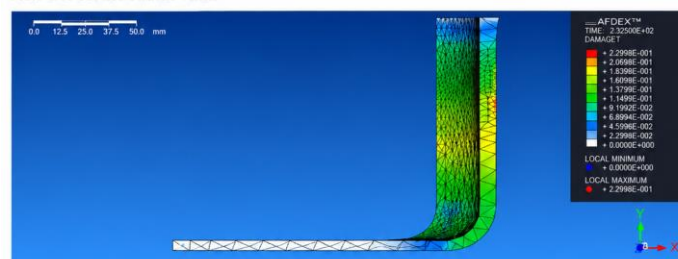


Fig9.13: Blank holder force 700N

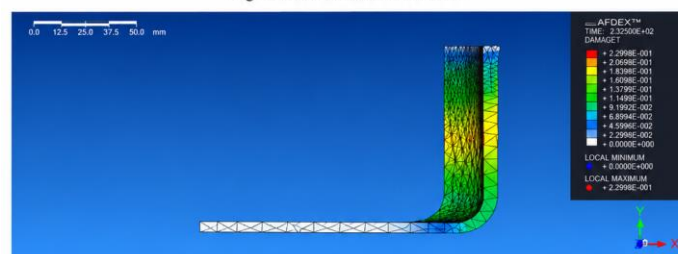


Fig9.14: Blank holder force 800N

Fig. A5. Additional simulation output retained from the thesis result section.

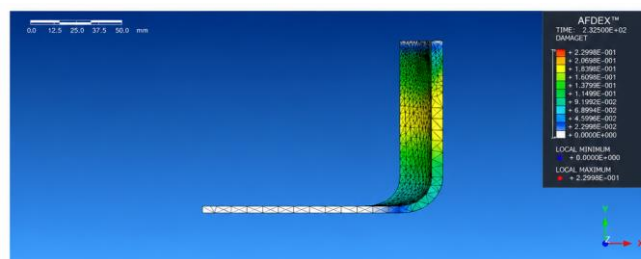


Fig9.15: Blank holder force 900N

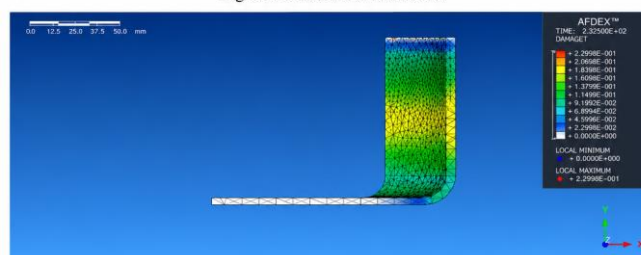


Fig9.16: Blank holder force 1000N

ITERATION 04

9.1.6 Die corner radius 8mm

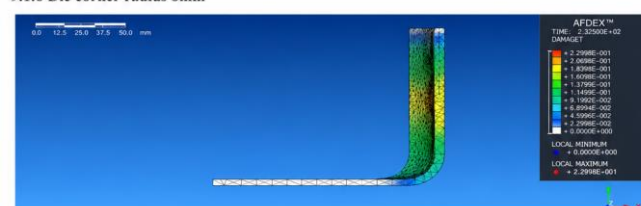


Fig9.17: Blank holder force 700N

Fig. A6. Additional simulation output retained from the thesis result section.

