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# Notch stress assessment of weld detail

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## Contents

The objective of this presentation is to demonstrate the stress raising at a notch

Topics:

- Background information
- Cruciform joint
  - The focus is on a cruciform joint

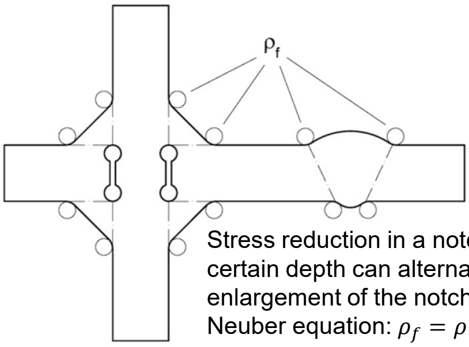
# Principle

- Notch stress approach:
  - Increase in local stress at notch formed by weld toe or weld root
  - Theory of elasticity – *no elastic-plastic constitutive model*
- Hypothesis of notch stress approach
  - Stress gradient approach (Siebel & Stieler, 1955)
  - Stress averaging approach (Nieuber, 1973, 1964 & 1968)
  - Critical distance approach (Peterson, 1959)
  - Highly stressed volume approach (Kuguel, 1961; Sonsino, 1994 & 1995)

Last three methods used for weld notch stress effects



# Stress averaging approach (Fictitious notch rounding approach)




(Fricke, 2010:4)

Fictitious notch rounding is done
Also known as the ***effective notch stress approach***

**How much rounding is required?**

Stress reduction in a notch due to averaging stress over a certain depth can alternatively be achieved by fictitious enlargement of the notch radius

Neuber equation: $\rho_f = \rho + s\rho^*$

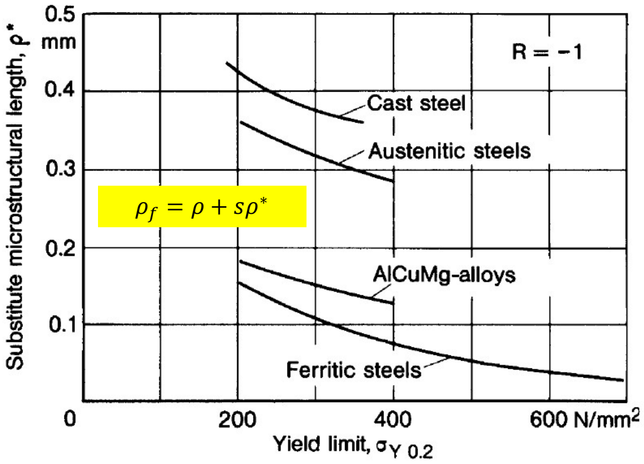
$\rho = actual\ notch\ radius$

$s = factor\ for\ stress\ multiaxiality\ \&\ strength\ criterion$

$\rho^* = substitute\ micro - structural\ length$

For welded joints, $s = 2.5$ for plane strain conditions at roots of sharp notches, combined with von Mises strength criterion

# Substitute micro-structural length




$\rho_f = \rho + s\rho^*$

$\rho^* = 0.4$ for low strength steel
This results in increase of 1 mm in radius

Worst case use $\rho = 0$
This gives:
$\rho_f = 0 + 2.5 \times 0.4$
$= 1\ mm$

For Aluminium, the notch radius is also approximately 1 mm

(Neuber, 1968)

Notch stress curves in some standards may require 50 $\mu m$ notch radius



# Critical distance approach

Employs material constant & notch radius to reduce the elastic stress concentration factor $K_t$ to the *fatigue notch factor* $K_f$

- Will be presented later as part of the stress life fatigue method

# Demonstration of the notch stress approach

**Characteristic fatigue strength for welds of different materials based on effective notch stress with $r_{ref} = 1.00\ mm$ (maximum principal stress)**

| Maximum principal stress, $P_s = 97.7\ \%, r_{ref} = 1\ mm$ | | |
|---|---|---|
| **Material** | **Characteristic strength** $\begin{pmatrix} P_s = 97.7\ \% \\ N = 2 \times 10^6 \end{pmatrix}$ | **Reference** |
| Steel | FAT 225, $m = 3$ for maximum principal stress<br>FAT 200, $m = 3$ for von Mises stress | Olivier et al (1989 & 1994) and Hobbacher (2008) |
| Aluminium alloys | FAT 71 | Morgenstern et al. (2004) |
| Magnesium | FAT 28 | Karakas et al. (2007) |
| Source: (Fricke, 2010, p. 18) | | |

