CAE-based Optimization Methodology for Stamping Process of Deep Drawn Automotive Component

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Abstract: Stamping process of deep drawn components involves consideration of various parameters such as material properties, blank holding pressures, punch velocity and their effect on forming quality parameters like wrinkling, tearing, spring-back etc. Simulation of stamping is a highly nonlinear phenomenon involving elastic-plastic material modeling and contact predictions. An Abaqus based stamping process template has been developed with an objective to achieve desired quality of deep-drawn components. This study demonstrates how to arrive at optimum values of forming process parameters viz. blank size and blank holding force. Stamping simulation of front side automotive panel made of high strength steel has been performed in Abaqus. The optimization process has been defined in Isight wherein above mentioned forming process parameters are varied to ensure all the strain paths are below forming limit diagram (FLD) using various optimization algorithms. Suitable optimization technique is suggested based on the results and performance.

Keywords: Deep Drawing, Abaqus, Isight, FLD

1. Introduction

Deep drawing process for automotive components is very complex and requires controlling of several input parameters to meet forming quality requirements. Objective of this study is to develop a CAE methodology for identifying optimum values of blank holding force (BHF), blank length and blank width to

- Minimize blank area
- Keep the thickness reduction within 20%
- Avoid tearing, wrinkling
- Arrive at an optimization algorithm that provides best results for the above parameters with minimum computational time.

For this study, the base tool model of the front side member outer panel is referred from NUMISHEET 2011 Benchmark 3 [1].

2. Material Properties

The blank material used for stamping of the front side member is a high strength steel (DP590) with the thickness of 1.8 mm. The detailed information about the material and FLD plot is provided below in Table 1 and Figure 1.

Table 1. Material properties for DP590

n	K (MPa)	Yield Strength (MPa)	R0	R45	R90	E (MPa)	μ
0.1795	1057.108	432	0.79	0.738	0.903	206	0.145

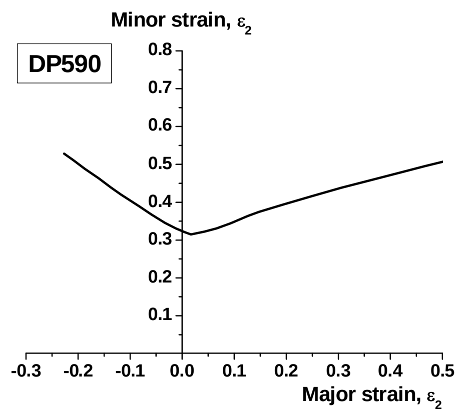

Figure 1. Forming limit diagram for DP590

3. Tooling Geometry

Figure 2 shows the schematic shape of the upper die, the blank holder and the lower punch. Draw-bead shape and location is shown in Figure 3. Stroke is 106.5 mm from the initial position and cushion stroke is 101.8 mm shown in Figure 4. Blank positioning and rolling direction of the blank must be coincident with the y-coordinate direction. Initial blank size considered is 1650 mm in length and 560mm in width.

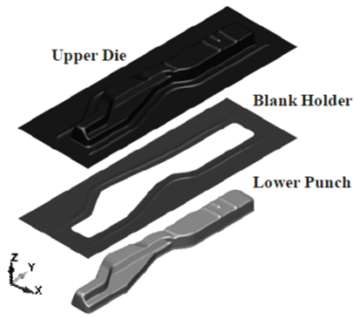

Figure 2. Tooling geometry

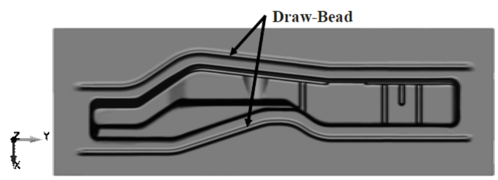

Figure 3. Draw-bead shape and location

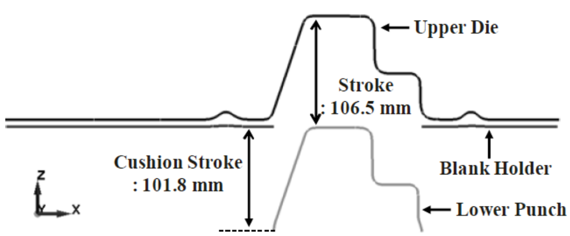

Figure 4. Stroke description

4. Numerical Simulation

Deep drawing process is simulated using the Abaqus/Explicit 6.10-3[2], DOE and optimization is carried using the Isight 5.6 [3].

