Twin Cities
ANSYS® User Meeting
August 2012

Weld Analysis
1. Explicitly Modeled Welds
2. Extracting Stresses for Hand-Calculations
   – Path Operations
   – Stress Linearization
3. Designing / Lifing Welds - -Chris Wright P.E.
Explicitly Modeled Welds

1. **Material Properties are undefined**
   - Heat affected zone
     - Composition varies spatially due to material mixing/cooling rates
     - Would need fatigue properties gathered at various R-ratios and compositions?
     - Welding/Cooling rates depend on weld process/operator

2. **Geometric Variations also hard to assess**

3. **Process would be similar to Soldering/Semiconductor**
   1. Model weld bead explicitly
   2. Use viscoplastic material model (e.g. Anands)
   3. Have modulus approach zero above weld temperature
   4. Use Element Birth/Death to “activate” along the weld line
   5. Use Heat Generation along weld as elements are activated
   6. Cool with HTC’s for quiescent air... 5 btu/ft^2/sec-F?

4. **Bound problem to assess (large) variation!**
Extracting Stress Data

1. Path Operations, extracts stresses along specified path.

- In classic steps are to define a path, and then map a result onto the path, then finally plot/list the results.
Extracting Stress Data

1. Path Operations, extracts stresses along specified path.
   - In classic steps are to define a path, and then map a result onto the path, then finally plot/list the results.
   - Highly Dependent on Mesh, and selection of points!

Coarse: 500

Fine: 840
Extracting Stress Data

1. Path Operations, Stress Linearization
   - Relatively sensitive to Mesh, and selection of points!
   - Will match hand-calc's with no KT’s applied (in theory)
   - Devolves stress into tensile and bending components!
Extracting Stress Data

1. Path Operations, Stress Linearization

**Fine:** 187

**Coarse:** 188

**Fine / Path 2:** 187
ANSYS and Weld Design

Twin Cities ANSYS User Group
August 22, 2012
Design Problem

**DESIGN FUNCTIONS**
- Connection (not weld) design
- Load transfer
- Load path definition
- Determine loading
  - Magnitude
  - Distribution
- Fabrication decisions
  - Weld type
  - Geometry constraints
  - Process variables
  - Quality assurance
- Criteria
  - Working stress
  - Fatigue Assessment

**CONSTRAINTS**
- Design code
- Prescriptive requirements
- Allowable stress
- Methodology
- Fabrication
- Material weldability
  - Set up and tooling
  - Thermal effects
- Labor intensive
  - Process qualifications
  - Welder skills
- Quality Assurance
  - Customer requirements
  - Code requirements
Modeling Problem

PARAMETERS
- Weld size
- Type
- Extent

BEHAVIOR
- Static strength
- Fatigue response
- Thermal response

CONVENTIONAL DESIGN
- Weld load carried by shear across throat
- Direct loads distributed uniformly
- Moment reactions vary radially

CRITERIA
- 0.3Fu (AISC)
- 0.6S for groove weld shear (ASME)
- 0.49S for fillet weld shear (ASME)
- Separate fatigue assessment

IMPLICIT WELD MODEL
- Weld joint defined by coupling or constraints
  - Weld loading developed by equilibrium and continuity
  - Nodal forces define connection load distribution
  - Apply design code requirements

EXPLICIT WELD MODEL
- Weld contour defined in nodal mesh
  - Peak stress calculated by path operation

TRADE-OFFS

<table>
<thead>
<tr>
<th>Implicit</th>
<th>Explicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld size determined by from results</td>
<td>Weld design required beforehand</td>
</tr>
<tr>
<td>Real world features implied by Code</td>
<td>Weld contours and metallurgy idealized</td>
</tr>
<tr>
<td>Mesh refinement not required</td>
<td>Refined mesh required</td>
</tr>
<tr>
<td>No remesh required to vary weld size or type</td>
<td>Weld redesign requires re-model</td>
</tr>
</tbody>
</table>
Weld Fabrication

- Spot weld
- Stiffener weld
- Fillet weld
- Fillet weld with porosity
- Flare bevel
Quality Issues

Porosity and root opening

Procedural errors

Start and stop craters

Undercut
Chain Link

Clevis Plate Stress

Clevis Weld Load
Elastic Method

Moment Loading:
\[ M = r_{ij}F_{ij} = F = r_{ij}F = F \]

Elastic Loadings:
\[ Q_{xy} = \frac{Mx}{J}, \quad Q_{yz} = \frac{My}{J} \]

Direct Loading:
\[ Q_{x} = \frac{V_{x}}{l}, \quad Q_{y} = \frac{V_{y}}{l} \]

Ultimate Strength Method

Ultimate Load:
\[ P = \frac{1.6}{1 + \frac{1}{\alpha + \frac{\gamma}{\beta}}} \]

Example:
\[ P = 3.16k, \quad A = 10 \text{ in}, \quad 1-10 \text{ in}, \quad kl = 5 \text{ in}, \quad xl = 1.25 \text{ in}, \quad y = 5 \]

Weld Stress:
\[ \sigma = \frac{P}{t_{w}} = 21,032 \text{ psi} \]

Allowable Load:
\[ C = \frac{0.928}{1 + \frac{1}{\alpha + \frac{\gamma}{\beta}}} = 0.5258 \]

Using the Ultimate Strength Method:
\[ C = 0.704, \quad P = 3.16(0.7) (1)(10)(6) = 42.2k \]
Bracket Plate

- 3/8 Bracket plate fillet welded to rectangular base plate fixed at edges
- Weld attachment simulated with rigid constraints
- Weld force distribution compared to AISC Elastic method
ASME Code Design

