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# Non-linear Assessment of Critical Failure Modes in the First Wall of the European TBM

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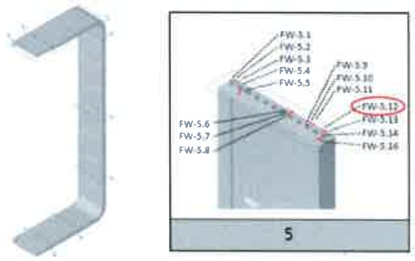
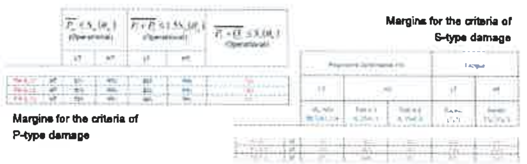
## Objectives

The assessment of the HCPB and HCLL Test Blanket Modules (TBMs) based on elastic finite element (FE) analyses considering operation at full power and reduced heat extraction capability for compliance with temperature targets to be relevant to DEMO blanket system reveals that many locations in the First Wall (FW) become critical in the sense that certain criteria are not fulfilled, particularly those for immediate plastic flow localization, progressive deformation (ratcheting) and creep-fatigue interaction. Therefore the critical failure modes are re-assessed performing non-linear analysis using the elasto-viscoplatic model developed for RAFM steels such as the structural material EUROFER97 by Aktaa & Schmitt, and considering the appropriate design criteria of the inelastic route of RCC-MRx and SDC-IC.

## Introduction

### Elastic analysis - critical failure modes / positions




➔ Critical failure modes: Immediate plastic flow localization, progressive deformation, and fatigue / creep-fatigue

## Non-linear structure analysis

- Elasto-viscoplastic FE simulations using the implementation of the model by Aktaa & Schmitt as User Material Subroutine in ABAQUS and its parameters determined for EUROFER97
- Assessment considering the design criteria of the inelastic route of RCC-MRx and SDC-IC

### First Wall model / submodel


→ Loading and boundary conditions from elastic analysis
→ Simulation of one loading cycle
→ Assessment of Immediate plastic flow localization

→ Loading and boundary conditions from elasto-viscoplastic analysis of FW model
→ Simulation of 351 cycles
→ Assessment of progressive deformation and fatigue / creep fatigue

## Assessment results

### Immediate plastic flow localization

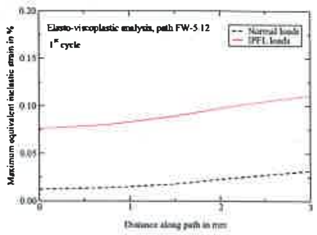
According to the criteria, elasto-viscoplastic simulations shall be performed considering amplified loads (IPFL loads):

- Mechanical loadings by the load factor 2.5
- Thermal and other deformation-controlled loadings by the strain factor 1.5

The calculated inelastic strains shall fulfill:

$$\varepsilon_{m,l}^{pl} \leq \frac{\varepsilon_u(T_m, \phi_m)}{2}$$

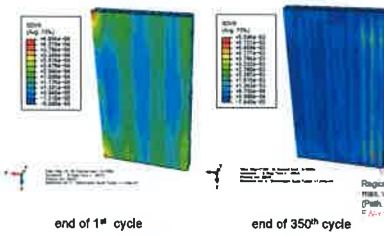
For EUROFER97: $\varepsilon_u(T_m, \phi_m) > 0.8$ %

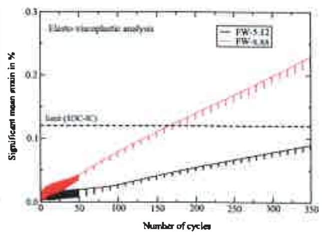



➔ Calculated strains far below the limit

### Progressive deformation (ratcheting)

Equivalent inelastic strain



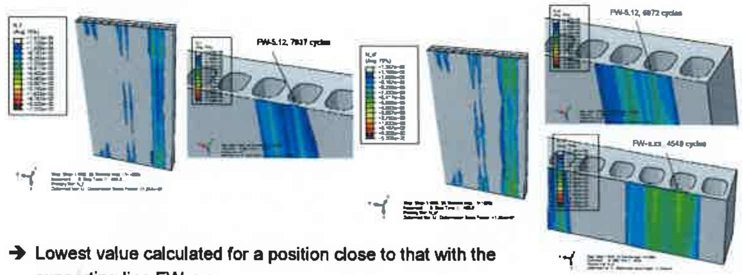

➔ Maximum shifted to new position not recognized in elastic analysis (FW-x.xx)

➔ Limit for mean strain exceeded within design lifetime while that of local strain is far above calculated values

### Fatigue / creep-fatigue

Allowable fatigue lifetime

Allowable creep-fatigue lifetime




➔ Lowest value calculated for a position close to that with the supporting line FW-x.xx

➔ Allowable number of cycles lower than design lifetime (11,000 cycles)

➔ Role of creep is low due to short dwell time at high temperature within the loading cycle

## Conclusions

Despite the conservatism in the design criteria of the inelastic route of RCC-MRx and SDC-IC, the results of the non-linear assessment show all-clear signal with respect to immediate plastic flow localization and at least much smaller breaches of the limits with respect to ratcheting and fatigue/creep fatigue. Thereby the most critical position for these two failure modes, not recognized in the elastic structure analysis, could be found. However, the assessment can be improved by releasing unnecessary conservatism in the design criteria and/or improving the description of ratcheting by using the modified elasto-viscoplastic model by Zhang and Aktaa.

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