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Review Paper

STUDY ON EFFECT OF DIE CORNER RADIUS IN DEEP DRAWING PROCESS

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Deep drawing plays a vital role in the manufacturing process of different parts in various process environments. There is a need to develop different die designs by varying input process parameters for the deep drawing process in an optimum manner. The objective of the present study is to determine the influencing of work piece material on die corner radius in deep drawing process. As, the die corner radius plays a vital role in manufacturing the product in deep drawing process. Lower the die corner radii the part is subjected to tearing effect and higher the die corner radii, wrinkling is observed. The present work deals with 1 mm thick Aluminium, Brass and Stainless steel blank. Static Analysis is carried out in ANSYS for (4mm, 5mm, 6mm, 7mm and 8mm) corner radii of the die.

Keywords: Deep Drawing, Corner radius, Aluminium, Brass, stainless steel, ANSYS.

INTRODUCTION

Many research works are carried out by many researchers in the process of deep drawing in assessing the die quality, optimization drawing process parameters and stresses, strains induced in the process. The stamping of thin metallic sheets is a widely used industrial material forming process. It allows the production of thin walled parts with complicated shapes such as automotive panels or structural parts. The process consists of the plastic deformation of a blank subjected to the action of a rigid punch and die while constrained on the periphery by a blank holder. The main variables involved in this type of process are die corner radius, friction, punch radius and blank thickness. These factors determine the maximum punch loading drawing, the sheet-thickness variation after drawing and the maximum limit drawing ratio. If the height of the work piece in industrial production is too high, multi-redrawing is necessary in order to obtain a successful product. The finite element method has recently been sufficiently developed for the analysis of metal forming processes. Hence, much research has been performed using the finite element method. The purpose of the present study is to clarify the mechanics of ductile fracture in bulk metal forming processes.

Despite its apparent simplicity, deep drawing of a cylindrical cup is a very complicated process that has attracted a lot of research work, as it involves setting a lot of process parameters in order to produce a desired product. Attempts to analyze the process and to evaluate the drawing forces have been made by many researchers. The early work of Siebel and Pomp [1] and separately by Sachs [2], laid the foundation for the subsequent theoretical treatment of the problem. The radial drawing problem was first studied by Hill [3] who considered the limiting cases of plane stress and strain. A comprehensive study of the elementary mechanics of the drawing process was carried out by Chung and Swift [4] who improved the model for bending over the die profile radius. The authors, however, unable to extend their solution to the punch nose region. The attempts to develop a simple method for the estimation of the drawing force were continued by Stoughton [5] and later by Panknin [6]. Numerical methods used in deep drawing process simulations were studied by Chiang and Kobayashi [7] and separately by Budiansky and Wang [8] in their application to the analysis of the radial drawing problem of anisotropic materials. The analysis was extended into the punch nose region by Woo [9] who also improved the formulation of the blank holding pressure boundary condition. The variation of stress with sheet material thickness was taken into account by Odell [10] who concluded that the membrane theory was adequate when cups of moderate die radius/material thickness ratios were analyzed. Seo [11] investigated the work hardening of the material during multiple forming. Jain et al. [12] conducted simulations on the progressive-die-sequence design

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for automotive parts. Gaieret.al [13] developed an algorithm for integrating the forming simulation of sheet metal and fatigue life prediction for application in the design of automotive structures. Ghouati and Chen [14] proposed different possibilities to be included in the closed loop design and optimization simulation of sheet metal forming.

The objective of the present study is to determine the influencing of die corner radius in deep drawing process and analyzing the process by varying the die corner radius and different material.

2. ANALYSIS PROCEDURE

Aluminium alloy 6061, Yellow Brass C26800 and Stainless Steel 310S are considered to study the effect of die radius.

2.1 Drawing force calculation

The drawing force required to perform a drawing operation can be approximately estimated by the following formula:

$$F_{d\,max} = n\times \pi \times d \times t \times UTS \qquad \text{Equation-1}$$

d = Diameter of cup

t = thickness

UTS = Ultimate Tensile Strength

n = Drawing coefficient (0.7 to 0.95)

While calculating optimum die corner radius selection of material is also having a prominent role in order to assess the force for performing deep drawing operation. The materials selected for the present work is Stainless Steel and calculated the maximum force from the Ultimate Tensile Strength of the material are given below.

