VII Improving the fatigue life of weldments
Outline

- Obvious things to do
- Problems the weld toe
- Fatigue life Improvement Strategies
- Light and heavy industry weldments
- Improving the “bad” weldments
Crude! (bad)
Better
Bad - planar weld discontinuities
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Weld toe is a stress concentration
Slag entrapments at toe?

Virtually eliminates fatigue crack initiation life NI
Cold-lap defects at weld toe

Cold laps virtually eliminate the fatigue crack initiation life (NI)

Such weldments may have an appreciable fatigue crack initiation life (NI)
Cold lap at a weld toe

- Weld Metal
- Heat Affected Zone
- Base Metal
- Curved Path
- Vertical Path
- Weld Toe Location Without Cold-Lap Defect
- Loading Direction

Symbols:
- $\theta$
- $D$
- $r$
- $\phi$

Direction of Loading
Effect of cold lap depth

\[ \frac{a}{T} \]

2-D FEM

- \( D = 0.0 \, \text{mm}, \, M_{K_{CG}} \)
  - curved path from weld toe location
- \( D = 1.0 \, \text{mm}, \, M_{K_{CG}} \)
  - curved path from cold-lap defect
- \( D = 1.0 \, \text{mm}, \, M_{K_{CG}} \)
  - vertical path from cold-lap defect
Effect of flank angle

Weld geometry correction factor, $M_K$

Crack length / main plate thickness, $(a/T)$

2-D FEM

$\theta = 30^\circ$
$\theta = 45^\circ$
$\theta = 60^\circ$

$D = 1.0 \text{ mm}$
Effect of cold root radius

- D = 0.00 mm, weld toe location
- D = 2.00 mm, r_{cl} = 0.146 mm
- D = 2.00 mm, r_{cl} = 0.025 mm

Weld geometry correction factor, M_{K} vs. Crack length / main plate thickness, (a/T)
Recent study on rail welds

- Toe Radius, $R$
- Base Metal Thickness, $T_0$
- Flank Angle, $\theta$
- Weld Reinforcement Height, $H$
- Weld Collar Width, $W$
Geometric Parameters

- Fin Length, $L_f$
- Cold Lap Length, $L_{cl}$
- Fin Thickness, $T_f$
- Flank Angle, $\theta$
Weld with a Fin and a Cold Lap
Deformed Shape

ELEMENT SOLUTION
STEP=1
SUB=1
TIME=1
S1 (NOAVG)
DXY = .351E-09
SMN = -.099948
SMX = 6.819

ANSYS
OCT 3 2003
16:06:08
Nominal Weld Geometry
Fin length

Elastic Stress Concentration Factor, $K_t$ ($-$)

Fin length, $L_f$ (mm)

Fin Thickness = .5mm

Fin Thickness = 1mm

Fin Thickness = 2mm
Fins and Cold Laps

For all Tests

\( R = 3\text{mm} \) and \( \theta = 30^\circ \)
Predicted effect of $S_{uBM}$

Trends in “Ideal” 1.0-in plate thickness, non-load carrying cruciform weldments fatigue strength.

- $R = 0$
- Welding residual stresses = 50% of $S_{YBM}$
- $S_{fab} \sim S_{YBM}$
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Good - grind off reinforcement
Good - burr grind weld toe
Very good - full face grinding
Shot peened weld toe
Remelted weld toe (laser)
TWI suggestions as to weld improvement procedures
Improvement strategies

Shot Peen

Residual stress

Geometry

Base metal strength

Fatigue Strength (ksi) at $10^6$ cycles

Base metal UTS (ksi)

Over Stressed

Stress Relieved

Plain plate

As Welded

Improvement strategies

Shot Peen

Residual stress

Geometry

Base metal strength

Fatigue Strength (ksi) at $10^6$ cycles

Base metal UTS (ksi)
Example

IP model predictions and experimental data.
ASTM A 36 butt weldment
ASTM A 514 butt weldment
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Light, heavy industry weldments

- Light industry weldments are presumed to be fabricated from 1/2” or smaller plate and not to have large fabrication stresses.

- Heavy industry weldments are presumed to be fabricated from larger than 1” thick plates and to possess large fabrication stresses.
Light industry weldments

Remote Stress Range, $\Delta S$ (ksi)

Fatigue Life, $N_T$ (cycles)

- Toe Ground (radius = 0.1 in.)
- Over Stressed
- Stress Relieved
- Weld Profile (flank angle 20°)
- As Welded

$t = 0.5$-in. (12mm); $R = 0$
Without Fabrication Stresses

Nominal

Ideal
Heavy industry weldments

Remote Stress Range, $\Delta S$ (ksi)

Fatigue Life, $N_T$ (cycles)

- Toe Ground (radius = 0.1 in.)
- Over Stressed
- Stress Relieved
- Weld Profile (flank angle 20°)
- As Welded

$t = 2.0$-in. (50 mm); $R = 0$
With Fabrication Stresses

Nominal

Ideal
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Good weldment

Weldment with a transverse attachment
Weldments with longitudinal attachments have a low fatigue resistance because of the presence of weld terminations. Starts and stops introduce weld discontinuities. Residual stresses very high. 3-D stress concentrations effects.
Examples of terminations
Placement of stress diffuser

Longitudinal attachment

Longitudinal attachment with stress diffusers

Stress diffuser
3-D FEM modeling
Effectiveness of a stress diffuser

Longitudinal attachment

Longitudinal attachment with stress diffuser
Effect on $M_K$ and $N_p$

![Graph showing the effect of weld geometry on $M_K$ and $N_p$. The graph plots the weld geometry correction factor, $M_K$, against the crack length / main plate thickness, $(a/T)$, and the fatigue crack propagation life, $N_p$, against the initial crack length / main plate thickness, $(a/T)$. The graph includes lines for L.A., L.A. with stress diffusers, and Transverse attachment.]
Fatigue test results

![Graph showing remote stress range vs. fatigue life for different series of L.A. and L.A. with stress diffusers.](image)

- L.A., Series 1
- L.A., Series 2
- L.A., Series 3
- L.A. with stress diffusers, Series 1
- L.A. with stress diffusers, Series 3
Fatigue test results

- Transverse attachments, database
- Longitudinal attachments, database
- LA specimens, Procedures 1 and 2
- LA specimens, Procedure 3
- SD specimens, Procedure 1
- SD specimens, Procedure 3
Summary

• The fatigue strength of “Ideal” weldments can be much improved; whereas, the fatigue strength of “Nominal” weldments cannot.

• Weld toe grinding or weld profile control works best for “Ideal” weldments at short lives. Beware of corrosion pitting.

• Smaller “Ideal” weldments are more susceptible to improvement than larger weldments.

• Fabrication stresses are critically important.
Summary

- The behaviors of light and heavy industry weldments are dissimilar.

- Stress relief annealing and over-stressing works best for “Ideal” weldment at long lives. Beware of compressive overloads.

- Fatigue behavior of weldments and effective life improvement methods depends upon weldment size and weld quality.

- Stress-diffuser can substantially improve the fatigue life of terminations without post-weld processing.