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Design, Simulation and Experimental Analysis of Sheet Metal Deep Drawing Process

RAJESH KUMAR. R

Vice President, Product Design and Product Marketing, EmbedSense Solutions Pvt Ltd, Bangalore, India

ABSTRACT*:* In this paper, a new approach has been tried to prove the drawability of a complex automotive exterior part made of QStE 500 hot rolled steel. Though the success of drawability depends on so many factors such as part material, part design, material properties, sheet thickness, press load, tool design, blank size, binder force, die radius, lubrication and so on, the paper took die and blank surface area as key parameter to success the drawability of the part without changing the existing press machine and part design. Since it was a completely new method, each stage of the draw was iterated using Autoform software andtooling was done based on the final validated design and got the parts successfully.

KEYWORDS*:* Deep Drawing Process, Forming Limit Diagram, Autoform, QStE 500

1. INTRODUCTION

One of the most important and cost-effective manufacturing processes for mass production is sheet metal forming process. Sheet metal forming involves conversion of flat thin sheet metal blanks into parts of desired shape and size by subjecting the material to large plastic deformation using punch and die [1]. Deep drawing is one of the most used of the forming process in many industries in which a blank is radially drawn into a die of desired shape by vertical motion of a punch as shown in figure 1. Usually in deep drawing process, the die opening diameter is less than the height of the punch used.

Al.Kazuhisa Kusumi [3] studied the improvement of cylindrical deep drawability in hot stamping by moving away binder from part to decrease heat loss. P Venkateshwar Reddy [4] evaluated sheet metal formability of 0.8mm of SS304 and 0.9 mm of Brassin deep drawing process with the effects of different die/blank holder angle and observed that strain formation was more for the brass sheet and stress was more for aluminum sheets.Adnan I. O. Zaid [5] presented and discussed the effects of die and punch radius in the quality of parts produced and reported the mechanism of deformation, effect of the geometrical parameters involved and the defects encountered in deep drawing process. V Buakaew [6] predicted the formability of SPCC and SPCE steel sheets of 0.8mm thickness using Autoform software and verified the Forming Limit Diagrams (FLD) obtained from the software tool with tooling experiments. Ruiqiang Zhang [7] covered a comprehensive review of modeling techniques to predictFLD of light weight steel sheets using theoretical and numerical based on bifurcation theory, geometrical imperfection theory and continuum damage mechanics.

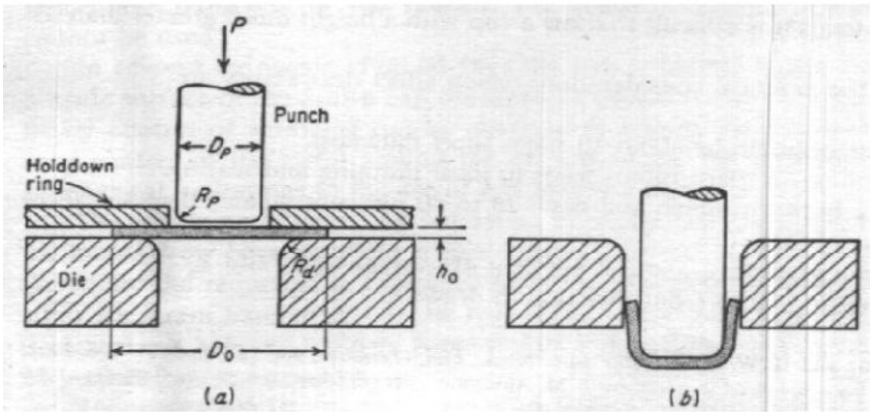

Figure: 1 Deep Drawing of a cylindrical cup (a) before drawing (b) after drawing [2]

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J Slota [8] investigated the comparative study of three mathematical models (M-K model, Hill-Swift model and Sing-Rao mdel as well as North American Deep Drawing Research Group (NADDRG) model in three different draw quality (DQ) sheets and found that the most accurate predictions of all the types of DQ sheets were given by NADDRG model.

