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

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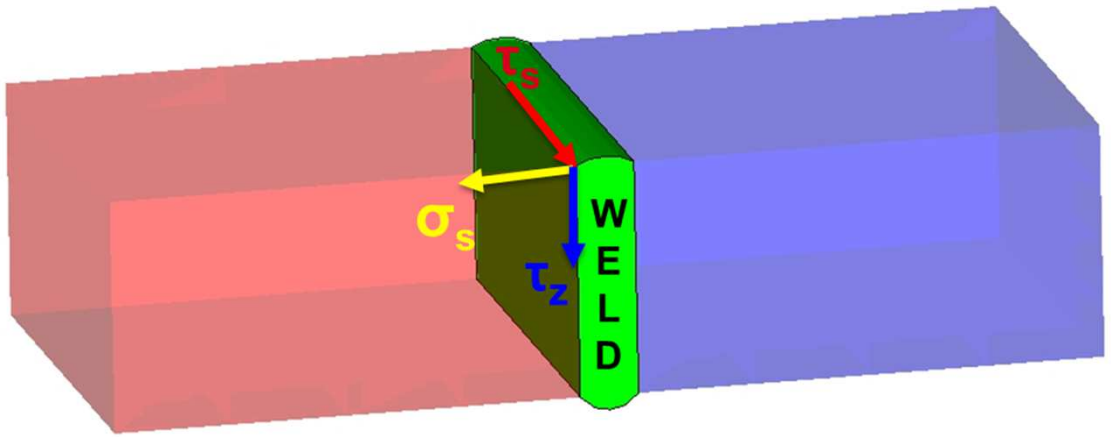
Presentation Outline

- Company overview
- Background
- Test correlation
- Best practices
- Significance of shear on axle welds
  - in-plane shear (τ_s)
  - transverse shear (τ_z)
- Summary



About AAM

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 FACILITES IN 13 COUNTRIES**

- Brazil
- China
- Germany
- India
- Japan
- Luxembourg
- Mexico
- Poland
- Scotland
- 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

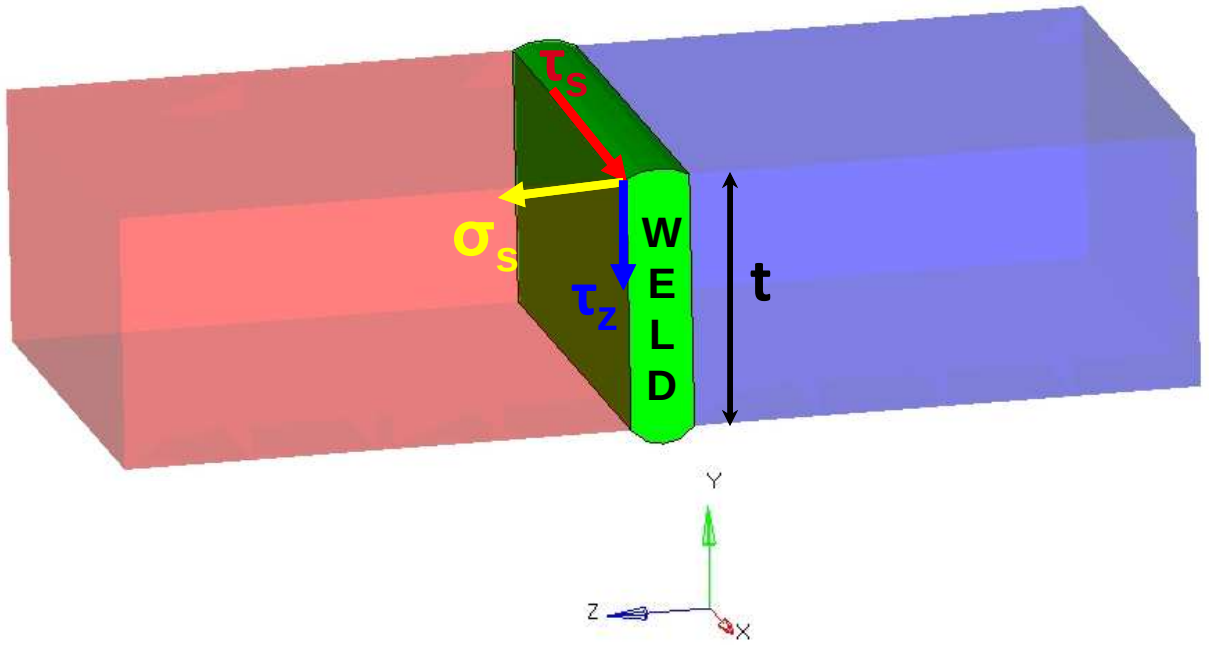
$$\sigma_s = \sigma_m + \sigma_b = \frac{f_z}{t} - \frac{6m_x}{t^2}$$

