DEEP DRAW DIE DESIGN FOR AUTOMOTIVE SHEET METAL COMPONENT USED IN FORMING ANALYSIS FOR VALIDATION

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Abstract: *Deep drawing is one of the most widely used metal-forming processes in the automotive industry, enabling the production of complex sheet-metal components with high structural integrity and dimensional accuracy. This study presents the systematic design and evaluation of a deep draw die developed for an automotive sheet-metal part, with a specific focus on validating the design through forming analysis. The die design process is outlined from initial component assessment and material selection to the determination of critical parameters such as blank size, draw radius, lubrication strategy, and draw bead configuration. Finite Element Forming Analysis is employed to predict thinning, wrinkling, earing, and potential fracture zones, ensuring that the die geometry provides robust formability under production conditions. Simulation outcomes are used to refine the die structure and optimize process parameters prior to manufacturing. The results confirm that the proposed die design meets formability requirements and provides acceptable stress distribution across the component, thereby minimizing the need for iterative tool modifications. This work demonstrates the effectiveness of integrating deep draw die design with forming simulation as a validation tool to enhance accuracy, reduce development time, and improve overall manufacturability in automotive sheet-metal production.*

Keywords: *Deep drawing, Forming, Finite element, Automotive, Sheet metal*

INTRODUCTION

Metal stamping is a manufacturing process used to shape and cut metal sheets into required forms. It is widely used to make parts for automotive components, structural assemblies, machinery, and many other engineering applications. It is also used for producing everyday products such as cans, kitchen utensils and cookware. Common materials used in metal stamping include steel, aluminum, zinc, and titanium.

In metal stamping, a flat sheet of metal is positioned inside a press tool or die that contains a cavity shaped like the final component. The top part of the die is attached to the press slide, while the bottom part is fixed to the press bed. When the punch moves downward, it pushes the sheet into or through the die cavity, causing the metal to bend, cut, or form into the required shape. After stamping, the metal part may undergo plating (such as zinc, nickel, or tin coating) to improve corrosion resistance, appearance, solderability and wear resistance. In some cases, the sheet is pre-plated before stamping and then cleaned. Most stamped components are also heat treated after forming to restore or improve their strength, and then deburring is done using abrasives or chemicals to remove sharp edges and burrs.

Problem Definition

The sheet metal industry faces several challenges during the design and development of tools (dies) for forming and deep drawing operations. These processes are highly complex and demand a high level of technical expertise. Successful die design not only depends on proper geometry and tool layout, but also on a deep understanding of material behavior, forming limits, friction, lubrication, and process parameters such as blank holding force, punch speed, and draw ratio.

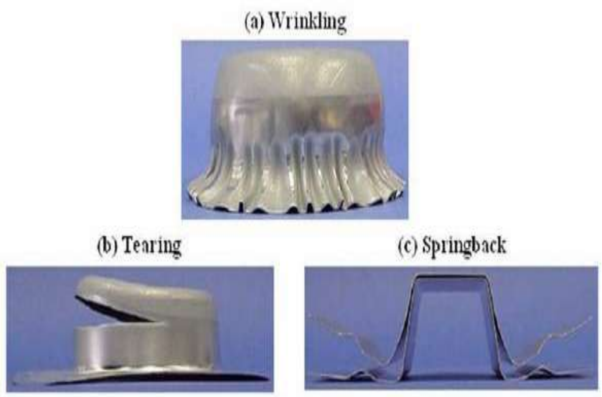

Figure no. 1: Defects

Objectives:

1. To capture the process for designing a Draw/Form Die.
2. To analyze the new part design using CAE - `Forming Simulation'.
3. To utilize the inference derived from the simulation results to design the Die.
4. To review and finalize the Die confirming to industrial standards.
5. To achieve consistently defect free component (free from wrinkling, tearing, thinning)
6. To carry out try-outs for experimentation and validation.
7. To recommend the best practice/s in this domain for future reference to the industry.

LITERATURE REVIEW

Hae Chang Gei et al. [1] proposed a numerical method aimed at improving the drawability of square shells by optimizing the blank shape. In their study, the deep drawing operation is formulated as an optimization problem, where the goal is to enhance drawability while preventing two critical types of failure: fracture failure and draw-in failure. In this method, blank design parameters (such as blank shape and size) are taken as the design variables. For the optimization scheme to work, it is necessary to have reliable numerical models that can predict the onset of fracture and draw-in failure under given process conditions. Therefore, the authors developed and discussed such predictive models and integrated them into the optimization framework. They then applied this scheme to three different case studies and obtained optimal blank designs for each case. By comparing the drawability and the uniformity of the final flange profile, the study concludes that a circular blank profile can be considered the optimal blank shape for deep drawing of square cups.

D. Risch et al. [2] presented the design and analysis of a combined process that uses deep drawing followed by in-process electromagnetic sheet metal forming for calibration of the part. Since these two forming methods involve significantly different strain rates, the authors also investigated the microstructural changes in the formed workpieces to understand the influence of the process on material behavior. The paper explains the design methodology for the integrated tool coil used in the electromagnetic forming stage and discusses the important design steps and considerations. Selected application examples are provided to illustrate the performance of the combined process. Finally, the authors describe the complete integrated setup and demonstrate the feasibility of this hybrid forming technique on a representative semi-industrial sheet metal component.

