Framework to optimize length and location of welded joints on a full beam axle

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2018 SIMULIA Great Lakes Regional User Meeting

Agenda

1. Company Overview
2. Research Objectives/ Challenges
3. Prediction Procedure
   ✓ Structural Stress Method
   ✓ Correlation to test data
4. Methodology
   ✓ Parametrization
   ✓ Optimization Framework
5. Results and Discussion
   ✓ Weld location optimization
   ✓ Weld length optimization
6. Conclusions
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6. Conclusions
AAM is a tier one global automotive supplier of driveline and drivetrain systems and related components for light trucks, SUVs, passenger cars, crossover vehicles and commercial vehicles.

Our intense focus on engineering and manufacturing allows us to build value for our customers through quality, technology leadership and operational excellence.

- ESTABLISHED: 1994
- WORLD HEADQUARTERS: DETROIT, MI
- CUSTOMERS: >700 WORLDWIDE
- LOCATIONS: >90 FACILITIES IN 17 COUNTRIES
- WORK FORCE: >25,000 ASSOCIATES
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Research Objectives/ Challenges

Test Setup
Weld Failure
Weld Cross-Section

VERTICAL BEAMING LOADING
TORSIONAL LOADING
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Traction Structural Stress Method

Normal Component: \( \sigma_s = \sigma_m + \sigma_b = \frac{f_x}{t} - \frac{6m_z}{t^2} \)

In-plane Shear Component: \( \tau_s = \tau_m + \tau_b = \frac{f_z}{t} - \frac{6m_x}{t^2} \)

Transverse Shear Component: \( \tau_z = \frac{f_y}{t} \)

- Three traction stress components
- Normal component represent the Mode I failure
- In-plane shear represent the Mode III failure
- Transverse shear is Mode II failure

TCCP: throat critical crack plane
RCP: root crack plane
TCP: toe crack plane

\( f_x, f_y, f_z \) are line forces and \( m_x, m_z \) are the line moments calculated from the nodal forces by solving simultaneous equations.
Traction Structural Stress Method (Cont.)

Equivalent Structural Stress Range

\[ \Delta S_e = \sqrt{ \left( \Delta S_s \right)^2 + 3 \cdot (\Delta \tau_s)^2 + (\Delta \tau_z)^2} \]

Effective Structural Stress Range

\[ \Delta S_e = \sqrt{ \left( \Delta S_s \right)^2 + 3 \cdot (\Delta T_s)^2 + (\Delta T_z)^2} \]

Structural Stress Range

Loading Mode effects

Effective Equivalent Structural Stress Range

\[ \Delta \sigma_e = \frac{\Delta \sigma_s}{t^{2m} \cdot I(r)^m} \]


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6. Conclusions
• Multiple geometries/assembly, for AAM parts are compared
• Prediction bands are created by making use of the Battelle Master SN curve relationship for the variation observed in their weld life test data
• Good correlation is observed between AAM test and CAE prediction
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Weld Size Quantification


- Brake flange (red) is subjected to torsional loading.
- Throat failure has the highest stress at $45^0$ throat angle.
- Weld leg size and weld penetration depth should be sufficiently high to prevent the weld root/throat failure.

\[
SCF = \frac{\left[\sigma_s^2 + 3\tau_s^2 + 3\tau_z^2\right]^{1/2}}{\sigma_n}
\]

SCF = Stress Concentration Factor
\(\sigma_n\) = nominal stress
TORSIONAL LOADING
- the inner weld has higher SCF than the two-sided weld while the outer weld has the highest SCF for throat failure.

VERTICAL BEAMING LOADING
- toe failure for the two-sided weld design has the highest SCF.

SCF = \[ \frac{[\sigma_s^2 + 3\tau_s^2 + 3\tau_z^2]^{1/2}}{\sigma_n} \]
<table>
<thead>
<tr>
<th>Weld Length (deg)</th>
<th>SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>14</td>
</tr>
<tr>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>150</td>
<td>10</td>
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<tr>
<td>200</td>
<td>8</td>
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<tr>
<td>250</td>
<td>6</td>
</tr>
<tr>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td>350</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**TORSIONAL LOADING**

- Increase in weld length decreases the SCF.
- The weld length is reduced, the throat failure is more susceptible to higher SCF.

<table>
<thead>
<tr>
<th>Weld Length (deg)</th>
<th>SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>0.4</td>
</tr>
<tr>
<td>220</td>
<td>0.6</td>
</tr>
<tr>
<td>260</td>
<td>0.8</td>
</tr>
<tr>
<td>300</td>
<td>1.0</td>
</tr>
<tr>
<td>340</td>
<td>1.2</td>
</tr>
<tr>
<td>360</td>
<td>1.8</td>
</tr>
</tbody>
</table>

**VERTICAL BEAMING LOADING**

- The increase in weld length results in the increase in SCF.
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6. Conclusions
• In the first stage, weld location optimization is performed on continuous welds
• In the second stage, weld length optimization is performed
• DOE based surrogate modeling techniques are utilized to obtain optimum weld length
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Weld Location Optimization

TORSIONAL LOADING

- outer-only weld design shows significant lower life along the throat than the other two designs

VERTICAL BEAMING LOADING

- toe-inner weld has the worst predicted life
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Problem Formulation

Maximize \( w_1 \times BFPFL + w_2 \times VBPFL \)

subjected to \( BFPFL \geq BFTFL \) & \( VBPFL \geq VBTFL \)

\[
f_i(X_1) = \beta_{B0i} + \beta_{B1i}X_1 + \beta_{B2i}X_1^2, \quad i=1,2,3,4,5,6
\]

\[
BFPFL(X_1) = \text{Min}(f_1, f_2, f_3, f_4, f_5, f_6)
\]

\[
g_i(X_1) = \beta_{V0j} + \beta_{V1j}X_1 + \beta_{V2j}X_1^2, \quad j=1,2,3,4,5,6
\]

\[
VBPFL(X_1) = \text{Min}(g_1, g_2, g_3, g_4, g_5, g_6)
\]

\( BFPFL \) is brake flange predicted fatigue life, \( VBPFL \) is vertical beaming predicted fatigue life, \( BFTFL \) – brake flange target fatigue life, \( VBTFL \) is vertical beaming target fatigue life, \( w_1 \) is the weight for \( BFPFL \), \( w_2 \) is the weight for \( VBPFL \), \( X_1 \) is the inner weld length \( (180^\circ \leq X_1 \leq 360^\circ) \), \( f_i \) is the response surface function for \( i \)th failure mode for \( BFPFL \), \( g_i \) is the response surface function for \( j \)th failure mode for \( VBPFL \), \( \beta_{B(0-2)i} \) are the regression coefficients of \( i \)th failure mode for \( BFPFL \), \( \beta_{V(0-2)j} \) are the regression coefficients of \( j \)th failure mode for \( VBPFL \).


- Inner weld length optimization is performed
- Can be extended to multiple welds
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Summary/ Conclusions

• A two-stage computational optimization method was implemented with weld location and weld length as the design variables
• Weld toe, root, and throat failure modes considered for this investigation
• Initial parametric studies can reduce the design space considerably
• Weld sizing and penetration depth can be quantified to prevent throat failure
• Good correlation is observed for welded axle components