S-N curve equation used in some standards:

$$C = \Delta\sigma^m N$$
$$C = FAT^m \cdot 2 \times 10^6$$
$$m = 3$$

With slope $m = 3$, IIW classes defined for nominal, structural hot-spot and effective notch stress approaches are compatible with each other



**Characteristic fatigue strength for welds of different materials based on effective notch stress with $r_{ref} = 0.05\ mm$ (maximum principal stress)**

| Maximum principal stress, $P_s = 97.7\ \%, r_{ref} = 0.05\ mm$ | | |
|---|---|---|
| **Material** | **Characteristic strength** $(P_s = 97.7\%, N = 2 \times 10^6)$ | **Reference** |
| Steel | FAT 640 | (Eibl, Sonsino, Kaufmann, & Zhang, 2003), (Sonsino, 2009) |
| Aluminium alloys | FAT 180 | (Eibl, Sonsino, Kaufmann, & Zhang, 2003), (Karakas, et al., 2007), (Sonsino, 2009) |
| Magnesium | FAT 71 | (Karakas, et al., 2007), (Sonsino, 2009) |
| Source: (Fricke, 2010, p. 18) | | |

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# Element sizes in FEA

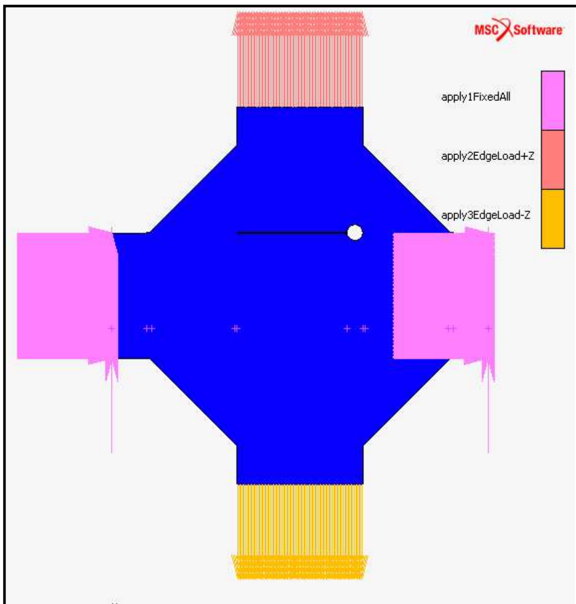
| Element type (displacement function) | Relative size | Size for $r = 1\ mm$ | Size for $r = 0.05\ mm$ | No. of elements over 45° arc | No. of elements over 360° arc | Estimated error |
|---|---|---|---|---|---|---|
| Quadratic (e.g. with mid-size holes | $\leq \frac{r}{4}$ | $\leq 0.25\ mm$ | $\leq 0.012\ mm$ | $\geq 3$ | $\geq 24$ | $\approx 2\%$ |
| Linear | $\leq \frac{r}{6}$ | $\leq 0.15\ mm$ | $\leq 0.008\ mm$ | $\geq 5$ | $\geq 40$ | $\approx 10\%$ |

Notes:

- Element subdivision along the weld length, should be chosen in accordance with the stress gradient expected. I the stress gradient is small, long elements should be suitable.
- Where simple linear elements are used with constant stress distribution, appropriate stress extrapolation to the free notch surface might be necessary.
- *Sub-modelling techniques* may be required for large models to enable computation of notch stresses in a fine-meshed sub-model.
  - Interpolate between nodal points to transfer coarser mesh displacements. Some FEA software does this for you.
  - The original coarse model must have the same stiffness than the sub-model. Otherwise notch stresses will be wrong.
  - Verify by comparing stresses at boundaries.
- The *super-element technique* is where the local model is inserted in the overall model as super element.

Source: (Fricke, 2010, p. 10)






For the fillet weld, the weld throat sizes are equal to the cross-section of the 16 mm plate
This give weld leg size 11.2 mm

# Cruciform joint

Material is steel with:

$E = 210\ GPa$

$\nu = 0.3$

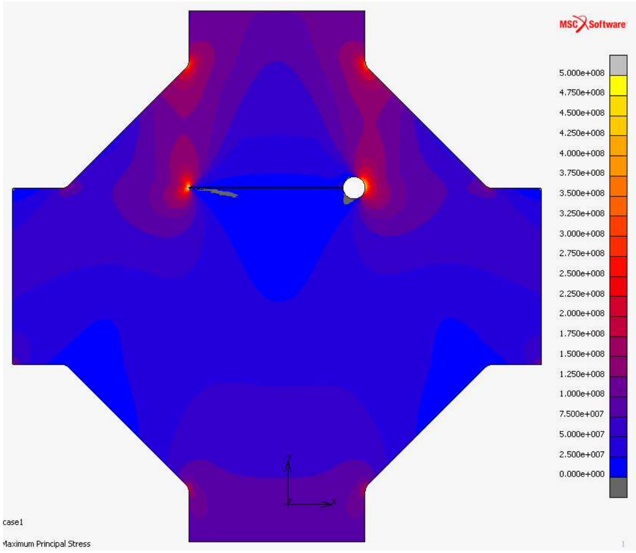
$\rho = 7850\ kg/m^3$

Fillet weld at top
Complete joint penetration weld at bottom

Weld toes have radius of 1 mm
Weld root has hole with diameter 2 mm

The edges on the horizontal section was constrained for translation in all directions
Edge loads of 100 MPa pressure were applied to the top and bottom sections

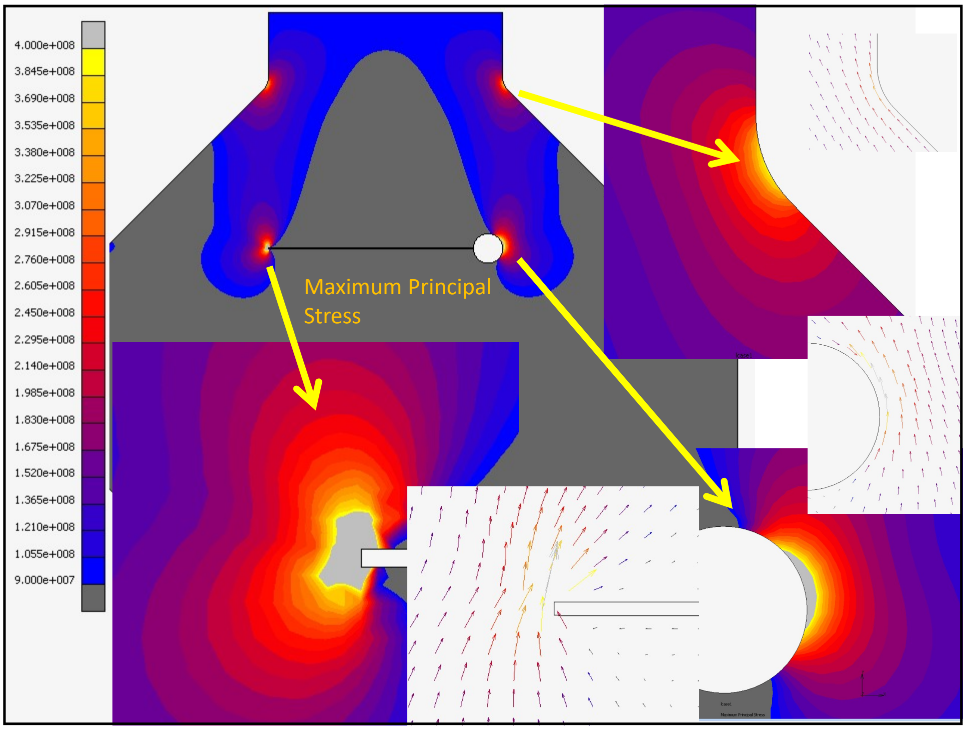
# 16 mm cruciform joint with 11.2 mm weld




Maximum principal stress in the 16 mm cruciform joint made with 11.2 mm fillet and complete joint penetration welds

Note the stress concentration caused by the geometrical changes at the weld toes and root





## Fracture mechanics approach to calculate fatigue life

- Method is in widespread use as an alternative to the S-N curve
- Assumes fictitious (or actual if present) initial crack
  - Assumed 0.150 mm = 150 μm
- Final crack size that defines fatigue life:
  - 0.75 % x (plate thickness)
    - If the initial crack is 150 μm, the plate thickness must be > 20 mm
  - Can also use detectable size, 0.5 mm as final crack size



## Conclusion

- Notches are stress concentrations
- Higher stress means lower fatigue life
- Weld toes are notches
  - Notches due to weld detail is the dominant reason for lower fatigue life of weld detail

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# Reference for next few slides

- Fricke, W. 2010. Guideline for the Fatigue Assessment by Notch Stress Analysis for Welded Structures. *International Institute of Welding, IIW-Doc. XIII-2240r2-08/XV-1289r2-08*