A. Pourkamali Anaraki et al. [3] carried out a study on the plastic forming of sheet metal, which is a key process in metal forming industries. They highlighted that traditional tool design methods for sheet forming are mostly experimental, time-consuming and costly. Being able to predict forming behaviour in advance—such as punch force, blank holder force and thickness distribution—can significantly reduce both production time and cost. In their work, they performed a multi-stage deep drawing simulation of an industrial part using the finite element method. The complete production sequence, including additional operations like intermediate annealing and springback, was modelled in ABAQUS under axisymmetric conditions. From these simulations, important results such as sheet thickness distribution, punch force and residual stresses were obtained at each stage. The predicted thickness distribution was then compared with experimental measurements. The comparison showed that the finite element model closely matched the experimental results, confirming that the FE-based simulation approach is reliable for analysing and optimising multi-stage deep drawing processes.

Andre Westeneng et. al. [4], reviewed the friction behaviour that occurs between sliding surfaces covered with adsorbed boundary layers. Their work shows that friction in these boundary layers is influenced by several factors, including the chemical makeup of the layer, sliding speed, temperature, layer thickness, and the pressure applied during contact. They developed a contact model based on the assumption that the workpiece asperities deform plastically. This model helps estimate the real contact area of the sheet material, which is essential for predicting friction. Their findings reveal that the real contact area does not increase in a simple linear way with nominal pressure. At higher pressures, the contact area grows at a slower rate, while at lower pressures it is strongly affected by the height distribution of asperities. The hardness of the workpiece is also important, as it controls how easily these asperities can be flattened, and therefore affects the friction behaviour seen in deep drawing and similar sheet metal forming operations.

Mihael Volk et al. [5] discussed how the demand for more complex sheet metal products has grown significantly in recent years, along with higher expectations for product quality and stable process conditions. To meet these requirements, they emphasized that the use of finite element method (FEM) has become essential for reliable product and process development in sheet metal forming. In their research, particular attention is given to blank holding force, which is identified as one of the most critical parameters in sheet metal forming. Using FEM-based simulations, they carried out the optimization of blank holding force, along with the geometry and structure of the blank holder itself. Their study showed that the best performance was achieved when using flexible, segmented blank holders. This type of design provides a wider technological window, meaning a larger range of process conditions under which good-quality parts can be produced consistently, with reduced risk of defects such as wrinkling or tearing.

Cevdet Meriç et al. [6] examined the deep drawing performance of SAE 6114 low-carbon steel. Sheet samples with thicknesses between 0.67 mm and 2 mm were first tested under tensile loading to determine key material properties, including the R-value (average normal anisotropy) and the n-value (strain hardening exponent. At the same time, Erichsen tests were performed to measure the cup height (h) and the reaction force (F) for each sheet thickness. A 2 mm sheet was then cold rolled at six different deformation levels, and all the above tests were repeated for the rolled sheets. The results from these experiments were compared, and an Artificial Neural Network (ANN) model was created using the collected data. This ANN was trained to estimate new values related to percentage deformation, sheet thickness, and deep drawing behaviour without needing further physical experiments. The findings showed good agreement between the ANN predictions and the actual test results, confirming that ANN can be a reliable tool for predicting the deep drawability of low-carbon steel sheets.

Hamid Mozafari et al. [7] studied the key parameters affecting the deep drawing process, such as punch diameter, die (mould) diameter, punch speed, blank holding force, friction, drawing force and drawing depth. Their work focused specifically on the behaviour of 2618 aluminium alloy under different precipitation hardening (heat treatment) conditions. They investigated how heat treatment influences the Limiting Drawing Ratio (LDR) of 2618 Al alloy. The study showed that the LDR value changes with the heat treatment condition, and the maximum LDR of about 1.33 was obtained in the best condition. However, comparison of different conditions indicated that precipitation hardening generally reduces the LDR, which means it negatively affects the drawing ability of the alloy. In particular, for the solution-annealed (SA) and solution-treated and water-quenched (SW) conditions, the LDR was lower. The paper also examined the effect of temperature on earing during deep drawing of 2618 Al alloy. The results revealed that when the forming temperature was increased to around 350°C, the earing tendency was minimized, leading to better flange uniformity and improved part quality.

Johannes Winklhofer [8] studied the deep drawing process for aluminium sheet metal, which is generally less formable than steel at room temperature. To overcome this limitation, the work focused on deep drawing at elevated temperatures as a method to improve formability. The study discussed how raising the forming temperature enhances the ductility and drawability of aluminium sheets, making it easier to produce deeper and more complex shapes. In addition, a corresponding simulation method was presented to model the behaviour of aluminium under these elevated temperature conditions. The author also described a characteristic high-temperature deep drawing process and carried out its optimization, demonstrating how process parameters can be adjusted to achieve better formability and part quality when forming aluminium at elevated temperatures.

CALCULATIONS AND ANALYSIS OF BLANK

5.1. Calculations of Blank

Deep drawing is one of the most widely used sheet metal forming processes for producing cup-shaped and shell-type components. In this process, a flat blank is forced into a die cavity using a punch, causing the metal to plastically flow and form a hollow part.

The component considered in this project is a horn cup having:

- Final cup height, H = 20.1 mm
- Final punch / cup diameter, Dp = 25 mm

The objective of this work is to design a suitable multi-stage deep drawing die, determine the number of drawing stages, and study the draw reduction conditions such that defects like wrinkling, tearing, excessive thinning and fracture are avoided.

