Failure Assessment of a Thin-Walled Pipe Subjected to an Overload During Manufacturing

Uwe Zerbst

GKSS Research Centre Geesthacht
Institute of Materials Research,
Materials Mechanics

Germany

The presentation is based on a study performed by

Uwe Zerbst

GKSS Research Centre Geesthacht, Institute of Materials Research, Materials Mechanics, Germany

Gundula Stadie-Frohbös & **Thomas Plonski**

Germanischer Lloyd, Hamburg, Germany

Jonathan Jury

RiserTec Limited, Westhill, Aberdeenshire, U.K.

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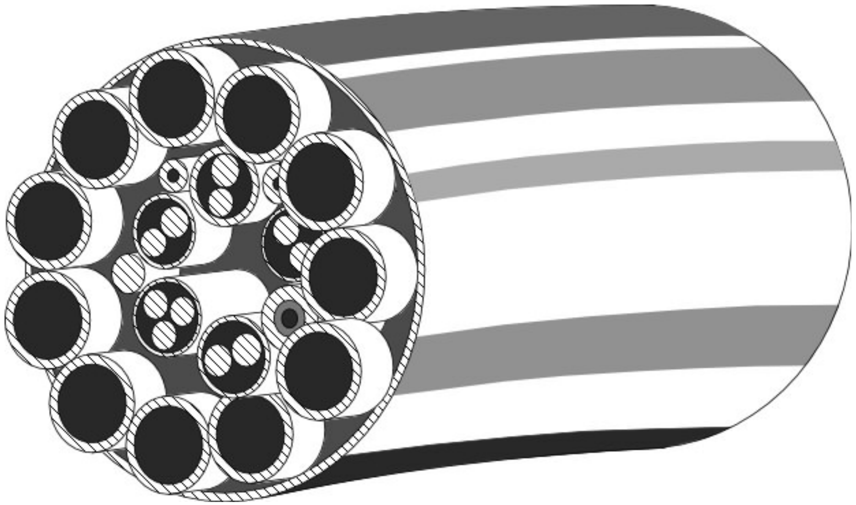
Subsea Umbilicals



Subsea umbilicals: composite cable and small diameter tubular bundles deployed on the seabed in conjunction with offshore installations for oil or gas exploitation.

Their purpose: to supply necessary power and control to remote production valves, chokes and control systems.

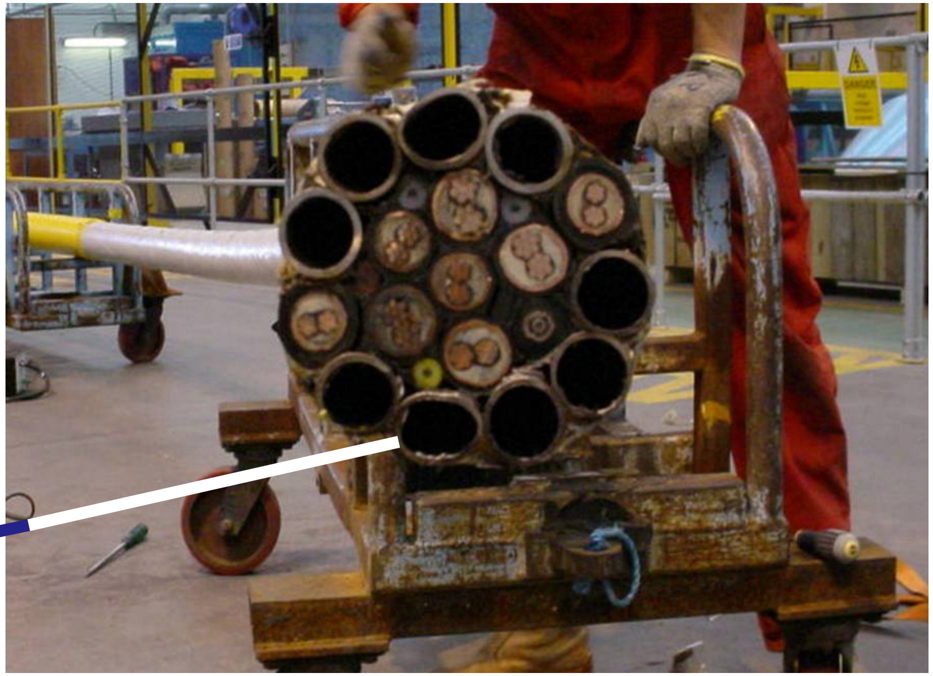
Loading: alternating internal pressure

Once an umbilical is installed on the seabed failure-free operation is intended over its whole lifetime (safe-life design philosophy).