Aluminum (6061 T6): UTS: 310Mpa, T: 0.7

$$F_{d\,max} = 0.7\times\pi\times22\times1\times290=14030.35\ \text{N} \qquad \text{Equation-2}$$

Brass (C26800 yellow brass): UTS: 315 Mpa, T: 0.7

$$F_{d\,max} = 0.7\times\pi\times22\times1\times175=8466.59\ \text{N} \qquad \text{Equation-3}$$

Stainless Steel (310s): UTS: 515 Mpa, T:0.7

$$F_{d\,max} = 0.7\times\pi\times22\times1\times380=18384.60\ \text{N} \qquad \text{Equation-4}$$

Blank Diameter, Force required to punch the blank to cup shape values are calculated mathematicaly. These values are taken as inputs in the finite element analysis of the Deep Drawing process.

2.2. Element Type

SOLID186 Element is considered in the analysis. SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection and large strain capabilities. It also has the mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials and fully incompressible hyper elastic materials.

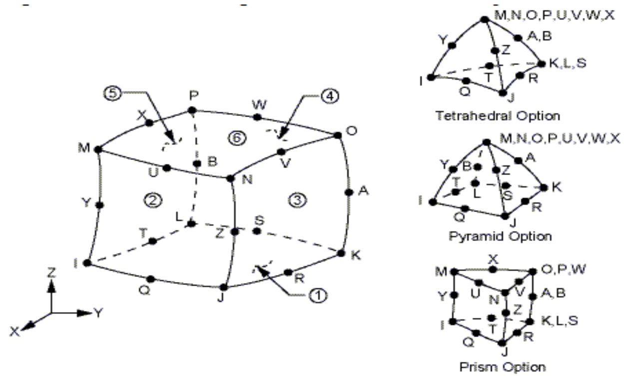

Fig 1: SOLID186 Homogenous Structural Solid Geometry

The geometry node locations and the element coordinate system for this element are shown in Figure.2. A prism-shaped element may be formed by defining the same node numbers for nodes K, L and S, nodes A and B and nodes O, P and W. A tetrahedral-shaped element and a pyramid-shaped element may also be formed as shown in Fig.5.2 SOLID186. Figure 3 shows the area model of the extrusion die developed in Pro-engineer imported in to the ANSYS multi physics and the element type is set as SOLID 186.

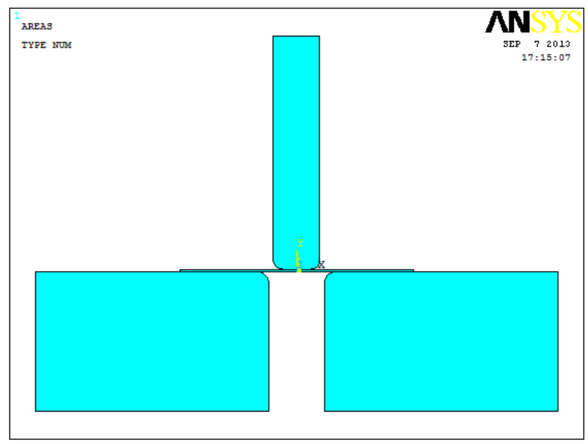

Fig 2: Area model of the Deep drawing die

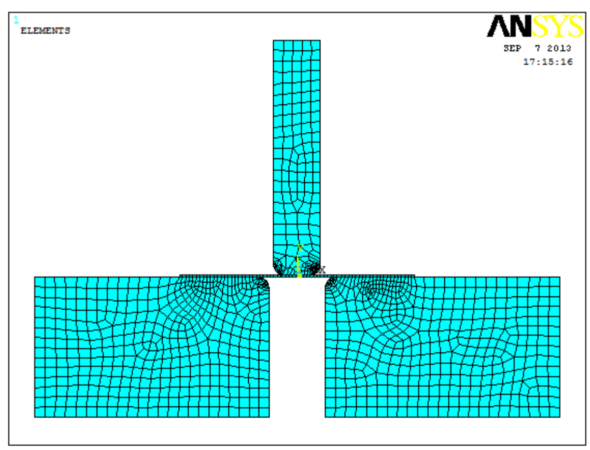

Fig 3: Finite element model of the Deep drawing die

2.3. Criteria in selection of material for the blank in Deep drawing process

The samples of thickness 1mm are analyzed and values such as (Displacement, Von-Mises stress, Principal stress, Effective strain, Principal strain) is computed for every Die corner radii i.e. 4mm, 5mm, 6mm, 7mm and 8mm by applying the calculated forces, which is calculated manually.