In-plane Shear

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

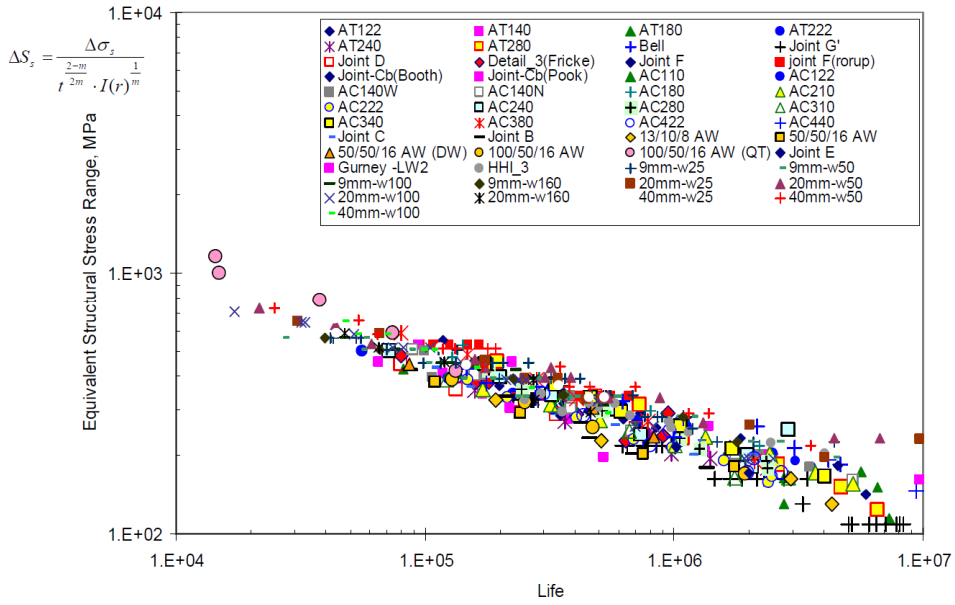
Transverse Shear

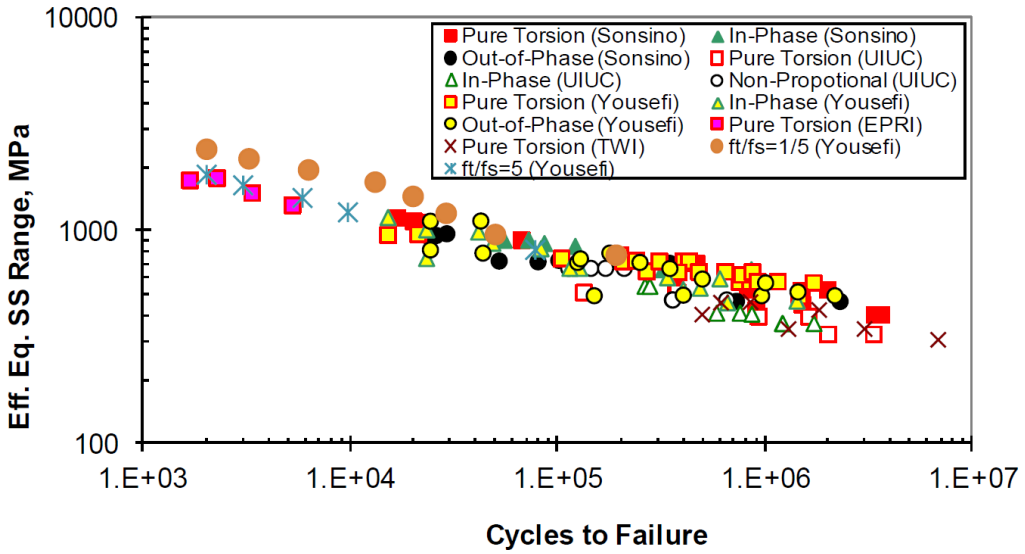
$$\tau_z = \frac{f_y}{t}$$



- 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





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

Equivalent Structural Stress Range Equation

$$\Delta S_s = \frac{\Delta\sigma_s}{t^{\frac{2-m}{2m}} \cdot I(r)^{\frac{1}{m}}}$$

Structural Stress Range

Loading Mode effects

thickness

Effective Structural Stress Range Equation

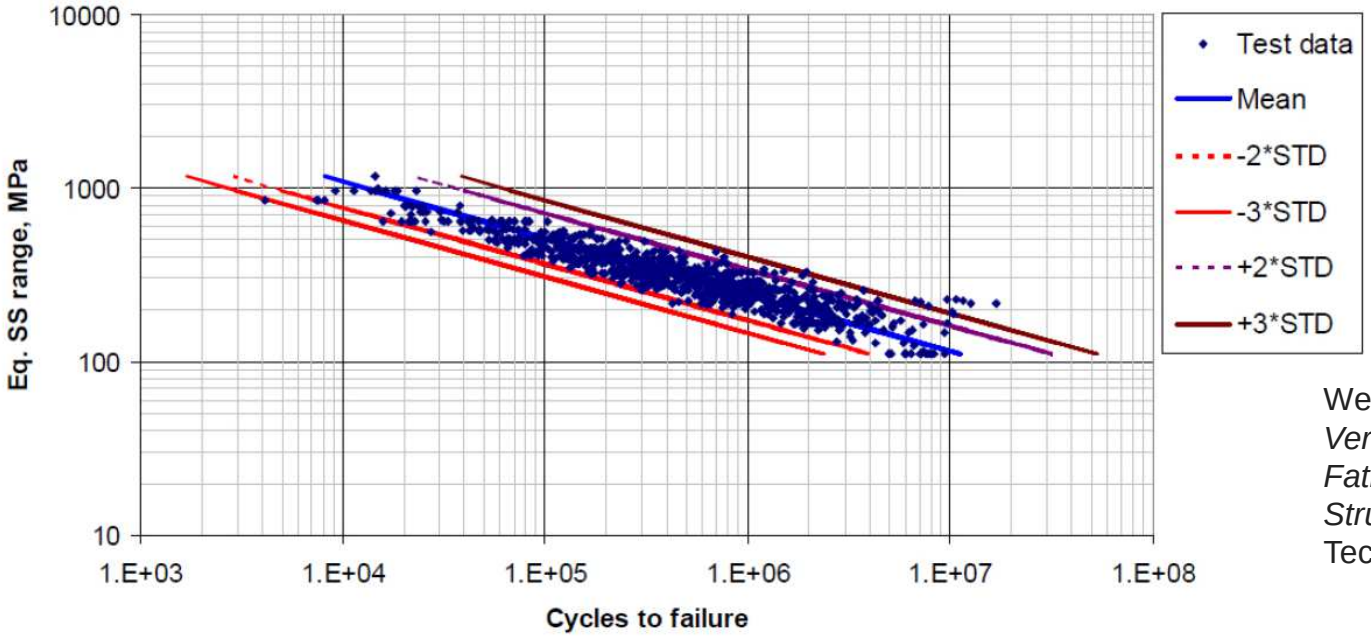
$$\Delta\sigma_e = \sqrt{(\Delta\sigma_s)^2 + 3\cdot((\Delta\tau_s)^2 + (\Delta\tau_z)^2)}$$

Effective Equivalent Structural Stress Range Equation

$$\Delta S_e = \sqrt{(\Delta S_s)^2 + 3\cdot((\Delta T_s)^2 + (\Delta T_z)^2)}$$

Hong, Jeong K., and Thomas P. Forte. "Fatigue evaluation procedures for multiaxial loading in welded structures using Battelle structural stress approach." *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering*. American Society of Mechanical Engineers, 2014.

Master SN Curve



Wei, Zhigang, et al. *Comparison of Verity and Volvo Methods for Fatigue Life Assessment of Welded Structures*. No. 2013-01-2357. SAE Technical Paper, 2013.

