Simplified Interactive Tools for Prediction of Oil Canning and Dent Resistance
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Outline

• Introduction
• Summary of Past Experimental Results
• Comprehensive FEA Approach
• Creation of Efficient Predictive Tools
• Conclusions
Introduction

- For effective lightweighting of closures with steel, it is important to maintain stiffness, dent resistance and oil canning resistance.

- Because of compressed design cycles, it is also important to develop predictive tools applicable at different stages:
  - Guidelines to enable appropriate material and thickness decision
  - Comprehensive FEA when the design is close to final
  - Physical testing when prototypes are ready and to validate design

- ArcelorMittal has been working on solutions to assist customers in design of lightweight closures while meeting performance.
Introduction: Evaluation of Dent Resistance

• Test Procedure
  - Auto/Steel Partnership
  - Incremental loading sequence using a 25.4mm hemispherical indenter
  - Determine performance metric
    - Load for dent of 0.1mm depth
  - Quasi-static or dynamic loading
Introduction: Evaluation of Oil Canning Resistance

- Test Procedure
  - No pre-existing standard
  - Testing is typically done using an indenter
    - Displacement controlled loading sequence
  - Performance metric
    - Peak load in the load displacement cycle

![Graph showing load vs. deflection](image)

![Image of testing equipment](image)
Summary of Past Experimental Results

• Dent Resistance
  – Significant interactions between panel curvature, steel grade, thickness, and stretch
  – In general, dent resistance increases with increase in stretch
  – Effect of stretch, strain path and steel grade less significant for the sharper curvatures

• Oil Canning Resistance
  – Oil canning load depends on thickness, but not on steel grade
  – Strong influence of support conditions
  – The drop in load during testing does not necessarily correlate to audible noise
    – More vertical drop in load leads to a higher noise
Comprehensive FEA Prediction

- Map stretching and thinning results from stamping FEA into structural model
  - Areas of equal effective plastic strain and thinning
  - Local mesh refinement at loading location; element size ~ 1mm
- Adjust as-received stress-strain properties with magnitude of prestrain
- Contact based loading using ABAQUS or LS Dyna
- Result measures
  - Dent Resistance: Load at 0.1mm dent depth
  - Oil Canning Resistance: Load at point of instability – max. load
Comprehensive FEA Prediction: Dent Resistance

Very good correlation between experiments and FEA
Comprehensive FEA Prediction: Oil Canning

Very good correlation between experiments and FEA
Creation of Efficient Predictive Tools: Approach

- Prediction tools to provide **early design guidance** in the vehicle program concept stage

**ArcelorMittal Technical Approach**
- Benchmarking to determine representative area of panel for analysis
- Simplify panel and support conditions
- Combination of FEA (Finite Element Analysis) & DOE (Design of Experiments) to determine significant interactions
- Use of mathematical and statistical analysis to yield output
- Creation of a user friendly interface available on [pc.arcelormittal.com](http://pc.arcelormittal.com)

- Combine output from different loadcases
  - Doors (developed earlier ~ 2003)
    - Dent resistance only
  - Roofs (Recent development ~ 2011)
    - Dent resistance and oil canning resistance
Benchmarking of Select Panels

- More variety in supported area for front fenders and hoods
  - Easy simplification may not be feasible
Benchmarking of Select Panels

- Large unsupported areas for doors and roofs
- Rectangular plate assumption may be satisfactory for doors and roofs
Creation of Efficient Predictive Tools

• Panels
  – Doors
    – Model developed in ~ 2002
    – Number of different steel grades: DDQ+, DQSK, BH210, BH250, DP500
    – Minimum thickness: 0.65mm
    – Dent resistance only
  – Roofs
    – Model developed in ~ 2010
    – Only two steel grades: DDQ and BH210
    – Minimum thickness: 0.55mm
    – Dent Resistance and Oil Canning Resistance
Creation of Efficient Predictive Tools: Doors