Determination of Number of Draws

For the horn cup, the following empirical relation is used to estimate the number of draw strokes (P)

Draw limiting ratio, $P = \frac{H}{Dp}$

Where,

P = number of draw needed per chart

H = Height of cup, mm

t = Thickness of cup, mm

Dp = Punch /Cup diameter, mm

r = Radius, r > t×4

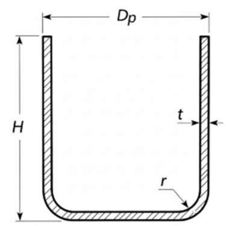

Figure no. 2: Schematic diagram of deep drawing operation

Thus the no of draw strokes are calculated as following

$$P = \frac{H}{Dp} = \frac{20.1}{25} = 0.85$$

Here, $P = 0.80$ lies in the range 0.75–1.5, hence Number of draw stages required = 2

Thus, the horn cup must be produced using a multi-stage draw die, at least two drawing operations (Stage 1 and Stage 2). In our design additional ironing stage need to be considered for refining the dimensions, we called it as stage 3.

From the sectional sketch of the cup:

- Each vertical wall height ≈ 10.1 mm
- Bottom width = punch diameter = 25 mm

If the cup wall and bottom are “unfolded” into a straight line, the developed length between points A and B is:

$Length_{AB}$= 10.1+25+10.1=45.2 ≈45 mm

So, a length of about 45 mm of material must be accommodated in the drawn profile of the horn cup.

Attempting to generate 45 mm of surface from only 25 mm of original length in a single draw would result in very high strain, leading to risk of tearing and excessive thinning. Hence, the requirement of multi-stage drawing is justified.

Stage 1:-

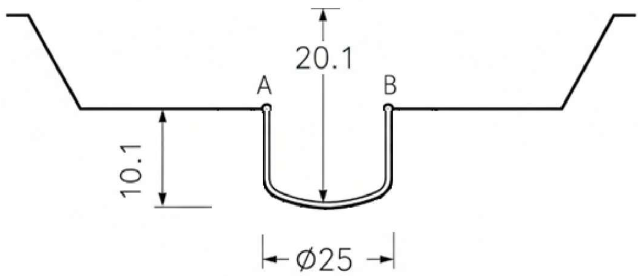

Figure no. 3: Schematic diagram of Blank

In Stage 1, an intermediate cup shape is designed so that the surface (arc) length of the formed profile approximately equals the calculated developed length of 45 mm.

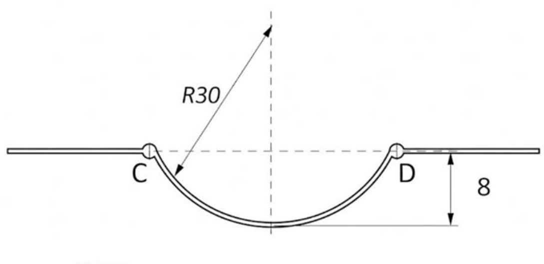

Figure no. 5: Required shape of Blank

- A radius R = 30 mm is selected such that the arc length from point C to point D ≈ 45 mm.
- The intermediate draw depth is taken as about 80% of the final wall height:

This first draw: Intermediate depth $\approx 0.8 \times 10.1 \approx 8$ mm

- Forms a shallow, smooth profile with large radius
- Distributes strain more uniformly
- Avoids sudden high deformation in one step

Thus, Stage 1 gently shapes the blank while keeping the material safely within its formability limits.

5.1.3. Description of Drawing Stages

Stage 1:

Operation: Convert flat blank to shallow cup with large bottom radius (R30) and partial depth (~8 mm).

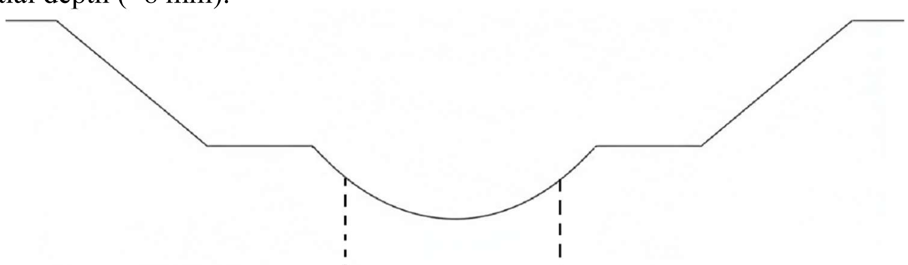

Figure no. 5: Stage 1 blank

Stage 2:

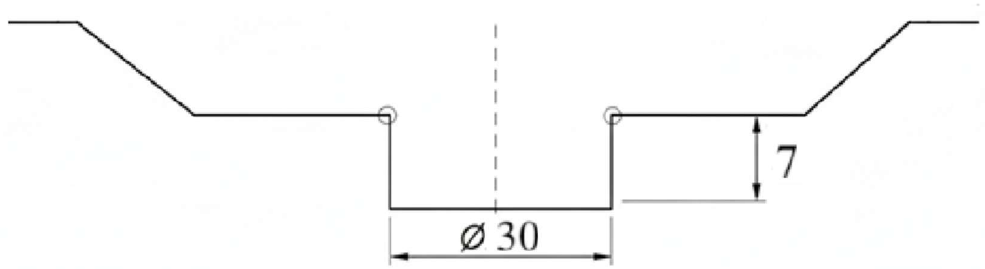

Figure no. 6: Stage 2 blank

Stage 3:

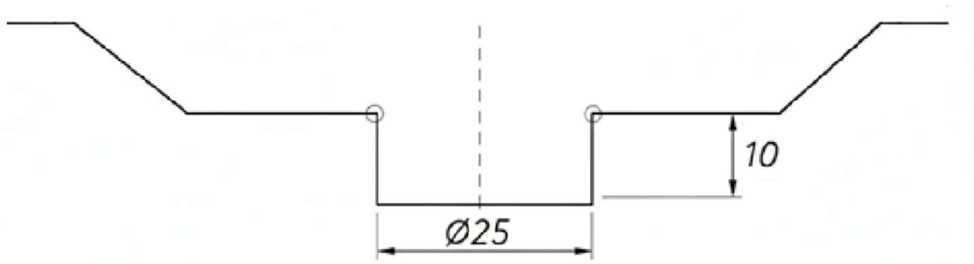

Figure no. 7: Stage 3 blank

CHAPTER VI
MODELLING, MESHING & ANALYSIS

In the previous chapter, the calculations for the blank size were carried out and the deep drawing process was planned in different stages. Based on the height-to-diameter ratio and draw reduction conditions, the component was divided into Stage 1, Stage 2, and Stage 3 drawing operations.

In this chapter, the theoretical design is converted into a 3D model and then prepared for finite element analysis (FEA) through meshing. The 3D modelling of each stage is done using CATIA, and the meshing of the corresponding models is carried out in HyperMesh.

6.1. Stage 1- Initial Blank Geometry

Analysis Details:

Material Specification

Material Name: DP-590

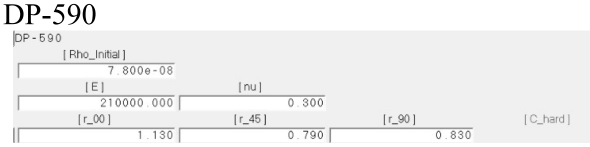

Figure no. 8: Material details of blank

Blank Thickness – 1mm n=0.381

Element Type: Quad

Element Size: 1mm

Blank Mesh : R-mesh

Die Mesh: B-mesh

Blank Holding Force – 25000 N

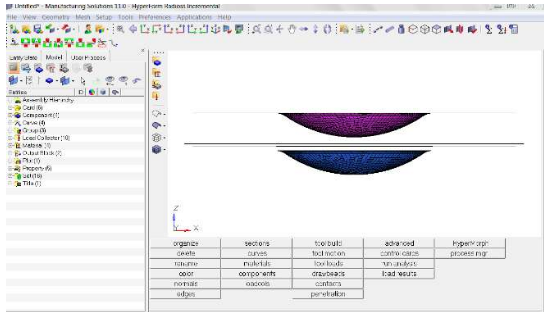

Figure no. 9: Meshing of Initial Blank Geometry-2

Displacement Plot

- The maximum displacement occurs at the bottom region of the cup and along the drawn wall, as this material is pulled deepest into the die cavity by the punch.
- The displacement pattern indicates that the material is flowing smoothly from the flange towards the bottom, without any abrupt jumps or localized locking.

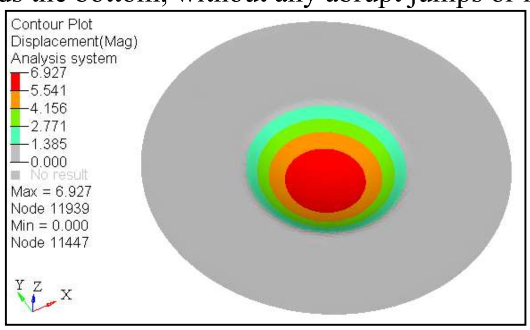

Figure no. 10: Displacement plot of Initial Blank Geometry

Strain Plot

- Higher plastic strain is observed in the corner region and along the wall, where the material is bent and stretched simultaneously.
- The bottom region usually experiences moderate strain, mainly due to bending over the punch nose.

The strain distribution in Stage 1 is gradual and continuous, indicating that the material is not being overstretched in a single step. This supports the decision to use multiple drawing stages for the horn cup.

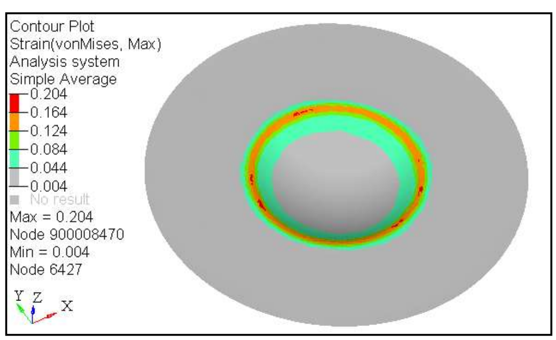

Figure no. 11: Strain plot of Initial Blank Geometry

Stress Plot

- The maximum stress is usually concentrated in the corner region and near the punch nose, where bending and stretching are combined.

- The stress distribution is smooth, with no sharp peaks that would suggest tooling defects or excessive local deformation.

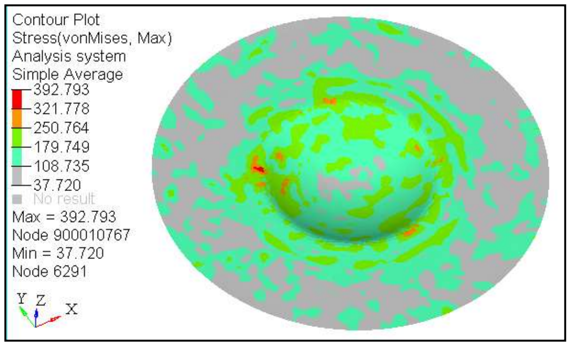

Figure no. 12: Stress plot of Initial Blank Geometry

Thinning Plot

- Maximum thinning is typically observed in the cup wall, especially near the transition from flange to wall and around the punch radius.
- In Stage 1, the thinning of maximum 5% happens in bottom and corner faces, which remains within acceptable limits, indicating that the material is not being overstretched in this first operation.
- The bottom portion retains thickness close to the original, while the flange shows minimal change.