Case History

Present case: The performance check revealed that one tube of an umbilical was not able to carry load, i.e., it had a leak.

To find the reason a spare line section was investigated which had experienced the same treatment during manufacture.



Material: SAF 2507
- Yield strength: 756 MPa
- Tensile strength: 947 MPa
- Elongation: 31 %,

It was found that some of the tubes were largely ovalised (to an extent of 55%).

Subsequently the tubes were subjected to internal pressure in order to re-round them.

The Question to be Answered

Problem: It could not be excluded that potential cracks just small enough not to snap through the wall existed in the re-rounded umbilical.

Question: Could such a crack cause the failure of one or more of the tubes within the projected lifetime?

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Two-Steps Fracture Mechanics Analysis

Step 1: Determine the potential maximum crack size that could have survived the re-rounding process.

Step 2: Determine the minimum residual lifetime based on this crack size and compare it with the projected lifetime.

Two Steps Analysis

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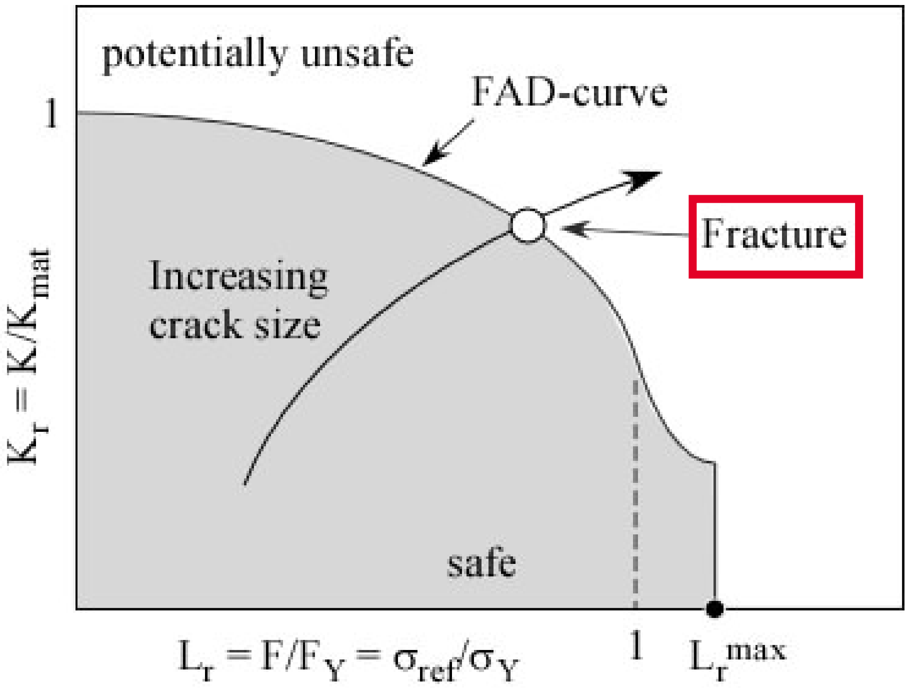
Failure Assessment Diagram Analysis (1)

Step 1: Determine the potential maximum crack size that could have survived the re-rounding process.



FAD curve: $K_r = f(L_r)$

$$K_r = K/K_{mat}$$

K – Stress intensity factor (K factor)