The force of 18384.60 N (Mathematically calculated) is applied to the Brass blank of 1mm thickness for 6mm corner radius, the Displacement, Von-Mises stress, Principal stress, Effective strain and Principal strain are found out. Fig 4 (a-f) describes all the parameters along the depth of the cup are observed.

2.4. Stainless Steel blank of 1mm thickness for 6mm die corner radius

The force of 18384.60 N (Mathematically calculated) is applied to the Brass blank of 1mm thickness for 6mm corner radius, the Displacement, Von-Mises stress, Principal stress, Effective strain and Principal strain are found out. Fig 4 (a-f) describes all the parameters along the depth of the cup are observed.

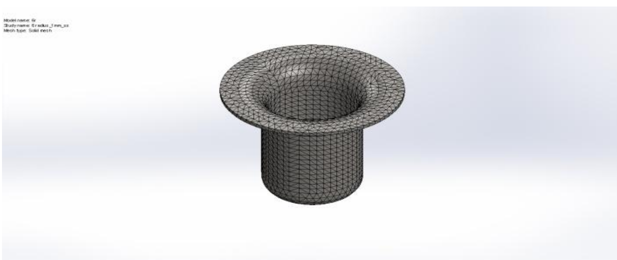

Fig 4(a): Stainless Steel cup meshed model

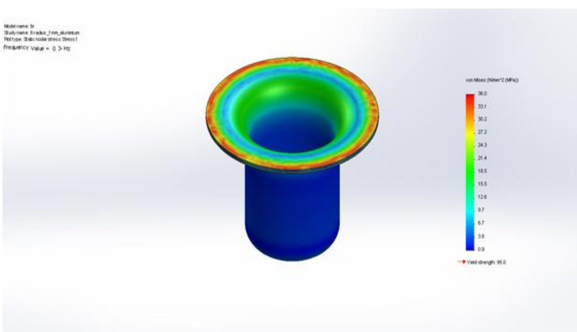

Fig 4(b): Displacement of 1mm Stainless Steel blank for 6mm die corner radius.

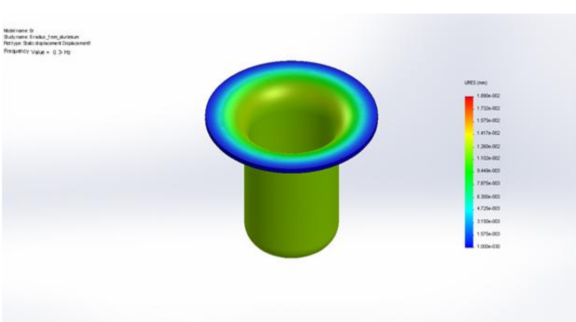

Fig 4(c): Von-Mises stress of 1mm thick Stainless Steel blank for 6mm die corner radius.

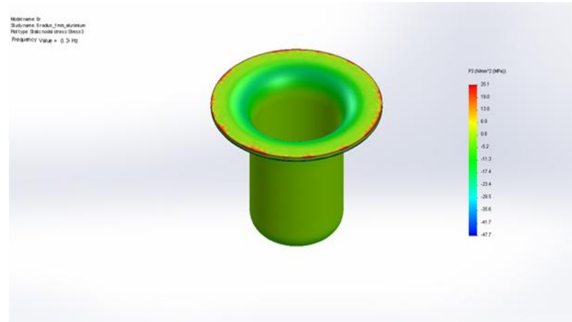

Fig 4(d): Principal stress of 1mm thick Stainless Steel blank for 6mm die corner radius.