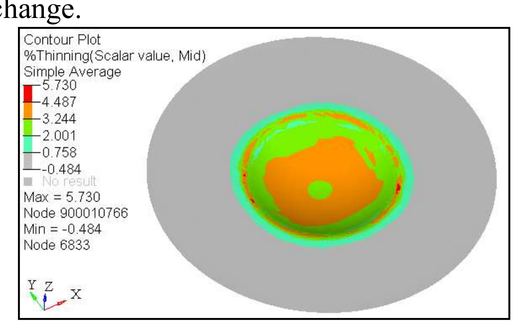

Figure no. 13: Thinning plot of Initial Blank Geometry

FLD Plot

- The FLD plot shows major strain vs minor strain, overlaid with forming limit curves.
- The strain points corresponding to Stage 1 deformation lie mostly below the forming limit curve, which indicates that no necking or failure is expected in this stage.
- Regions approaching the limit curve may be identified as critical zones, but in Stage 1 they remain generally within the safe zone.

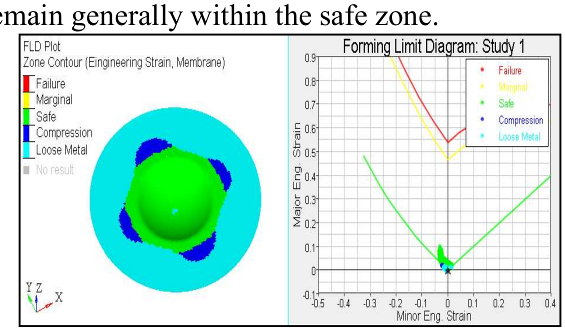

Figure no. 14: FLD plot of Initial Blank Geometry

From the Stage 1 analysis:

- Material flow is smooth and continuous, as seen from the displacement and strain plots.
- Stresses are within acceptable limits, with no indication of tearing.
- Thinning is controlled and remains within the safe range for the selected material.
- The FLD confirms that the forming condition is safe and does not exceed the forming limit of the sheet.

Therefore, the Stage 1 draw die design is validated, and the preformed component from Stage 1 can be safely used as input for Stage 2 drawing.

4.2. Stage 2- Intermediate blank geometry

The 3D modelling of the Stage 2 blank was carried out using CATIA.

- Based on the calculated draw schedule, a new intermediate profile was created for Stage 2,
- The Stage 2 model thus represents the partially drawn cup that will undergo one more forming operation to reach the final horn cup shape.

This intermediate blank geometry is used as the input for meshing and further FEA-based analysis to check material behavior during Stage 2 forming.

1. Analysis

In Stage 2, the intermediate blank obtained from Stage 1 is further drawn towards the final horn cup geometry. The finite element simulation for this stage was carried out on the meshed model of the Stage 2 blank, and the results are evaluated in terms of displacement, strain, stress, thinning and FLD (Forming Limit Diagram). The material is used same as it is used on previous stage 1.

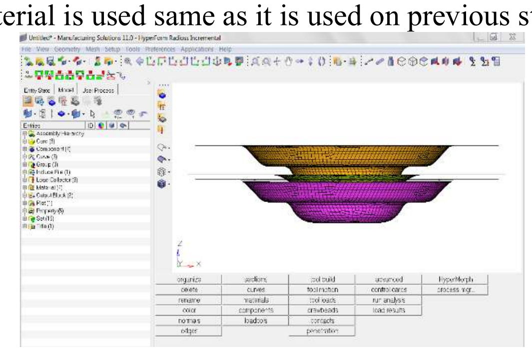

Figure no. 15: Meshing of Intermediate Blank Geometry-2

Displacement Plot

- The maximum displacement occurs at the bottom and along the side walls of the cup, as these regions are drawn further into the die cavity.
- The flange region continues to act as a feeding zone, showing smaller displacements than the wall and bottom.

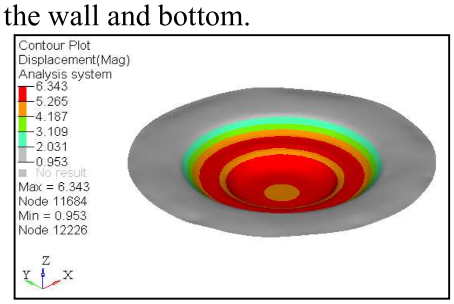

Figure no. 16: Displacement plot of Intermediate Blank Geometry

Strain Plot

- Higher plastic strain is observed in the wall region and corner areas, where the material is subjected to combined bending and stretching as cup depth increases.
- The flange shows relatively lower strain, as its main role is still to feed material into the drawn wall.