4.1 Modeling in Abaqus/CAE

The punch, draw bead and die are considered as rigid bodies as shown in Figure 5. Blank is meshed using S4R elements. Surface to surface finite sliding formulation is used for defining the contact. The material is modeled as an elastic-plastic material with isotropic elasticity, using the Hill anisotropic yield criterion for the plasticity. The following anisotropic yield criterion is used.

R_{11}=1.0, R_{22}=1.036, R_{33}=0.977, R_{12}=1.0755, R_{13}=1.0, R_{23}=1.0

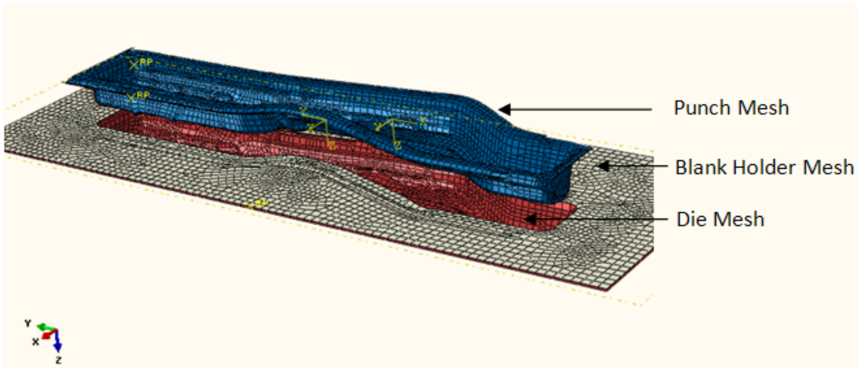

Figure 5. Meshes for the punch, blank holder and die

4.2 Workflow in Isight

Design of Experiments (DOE) is used to explore design space and carry out sensitivity analysis using Pareto plots. Range of variables thus identified is provided as input to different optimization techniques. The best suitable optimization technique is the one that provides best results with minimum computation time.

4.2.1 DOE Formulation

Latin Hypercube DOE technique is used since it uniformly explores the design space. Blank length, blank width and blank holding force are DOE variables. Blank width is divided into two variables (blank width1 and blank width2) to account for the un-symmetric distribution as shown in Figure 6. The response parameters are overall thickness reduction and FLD values. The DOE workflow is shown in Figure 7.

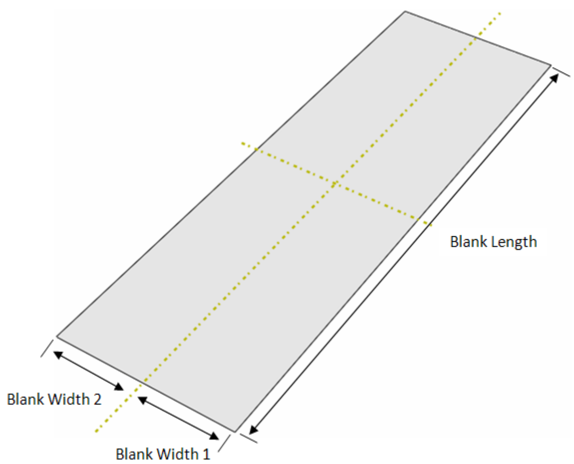

Figure 6. Blank parameters for DOE

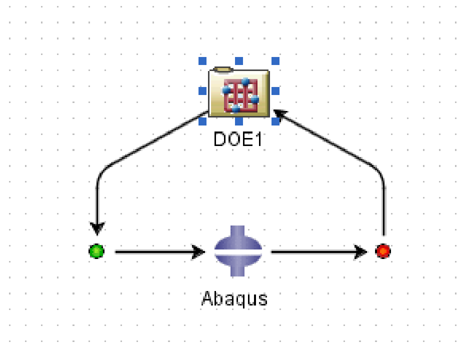

Figure 7. Abaqus Isight integration: DOE Workflow

4.2.2 Optimization Formulation

Optimization formulation is as follows.