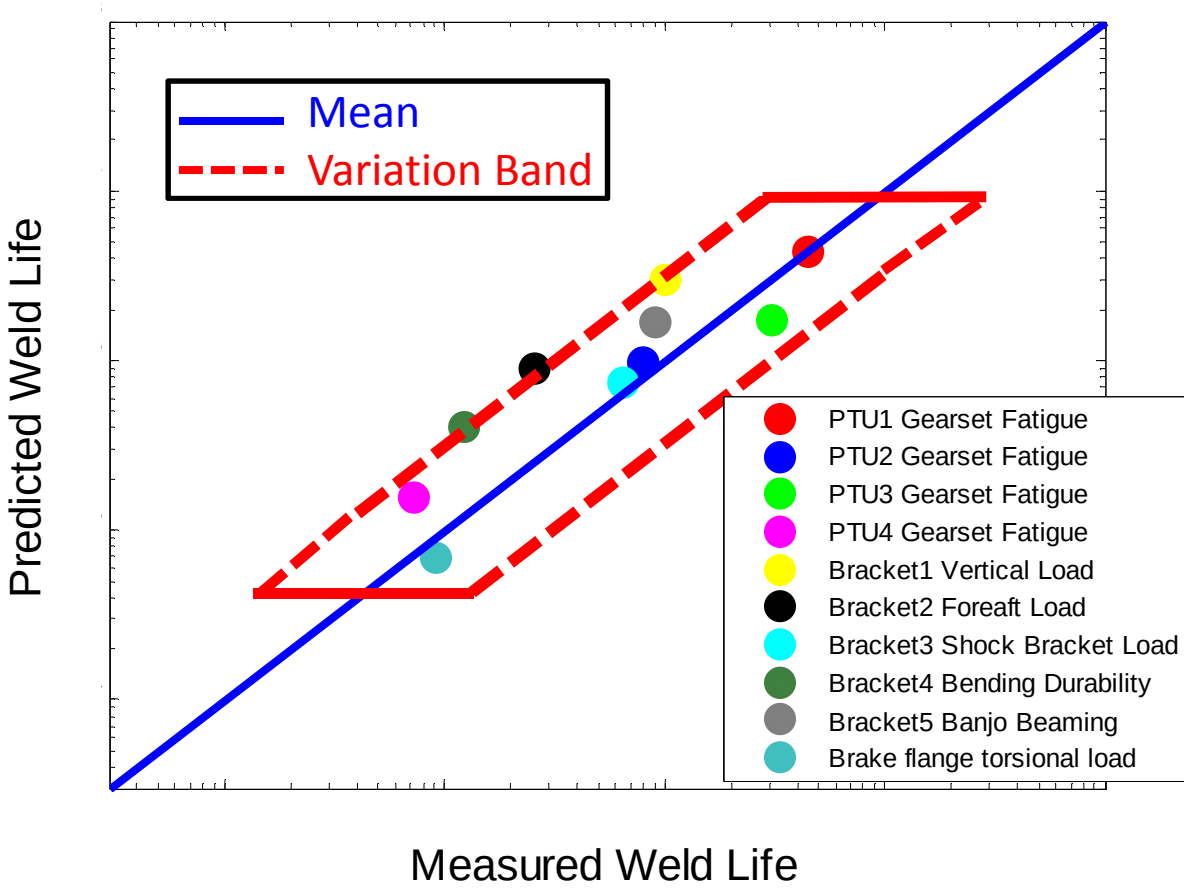
- Scatter in SN curve is higher in welds compared to structural components
- The database is built on simplified weld geometries
- Multiple weld sizes, shapes, and loading conditions collapsed into one curve

TEST CORRELATION

Predicted vs Experimental Weld Life

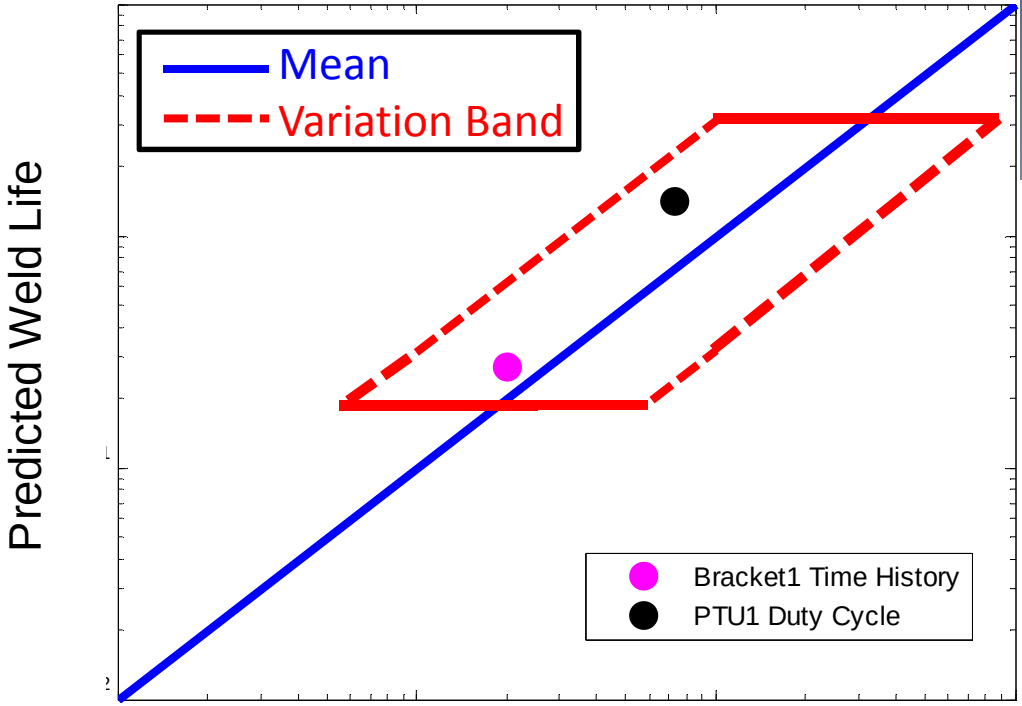
Constant Amplitude Loading

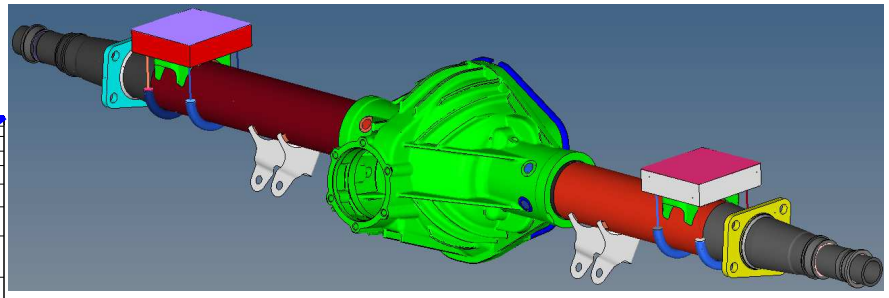
- Multiple geometries/ assembly, for AAM parts are compared
- Prediction bands are created by making use of the Battelle Master SN curve relationship for the variation observed in their weld life test data
- Good correlation is observed between AAM test and CAE prediction