K_{mat} – Fracture resistance of the material

$$L_r = F/F_Y = \sigma_{ref}/\sigma_Y$$

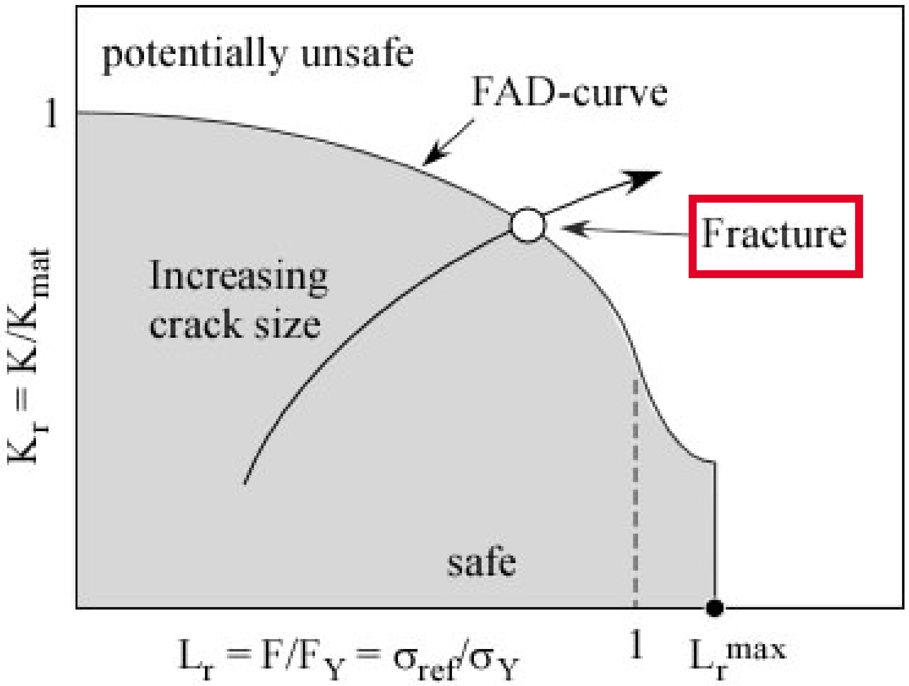
F – Load; F_Y – Yield load

σ_{ref} – (Net section) reference stress

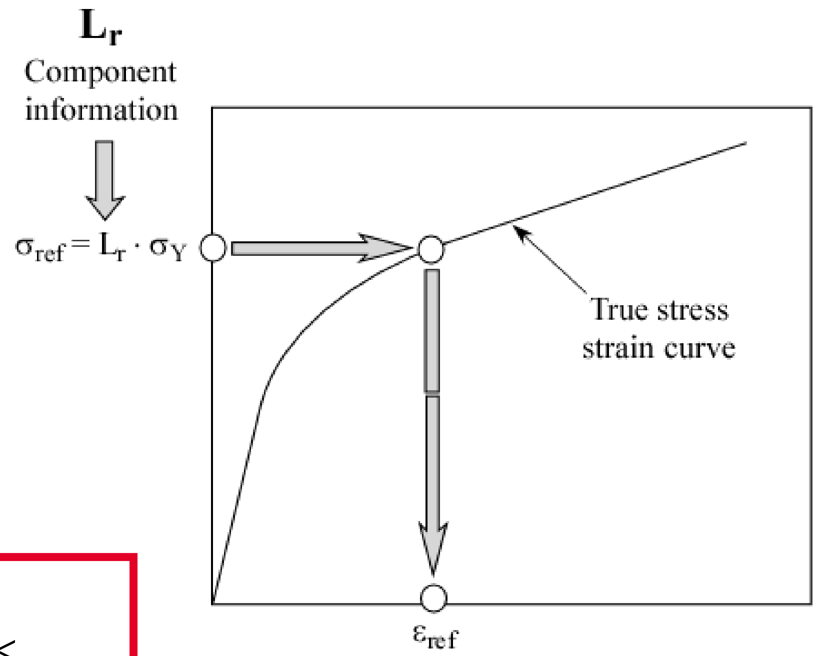
σ_Y – Yield strength of the material

Failure Assessment Diagram Analysis (2)

Step 1: **Determine the potential maximum crack size that could have survived the re-rounding process.**



FAD curve: $K_r = f\left(L_r\right)$



$$f\left(L_r\right) = \begin{cases} \left[\dfrac{E \cdot \varepsilon_{ref}}{\sigma_{ref}} + \dfrac{1}{2} \dfrac{L_r^2}{E \cdot \varepsilon_{ref} / \sigma_{ref}} \right]^{-1/2} & \text{for } L_r < L_r \\ 0 & \text{for } L_r = L_r^{max} \end{cases}$$

Conservatism

Usually, in the context of a structural integrity analysis, conservatism means that the the critical crack size is underestimated.

However, in the context of overload based analyses, things are different:

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In this case conservatism means that the critical crack size has to be overestimated!

Caution: Whilst, in principle, a fracture mechanics analysis of a tube subjected to internal pressure is state-of-the-art the problem of reversed conservatism is usually not covered.

