Prediction of Weld Life With Structural Stress Approach for Automotive Axle Components Using Verity in fe-safe

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Presentation Outline

• Company overview
• Background
• Test correlation
• Best practices
• Significance of shear on axle welds
  - in-plane shear ($\tau_s$)
  - transverse shear ($\tau_z$)
• Summary
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: >100 WORLDWIDE
- LOCATIONS: >35 FACILITIES IN 13 COUNTRIES
  - Brazil
  - China
  - Germany
  - India
  - Japan
  - Luxembourg
  - Mexico
  - Poland
  - Scotland
  - South Korea
  - Sweden
  - Thailand
  - United States
Background

- Verity structural stress method was developed by Battelle
- Nodal force/moment based traction stress procedure
- Mesh insensitive nature validated
- Can be applied to multi-axial fatigue
- Adopted by ASME Sec. VII Div.2 and API 579-1/ASME FFS-1 2007
Background (Cont.)

Normal

\[ \sigma_s = \sigma_m + \sigma_b = \frac{f_z}{t} - \frac{6m_x}{t^2} \]

In-plane Shear

\[ \tau_s = \tau_m + \tau_b = \frac{f_x}{t} - \frac{6m_z}{t^2} \]

Transverse Shear

\[ \tau_z = \frac{f_y}{t} \]

- 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
Structural Stress Equation incorporating shear stress

\[ \Delta S_s = \frac{\Delta \sigma_s}{2 \cdot m} \cdot \frac{1}{f(r) \cdot m} \]

Effective Structural Stress Range Equation

\[ \Delta \sigma_e = \sqrt{(\Delta \sigma_s)^2 + 3 \cdot ((\Delta \tau_s)^2 + (\Delta T_z)^2)} \]

Effective Equivalent Structural Stress Range Equation

\[ \Delta S_e = \sqrt{2 \cdot m \cdot \Delta \sigma_s} \]

Dong, P., VERITY WELD FATIGUE METHOD IN FE-SAFE USING FEA Software

Master SN Curve

- Scatter in SN curve is higher in welds compared to structural components
- The database is built on simplified weld geometries
- Multiple weld sizes, shapes, and loading conditions collapsed into one curve

TEST CORRELATION
Predicted vs Experimental Weld Life

Constant Amplitude Loading

- 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
**Variable Amplitude Loading**

- Duty cycle comparison is made
- Good correlation is observed within the prediction band

**Graph Details**
- Mean
- Variation Band
- Bracket1 Time History
- PTU1 Duty Cycle

**Weld Life Comparison**
- Measured Weld Life
  - Rear axle bracket weld
  - PTU gear-shaft weld
BEST PRACTICES
Effect of Weld Sizing on Toe/Root Cracking

- Weld root failure has significant variability because defects are often present there in addition to weld throat size and penetration
- Weld S/T ratio should be considered carefully


Life prediction of welds under compression

- Weld can fail under compression
- However, same life for same magnitude under compression and tension is questionable

Mean Stress Effect on the Fatigue Life of the Weld

- Mean stress effect might be able to reduce the scatter
- Could be used in compressive loading cases

\[ \Delta S_s = \frac{\Delta \sigma}{(1-R)^m \cdot f(t)^{2m} \cdot I(r)^m} \]

\[ R = \text{Stress ratio} \]

SIGNIFICANCE OF SHEAR COMPONENTS
Normal component (Mode I)

- Fore-aft loading applied on the seat results in higher normal component on the weld
- Shear component has minimal effect

\[ \text{Life} = f(\Delta S, \Delta T_S, \Delta T_Z) \]

- Predicted Life: 1.12X
- Test Life: X
In-plane shear component (Mode III)

- Torsional loading applied on the flange results in higher in-plane shear on the weld

\[ \text{Life} = f(\Delta S_s, \Delta T_s, \Delta T_z) \]
Weld Life Prediction Comparison of Test Load Case (torsionally dominated loading) with Shear effect

- An in-house code is able to predict the combined shear effect
- The predicted result is close to the test result
- However, root cracking should be completely avoided
Transverse shear component (Mode II)

- The weld is pulled axially causing high transverse shear
- Not including transverse shear can result in over-predicting life

\[ \text{Life} = f(\Delta S_s, \Delta T_s, \Delta T_z) \]
Traction stress in a typical PTU loading scenario

- All three components have an effect
- Mode I is the dominating mode
- Combining the three modes should be correlated with test results

\[ Life = f(\Delta S_n, \Delta T_s, \Delta T_z) \]
Verity in fe-safe is a very useful tool in predicting weld life
Weld sizing and penetration can affect the failure mode
Effect of mean stress for compressive stress generating load cases need to be further studied
Shear components can play a significant role in test CAE correlation for axle welds