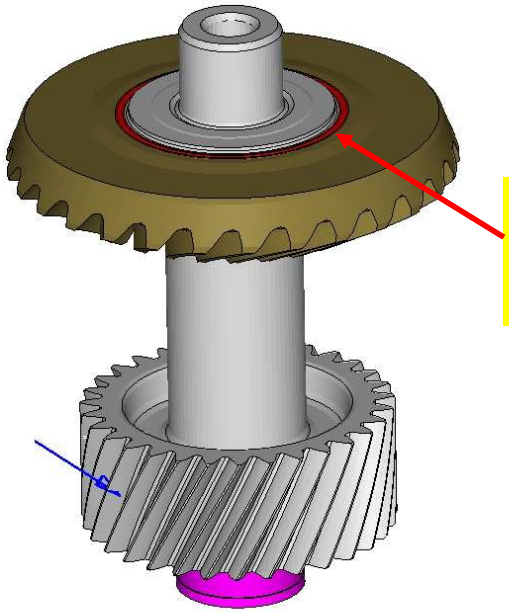
Predicted vs Experimental Weld Life

Variable Amplitude Loading





Rear axle bracket weld

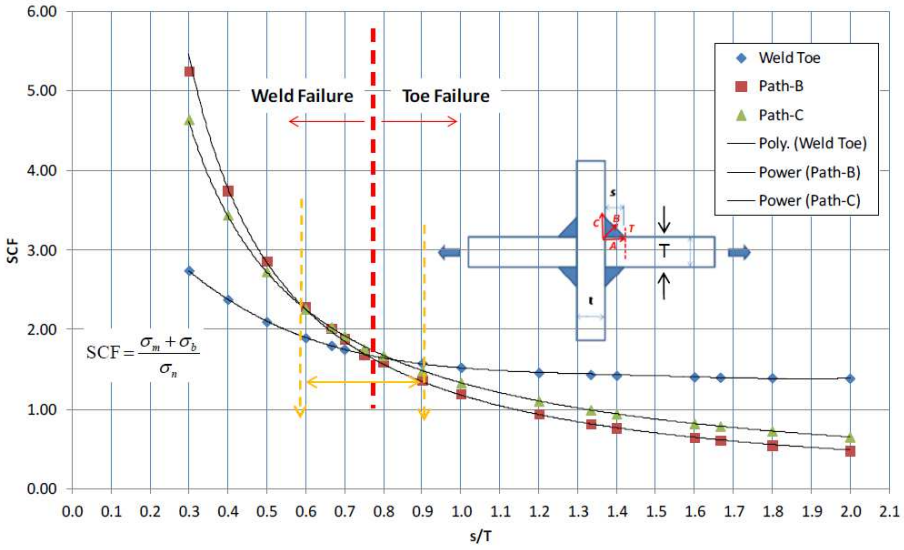


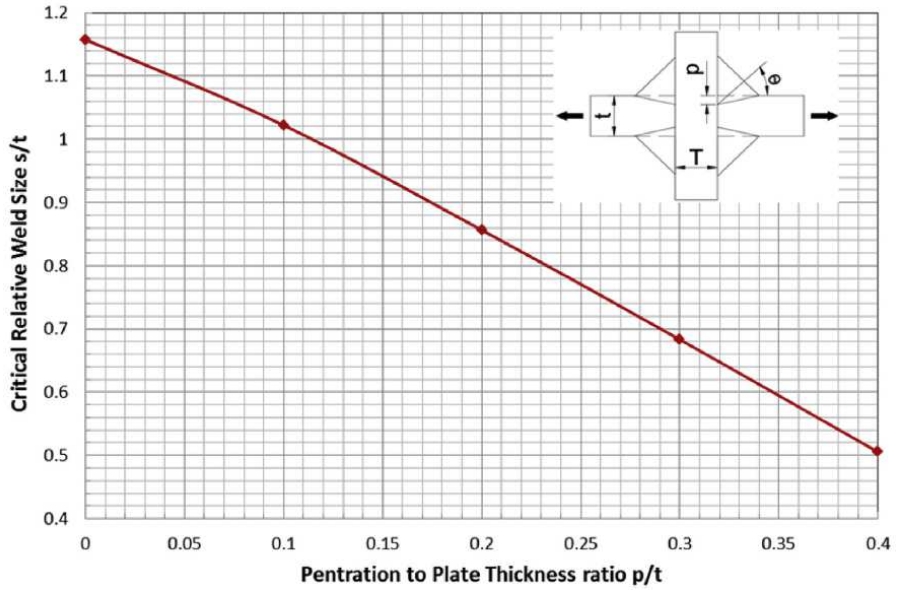
PTU gear-shaft weld

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

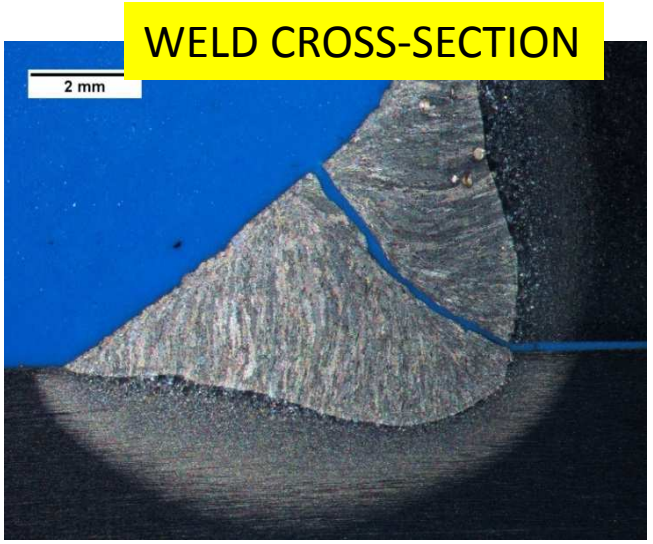
BEST PRACTICES

Effect of Weld Sizing on Toe/Root Cracking





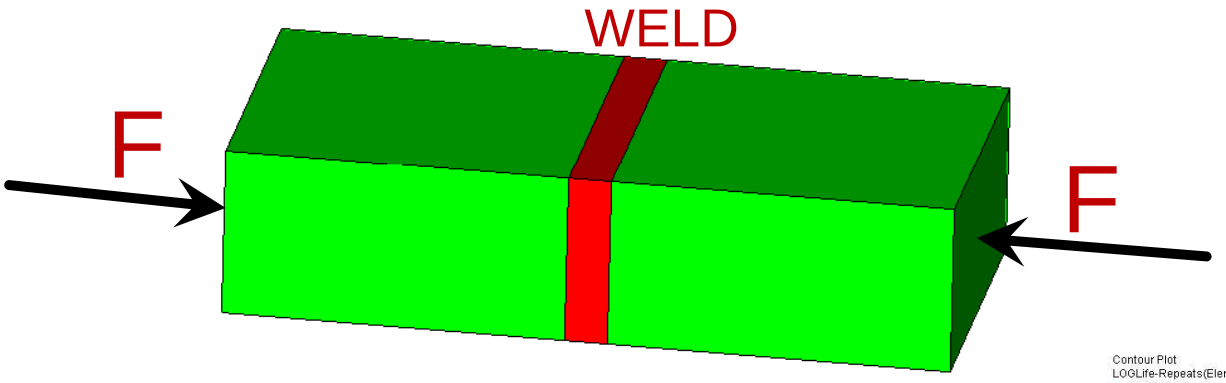
Huang, T. D., et al. "Reduction of Overwelding and Distortion for Naval Surface Combatants. Part 2: Weld Sizing Effects on Shear and Fatigue Performance." Journal of Ship Production and Design 32.1 (2016): 21-36.

