WPMAG 2025 Final Meeting, 15-Jan-2026

Advanced finite element modeling to support the experimental test

MAG-S.01.04-T023-D001

F. Giorgetti

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Outline

- Overview of the ENEA PC-RINGS Testing Facility.
- FE model to support the experimental test and determine the testing cycle amplitude.
- Code developed for crack growth analysis.

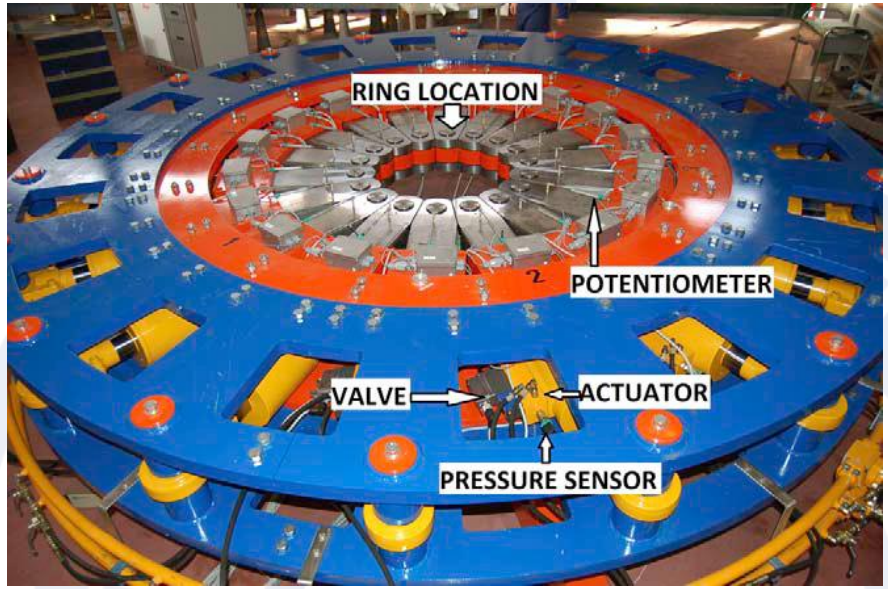
ENEA PC-RINGS Testing Facility

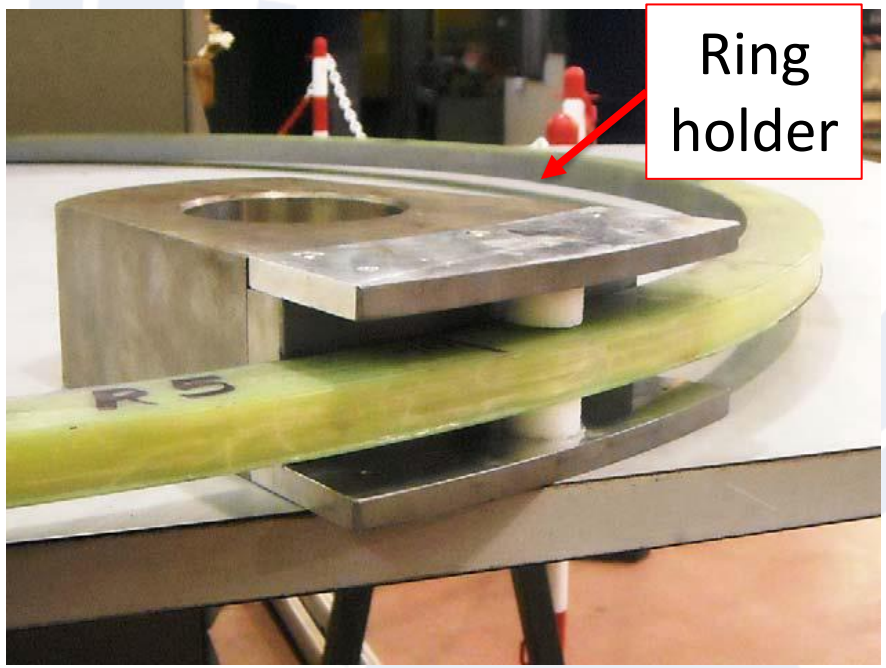
Facility Key features

- Based on eighteen (18) hydraulic cylinders with maximum pulling capability of 57tons and a maximum stroke of 70mm each, thus total σ_{Hmax} is 1.6MN.
- **Position control precision** is 0.1mm (below 0.1mm radial movement accuracy cannot be guaranteed).
- Mounting and demounting procedures are very time-consuming (intermediate disassembly not recommended).
- Cycle duration 10s÷20s (after software modification)