Objective:

- Minimize blank area

Constraints:

- Allowable ~20% thickness reduction (STH>1.44mm)
- Limiting strains should not exceed corresponding FLD values (FLDCRT<1)

Following direct numerical search optimization techniques are used:

- NLPQL: Nonlinear Programming with Quadratic Line Search algorithm
- MOST: Multifunction Optimization System Tool
- EVOL: Evolutionary Optimization Algorithm

The Isight optimization workflow is shown in Figure 8.

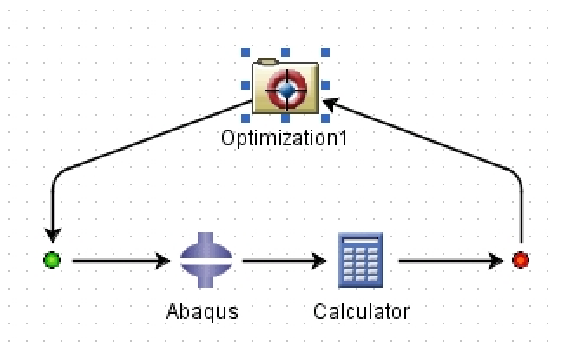

Figure 8. Abaqus Isight integration: Optimization Workflow

5. Results and Discussion

5.1 Abaqus Results

Thickness reduction is measured using STH output variable as shown in Figure 9. Limiting strains are measured in terms of Forming Limit Diagram failure criterion (FLDCRT) as shown in Figure 10.

First run results:

- Minimum section thickness: 1.387 mm
- FLDCRT Max: 1.180

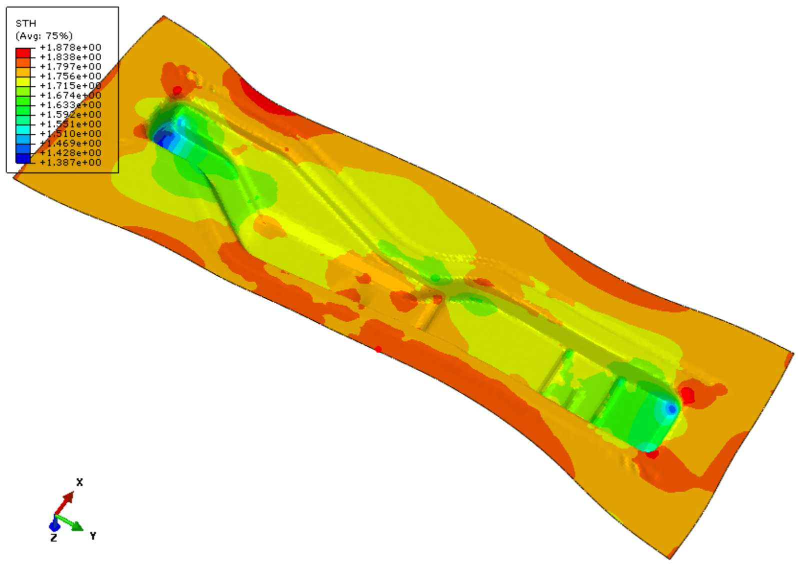

Figure 9. Section Thickness (STH) Plot

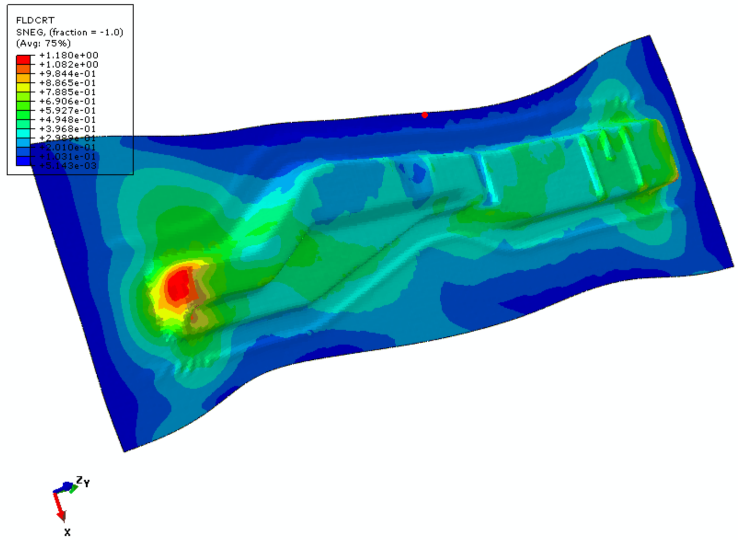

Figure 10. Forming Limit Diagram failure criterion (FLDCRT) Plot

5.2 DOE Results

The Pareto chart shown in Figure 11 shows that major impacting variables are blank length, blank width1, blank width2 and BHF for the response variables. The Figure 12 displays the variation of the selected parameters with the response variables. Based on the DOE results, range for these parameters are provided to the optimization techniques as shown in Table 2.

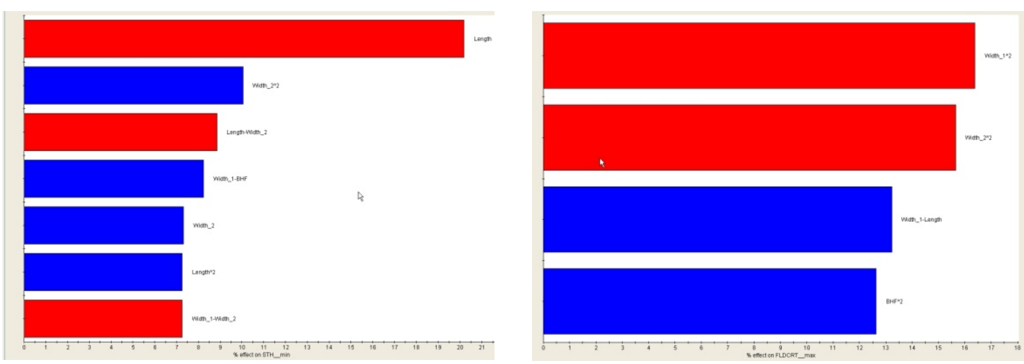

Figure 11. Pareto charts for the response variables

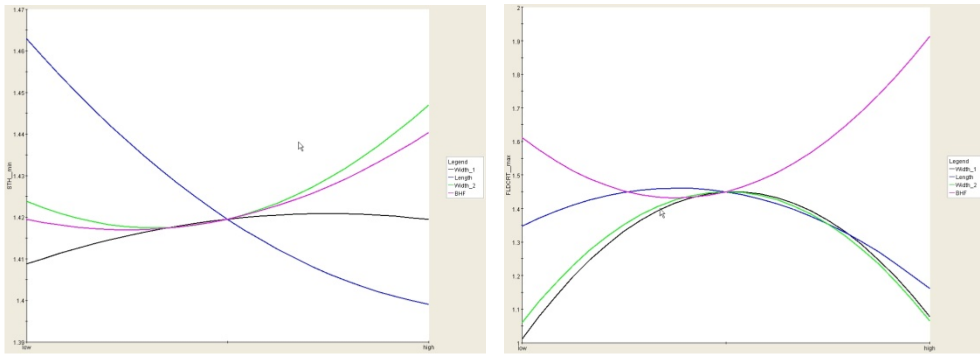

Figure 12. Pareto charts for the response variables

Table 2. Parameter Range for optimization

Range	Blank Width1 (mm)	Half Blank Length (mm)	Blank Width2 (mm)	Blank Holding Force (KN)
Lower	220	750	240	800
Baseline	250	790	260	900
Upper	280	825	280	1000

5.3 Optimization Results

Table 3 and Table 4 show the comparative results obtained for the three optimization techniques.

