IV Modeling Weldment Fatigue Behavior

before

after
Outline

- Modeling difficulties posed
- Basic Information
- Possible models
Applied stresses are always uncertain!

A factor of 2 uncertainty in the applied load causes the life to vary by a factor of 10!
Distortions cause secondary stresses!

\[ S_B = \frac{3}{2} \alpha S_A \left( \frac{L}{t} \right) \tanh \frac{\beta}{\beta} \]

\[ \beta = \frac{L}{t} \sqrt{\frac{3 S_A}{4E}} \]
Weldment fatigue behavior is dependent on the manner of loading!

Fatigue resistance depends upon loading conditions.
So many geometries!

There is an infinite number of weldment geometries.
A simple weld may have many failure modes!

While the weldment may be simple, many different failure scenarios may exist.
Weldment geometry may actually be undefined!

Example: T-joint with a variable fit-up

Tight fit-up: $K_t = 3.6$

Normal fit-up: $3.6 < K_t < 6.4$

Loose fit-up? $K_t = 6.4$
Weld shape may vary!

The geometry of a weldment may vary with location.
Weld quality variable!

"Nominal" Weldment

Undercut, Slag Entrapment and/or other Discontinuities

Base Metal

HAZ

Fatigue Cracks

Weld Metal

0.1 in

"Ideal" Weldment

Weld Metal

HAZ

Base Metal

AM 11/03
Mean stresses alter fatigue life!

Applied mean stresses, welding residual stresses, and fabrication residual stresses
Weldment size affects fatigue life!

Longer Fatigue Life

Region of high stress

Shorter Fatigue life

Same initial size, crack grows to 2x initial length
Material properties generally unknown!

Fatigue cracks begin in WM or HAZ not in BM!

Good news: Material properties don’t matter too much!
Summary

- The variables influencing weldment fatigue life can be thought of as being only two:
  - the magnitude of the notch root stresses.
  - the properties of the notch root material.

- In this sense, the applied stresses, the degree of bending, the welding residual stresses, the fabrication residual stresses, the applied mean stresses, the weldment geometry, the notch root weld defects, and the weldment size all influence the magnitude of the notch root stresses.
Summary

- The fatigue behavior of a weldment is controlled by the local (notch root, hot-spot) stress-strain history.

- For structural steel weldments: material properties are of minor importance except (as we shall see) to the degree that they determine and limit the value of the residual stresses.
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Fatigue of a component

The fatigue life of an engineering component consists of two main life periods:

Initiation or nucleation of a fatigue crack (NI)

And

Its growth to failure (NP)

A smooth specimen
Fatigue test data from strain-controlled tests on smooth specimens.

Elastic component of strain, $\Delta \varepsilon_e$

Plastic component of strain, $\Delta \varepsilon_p$

Smooth specimen behavior

\[
\Delta \varepsilon_t = \Delta \varepsilon_e + \Delta \varepsilon_p = \frac{\sigma_f}{E} (2N_f)^b + \varepsilon'_f (2N_f)^c
\]
Basic Information - crack growth

I Sensitive to microstructure and environment. Dominated by crack closure effects.

II Paris power Law.

III Approaching fracture when $K_{\text{max}} \sim K_{\text{IC}}$.

Paris Power Law

$$\frac{da}{dN} = C (\Delta K)^m$$

Log Crack Growth Rate, $da/dN$ (m/cycle)

Log Range in Stress Intensity Factor, $\Delta K$ (MPa$\cdot$m)

Near threshold

Long cracks
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Modeling options

$\Delta a_i = ?$

- **Actual**
  - Crack Nucleation
  - Short Crack Growth
  - Long Crack Growth

- **IP Model**
  - $N_I$

- **Modified PICC-RICC Model**
  - $N_F$

- $a_i = 0.01$-in. (0.25mm)

- Smooth specimen
Models

- $N_I$ only - Strain controlled fatigue
- $N_{P2}$ - Current TWI models
- $N_F$ only - Dong et al.
- $N_N + N_F$ - PICC-RICC model
- $N_I + N_{P2}$ - The I-P model
The relative importance of fatigue crack initiation and propagation in smooth specimens of SAE 1045 steel. (after Socie)
IP Model details

\[ N_T = N_I + N_{P2} \]

- Laboratory fatigue tests on smooth specimens
- Mechanics analysis (FEA)
- Laboratory tests on pre-cracked specimens
- Fatigue notch size effect
- Set-up cycle
- Estimation of \( N_T \)
- \( \sum \frac{N'_i}{N'} = 1 \)
- \( \sigma_m \)
- \( \varepsilon_f, \sigma_f, b, c \)
- \( K, K', n, n' \)
- \( K_t \rightarrow K_{fmax} \)
- \( K_{fmax} \)
- \( M_k \)
- \( C, n, U \)
- \( a_i = ? \)
- \( N_T = N_I + N_P \)
CCN model

\[ N_T \sim N_F \]

Crack closure at a notch model. Information about \( U(a) \) becomes the “sticking point.”

\[ N_F = \int_{a_i}^{a_f} \left( \frac{da}{dN} \right)^{-1} \, da \]
Model performance

Test data [1]
A' - LEFM, straight-front crack
B' - LEFM, crack-shape development
C' - Crack-closure model, linear Paris law
D' - Crack-closure model, bilinear Paris law
E - I-P model
Unresolved modeling difficulties

- IP - What is the size of the crack at the end of the \( N_1 \) stage? 0.01-in? \( a_{th} \)?
- IP - What is the meaning of \( K_f \)?
- CCN - What is the value of \( U \) as a function of crack length? What is the value of \( U \)?
- All - What are the residual stresses, and how do they vary with location and change during the service life of the weldment?