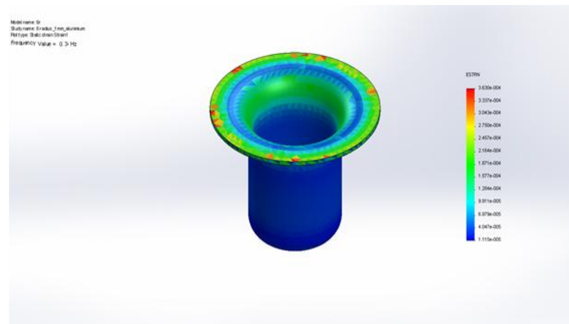

Fig 4(e): Effective strain of 1mm thick Stainless Steel blank for 6mm die corner radius.

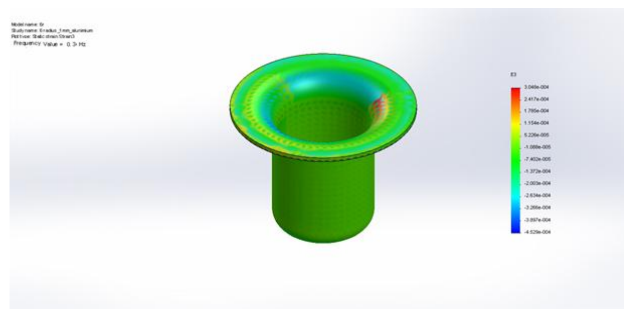

Fig 4(f): Principal strain of 1mm thick Stainless Steel blank for 6mm die corner radius

- The Fig 4(b) shows that displacement in the 1 mm thickness Stainless Steel blank of 6mm corner radius drawing part when applied load is 10000N. From the figure it is observed that maximum value is 0.2836072 mm and the minimum value is 0 mm.

- The Fig 4(c) shows that Von-Mises stress in the 1 mm thickness Stainless Steel blank of 6mm corner radius drawing part when applied load is 10000N. From the figure it is observed that maximum value is 330.039 N/mm² and the minimum value is 0.873N/mm².

- The Fig 4(d) shows that Principal stress in the 1 mm thickness Stainless Steel blank of 6mm corner radius drawing part when applied load is 10000N. From the figure it is observed that maximum value is 366.2147 N/mm² and the minimum value is -98.548N/mm².

- The Fig 4(e) shows that Effective strain in the 1 mm thickness Stainless Steel blank of 6mm corner radius drawing part when applied load is 10000N. From the figure it is observed that maximum value is 0.00099921 and the minimum value is -5.644e-005.

- The Fig 4(f) shows that Principal strain in the 1 mm thickness Stainless Steel blank of 6mm corner radius drawing part when applied load is 10000N. From the figure it is observed that maximum value is 0.00109694 and the minimum value is -5.753e-005.

In the similar manner by varying die corner radii 4mm to 8mm in the steps of 1mm increase, the above mentioned parameters are obtained and tabulated in table 1.

Table 1 Stainless Steel blank of 1mm thickness with force = 10000N

Stainless Steel	DISPLACEMENT mm	VON-MISES STRESS N/mm²	PRINCIPAL STRESS N/mm²	EFFECTIVE STRAIN	PRINCIPAL STRAIN
4 RADIUS	0.264962	324.018	358.8736	0.00094103	0.00105025
5 RADIUS	0.251554	325.246	361.5269	0.00094776	0.00104543
6 RADIUS	0.2836072	330.039	366.2147	0.00099921	0.00109694
7 RADIUS	0.2419634	323.2676	351.543	0.00095224	0.00102627
8 RADIUS	0.2304169	327.4902	352.955	0.00093098	0.00102497

From the Table 1 Displacement, Von-Mises stress, Principal Stress, Effective strain and Principal strain values are plotted for 1 mm thickness Stainless Steel blank when applying a force of 10000 N for different corner radii like 4mm, 5mm, 6mm, 7mm and 8mm. 6mm die corner radius has shown optimal results compared to other radii.

Similarly the same analysis is carried out with blank material as Aluminium and Brass for the same thickness of 1mm, with the same forces.