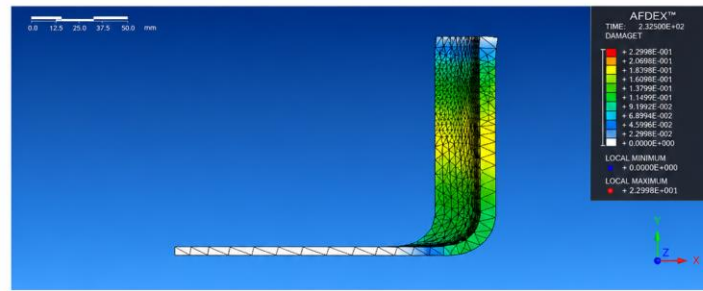


Fig9.18: Blank holder force 800N

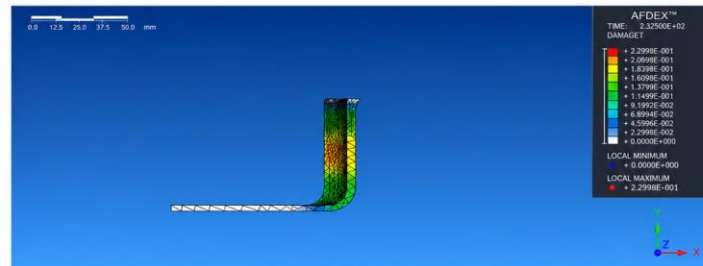


Fig9.19: Blank holder force 900N

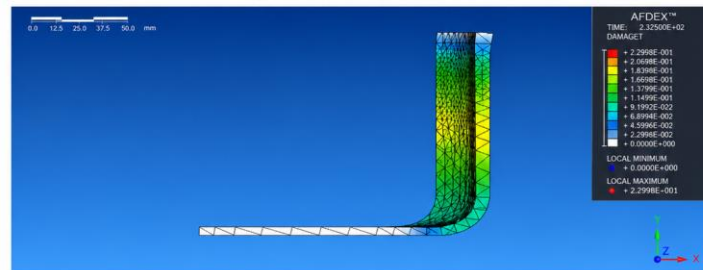


Fig9.20: Blank holder force 1000N

Fig. A7. Additional simulation output retained from the thesis result section.

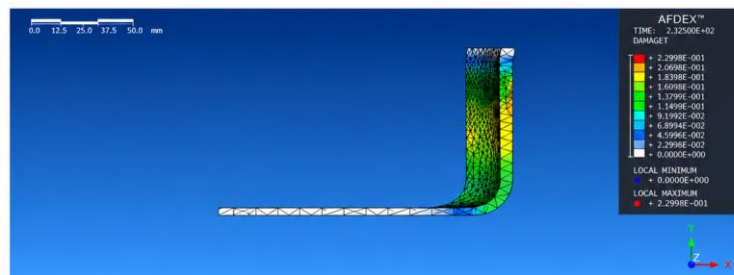


Fig9.21: Blank holder force 700N

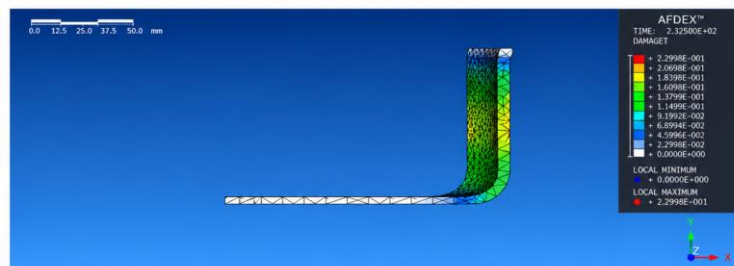


Fig9.22: Blank holder force 800N

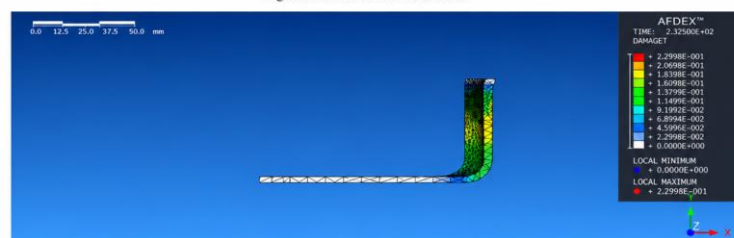


Fig9.23: Blank holder force 900N

Fig. A8. Simulation output retained for the 9 mm die corner radius case.