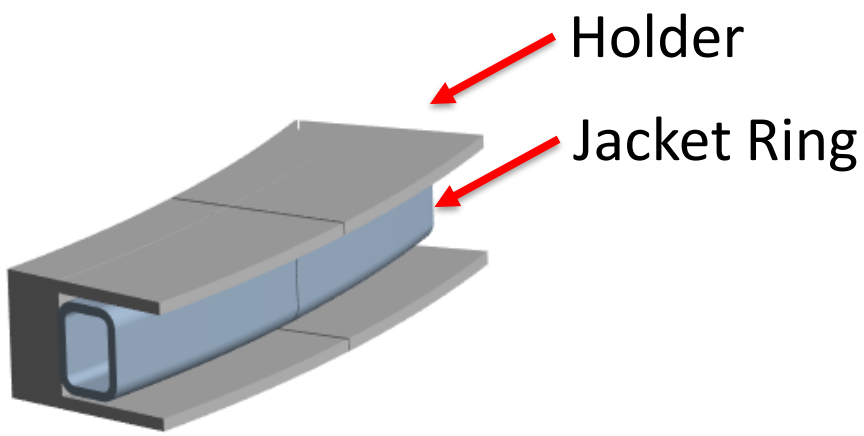
Testing requirements

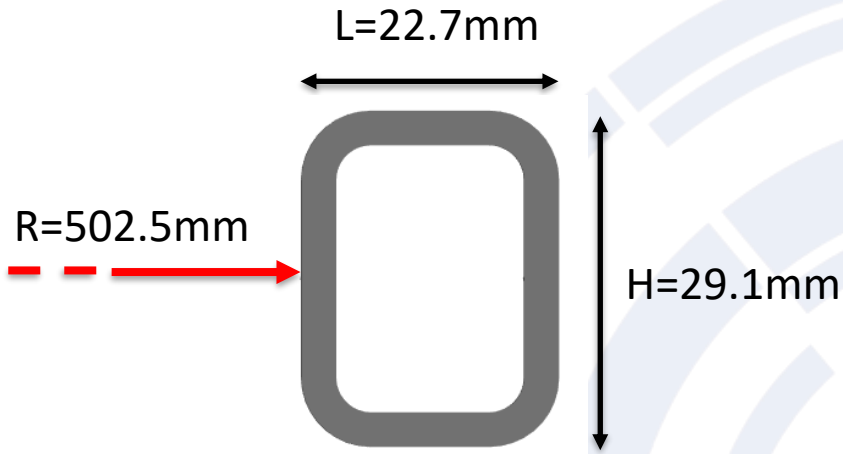
- Ring mock-up dimensions: Internal diameter of 1005mm±1mm, maximum cross section of 45x45mm.
- Maintaining the ring **below the yielding**.
- The tests need to be **always supervised**.



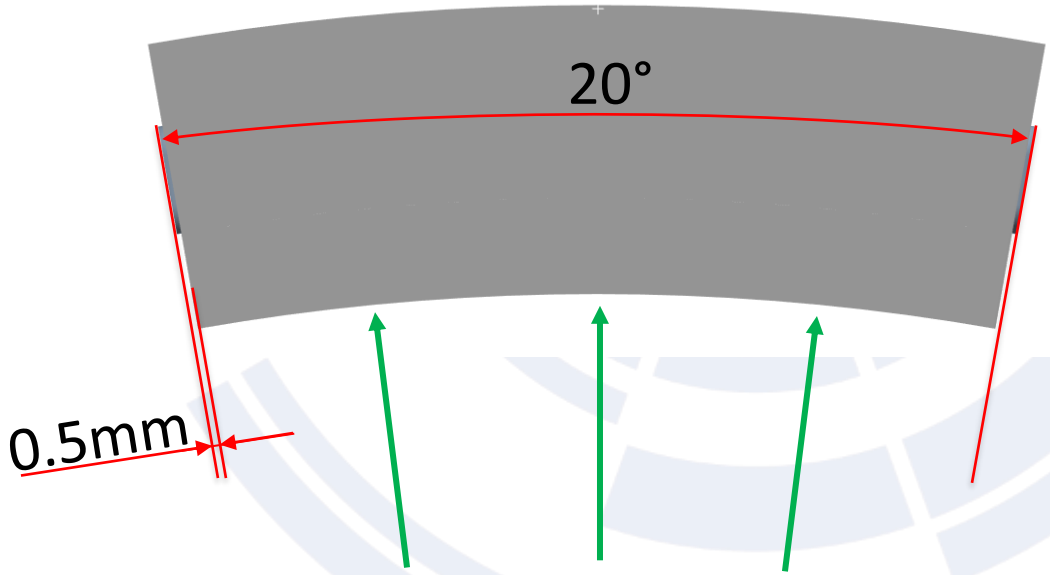


FEM simulation of jacket ring



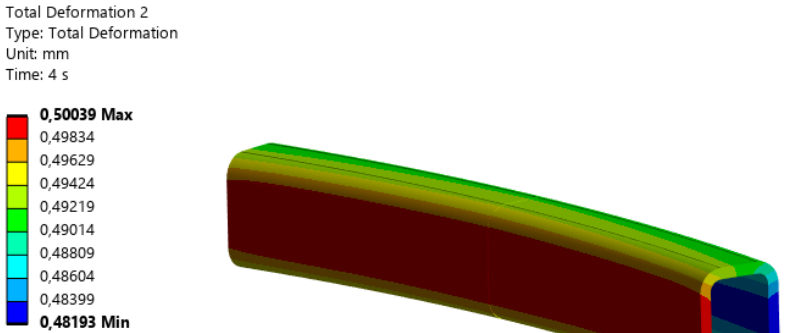


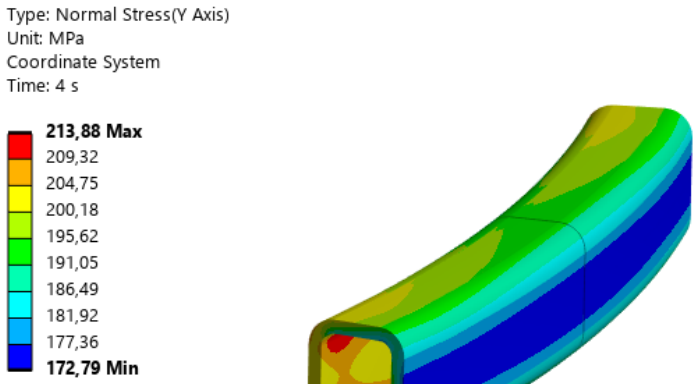
- Cyclic symmetry with 20° sectors (only jacket)
- Ring/holder contact
- Imposed displacements to holder (0.1mm steps)
- Yielding of 316LN @20°C is 220MPa (E=200GPa)*