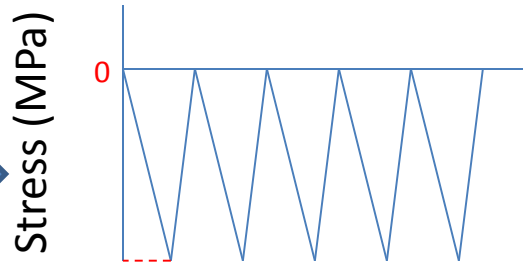


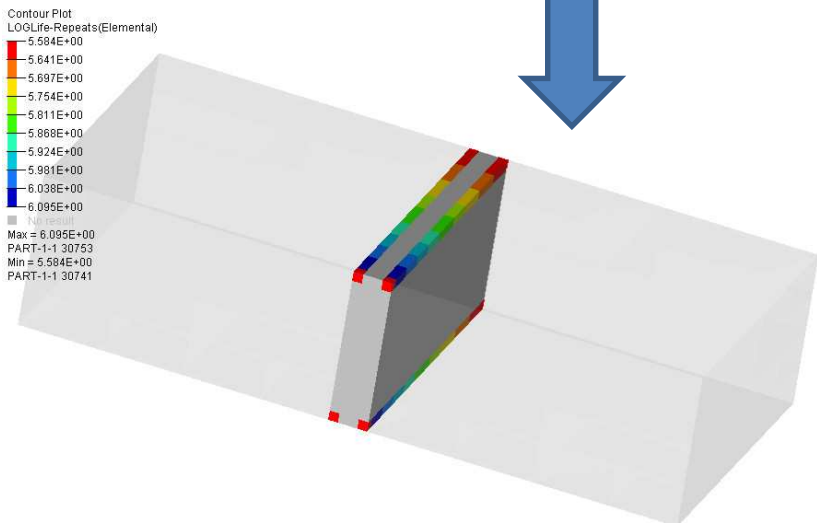
- Weld root failure has significant variability because defects are often present there in addition to weld throat size and penetration
- Weld S/T ratio should be considered carefully

Xing, Shizhu, and Pingsha Dong. "An analytical SCF solution method for joint misalignments and application in fatigue test data interpretation." *Marine Structures* 50 (2016): 143-161.

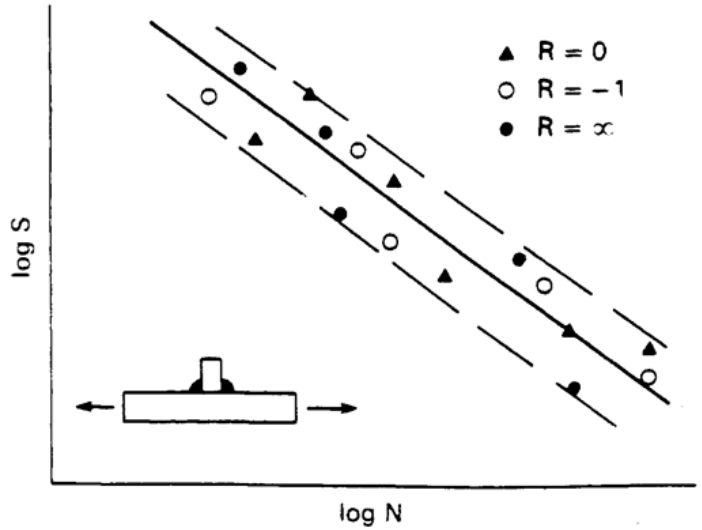
Life prediction of welds under compression







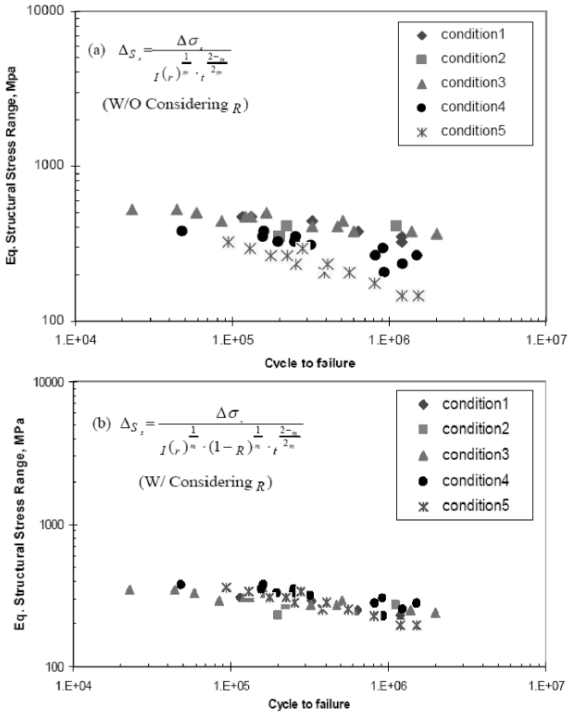
Gurney, T.R., 1979. *Fatigue of welded structures*. CUP Archive.