However, there has not been any paper which discussed about the drawability of hot rolled sheet metal particularly QsTE 500, a commonly used steel sheet in automotive applications,using deep drawing process in atrue automotive component. The aim of this paper is to analyze the drawability of the hot rolled sheet in a real-world automotive part using Autoform software and to verify the results with tooling experiments.

II. MATERIAL AND METHODS

The research used a true automotive part as shown in figure 2. Usually cold rolled sheets are preferred for deep drawing process because of its high tensile strength and ductility, but the part is made of QsTE 500 which is a hot rolled steel. So, the complexity was started in the material itself. The part size is 450mm L X 80mm W and 90mm H with thickness of 2.5mm. Handling this kind of heavy part in finite element software like Autoform is very difficult and requires lot of skill to analyse the results. Another complexity is tooling development. It requires lot of effort, skill and investment to trail and iteratea part with these kinds ofsize, shape and material.

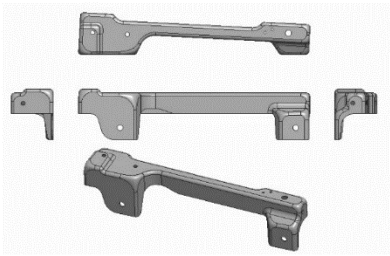
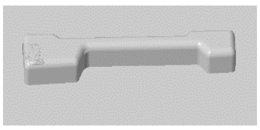
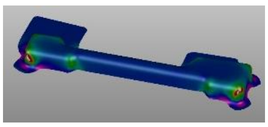
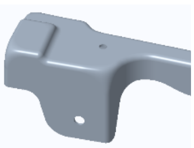
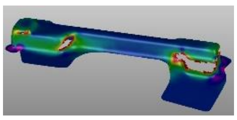
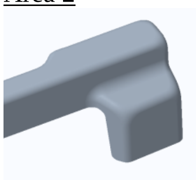
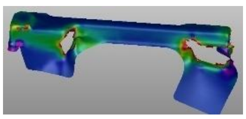


Figure: 2 Isometric and Orthographic views of part used

The design process was initiated as usual deep drawing process. Number of draw stages required and depth of each draws was calculated using standard formula and techniques available inTool design data book [9] and the simulations were conducted in Autoform software. These die surface designs; simulation results and outcomesare tabulated in Table 1.

Table 1: Simulation results for standard formulas

No of Stages 3	Die surface Design	Autoform Simulation	Result	Critical Areas
Stage 1 41.5 mm Depth			Passed	Area 1 
Stage 2 48.5 mm Depth			Failed	Area 2 
Stage 3 Full Depth			Failed	

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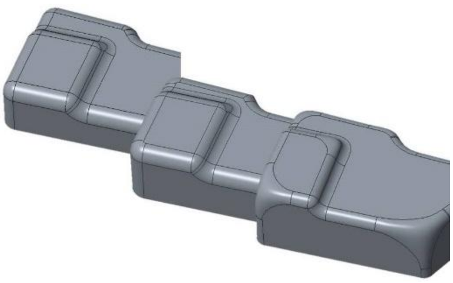
From the initial design and simulations as tabulated in Table 1,it is clear that, only the first stage is success andthe drawability of the whole part cannot be achieved using the standard formulas and calculations. Also, two critical areas were found in the part design. The counters and steps in the area 1 and area 2, as shown in figure 3a and 3b, was making the process more difficult and fillets in these areas were also not sufficient for the process.Hence a new method isapproached to solve the problem i.e., during deep drawing process, area under binder will undergo compressive stress and area under punch surface will undergo very high tensile strength which makes the blank to thin gradually and finally enters into plastic deformation sate. Due to all the stresses induced in the blank during drawing, considerable amount of residual stress will be generated in the blank. Drawing the formed sheet with all the residual stresses is very difficult and more prone to failure. So, in this paper, the area required to form the contours and steps was calculated and the blank material required to form the area was merged with the base material area as shown in figure 3a and 3b. Also, dedicated draw stages were used to form area 1 and area 2. Since the number of draw stages is proportional to tooling and operational costs, the iterations shouldbegin with minimum of draw stages.