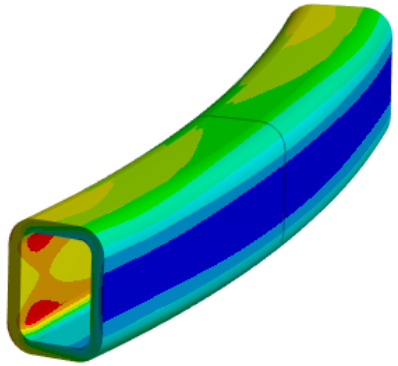


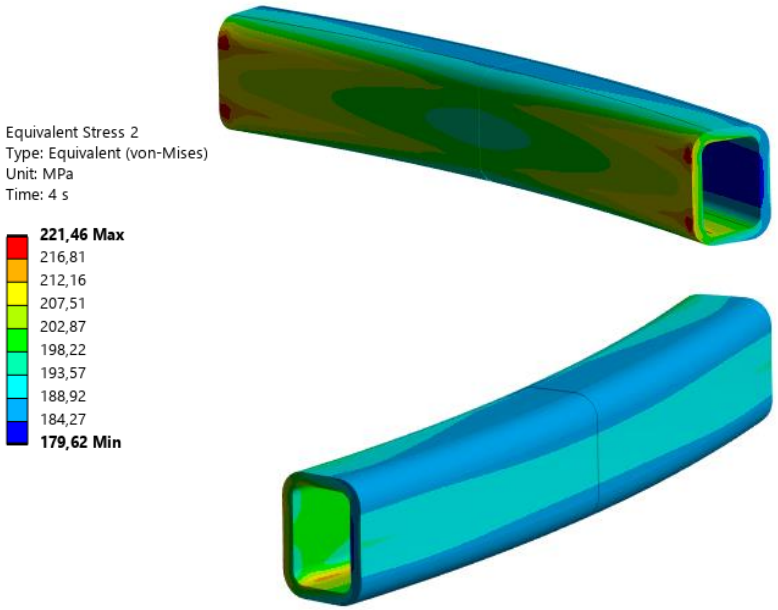
*ITER Appendix A, Materials Design Limit Data (222RLN)

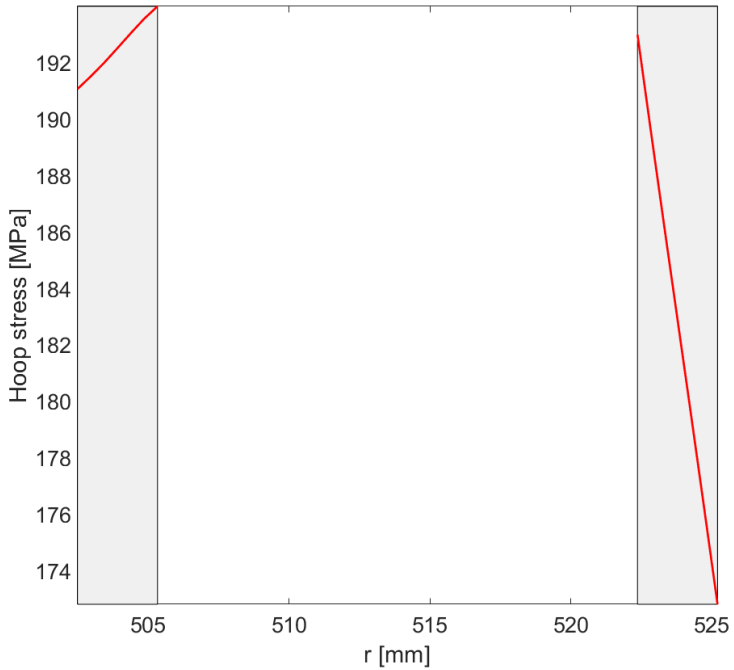
FEM simulation of jacket ring









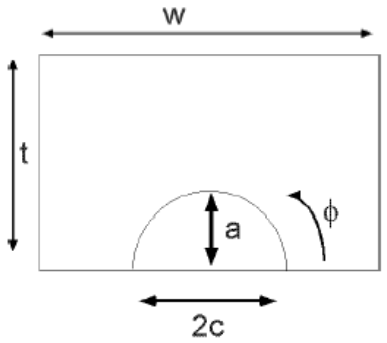


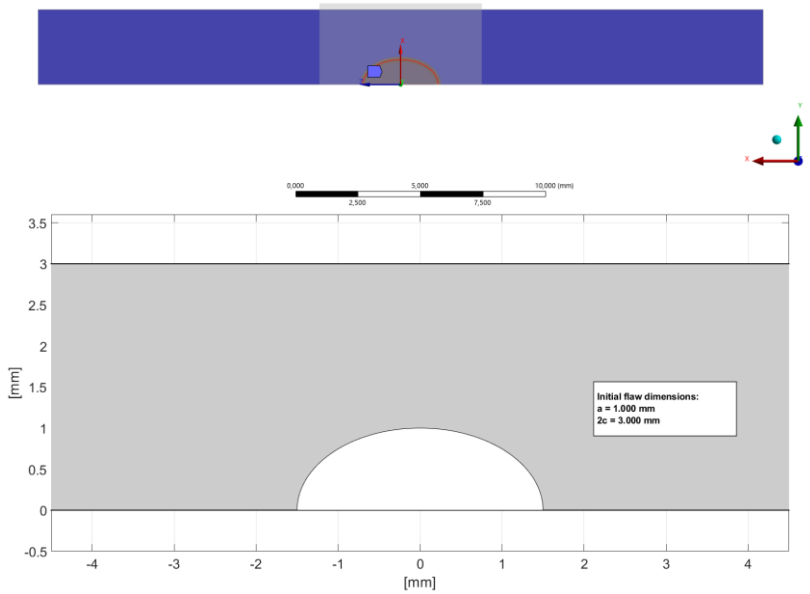
- Maximum allowable radial displacement is 0.5mm
- Estimated loading cycle: 0.1mm to 0.5mm.