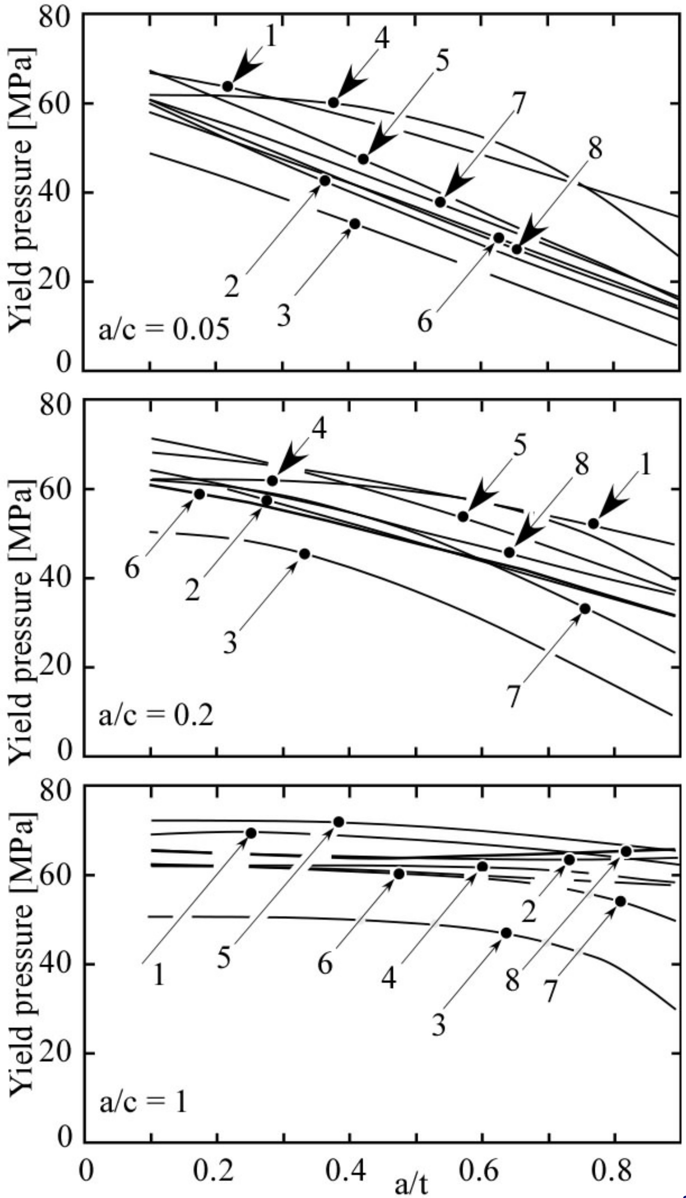
The relevant parameters are:

the fracture resistance of the material (K_{mat}) and

the net section yield load of the structure with crack (F_Y or σ_{ref})

For both parameters upper bound values or solutions are needed.

Yield Load Solutions for Hollow Cylinders with Axial Surface Cracks



(1) Kim & Shim (2005)

(2) R6, Rev. 4 (2001)

(3) BS 7910 (2005) (standard solution)

(4) Sattari-Far & Dillström (2004)

(5) Staat & Khoi Vu (2007)

(6) API 579-N (2000)

(7) API 579-L (2000)