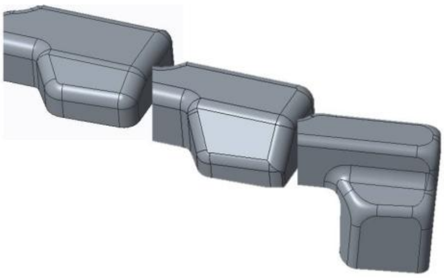


Figure 3 A. Stages of Critical area 1 and 3 B. Stages of Critical area 2

First, the area 1and area 2 were drawn as shell forming so that the material in area1 and area 2 was elastic in nature and very small amount of residual stresswasformed. In the next step, the main area of blank was drawn with the critical areas. Here, the critical areas were acted as draw beads for the remaining material and it controlled the flow of the sheet. The blank area was calculated and the corners of the blank were chamfered and filleted to avoid stress concentration as shown in figure 4.

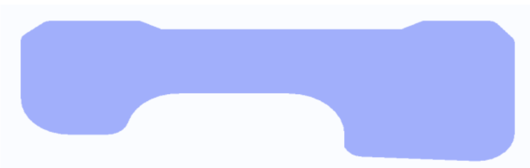


Figure: 4Development area of Blank

III. SIMULATION&RESULTS

A. ITERATION A

Table 2: Process Parameters

	Stage 1	Stage 2	Stage 3	Stage 4
Iteration A	32mm depth with B Shown in figure 5 Result: Pass	40mm depth with B Shown in figure 6 Result: Pass	47mm depth with A Shown in figure 7 Result: Pass	Completion stage Shown in figure 8 Result: Fail

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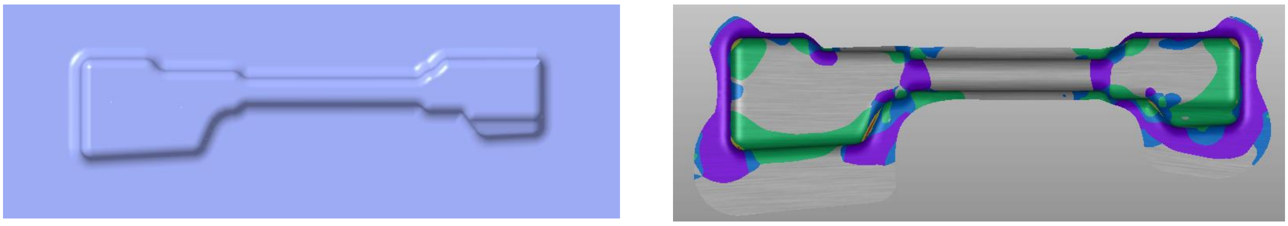