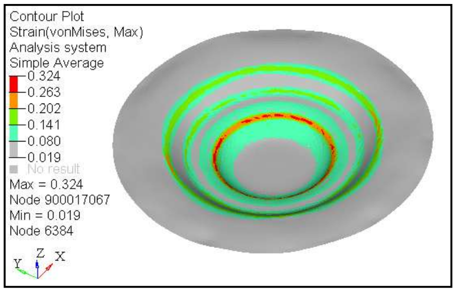

Figure no. 17: Strain plot of Intermediate Blank Geometry

Stress plot

- Maximum stresses are again located near the corner radius, punch nose region and along the upper part of the wall, where the sheet bends and stretches simultaneously.
- The stress distribution is smooth and continuous, suggesting that the tool radii, clearances and draw depth are suitably chosen.

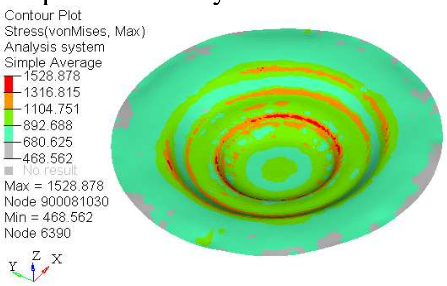

Figure no. 18: Stress plot of Intermediate Blank Geometry

Thinning plot

- The maximum thinning occurs in the cup wall region, especially near the transition from flange to wall and around the bottom corner.
- The thinning observed in Stage 2 is higher than in Stage 1, because the material is drawn to a greater depth and experiences more stretching.

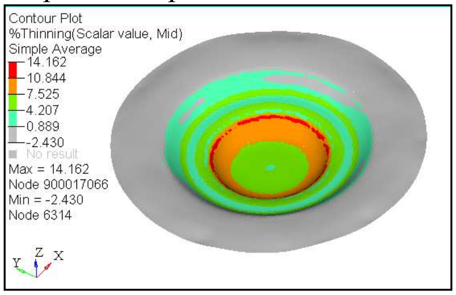

Figure no. 19: Thinning plot of Intermediate Blank Geometry

FLD Plot

- In Stage 2, the strain points from different regions of the component are plotted on the FLD.

- Most of the points lie below the forming limit curve, which indicates that the material is still deforming safely without local necking or failure.

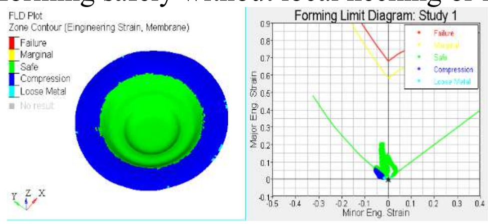

Figure no. 20: FLD plot of Intermediate Blank Geometry

Thus, Stage 2 forming conditions are acceptable from the formability viewpoint, and the component is suitable for further final forming or calibration.

From the Stage 2 analysis, the following conclusions can be drawn:

- The displacement and strain plots show smooth and progressive deformation, with material flowing correctly into the deeper cup shape.
- Stress levels are higher than Stage 1 but still within safe limits, with no indication of tearing or cracking.
- Thinning is more pronounced but remains within acceptable percentage, confirming that the multi-stage draw concept is working as intended.
- The FLD plot verifies that the material is still in the safe forming region.
- Therefore, the Stage 2 drawing operation is validated, and the intermediate component obtained from this stage can be used for final drawing or calibration in Stage 3.

Stage 3- Final Blank geometry

1. Analysis of Final Blank Geometry

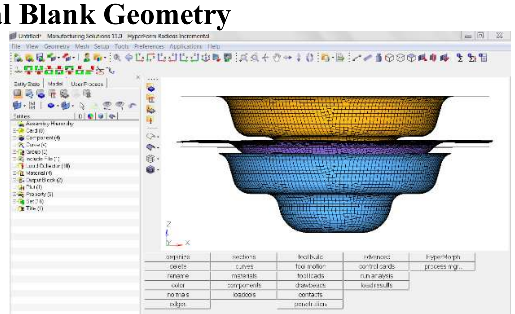

Figure no. 21: Meshing of Final Blank Geometry-2

Displacement Plot

- The maximum displacement is observed at the bottom and along the cup wall, where the component reaches its final depth.
- The flange area experiences relatively less movement, as most of the material has already flowed into the wall in earlier stages.

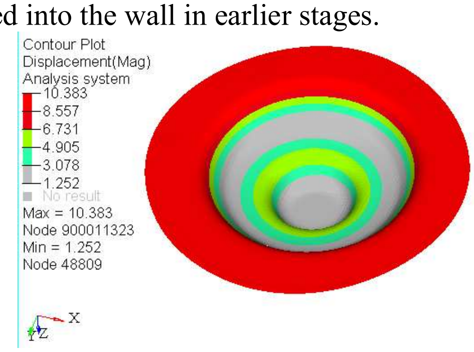

Figure no. 22: Displacement plot of Final Blank Geometry

Strain plot

- The highest strain is again concentrated in the wall and corner regions, where the sheet undergoes bending, stretching and slight ironing.
- The bottom of the cup shows moderate strain, mainly due to bending and final seating of the punch.
- Compared to earlier stages, the strain values in some critical zones may be higher, but they are the result of cumulative deformation from all three stages.

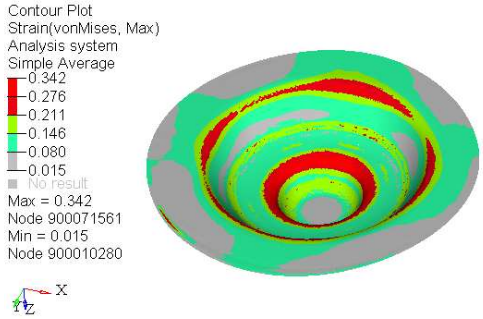

Figure no. 23: Strain plot of Final Blank Geometry

Stress Plot

- Maximum stresses are found near the corner radius and upper wall region, where the final adjustments to shape and thickness occur.
- Although stress levels in Stage 3 are generally higher than earlier stages, they remain below the material's ultimate tensile strength, indicating that fracture or tearing is unlikely.