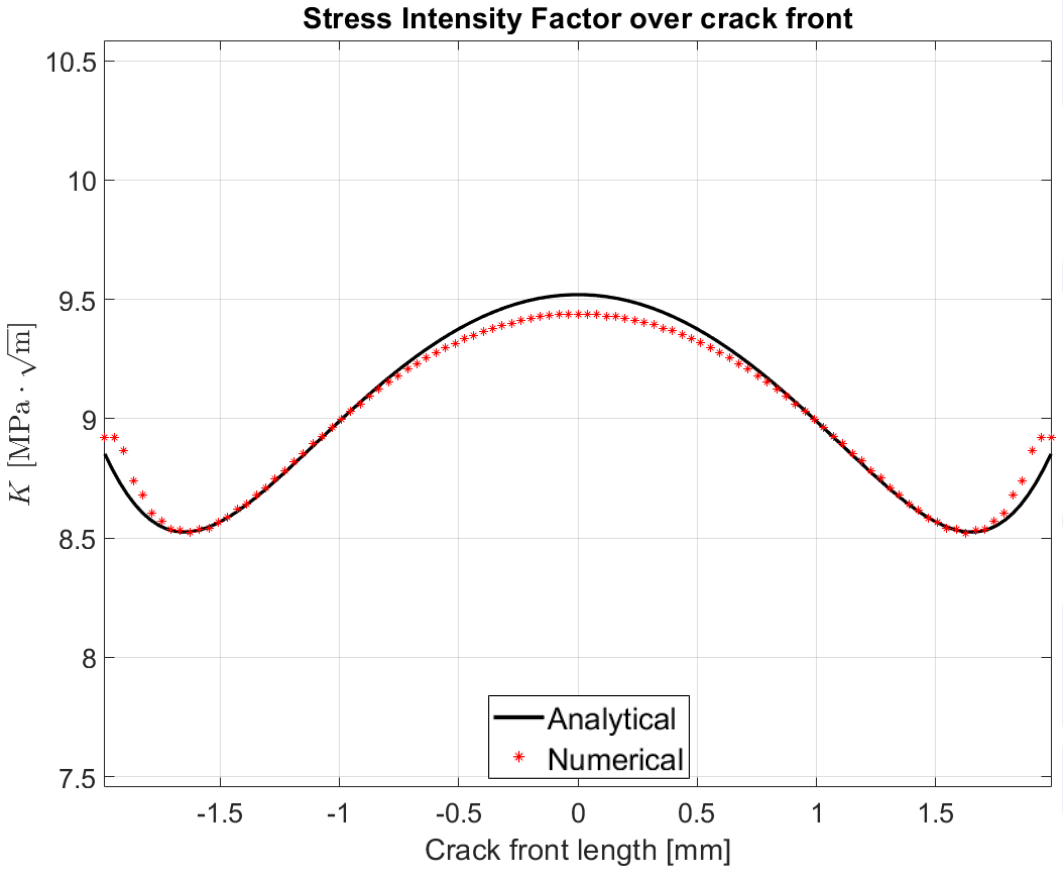
	Internal	External
σ_H max [MPa]	193.98	192.97
σ_H min [MPa]	191.10	172.79

Fracture mechanics simulation

- A code for the simulation of crack growth has been developed following the ITER codes*
- The results are cross-checked (in terms of stress intensity factors) with FEA results
- Input data:
  - a=1mm; 2c=3mm
  - t=3mm; w=29mm
  - σ_t=200MPa





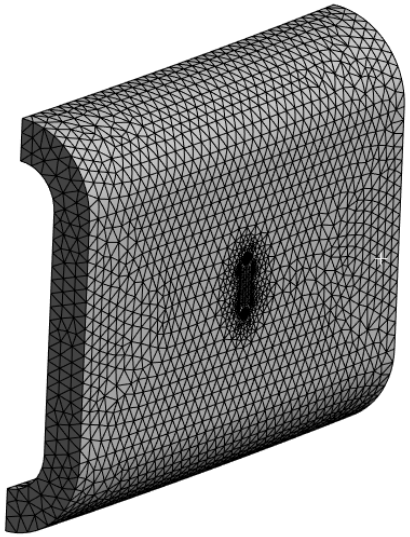


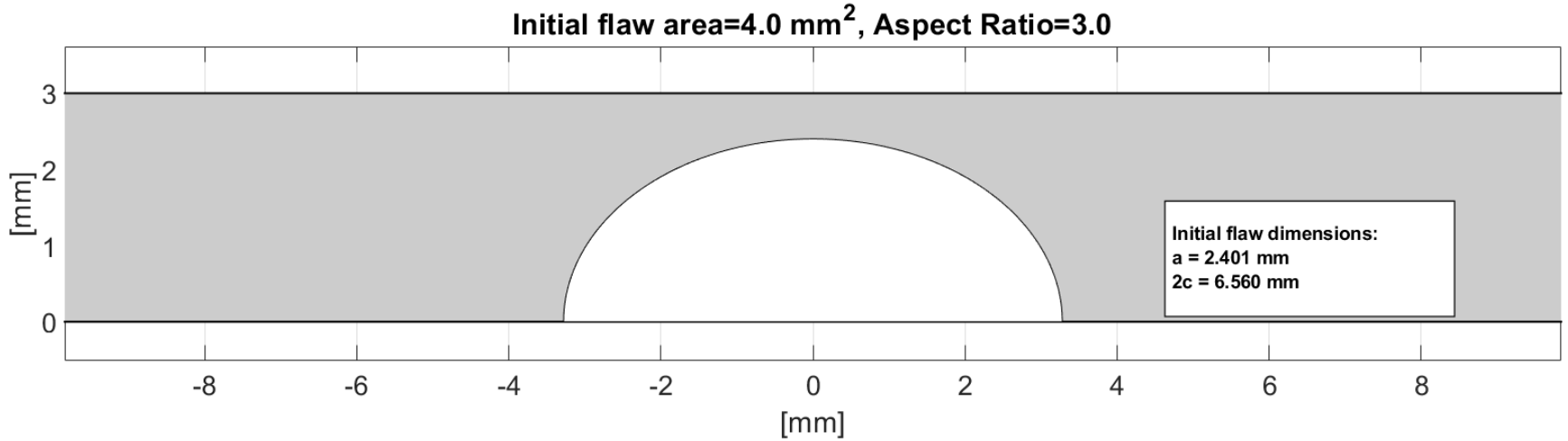
*ITER Magnet Structural Design Criteria Part 1: Main Structural Components and Welds (2FMHHS)

Crack simulation on jacket ring: external crack

External crack

- Initial defect area: 4mm^2 (2mm^2 with SF_A=2*)
- Semi-elliptical crack: a=1.3mm, 2c=3.91mm
- σ_t=182.6MPa, σ_b=9.8MPa, R=0.2
- Paris coefficient: C=3.86e-11, m=2.394 (316LN)
- da = 0.001mm
- K_{IC}=86.7MPa$\sqrt{m}$ (130MPa$\sqrt{m}$ with SF_K=1.5*)