Figure: 5Iteration A Stage 1 Die surface and Formability Analysis

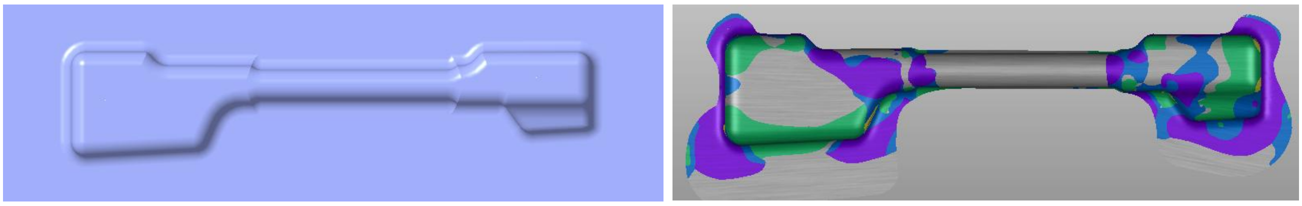

Figure: 6Iteration A Stage 2 Die surface and Formability Analysis

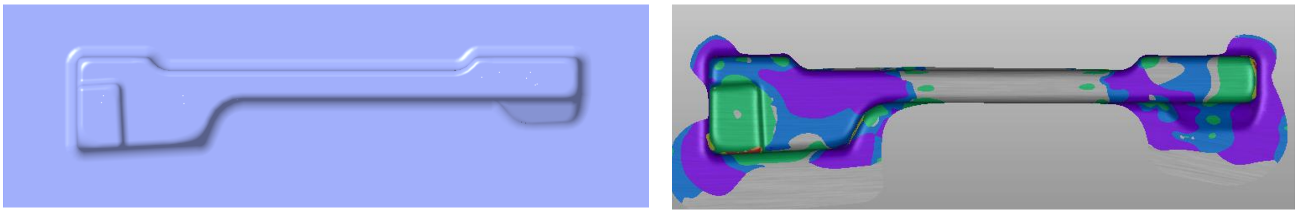

Figure: 7Iteration A Stage 3 Die surface and Formability Analysis

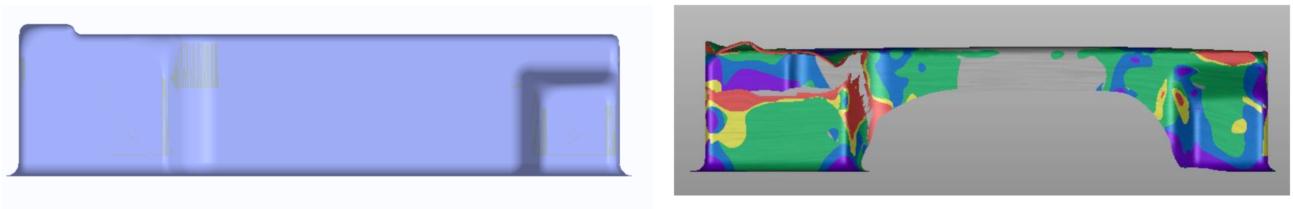

Figure: 8 Iteration A Stage 4 Die surface and Formability Analysis

B. . ITERATION B

Table 2: Process Parameters

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Iteration A	32mm depth with B Shown in figure 9 Result: Pass	40mm depth with B Shown in figure 10 Result: Pass	47mm depth with A Shown in figure 11 Result: Pass	51mm depth with A Shown in figure 12 Result: Pass	Completion stage Shown in figure 13 Result: Pass

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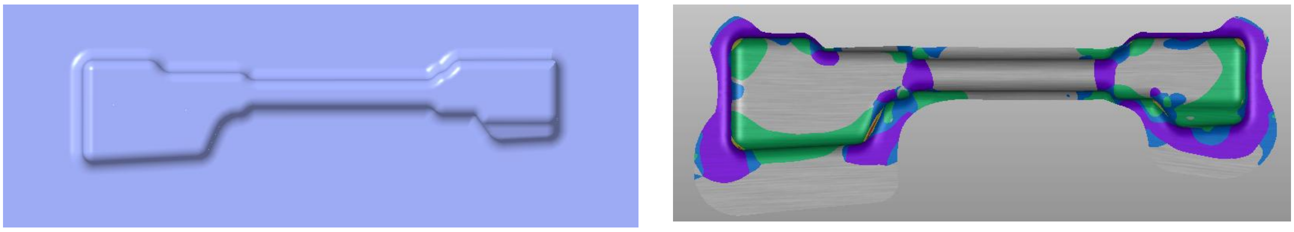