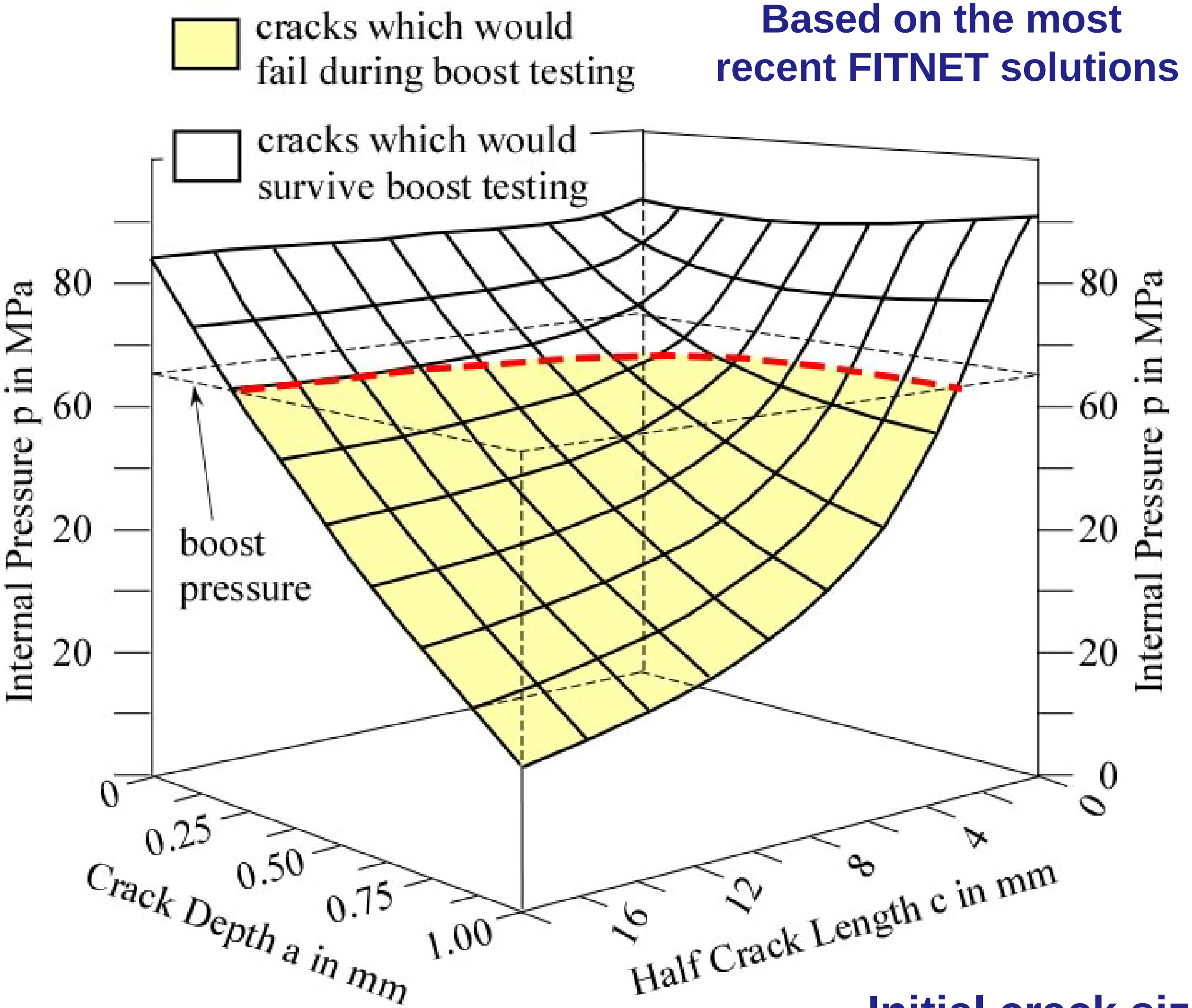
(8) FITNET (2006)

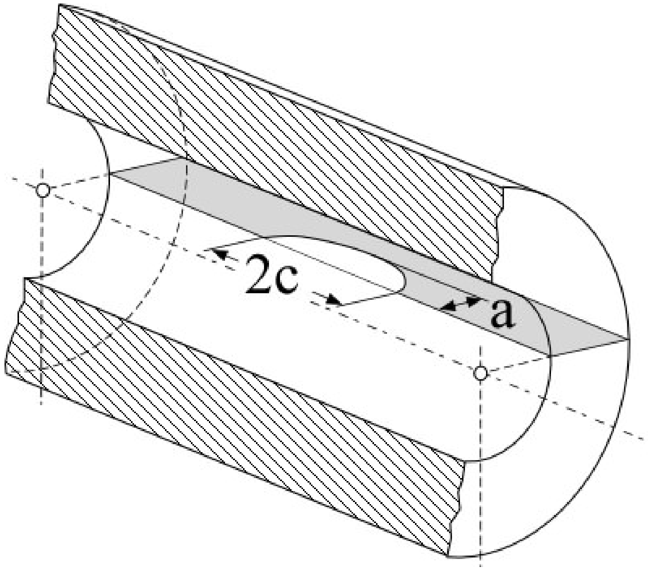
Aspects of different solutions:

- Definition and determination
- Local and global solutions
- Crack face pressure

Maximum Crack Size After Re-rounding

Based on the most recent FITNET solutions





Dependent on its length at surface (2c) the maximum depth (a) of the crack according to the internal pressure at re-rounding is identified.