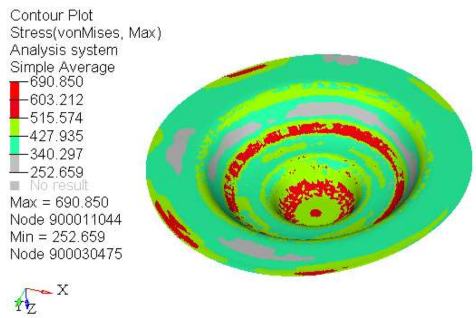

Figure no. 24: Stress plot of Final Blank Geometry

Thinning plot

- The maximum thinning is observed along the cup wall and corner transition region, where the combined effect of all three drawing stages is visible.
- The final thinning percentage should be compared with the allowable limit for the material DP-590. The Allowable limit of thinning in industry was 30%.

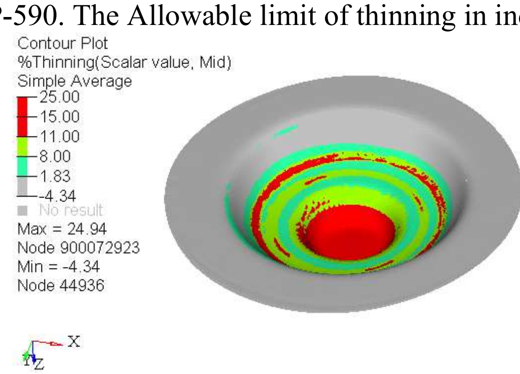

Figure no. 25: Thinning plot of Final Blank Geometry

FLD Plot

- The strain state at various locations on the component is plotted on the FLD for Stage 3.
- Most of the data points lie below the forming limit curve, which indicates that the material has not entered the failure (necking) zone even after the final drawing operation.
- Some points may be close to the critical region, especially in the wall and corner, but they remain on the safe side of the forming limit curve.

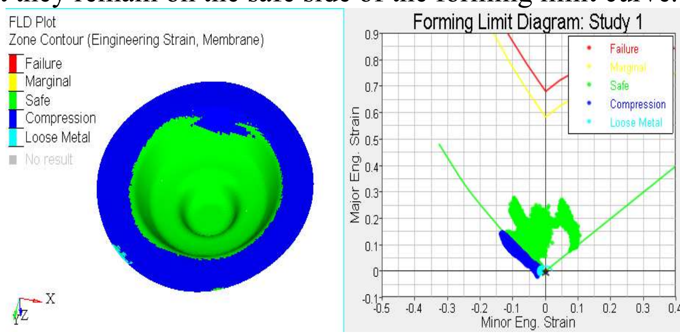

Figure no. 26: FLD plot of Final Blank Geometry

From the Stage 3 analysis, the following conclusions can be drawn:

- The displacement and strain plots confirm that the material successfully reaches the final horn cup geometry without abnormal flow or distortion.
- The stress distribution remains within safe limits, with no indication of tearing or fracture.
- The thinning pattern shows acceptable reduction in thickness, concentrated mainly in the wall region, and within permissible limits for the chosen material.
- The FLD plot verifies that, even after the final draw, the component remains within the safe forming zone.

Therefore, the Stage 3 drawing operation and the overall multi-stage deep drawing design for the horn cup are validated as safe and effective.

RESULTS AND DISCUSSION

This chapter presents the results obtained from finite element analysis (FEA) of the multi-stage deep drawing process and compares them with the experimental try-out results carried out at Ethika Engineering Solutions (I) Pvt. Ltd., Pune. The discussion focuses on:

- Material flow and deformation behavior,
- Stress and strain distribution,
- Thinning of the sheet metal,
- Formability assessment using FLD, and
- Correlation between simulation and experimental validation.

The component considered is a horn cup / contour speaker part made from DP-590 high strength formable steel of 1 mm thickness, formed in three drawing stages.

FEA Results – Stage Wise Summary

Stage 1

In Stage 1, the flat blank is drawn into a shallow cup.

Stage 1 successfully initiates the drawing without causing any damage to the material. The results justify the need for a multi-stage draw, ensuring that deformation is introduced gradually rather than in a single severe step.

Stage 2

In Stage 2, the intermediate blank is drawn further to increase depth and reduce diameter.

Stage 2 is the **most critical forming step**, where the majority of depth is achieved. The FEA results show that although deformation and thinning are higher, the process is still safe. This confirms that the selected **draw reduction ratio** and **tool radii** for Stage 2 are appropriate.

Stage 3

Stage 3 gives the final horn cup geometry and thickness distribution.

The Stage 3 results validate the overall multi-stage strategy. Although thinning and strain peak in this stage, they are still within acceptable values for DP-590. The tool design, clearances and blank holder force successfully prevent defects such as necking, tearing, or excessive wrinkling.

Comparison of Experimental Results with FEA

The FEA carried out earlier predicted:

- Progressive thinning of the cup wall with maximum thinning occurring in the formed region during Stage 3.
- The final thinning percentage was expected to be within the allowable range for DP-590 material.
- FLD plots for all three stages indicated that the strain state remained below the forming limit curve, suggesting safe forming without necking or fracture.