Figure: 9Iteration B Stage 1 Die surface and Formability Analysis

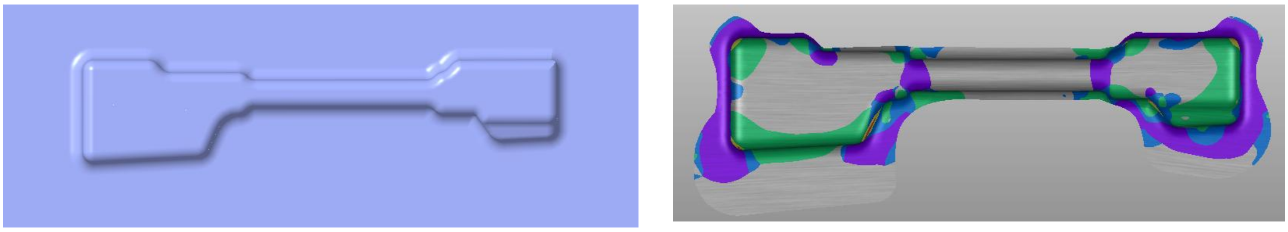

Figure: 10Iteration B Stage 2 Die surface and Formability Analysis

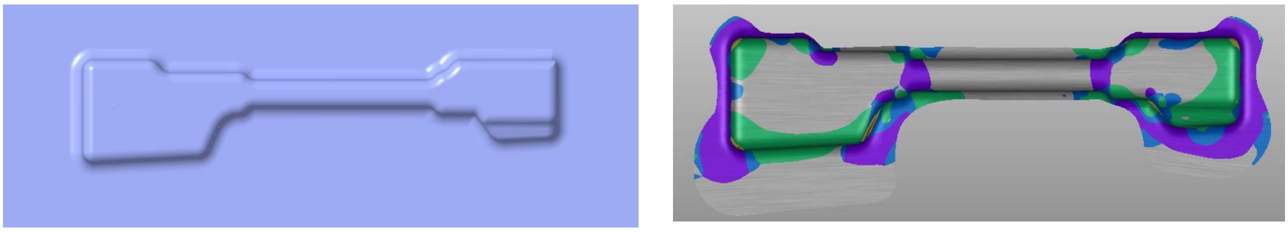

Figure: 11Iteration B Stage 3 Die surface and Formability Analysis

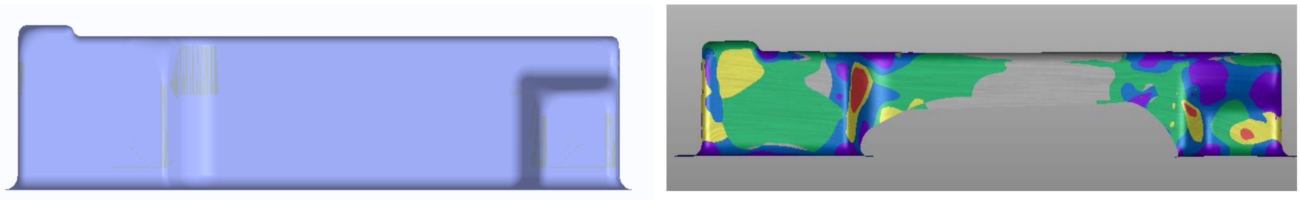

Figure: 12Iteration B Stage 4 Die surface and Formability Analysis

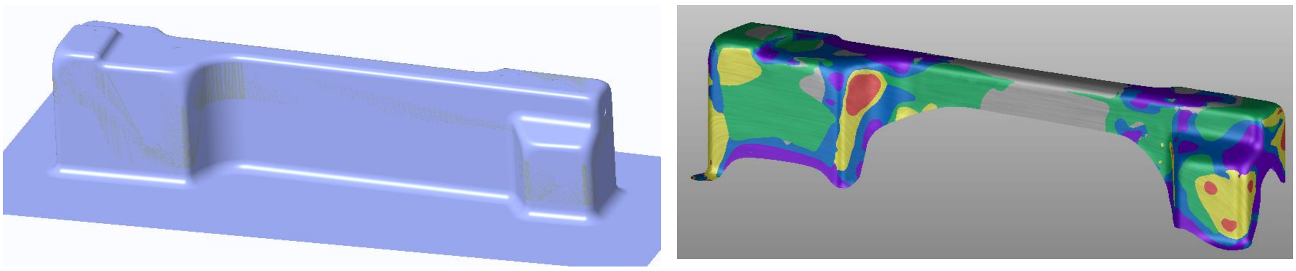

Figure: 13Iteration B Stage 5 Die surface and Formability Analysis

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C. THINNING AND MAXIMUM FAILURE ANALYSIS OF ITERATION 2 STAGE 5

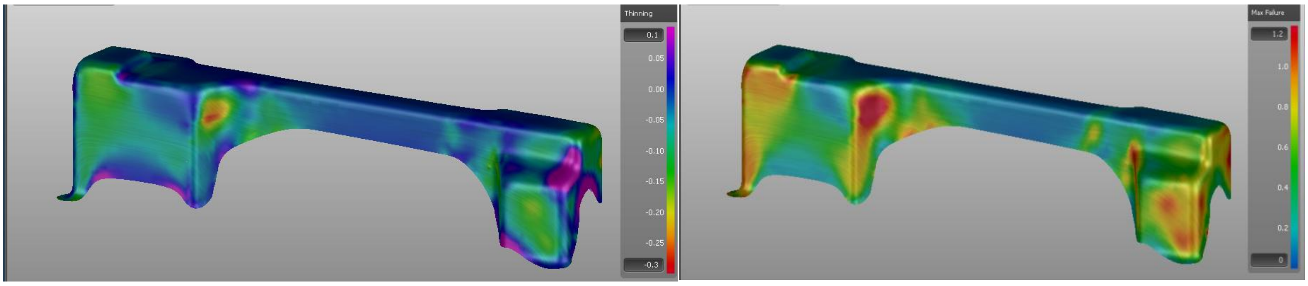
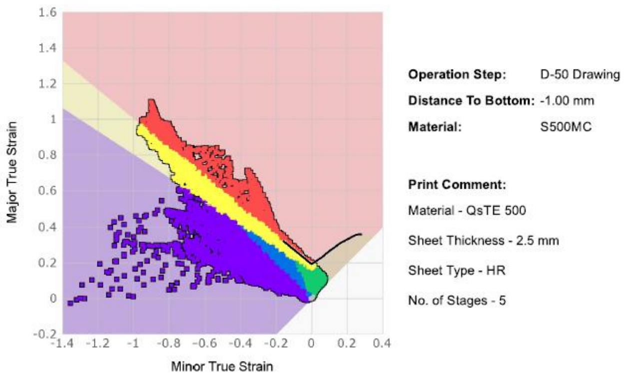


Figure: 14Iteration B Stage 5 Thinning and Maximum Failure Analysis Analysis

IV. DISCUSSION

Formability Limit Diagram (FLD) together with the Forming Limit Curve (FLC) provide a method for determining process limitations in sheet metal forming and are used to assess the stamping characteristics of sheet metal materials. Usually, FLD is used in method planning, tool manufacturing and in tool shops to optimize stamping tools and their geometries. The comparison of deformations on stamped metal sheets with the FLD leads to a security estimation of the stamping process. The forming analysis and the comparison of the data with the FLC provide for a reliable assessment of sheet metal forming processes [10]. Using Autoform software, FLD is generated for the Iteration 2 stage 5 process as shown in Figure 15. From the plot it is clear that the sheet was subjected to pure shear and uniaxial tension and compression. The splits and excess thinning were actually happening in the excess blank area those might be trimmed off using a trimming tool. Based on the Iteration 2, the tools for all the stages were made as shown in figure 16 a and parts were drawn successfully as shown in figure 16 b.



	Thickening	Compress	Insuff Stretch	Safe	Risk of Splits	Excess Thinning	Splits
Area	19.88 %	20.44 %	20.12 %	26.04 %	11.48 %	0.00 %	2.03 %
Limits	0.01		< 0.02		20.00 %	> 0.20	0.00 %

Figure: 15Forming Limit Diagram (FLD) for Iteration B Stage 5

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Figure 16A. Tool development B. Part from Deep drawing process

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