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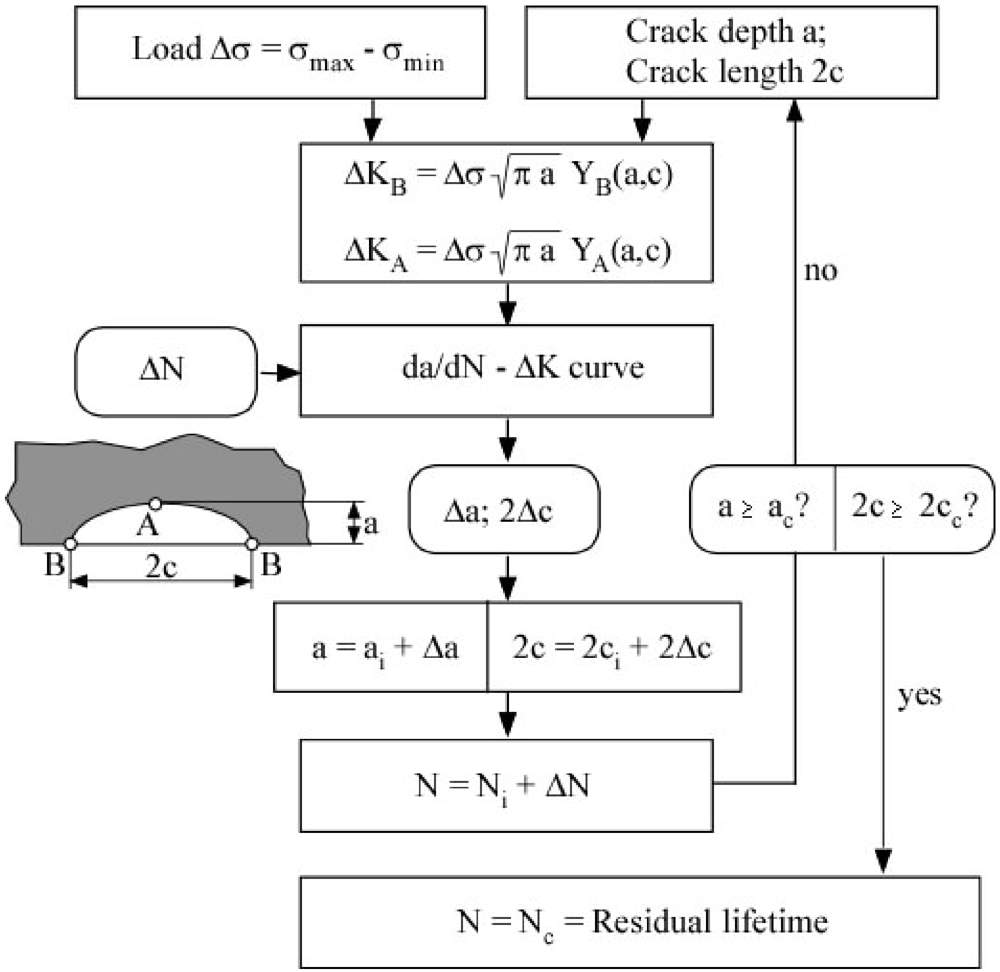
Initial crack size for Step 2 of the analysis

Two Steps Analysis

Step 1: Determine the potential maximum crack size that could have survived the re-rounding process.