- 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

Condition	Loading mode
1	Pre-load=0 Mean stress=0
2	Pre-load= 0.5σ_a Mean stress=0
3	Pre-load= 0.85σ_a Mean stress=0
4	Pre-load= 0.85σ_a Mean stress= 0.5σ_a
5	Pre-load= 0.85σ_a Mean stress= 0.85σ_a



$$\Delta S_s = \frac{\Delta\sigma_s}{(1-R)^{\frac{2}{m}} \cdot t^{\frac{2-m}{2m}} \cdot I(r)^{\frac{1}{m}}}$$

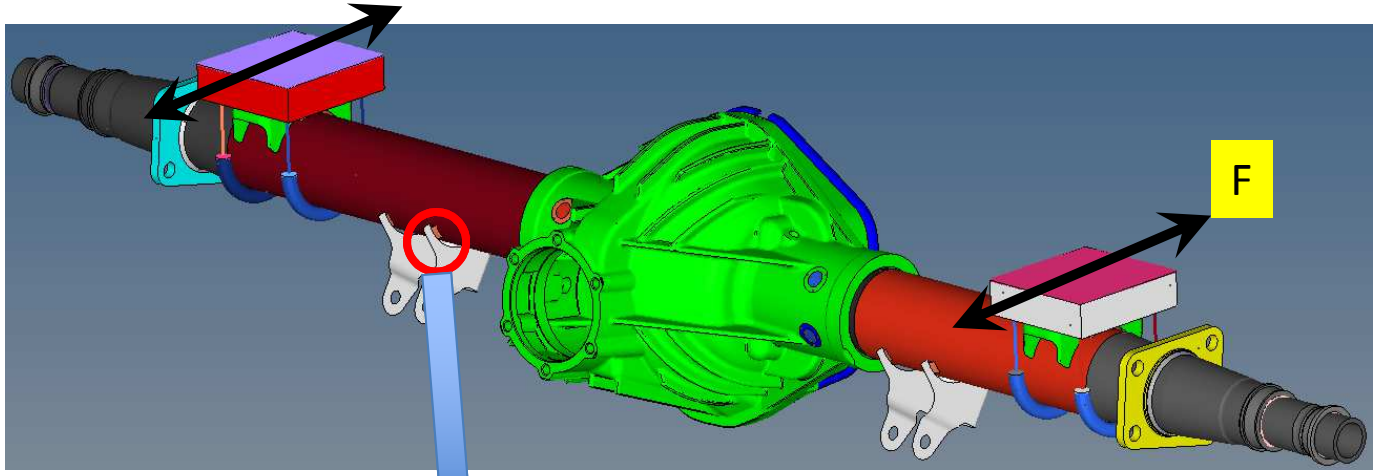
R=Stress ratio

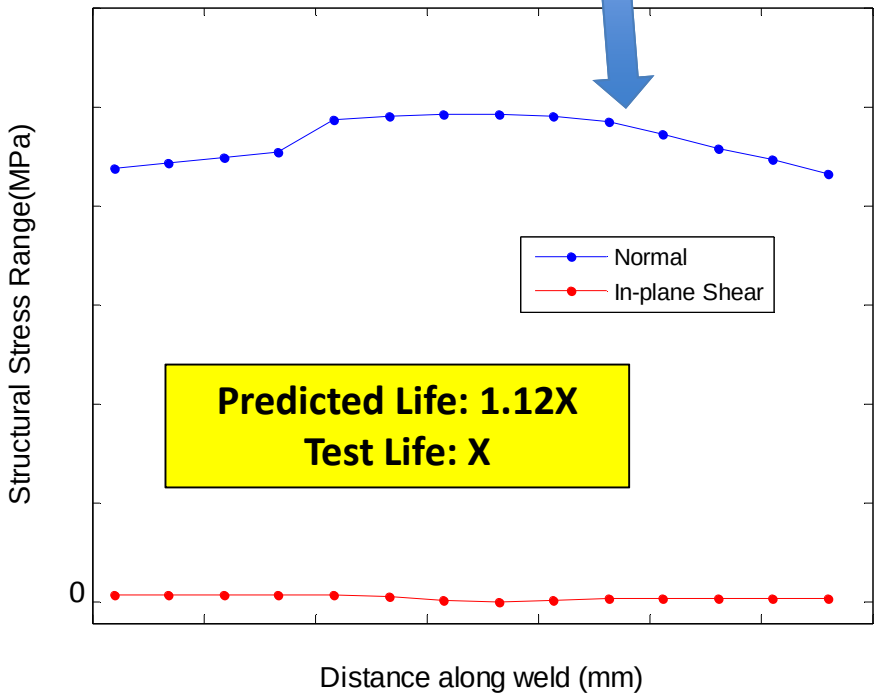
Kim, Jong-Sung, et al. "Mean Load Effect on Fatigue of Welded Joints Using Structural Stress and Fracture Mechanics Approach." *Nuclear Engineering and Technology* 38.3 (2006): 277-284.

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

SIGNIFICANCE OF SHEAR COMPONENTS

Normal component (Mode I)





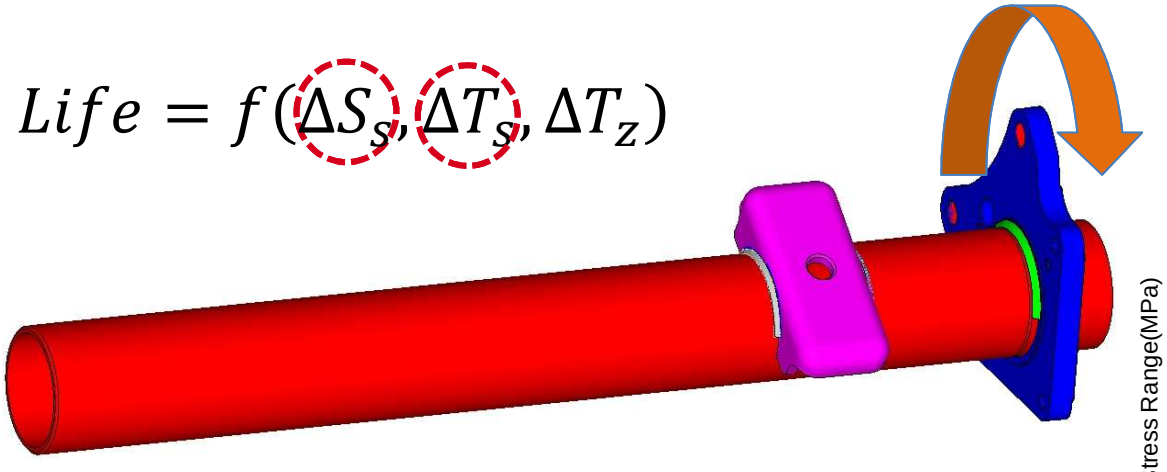
$$Life = f(\Delta S_s, \Delta T_s, \Delta T_z)$$