Table 2 Aluminium Steel blank of 1mm thickness with force = 10000N

Aluminium	DISPLACEMENT mm	VON-MISES STRESS N/mm²	PRINCIPAL STRESS N/mm²	EFFECTIVE STRAIN	PRINCIPAL STRAIN
4 RADIUS	0.929114	236.0128	274.1401	0.0017364	0.00141093
5 RADIUS	0.910491	235.2466	276.6932	0.00186882	0.00144953
6 RADIUS	0.988989	240.0339	279.1097	0.00198901	0.00153482
7 RADIUS	0.966159	235.2676	275.1715	0.00189923	0.00147404
8 RADIUS	0.964468	236.4902	276.7025	0.00187799	0.0014918

From the Table 2 Displacement, Von-Mises stress, Principal Stress, Effective strain and Principal strain values are plotted for 1 mm thickness Aluminium Blank when applying a force of 10000 N for different corner radii like 4mm, 5mm, 6mm, 7mm and 8mm. 6mm die corner radius has shown optimal results compared to other radii.

Table 3 Brass Steel blank of 1mm thickness with force = 10000N

Brass	DISPLACEMENT mm	VON-MISES STRESS N/mm²	PRINCIPAL STRESS N/mm²	EFFECTIVE STRAIN	PRINCIPAL STRAIN
4 RADIUS	0.725211	264.6158	327.9392	0.00127983	0.001371
5 RADIUS	0.7467636	265.1941	326.3388	0.00128769	0.00137258
6 RADIUS	0.789239	270.0012	329.4798	0.00130248	0.00139097
7 RADIUS	0.7606174	265.4905	327.7312	0.00128625	0.00137509
8 RADIUS	0.7527913	264.559	326.6886	0.00128846	0.00137696

From the Table 3 Displacement, Von-Mises stress, Principal Stress, Effective strain and Principal strain values are plotted for 1 mm thickness Brass blank when applying a force of 10000 N for different corner radii like 4mm, 5mm, 6mm, 7mm and 8mm. 6mm die corner radius has shown optimal results compared to other radii.

3. RESULTS AND DISCUSSION

Graphs are plotted for the obtained results, comparing different materials such as Aluminium, Brass and Stainless Steel.

Individual graphs are drawn from varying the materials (Aluminium, Brass and Stainless Steel) are plotted.

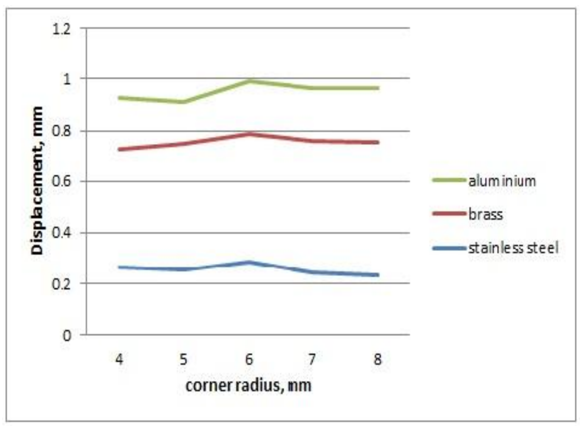

Fig 5(a): Comparing the Displacement for different materials of 1mm thickness blank by varying die corner radius.

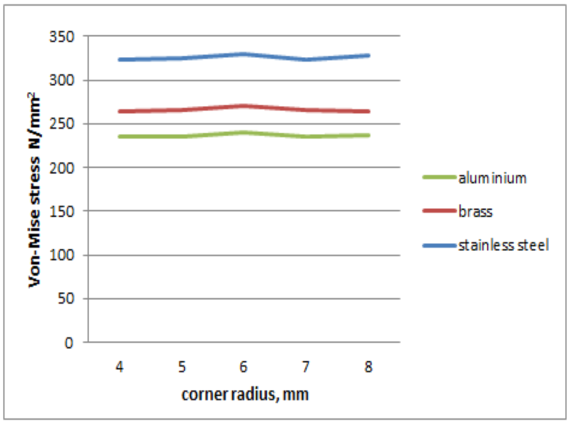

Fig 5(b): Comparing Von-Mises stress for different materials of 1mm thickness blank by varying die corner radius.