Simplification: Bi-curved rectangular plate
Creation of Efficient Predictive Tools: Doors

- **Initial Variables Considered**
  - Panel Radii ($R_1$ & $R_2$)
  - Nominal incoming thickness
  - Effective plastic strain during forming (stretch)
  - Steel Grade
  - Feature Lines
  - Span ($L_1 \times L_2$)
  - Boundary Conditions

- **Summary of Screening Simulations**
  - Significant effect of panel radii and interactions with other variables
  - Minor effect of feature lines on dent resistance of main feature
  - Minor effect of span length and boundary conditions
Creation of Efficient Predictive Tools: Doors

- Statistical Methodology
  - DOE with final selected variables
  - Result of interest: Load for 0.1mm dent depth
  - Five Factors
    - $1/R_1$ (7 levels -- linear, quadratic, cubic terms)
    - $1/R_2$ (3 levels -- linear, quadratic terms)
    - Thickness (3 levels -- linear, quadratic terms)
    - Effective plastic strain (3 levels -- linear, quadratic terms)
    - Steel Grade
  - Determine relative impact of various terms on regression sum of squares
  - Identify most important terms
  - Construct a final regression (steel grade specific) with selected terms
Creation of Efficient Predictive Tools: Doors

Model Validation

Materials: BH210, BH250, DP500
Thicknesses: 0.65mm – 0.8mm

Load for 0.1mm dent depth

- Average absolute difference: 6%
- Maximum difference: 18%
- In most cases, difference < 10%
Creation of Efficient Predictive Tools: Roofs

- **DOE details**
  - Design intent variables
    - Front view radius
    - Side view radius
    - Thickness
    - Unsupported length between roof bows
  - Manufacturing variables
    - Expected stretch during stamping
  - Fixed Variables
    - Bow thickness and cross section
    - Mastic thickness
    - Mastic width
  - L27 Matrix for front view radius, side view radius, and thickness
  - Fully orthogonal design with three levels of each variable

Oil Canning
150mm flat indenter

Dent Resistance
25.4mm hemispherical indenter
Creation of Efficient Predictive Tools: Roofs

• Summary of mathematical & statistical analysis

• Prediction of oil canning behavior
  – Each load-deflection curve was considered as two curves,
    – “stable” response and
    – an “unstable” or ‘collapsed” response, with a transition point
  – Specific points on the generated curves were fitted to levels of the factors
    – At zero deflection, the initial slope of the curve
    – At the transition point, the values of load and deflection
  – Quadratic or cubic interpolation was used to generate the two curves

• Prediction of dent resistance
  – Use of a response surface methodology in combination with traditional ANOVA
  – Similar to the model for doors
Good overall prediction of load deflection curves in comparison with FEA results for the same geometry

The dependence of load deflection behavior on the span length between bows (L2) is captured
Creation of Efficient Predictive Tools: Roofs

Model Validation

Very good correlation of predictive model with full panel FEA.

Overall structure

w/o roof panel
Deployment of Efficient Predictive Tools

Tools can be accessed on ArcelorMittal Partner Centre
Predictive Tools for Doors

- Drop down menus for steel grade, thickness and variables
- Almost instantaneous display of dent resistance predictions
**Predictive Tool for Roofs**

- Interactive dial input for variables
- Almost instantaneous display of oil canning load deflection behavior and dent resistance
Conclusions

• Early design guidance on select closure panel performance under localized loading conditions
  – Dent Resistance
    – Doors and Roofs
  – Oil canning load and load deflection behavior
    – Roofs

• Reasonable solutions are available in a matter of seconds rather than many CPU hours or weeks in some instances enabling significant reduction in design cycle time

• The model is available on pc.arcelormittal.com and could be accessed easily using a desktop computer with Internet access

• Feasible to develop similar models for other closure panels
Celebrating 15 Years of Great Designs in Steel

Presentations will be available May 16 at www.autosteel.org