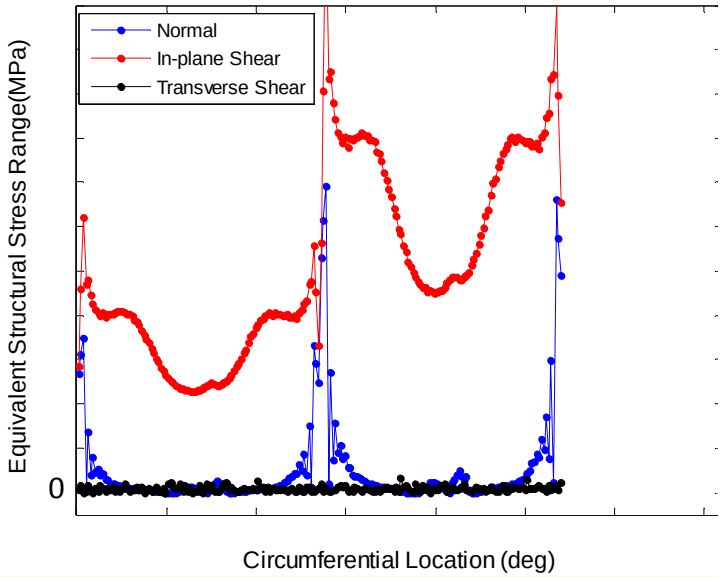
- Fore-aft loading applied on the seat results in higher normal component on the weld
- Shear component has minimal effect

In-plane shear component (Mode III)

TEST SPECIMEN

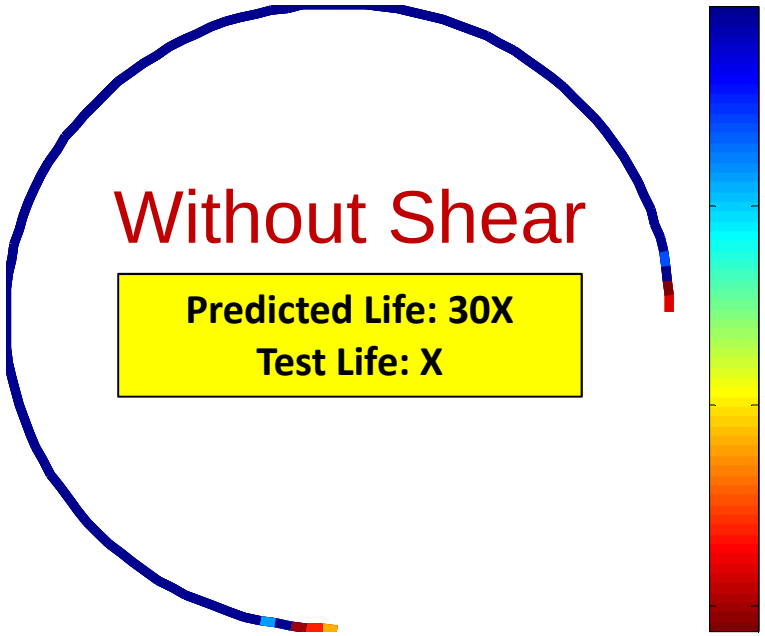
$$Life = f(\Delta S_s, \Delta T_s, \Delta T_z)$$

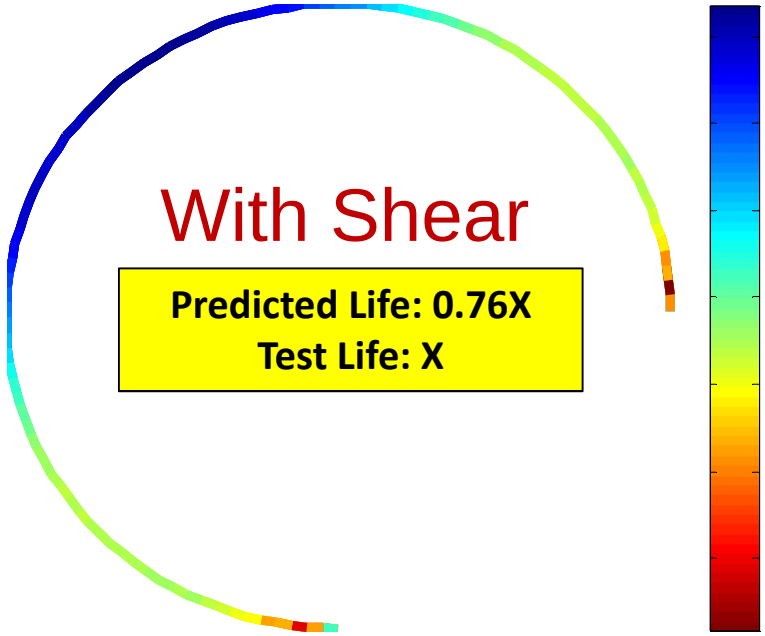




- Torsional loading applied on the flange results in higher in-plane shear on the weld

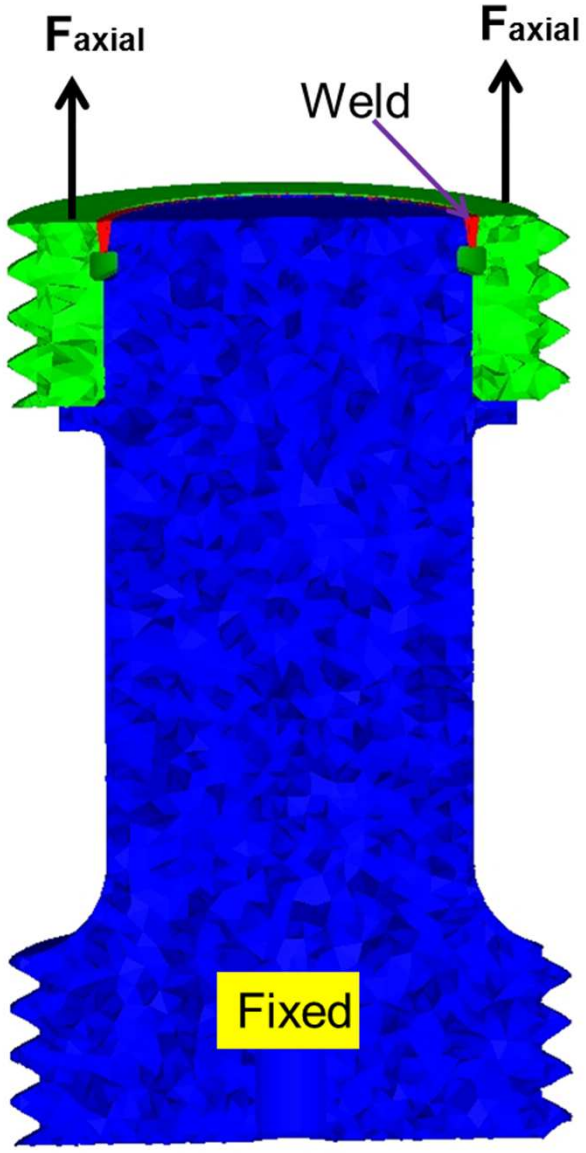
Weld Life Prediction Comparison of Test Load Case (torsionally dominated loading) with Shear effect