The experimental measurements confirm these predictions:

Thinning

- Final measured thickness = 0.75 mm
- Initial thickness = 1.0 mm
- Thinning = $(1.0 - 0.75)/1.0 \times 100 \approx 25$
- This value lies within the acceptable limit for DP-590, and matches well with the thinning range predicted by FEA.

Defects

- Both simulation and experiment showed no wrinkling, tearing or fracture in any stage.
- Stress and strain levels predicted in FEA were below critical limits, which is supported by the absence of defects in physical trials.

Process Parameters

- The BHF values used in experiments (2.7 T to 3.0 T) are in line with the values assumed during simulation.
- The success of the trials validates the chosen blank holder forces, tool radii and clearances.

Overall, the experimental results strongly correlate with the FEA predictions, thereby validating the die design and multi-stage drawing process proposed in this project.

CONCLUSION AND FUTURE SCOPE

Conclusion:

The project titled "Deep Draw Die Design for Automotive Sheet Metal Component used in 'Forming Analysis' for Validation" focused on developing and validating a complete methodology for the design of a multi-stage deep draw die for an automotive sheet metal part (horn cup / contour speaker) made from DP-590, 1 mm sheet.

The work covered: blank calculations, draw schedule, die design, 3D modelling, meshing, forming simulation (FEA), and finally shop-floor try-outs on a 25-ton hydraulic press at Ethika Engineering Solutions (I) Pvt. Ltd., Pune.

Based on the analytical, numerical and experimental study, the following conclusions are drawn.

Systematic Die Design Methodology Established

A clear, step-by-step process for deep draw die design was developed – starting from blank size estimation, draw reduction ratio, number of stages, selection of punch / die radii, clearance, blank holder force, and shut height. This process is generic and can be reused for similar automotive sheet metal components.

Effective Use of CAE – Forming Simulation

The component was modelled in CATIA, meshed in HyperMesh and analysed using forming simulation for all three stages. The simulations provided detailed information on displacement, strain, stress, thinning and FLD behaviour of DP-590 during forming.

Validated Multi-Stage Draw Strategy

The analysis proved that forming the part in three stages is necessary to keep the deformation within safe limits. The staged process ensured gradual drawing, controlled material flow and avoided excessive local strain and thinning.

Control of Defects – Wrinkling, Tearing and Thinning

- FLD plots for all stages showed strain states below the forming limit curve, indicating safe formability.
- Thinning plots predicted a final minimum thickness of ~0.75 mm, i.e. about 25% thinning, which is acceptable for DP-590.
- Experimental trials confirmed that no wrinkling, tearing or fracture occurred in any stage.

Thus, the die design and process parameters successfully produced consistently defect-free components.

Excellent Correlation Between Simulation and Experiment

The measured minimum thickness in the formed region at each stage (0.95 mm, 0.85 mm and 0.75 mm) matched very closely with the FEA predictions. The absence of defects in both simulation and trial parts validates the accuracy of the CAE model and the soundness of the design approach.

Industrial Feasibility Demonstrated

The recommended combination of material (DP-590, 1 mm), blank size, three-stage draw, and blank holding force ≈ 3 ton was successfully implemented on a 25-ton hydraulic press. The test report from Ethika Engineering Solutions confirms that the process is suitable for industrial production.

REFERENCE

[1]. H. Chang and R. Ramamurthy, “Blank design optimization on deep drawing of square sheet,” IIE Transactions, vol. 30, pp. 913–921, 1998.
[2]. D. Risch, G. Gersteyn, W. Dudzinski, C. Beerwald, A. Brosius, M. Schaper, A. E. Tekkaya, and F.-W. Bach, “Design and analysis of a deep drawing and in-process electromagnetic sheet metal forming process,” Research Unit FOR443, (publication details not fully specified).
[3]. A.P. Anaraki, M. Shahabizadeh, and B. Babaee, “Finite element simulation of multi-stage deep drawing processes and comparison with experimental results,” World Academy of Science, Engineering and Technology, vol. 61, pp. 201–205, 2012. (page range approximated if not given)
[4]. Andre Westerneng and Proefschrift, “Modelling of Contact and Friction in Deep Draw Process”, Enschede, The Netherlands: Univ. of Twente, 2001, ISBN 90-365-1549-1.
[5]. M. Volk, B. Nardin, and B. Dolšak, “Application of numerical simulations in the deep-drawing process and the holding system with segments’ inserts,” Strojniški vestnik – Journal of Mechanical Engineering, vol. 57, no. 9, pp. 697–703, 2011, doi: 10.5545/sv-jme.2010.258.
[6]. C. Meriç, N. S. Koksal, B. Karlik, S.-H. Kim, S.-H. Kim, and H. Huh, “An investigation of deep drawing of low carbon steel sheets and applications in artificial neural networks,” Mathematical and Computational Applications, vol. 2, no. 1, pp. 119–125, 1997.
[7]. H. Mozafari, M. Hassanipour, and A. Ayob, “Investigation of thickness and thermal treatments on the deep drawing process for the aluminum plate,” International Journal of Engineering Science and Technology, vol. 2, no. 10, pp. 5915–5920, 2010.
[8]. J. Winklhofer and G. Trattnig, “Simulation of aluminium sheet metal deep drawing at elevated temperature using LS-DYNA,” in Proc. 9th LS-DYNA Forum, Bamberg, Germany, 2010.