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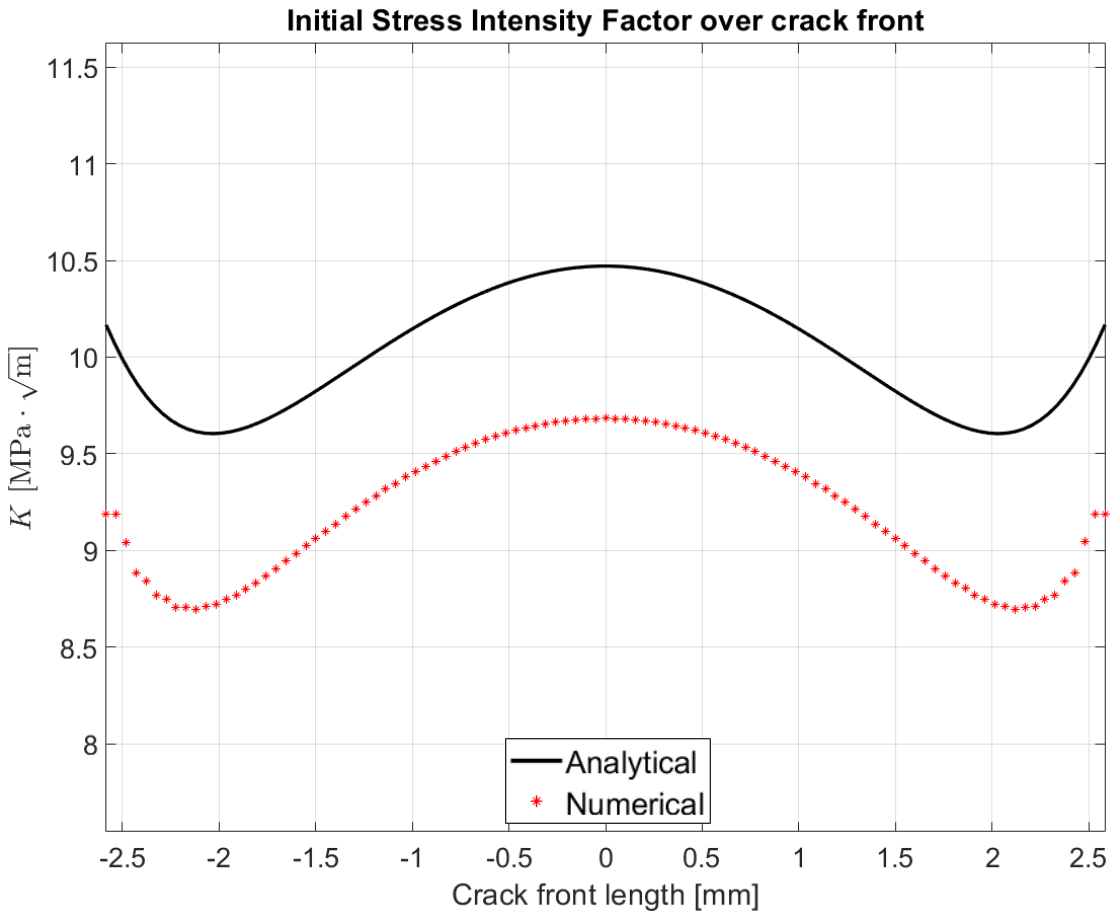
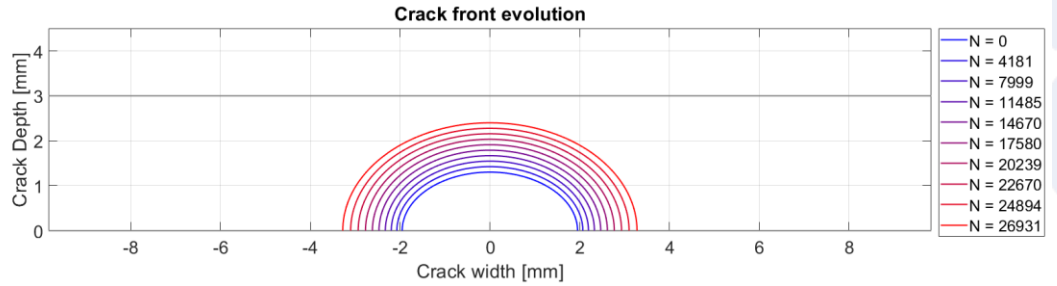


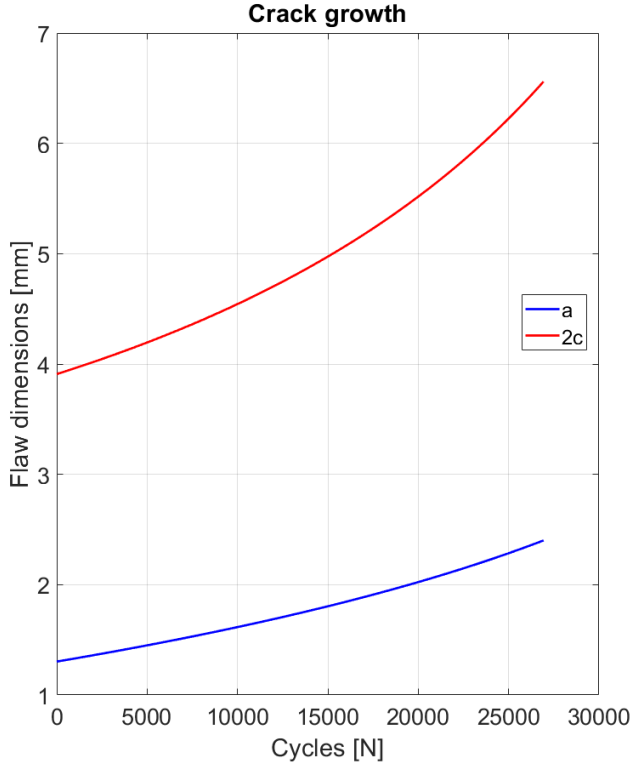
Analytical vs Numerical:

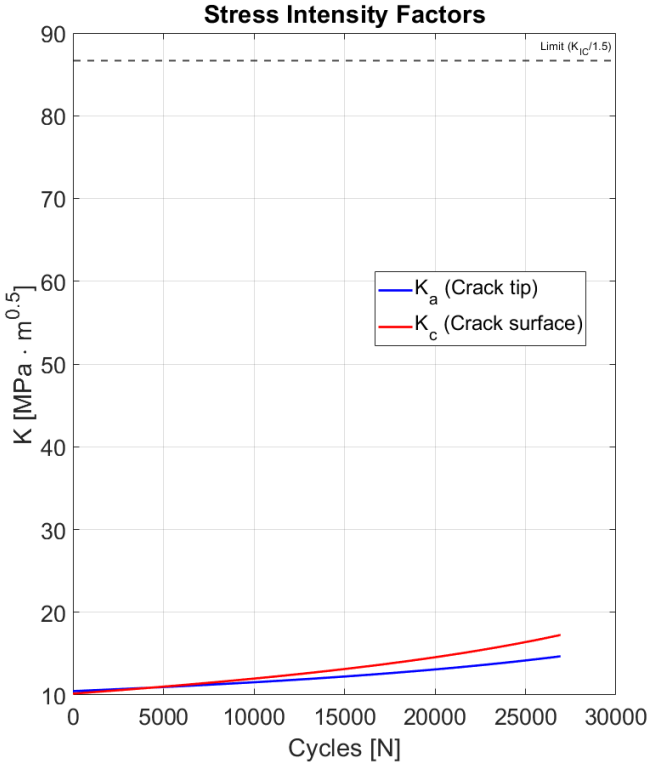
- Similar trend
- Analytical model provides greater values (~8%) with respect to numerical ones
- This discrepancy can be attributable to:
  - the conservative nature of the analytical solution
  - inherent structural stiffness of the ring geometry, which provides greater crack-closure constraint compared to the equivalent flat plate model

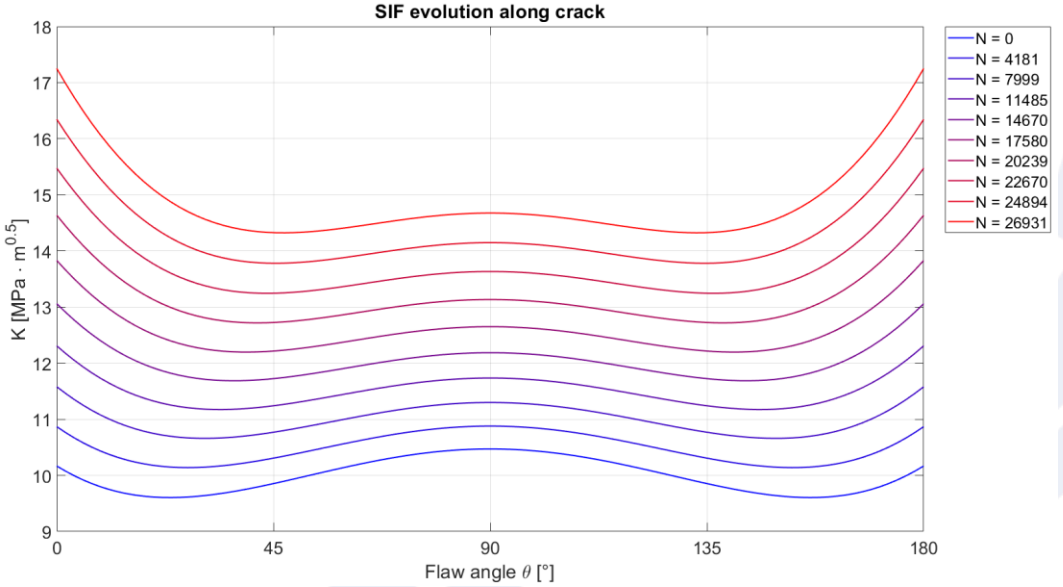
Crack simulation on jacket ring: external crack

- Number of cycles before failure: 26931 (with SF_N=2)
- Failure mode: a=0.8·t
- K<<K_{IC}
- Minimum 25 days test
  (20s/cycle - 6h/d - no issues)