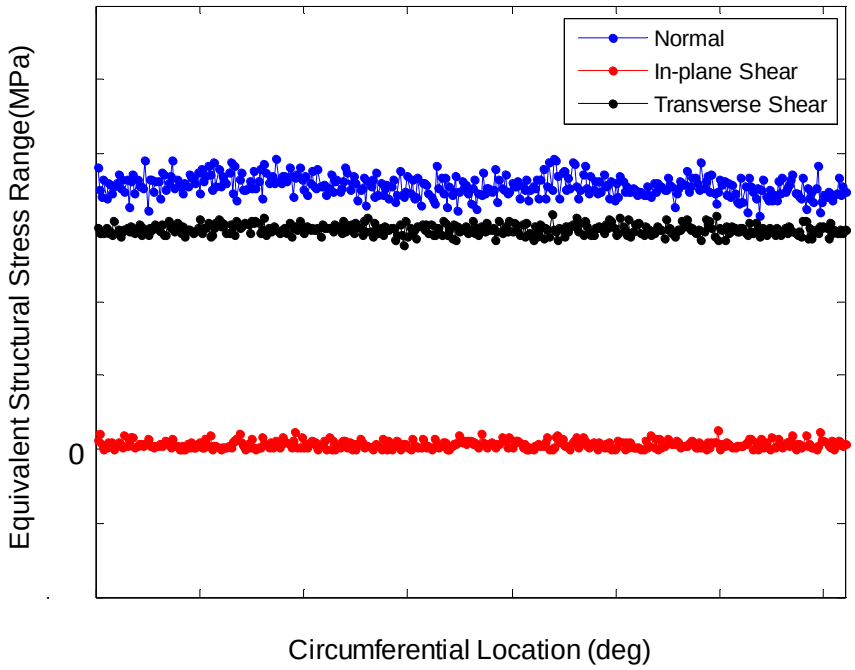




- An in-house code is able to predict the combined shear effect
- The predicted result is close to the test result
- However, root cracking should be completely avoided

Transverse shear component (Mode II)

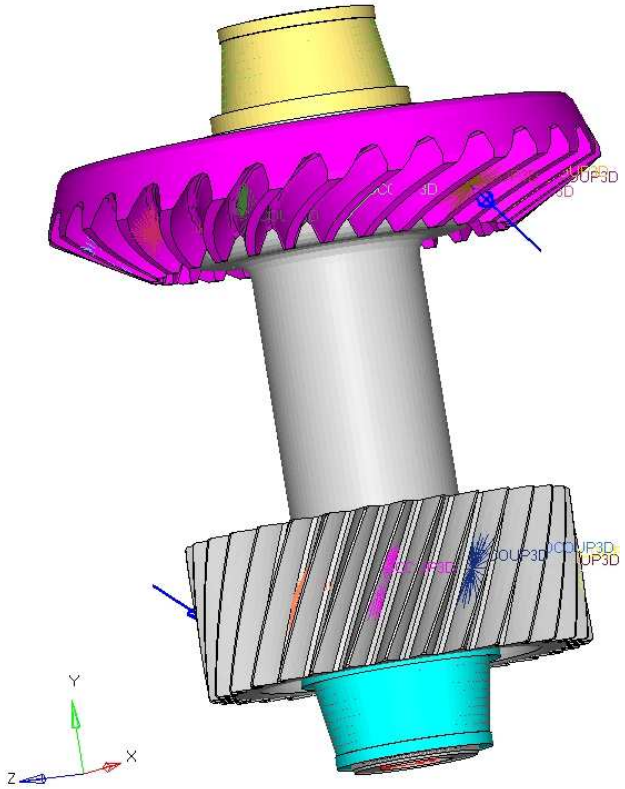


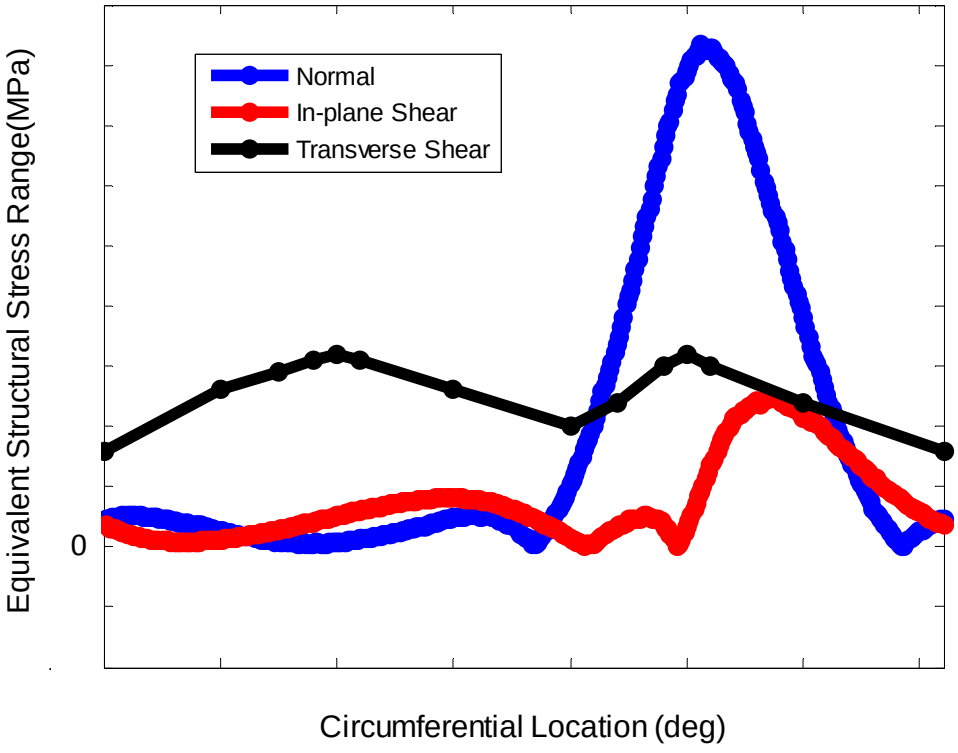


$$Life = f(\Delta S_s, \Delta T_s, \Delta T_z)$$

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

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

$$Life = f(\Delta S_s, \Delta T_s, \Delta T_z)$$

Summary

- 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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