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

Nilesh BIRAJDAR, Rajesh NAGOSE, Yogesh UKE, Anil MASHALKAR
SIMULIA, Pune - INDIA
Contents

• Objective & Problem Definition

• Workflow

• Deep Drawing Simulation in Abaqus CAE

• Optimization Process in Isight

• Results and Discussion

• Conclusion
Objective & Problem Definition

• **Study Objective**
  - Develop a methodology for optimizing deep drawing process using Abaqus-Isight integration

• **Component**
  - Automotive front side member outer panel with DP590 steel
  - Blank Size (Length 1650mm * width 560mm)
  - Blank Thickness 1.8 mm

• **Tooling Reference**
  - NUMISHEET 2011 Benchmark 3 [1]

• **Optimization problem**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Blank Holding Force</th>
<th>Blank Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints</td>
<td>Overall thickness reduction about 20%</td>
<td>No tearing</td>
</tr>
<tr>
<td>Objectives</td>
<td>Minimizing blank area</td>
<td>Arrive at an optimization algorithm that provides best results with minimum computational time</td>
</tr>
</tbody>
</table>
Workflow

Deep Drawing Process Considerations

FEA modeling in Abaqus CAE

Feasible Design Space with DOE in Isight

Optimize 1 (MOST)  Optimize 2 (NLPQL)  Optimize 3 (EVOL)

Optimum process parameters  Suitable optimization technique

Abaqus

Isight

Isight- Abaqus Integration
FEA Simulation

- **Material model**
  - Elastic-plastic with Hill anisotropic yield
  - FLDCRT damage criterion parameters

- **Post processing parameters**
  - FLDCRT
  - STH: Thickness Plot

- **Model**
  - Size: 224,418 DOFs
Initial Abaqus Run Results

- Minimum section thickness: 1.387 mm (~26% thickness reduction)
- FLDCRT Max: 1.18 (indicating Tearing)

![Section Thickness (STH) Plot](image1)

![Forming Limit Diagram failure criterion (FLDCRT) Plot](image2)
Optimization

- **Why Optimization?**
  - Multi objective, multi constraint problem

- **Optimization Statement**
  - **Variables**
    - Blank Width 1
    - Blank Width 2
    - Blank Length
    - BHF
  - **Constraints**
    - Allowable thickness reduction ~20%
      - STH MIN > 1.43mm
    - No Tearing
      - FLDCRT MAX < 1
  - **Objective**
    - Minimize Area
      - Blank Width 1
      - Blank Width 2
      - Blank Length

- Forming Limit Diagram with FLDCRT criterion

Multi objective, multi constraint problem
Optimization

- **Latin Hypercube DOE technique**
  - The points of experiments are distributed as uniformly as possible in the design space
  - 4 variables, 2 response parameters and 25 points

- **Pareto Analysis**
  - Pareto analysis confirmed that variables Blank length, Blank width1, Blank width2 and BHF are all significant contributors

![Pareto Analysis Diagram]

**Pareto Plot for Response STH_{min}**
- 20% Length
- 10% Width_{2*2}
- 9% Length-Width_{2}
- 8.5% Width_{1*BHF}
- 7.5% Width_{2}
- 7.25% Length_{2}
- 7.25% Width_{1-Width_{2}}

% Effect on STH Min

**Pareto Plot for Response FLDCRT_{max}**
- 16.5% Width_{1/2}
- 15% Width_{2*2}
- 13.25% Width_{1*Length}
- 12.75% BHF^2
- 8% Length_{2}
- 7.5% Width_{1-Width_{2}}
- 7% Length-Width_{2}

% Effect on FLDCRT Max
DOE Results

- Identification of feasible design space based on FLDCRT values

<table>
<thead>
<tr>
<th>Range</th>
<th>Blank Width1 (mm)</th>
<th>Half Blank Length (mm)</th>
<th>Blank Width2 (mm)</th>
<th>Blank Holding Force (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>250</td>
<td>790</td>
<td>260</td>
<td>900</td>
</tr>
<tr>
<td>Lower</td>
<td>220</td>
<td>750</td>
<td>240</td>
<td>800</td>
</tr>
<tr>
<td>Upper</td>
<td>280</td>
<td>825</td>
<td>280</td>
<td>1000</td>
</tr>
</tbody>
</table>
Optimization

- **Shortlisted optimization techniques**
  - **NLPQL**: Nonlinear Programming with Quadratic Line Search Algorithm
    - Use sequential quadratic programming for exploration
  - **MOST**: Multifunction Optimization System Tool
    - Uses branch-and-bound approach.
  - **Evol**: Evolutionary Optimization Algorithm
    - Mutates designs by adding a normally distributed random value to each design variable

- **Isight Workflow**
## Optimization Results

<table>
<thead>
<tr>
<th>Optimization Algorithm</th>
<th>NLPQL</th>
<th>EVOL</th>
<th>MOST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimized Iteration</td>
<td>17</td>
<td>51</td>
<td>6</td>
</tr>
<tr>
<td>Blank Width 1 (mm)</td>
<td>225</td>
<td>225</td>
<td>225</td>
</tr>
<tr>
<td>Blank Width 2 (mm)</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Half Blank Length (mm)</td>
<td>789.41</td>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>Blank Holding Force (KN)</td>
<td>895.26</td>
<td>848</td>
<td>832.526</td>
</tr>
<tr>
<td>FLDCRT Max</td>
<td>1.026</td>
<td>0.9635</td>
<td>0.9878</td>
</tr>
<tr>
<td>STH Min (mm)</td>
<td>1.408</td>
<td>1.433</td>
<td>1.433</td>
</tr>
<tr>
<td>Thickness Reduction (%)</td>
<td>21.77</td>
<td>20.3</td>
<td>20.3</td>
</tr>
<tr>
<td>Blank Area (mm²)</td>
<td>749936.1</td>
<td>722000</td>
<td>722000</td>
</tr>
<tr>
<td>Total Execution Time (min)</td>
<td>180</td>
<td>300</td>
<td>100</td>
</tr>
</tbody>
</table>

### Graphical Representation

- **Getting stuck on local design objective**
- **Takes more iterations for achieving objective function**
- **Speedily achieves objective function**
Results & Discussion

• Final Section thickness and FLDCRT plots with MOST technique
  • Minimum section thickness: 1.433 mm (Initial Run value 1.387 mm)
  • FLDCRT Max: 0.9878 (Initial run value: 1.180)
  • 22% reduction the blank area
Conclusion

- ~22% blank area reduction is achieved as compared to initial run
- The methodology proposed can help in reducing prototyping
- Abaqus\Explicit, Latin Hyper cube DOE and Isight MOST optimization are suitable for deep drawing forming process to identify optimum process parameters
- Abaqus and Isight integration is found to be robust enough to perform the complex forming simulation and process optimization
Thank You