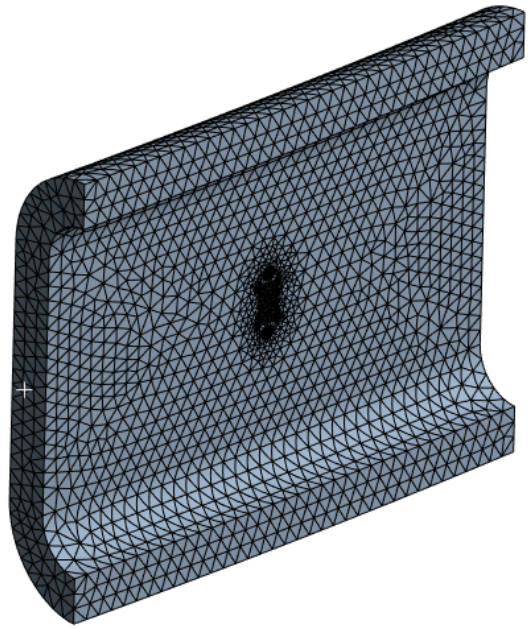




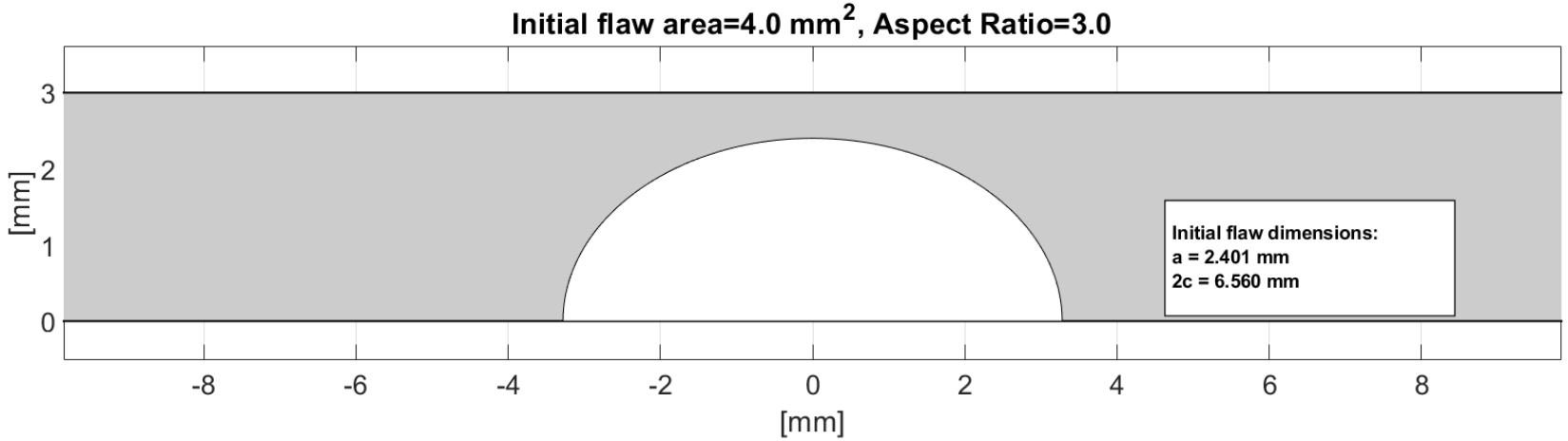


Crack simulation on jacket ring: Internal crack

External crack



- Initial defect area: 4mm^2 (2mm^2 with SF_A=2*)
- Semi-elliptical crack: a=1.3mm, 2c=3.91mm
- σ_t=191.6MPa, σ_b=0MPa, R=0.2
- Paris coefficient: C=3.86e-11, m=2.394 (316LN)
- da = 0.001mm
- K_{IC}=86.7MPa$\sqrt{m}$ (130MPa$\sqrt{m}$ with SF_K=1.5*)



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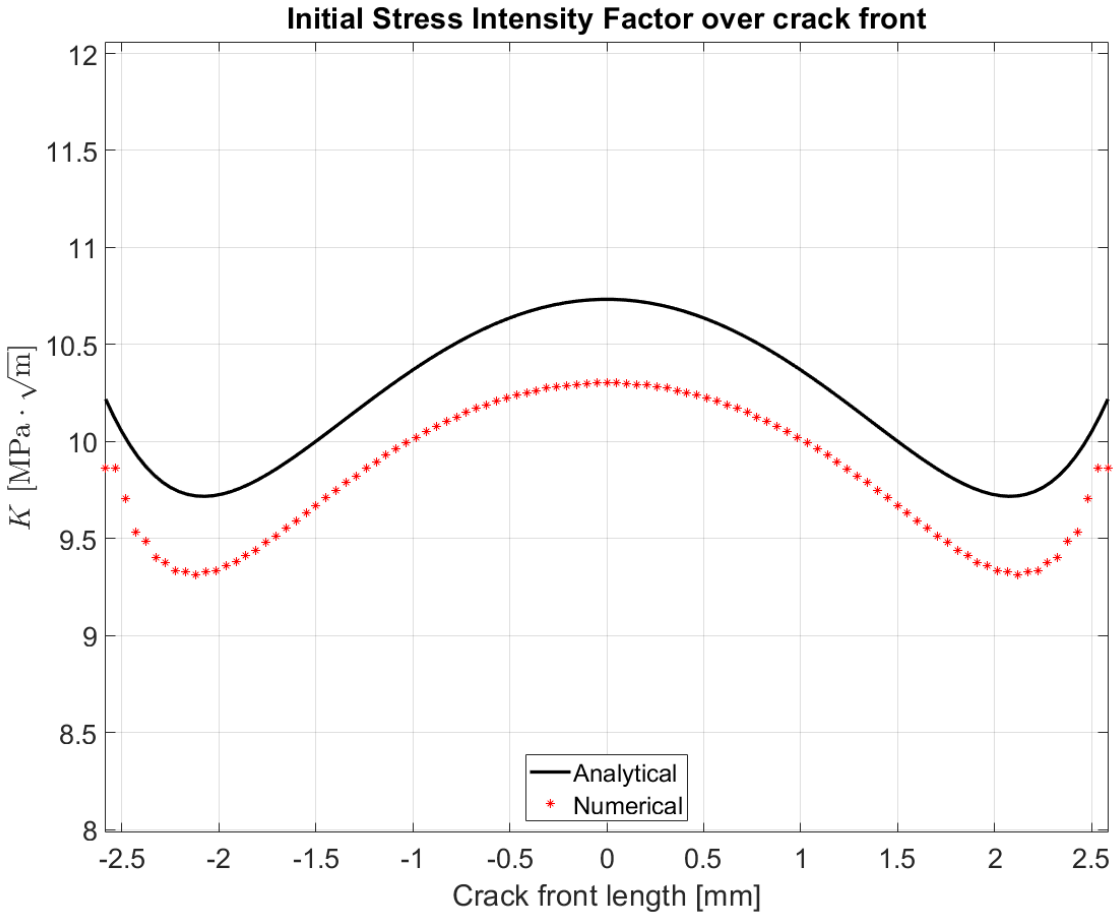
Crack simulation on jacket ring: Internal crack