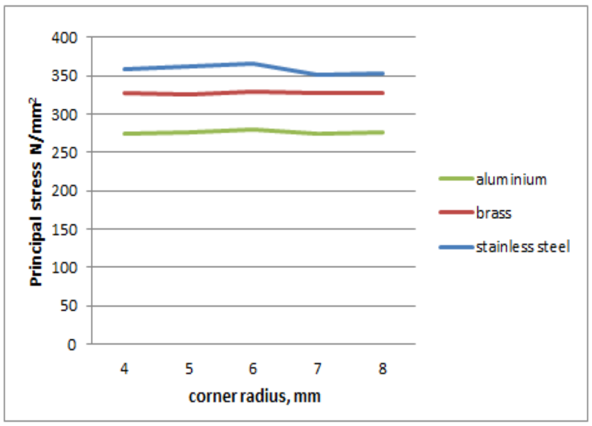

Fig 5(c): Comparing the Principal stress for different materials of 1mm thickness blank by varying die corner radius

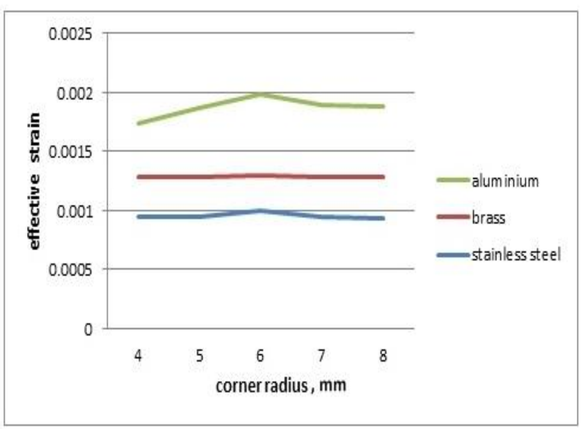

Fig 5(d): Comparing the Effective strain for different materials of 1mm thickness blank by varying die corner radius.

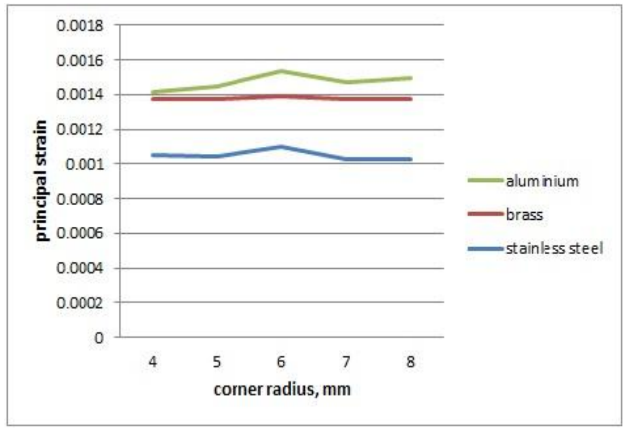

Fig 5(e): Comparing the Effective strain for different materials of 1mm thickness blank by varying die corner radius.

- Fig 5(a) shows the displacement (mm) vs Die corner radius (mm) of Aluminium, Brass and Stainless Steel when 10000N force is applied, 6mm Die corner radius giving the more displacement.

- Fig 5(b) shows the Von-Mises stress (N/mm²) vs Die corner radius (mm) of Aluminium, Brass and Stainless Steel when 10000N force is applied, 6mm Die corner radius giving the higher Von-Mises stress.

- Fig 5(c) shows the Principal stress (N/mm²) vs Die corner radius (mm) of Aluminium, Brass and Stainless Steel when 10000N force is applied, 6mm Die corner radius giving the higher Principal stress.

- Fig 5(d) shows the Effective Strain vs Die corner radius (mm) of Aluminium, Brass and Stainless Steel when 10000N force is applied, 6mm Die corner radius giving the more Effective Strain value.

- Fig 5(e) shows the Principal Strain vs Die corner radius (mm) of Aluminium, Brass and Stainless Steel when 10000N force is applied, 6mm Die corner radius giving the more Principal Strain value.

4. CONCLUSIONS

The conclusions made from the present work are:

1. Observation is done that as the Die corner Radius is reduced the amount of Force required to draw the material is increased.
2. A decreased Die corner Radius created stretching and earring type quality problems. Increased corner Radius created wrinkling marks.
3. Because of the above issues, an Optimum Die corner Radius was an important parameter which is obtained from the simulation studies.
4. It has been observed that a die corner radius of 6mm gave an optimum deformation levels for 1mm thickness blank.

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