Step 2: Determine the minimum residual lifetime based on this crack size and compare it with the projected lifetime.

Step 2: Determine the residual lifetime of the maximum crack of Step 1 under in-service conditions.



Loading:

Alternating internal pressure in-service

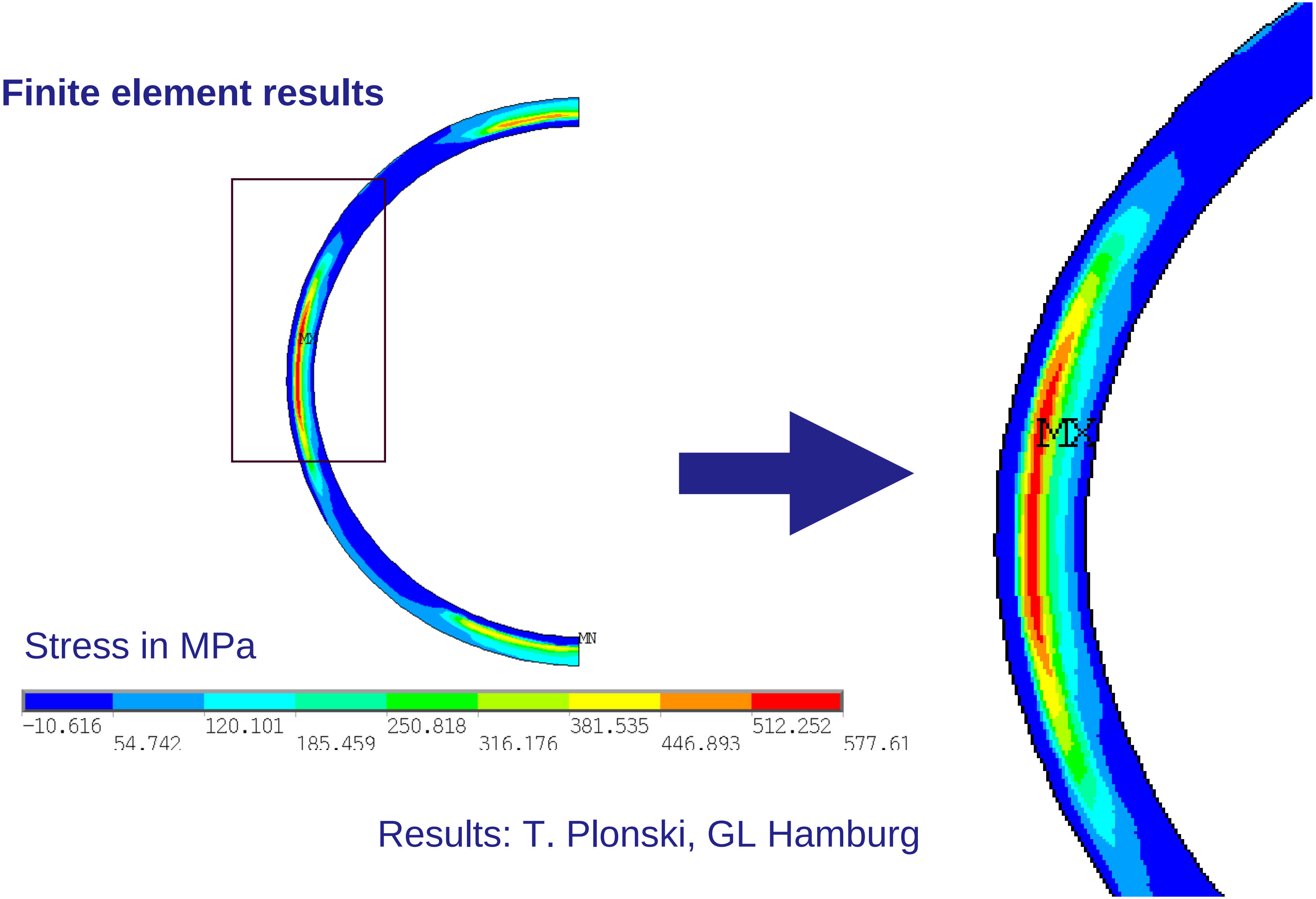
Caution:

1) Conservatism turns back to normal!

2) The residual stresses due to the re-rounding process have to be taken into account as an additional loading component!

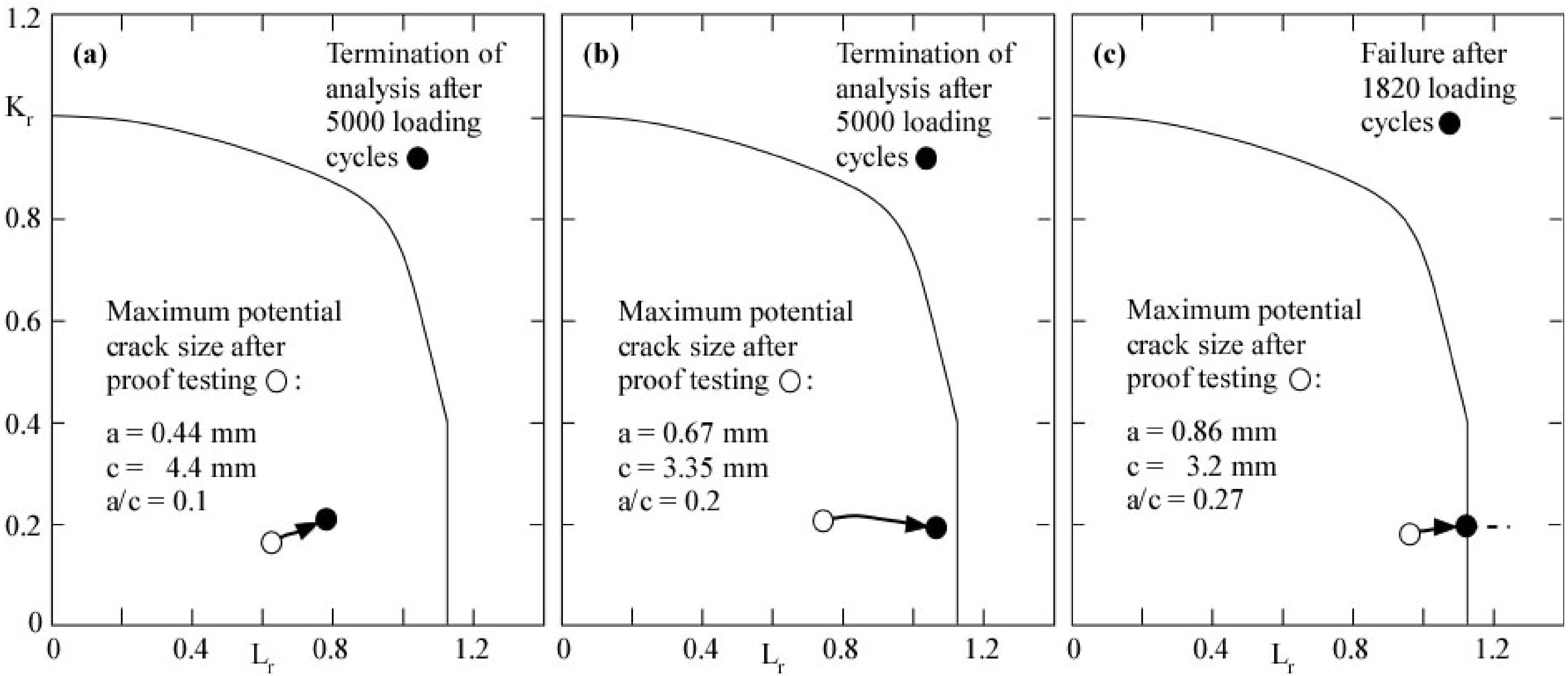
Residual Stresses After Re-rounding

Finite element results



Results: T. Plonski, GL Hamburg

Three possible maximum crack dimensions after re-rounding:



Termination after 5000 loading cycles (no failure)

Most critical case (failure after 1820 cycles)

Conclusions

- The critical crack dimensions a = 0.86 mm and c = 3.2 mm after re-rounding yielded final failure after only 1820 loading cycles which is less than the projected lifetime.
- Therefore, additional measures were necessary (e.g., refined non-destructive inspection or additional tests on the spare line sections)
- Note that the analysis followed a worst case scenario, i.e., it was based on a number of pessimistic assumptions:

  (a) Even little increase in pressure would have yielded failure already during re-rounding.

  (b) The applied yield load solutions for both, maximum crack size at boost loading and final failure are probably conservative. However, even moderate changes in the yield load could be of tremendous effect on the final result.
- Therefore, a throughout validation of the recently proposed yield load solutions and, perhaps, the development of further improved solutions is a key issue for reducing the inherent conservatism of fracture mechanics analyses in the context of an overload philosophy.

Outlook

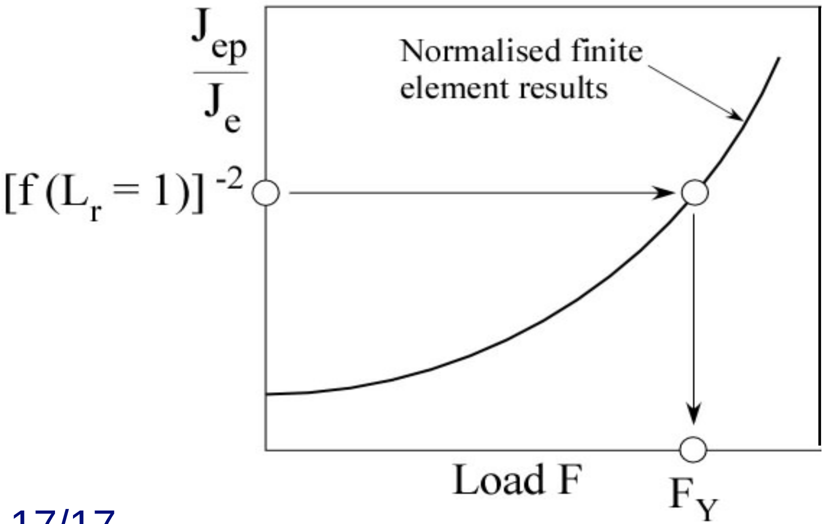
Further improvement possible by applying a „reference load“ instead of a limit load F_Y

Overview presentation of Zerbst & Schwalbe (this workshop)

For $L_r = 1$ ⟹ $\sigma_{ref} = \sigma_Y$ ⟹ specific value of $f(L_r)$ dependent on the material

Proposal

$$f(L_r) = \begin{cases} \left[\frac{E \cdot \varepsilon_{ref}}{\sigma_{ref}} + \frac{1}{2} \cdot \frac{L_r^2}{\left(E \cdot \varepsilon_{ref} / \sigma_{ref}\right)}\right] & \text{for } 0 \leq L_r \leq L_r^{max} \\ 0 & \text{for } L_r^{max} = \frac{\sigma_Y + R_m}{2\sigma_Y^2} \end{cases}$$



Defines a specfic ratio of J/J_e corresponding to F_Y

$$\frac{J}{J_e} = \left[f(L_r)\right]^{-2}$$

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F_Y = „Reference load“