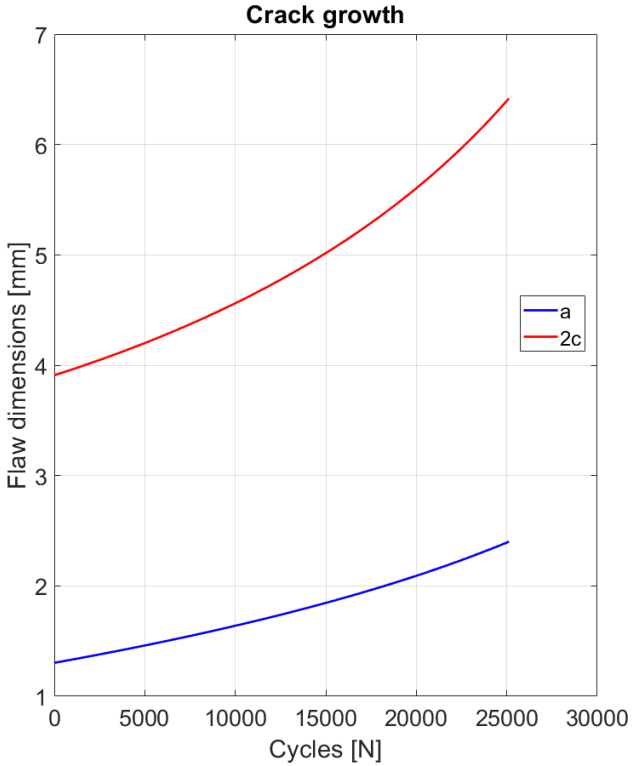


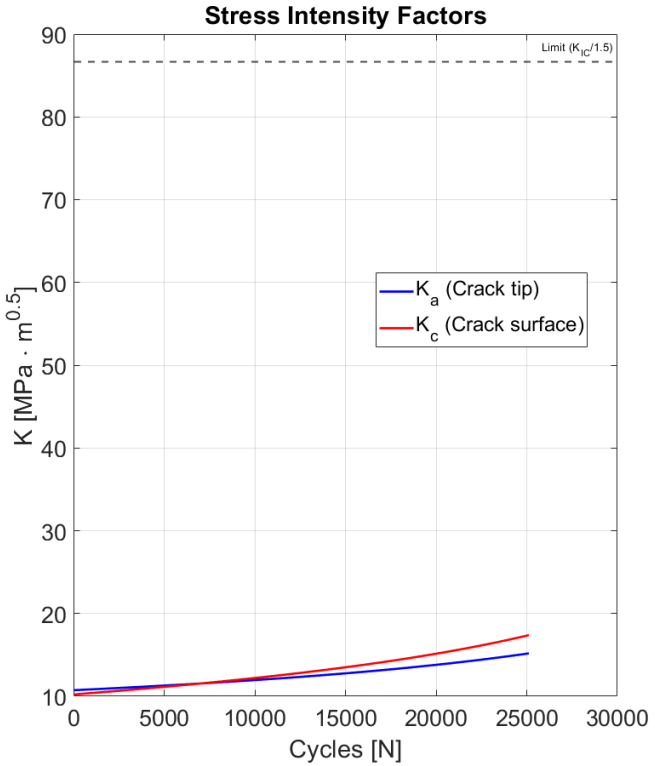
Analytical vs numerical:

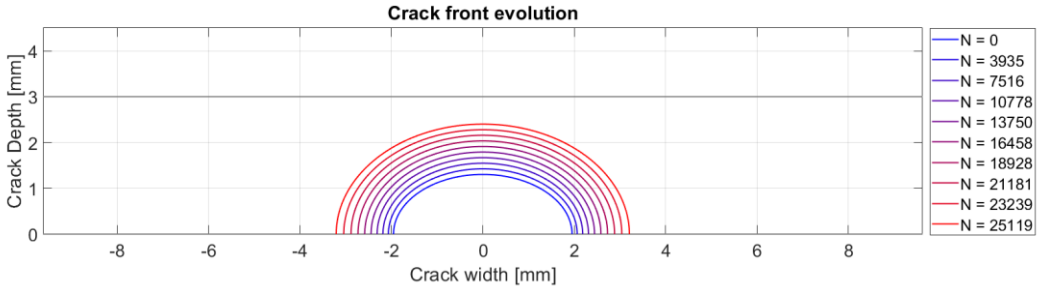
- Similar trend.
- Analytical model provides greater values (~4%) with respect to numerical ones.
- As for the external crack, the overestimation can be attributed to the conservative nature of the analytical solution and to the ring geometry.

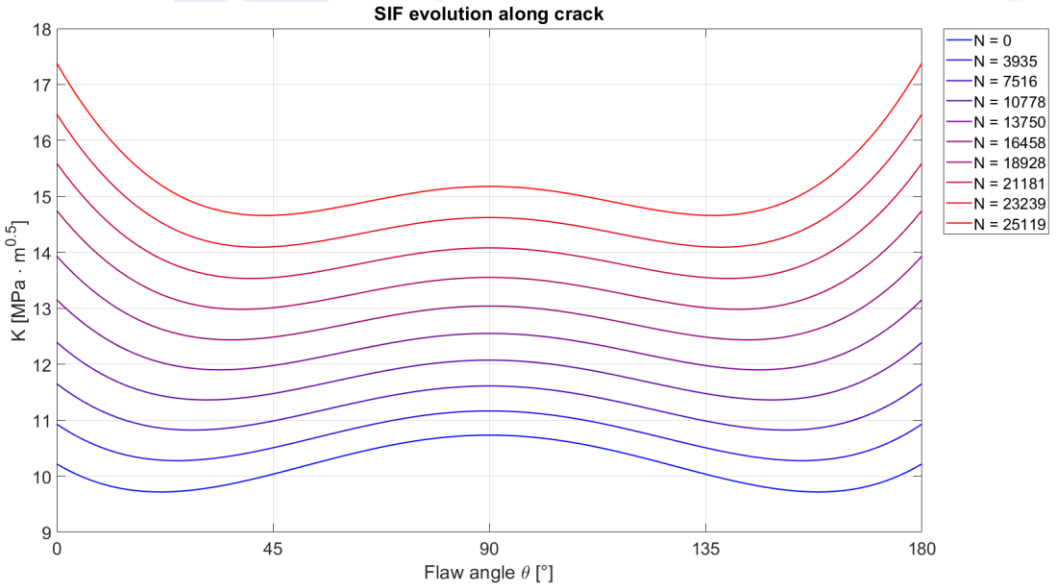
Crack simulation on jacket ring: Internal crack

- Number of cycles before failure: 25119 (SF_N=2)
- Failure mode: a=0.8·t
- K<<K_{IC}
- Minimum 23 days test
  (20s/cycle - 6h/d - no issues)









Summary

- A FEM model of the jacket has been developed and used to evaluate the experimental loading cycle amplitude, considering all the boundary constraints.

- A code the crack growth has been developed based on ITER design codes. The results, in terms of SIF along crack front, were successfully cross-checked against numerical simulations.

- Once available, the experimental results will be compared to those obtained by the developed code.

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Scope of the work

- Compare the **crack propagation,** on metallic components, predicted by means **ITER design codes** and experimentally derivate.

- A series of tests are planned to study the evolution of artificial defects on a steel jacket. Specifically, tests will be performed on a **linear jacket** (with a 4-point bending test) and on a **ring jacket**.

- Ring jacket test will be performed at ENEA making use of the Testing Facility already developed to test the ITER pre compression rings.