Table 3. Optimization Results Summary 1

Optimization Algorithm	Optimized Iteration	Blank Width 1 (mm)	Blank Width2 (mm)	Half Blank Length (mm)	Blank Holding Force (KN)	FLDCRT _Max	STH_Min (mm)
NLPQL	17	225	250	789.41	895.26	1.026	1.408
EVOL	51	225	250	760	848	0.9635	1.433
MOST	6	225	250	760	832.526	0.9878	1.433

Table 4. Optimization Results Summary 2

Optimization Algorithm	Optimized Iteration	Thickness Reduction (%)	Blank Area (mm2)	Total Execution Time (min)
NLPQL	17	21.77	749936.1	180
EVOL	51	20.3	722000	300
MOST	6	20.3	722000	100

Following are the observations:

- NLPQL technique does not respect constraints
- EVOL and MOST techniques respect constraints
- MOST technique achieves minimum area objective with minimum time as compared to all other techniques. ~20% thickness reduction and ~22% blank area reduction is achieved as compared to first cut assumption.

Final Section thickness and FLDCRT plots for MOST technique is shown in Figure 13 and Figure 14.

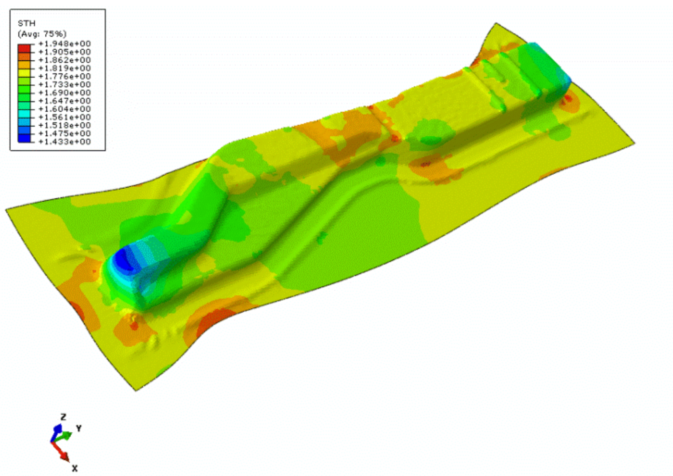

Figure 13. Section Thickness (STH) Plot

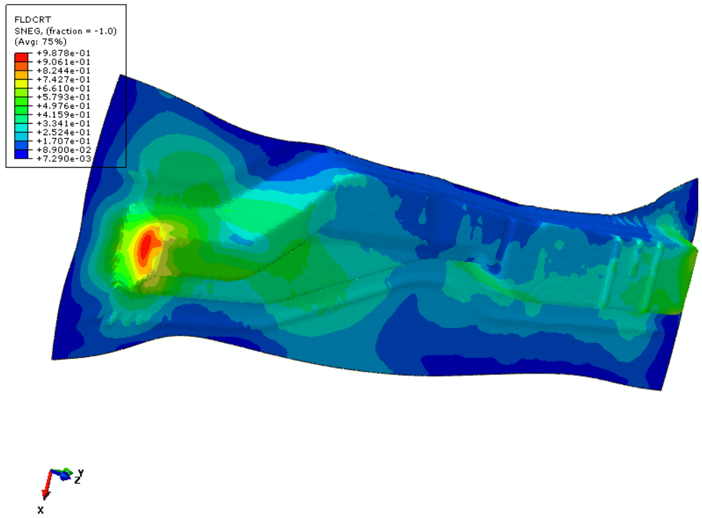

Figure 14. Forming Limit Diagram failure criterion (FLDCRT) Plot

6. Conclusion

From the above study, Abaqus\Explicit, Latin Hyper cube DOE and Isight MOST optimization are suitable for deep drawing forming process to identify optimum values of blank length, blank width and blank holding force. Abaqus and Isight integration is found to be robust enough to perform the complex forming simulation.

7. References

1. NUMSHEET 2011
2. SIMULIA Abaqus 6.10.3 User Manual
3. SIMULIA Isight 5.6 User's Guide