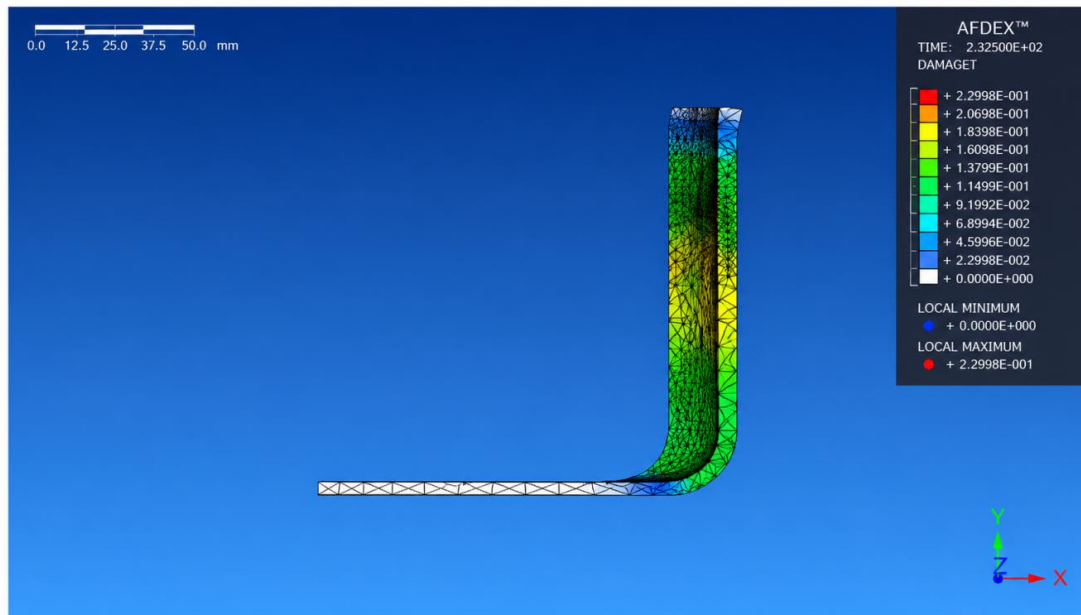


Fig. A9. Simulation output retained from the original Fig. 9.24 blank holder force 1000 N result.

REFERENCES

- [1] Koppanathi Gowtham, K.V.N.S. Srikanth and K.L.N. Murthy, "Simulation of the effect of die corner radius on deep drawing process," International Journal of Applied Research in Mechanical Engineering, Vol. 2, Issue 1, 2012.
- [2] Saari Shakil, Mostafa Hamed and Abdessalem Chamekh, "Single stage steel cup deep drawing analysis using finite element simulation," International Journal of Engineering Research and Technology, Vol. 4, Issue 2, February 2015.
- [3] R. Venkat Reddy, Dr. T. A. Janardhan Reddy, Dr. G. C. M. Reddy, "Effect of Die Corner Radius and Punch Corner Radius on Wrinkling and Fracture Limits in Deep Drawing of Cylindrical Cup," International Journal of Engineering and Material Science, Vol. 19, pp. 24–30, February 2012.
- [4] Tausif N. Momin, V. B. Bhagwat, A. H. Kolekar and Amitkumar R. Shelke, "Experimental and computer aided analysis for the reduction of damage in sheet metal forming," International Journal of Modern Trends in Engineering and Research, e-ISSN No. 2349-9745, July 2015.
- [5] P. V. Ravindra Reddy, G. Chandra Mohan Reddy and T. A. Janardhan Reddy, "Studies on the effect of die corner radius and blank holding force on limit strains in deep drawing process," International Journal of Engineering and Material Science, Vol. 19, pp. 24–30, February 2012.
- [6] Nikhunj D. Patel, Bhavesh C. Patel and Dr. Keyur J. Thakkar, "A Review of Deep Drawing Process and Interdependency of its Parameters," International Journal of Engineering Development and Research, Vol. 2, pp. 327–3322, Issue 3, 2014.
- [7] T. S. Hemanth, Y. Arunkumar and S. M. Jnt, "Design and Manufacturing Simulation of Preform for Thread Rolling Operation," International Journal of Engineering Research and Technology, Vol. 5, No. October, pp. 60–68, 2015.
- [8] H. S. Thulasi, V. Arunkumar, M. S. Srinath and T. Rakshith, "Manufacturing Simulation for Determining the Influence of Process Parameters on Quality of Forgings," International Journal of Engineering Research & Technology (IJERT), NCREAME, 2015, pp. 146–151.
- [9] ASM Metals Handbook, Volume 14: Forming and Forging, ASM International, Materials Park, Ohio, USA. Page 14A.1–14A.50.