ACP Process: Joint Stiffness Sensitivity and Optimization in Thin Gauge Study

Akbar Farahani, Ph.D.
Morteza Kiani, Ph.D.
Engineering Technology Associates Inc. (ETA)
Agenda

• Background
• Objective and Project Scope
• Methodology and Joint Stiffness Strategy
• Baseline Establishment and MetaModel
• Joint Stiffness Sensitivity Evaluation
• Joint Stiffness Optimization and Results
• Conclusion
Background

• Based on extensive recent research and advancement in **product design and development**, vehicle body-in-white (BIW) mass has been reduced dramatically, while the performance has improved.

• This was made possible by combining optimization-driven techniques, such as the Accelerated Concept to Product® (ACP) Process™, 3G-Optimization and application of AHSS such as FSV (Future Steel Vehicle) completed by WorldAutoSteel.

• FSV final project report, concluded that while we reduced mass of the BIW by **39%** (T6 Final Design) and improved both strength and stiffness of the vehicle, torsional stiffness of the vehicle becomes a controlling load case for any further mass reduction.
FSV Mass Evolution

- How can AHSS increase torsional stiffness with minimum mass penalty using minimum gauges of 0.5-0.6 mm or less?
Mass vs Stiffness

- Torsional Stiffness is function of mass and geometry.
Objective

- Develop Methodology to Enable the Design Process to:
  - Quick evaluation of joint stiffness sensitivity and identify the most critical joints.
  - Quick method to improve and optimize the critical joint stiffness performance to meet torsional stiffness targets.
  - Provide guidance for joint selection for detail design of joint stiffness 2G-Optimization™
Project Scope: JSP Methodology

- The performance of the structures is highly influenced by overall stiffness, especially stiffness of the joints.
- Elastic Modulus ($E^*$) Grade, Gauge and/or Geometry ($I^{**}$) determine the Joint stiffness.
- Change in the joint stiffness can be performed by artificially changing the Elastic Modulus.
- Use FSV torsional stiffness final results as baseline.
- Perform sensitivity analysis to identify critical joints.
- Improve joint stiffness using joint sensitivity process (JSP).

* Young’s Modulus  ** Moments of Inertia
Introduce Joint Stiffness Strategy

- Structural performance is highly influenced by joints stiffness (Crash and Stiffness attributes)
- Joint Stiffness is defined as:
  $$E^{\text{MaterialElasticModulus}} \times I^{\text{GeometryMomentofInertia}}$$
- All important joints are decoupled and defined as variables i.e. $x_i$
JSP Modeling

Apply Identical Elastic Modulus for All Joints
Baseline Establishment

- FSV final torsional stiffness at 35% mass Reduction

\[ F = 1200 \text{ N} \quad l = 1121.4 \text{ mm} \]

\[ K_{\text{Torsion}} = \frac{1200 \text{ N} \times 1121.4 \text{ mm}}{\text{Arctang} \left( \frac{|\delta_1| + |\delta_2|}{1121.44} \right)} = 19,239. \frac{\text{N.m}}{\text{degree}} \]
Joint Stiffness Sensitivity Evaluation

• Generate Design of Experiment (DoE) for torsional stiffness analysis (at least 3n cases must be used (n: number of joints i.e. 21 design cases)

• Develop MetaModel for torsional stiffness by using Response Surface Method (RSM)

\[
f(x_i) \approx \hat{f}(x_i) = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{i=1}^{k} a_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} a_{ij} x_i x_j
\]

• Differentiate derivation for torsional stiffness MetaModel
Joint Stiffness Sensitivity Analysis

\[ \frac{\partial f(x_i)}{\partial x_i} = i = 1, 2, \ldots, 7 \]

<table>
<thead>
<tr>
<th></th>
<th>df/(dx_1)</th>
<th>df/(dx_2)</th>
<th>df/(dx_3)</th>
<th>df/(dx_4)</th>
<th>df/(dx_5)</th>
<th>df/(dx_6)</th>
<th>df/(dx_7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1393</td>
<td>1383</td>
<td>593</td>
<td>474</td>
<td>736</td>
<td>90</td>
<td>993</td>
</tr>
</tbody>
</table>

Joints X1, X2 and X7 are highly effective in Torsional Stiffness
Joint Stiffness Sensitivity Evaluation

Plot Joint Stiffness Sensitivity Based on MetaModel

Torsional Stiffness (N.m/degree)

E (Modules) GPa

Joint ID in FSV

Joint
- X1
- X2
- X3
- X4
- X5
- X6
- X7

19900
19700
19500
19300
19100

18900

155
205
255
305
355

www.autosteel.org
Joint Stiffness Optimization and Results

Maximize \( f(x_i) \)

s.t. \( \sum_{i=1}^{7} x_i \leq \Psi : \Psi = 1470 \text{ GPa} \)

\( 75\% E_{\text{baseline}} \leq x_i \leq 175\% E_{\text{baseline}} \)

* \( E_{\text{baseline}} \) is 210 GPa

** \( f(x_i) \) is the Torsional Stiffness of the BIW

Optimized Joint Stiffness Values

<table>
<thead>
<tr>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( x_4 )</th>
<th>( x_5 )</th>
<th>( x_6 )</th>
<th>( x_7 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>283</td>
<td>307</td>
<td>157</td>
<td>157</td>
<td>157</td>
<td>157</td>
<td>240</td>
</tr>
</tbody>
</table>

Elastic Modulus GPa

- **Baseline Torsional Stiffness (19,239 N.m/degree)**
- **Optimized Torsional Stiffness (20,565 N.m/degree)**
Conclusion

- A quick method to evaluate joint stiffness sensitivity under multidisciplinary loading conditions
- A quick method to rank the joints for 2G (Geometry and Gauge) design optimization study
- Joint stiffness improvement through geometry and gauges is the most efficient method to improve torsional stiffness for “Steel Thin Gage BIW Strategy”.
- This methodology can help to implement thin gauge AHSS for additional weight reduction with minimum mass penalty.
PRESENTATIONS WILL BE AVAILABLE MAY 16

Use your web-enabled device to download the presentations from today’s event

Great Designs in Steel is Sponsored by:

AK Steel
ArcelorMittal Dofasco | Hamilton
ArcelorMittal
NUCOR
Severstal
U.S. Steel