Prescriptive provisions
Specific weld joint details
  Flange attachment
  Opening details
Weld details
  Types
  Sizes
Allowable stresses
  Construction dependent
Quality assurance
  Joint efficiencies

Non Prescriptive Provisions
Attachments
  Supports
  Machinery
External loading
  Piping loads
  Impact
Unique construction
  Non-circular openings
  Proprietary items
Design by analysis (VIII-2)
  Lower design margin
  More restrictive quality assurance
  Explicit weld analysis rules
Explicit Modeling

Solid Model

Shell Model

Nozzle Thickness

Head Thickness

Shell Model at Mean Radius of Nozzle and Shell

Weld Leg

Weld Throat Thickness (see Note 1)

Stress Evaluation Point
Non-Circular Opening

- Pressurized bulkhead 29.5 in OD x 1.75 in thick with reinforced 16.25 x 12.75 rectangular opening
- Face bar attachment simulated with rigid constraints
- Weld force distribution checked against ASME Code opening requirements
Fatigue ASME Code

ASME Code Fatigue rules originate from the Coffin-Manson rule: the product of the plastic strain amplitude (half the strain range under reversed loading) produced by a cyclic loading and the number of cycles to crack initiation equals half the fracture ductility:

\[ \varepsilon_f \sqrt{N} = \varepsilon_{fr} = \frac{1}{2} \ln \left( \frac{100}{100 - RA} \right) \]

where:
- \( \varepsilon_f \) amplitude of plastic strain
- \( N \) number of cycles to crack initiation
- \( RA \) Reduction of area from tensile test
- \( \varepsilon_{fr} \) fracture ductility

Taking the total strain amplitude as the sum of the plastic and elastic strain amplitudes and converting to stress by multiplying by the elastic modulus the cyclic stress amplitude to failure becomes

\[ S = \frac{E}{4\sqrt{\pi}} \ln \left( \frac{100}{100 - RA} \right) + \Delta S \]

For materials showing an endurance limit \( \Delta S \) is taken as the endurance limit

\[ S = \frac{E}{4\sqrt{\pi}} \ln \left( \frac{100}{100 - RA} \right) + S_e \]


### Table 5.11 Weld Surface Fatigue-Strength-Reduction Factors

<table>
<thead>
<tr>
<th>Weld Condition</th>
<th>Surface Condition</th>
<th>Quality Levels (see Table 5.12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full penetration</td>
<td>Machined</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
</tr>
<tr>
<td></td>
<td>As-welded</td>
<td>1.0, 1.5, 1.5, 2.0, 2.5, 3.0, 4.0</td>
</tr>
<tr>
<td>Partial Penetration</td>
<td>Final Surface Machined</td>
<td>NA, 1.5, 1.5, 2.0, 2.5, 3.0, 4.0</td>
</tr>
<tr>
<td></td>
<td>As-welded</td>
<td>NA, 1.6, 1.7, 2.0, 2.5, 3.0, 4.0</td>
</tr>
<tr>
<td>Fillet</td>
<td>Root</td>
<td>NA, 1.5, NA, NA, NA, NA, NA</td>
</tr>
<tr>
<td></td>
<td>Toe machined</td>
<td>NA, NA, 1.5, NA, 2.5, 3.0, 4.0</td>
</tr>
<tr>
<td></td>
<td>Toe as-welded</td>
<td>NA, NA, 1.7, NA, 2.5, 3.0, 4.0</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>NA, NA, NA, NA, NA, NA, NA</td>
</tr>
</tbody>
</table>

### Table 5.12 Weld Surface Fatigue-Strength-Reduction Factors

<table>
<thead>
<tr>
<th>Fatigue-Strength-Reduction Factor</th>
<th>Quality Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1</td>
<td>Machined or ground weld that receives a full volumetric examination, and a surface that receives MT/PT examination and a VT examination.</td>
</tr>
<tr>
<td>1.2</td>
<td>1</td>
<td>As-welded weld that receives a full volumetric examination, and a surface that receives MT/PT and VT examination.</td>
</tr>
<tr>
<td>1.5</td>
<td>2</td>
<td>Machined or ground weld that receives a partial volumetric examination, and a surface that receives MT/PT examination and VT examination.</td>
</tr>
<tr>
<td>1.6</td>
<td>2</td>
<td>As-welded weld that receives a partial volumetric examination, and a surface that receives MT/PT and VT examination.</td>
</tr>
<tr>
<td>1.5</td>
<td>3</td>
<td>Machined or ground weld surface that receives MT/PT examination and a VT examination (visual), but the weld receives no volumetric examination inspection.</td>
</tr>
<tr>
<td>1.7</td>
<td>3</td>
<td>As-welded or ground weld surface that receives MT/PT examination and a VT examination (visual), but the weld receives no volumetric examination inspection.</td>
</tr>
<tr>
<td>2.0</td>
<td>4</td>
<td>Weld has received a partial or full volumetric examination, and the surface has received VT examination, but no MT/PT examination.</td>
</tr>
<tr>
<td>2.5</td>
<td>5</td>
<td>VT examination only of the surface; no volumetric examination nor MT/PT examination.</td>
</tr>
<tr>
<td>3.0</td>
<td>6</td>
<td>Volumetric examination only.</td>
</tr>
<tr>
<td>4.0</td>
<td>7</td>
<td>Weld backside that are non-definable and/or receive no examination.</td>
</tr>
</tbody>
</table>

Notes:
1. Volumetric examination is RT or UT in accordance with Part 7.
2. MT/PT examination is magnetic particle or liquid penetrant examination in accordance with Part 7.
3. VT examination is visual examination in accordance with Part 7.