Karlsruhe Institute of Technology

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Brittle Fracture Assessment for Tungsten and Tungsten alloy components

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Motivation

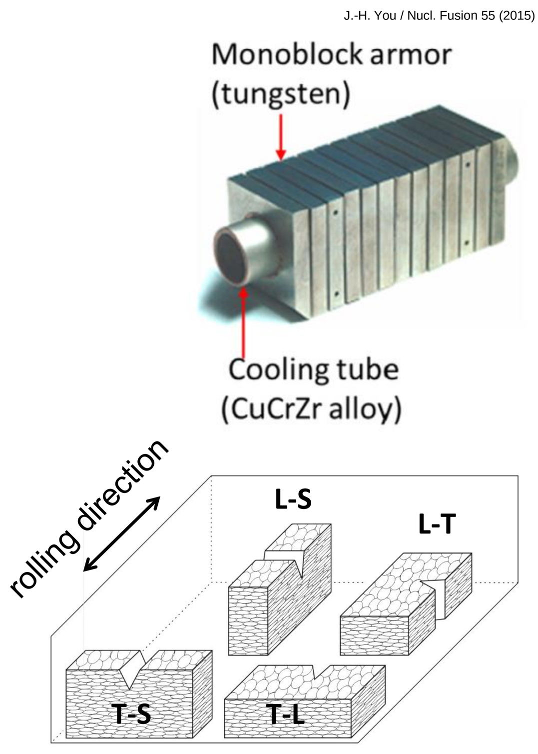
- Sintered and rolled polycrystalline W / WL10

Application of W / W alloys

- Armour material for plasma facing components in fusion reactors

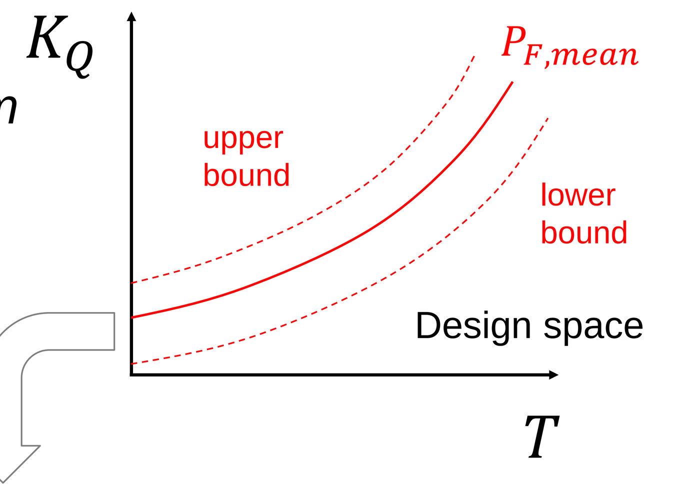
Challenges in using W / W alloys

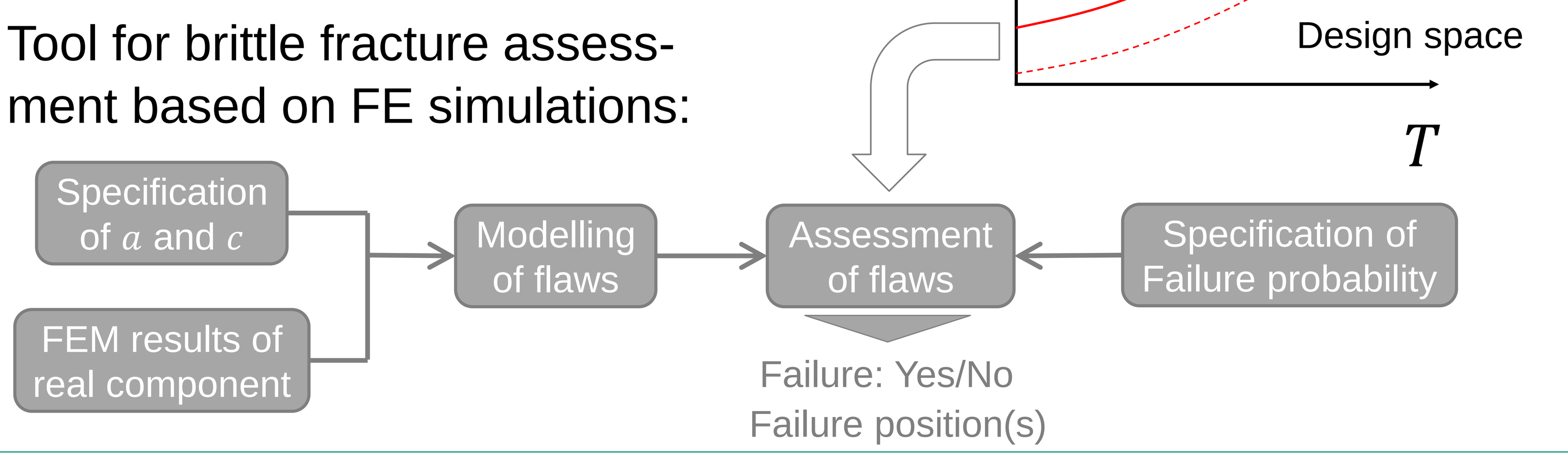
- Inherent low fracture toughness
- Scatter in material properties
- High brittle-to-ductile-transition temperature
- Anisotropy due to processing route



Objectives

- Development of *Fracture toughness-Temperature-Failure Probability-diagram*
- Determination of design space → Design criterion
- Tool for brittle fracture assessment based on FE simulations:





Results

Probabilistic failure analysis

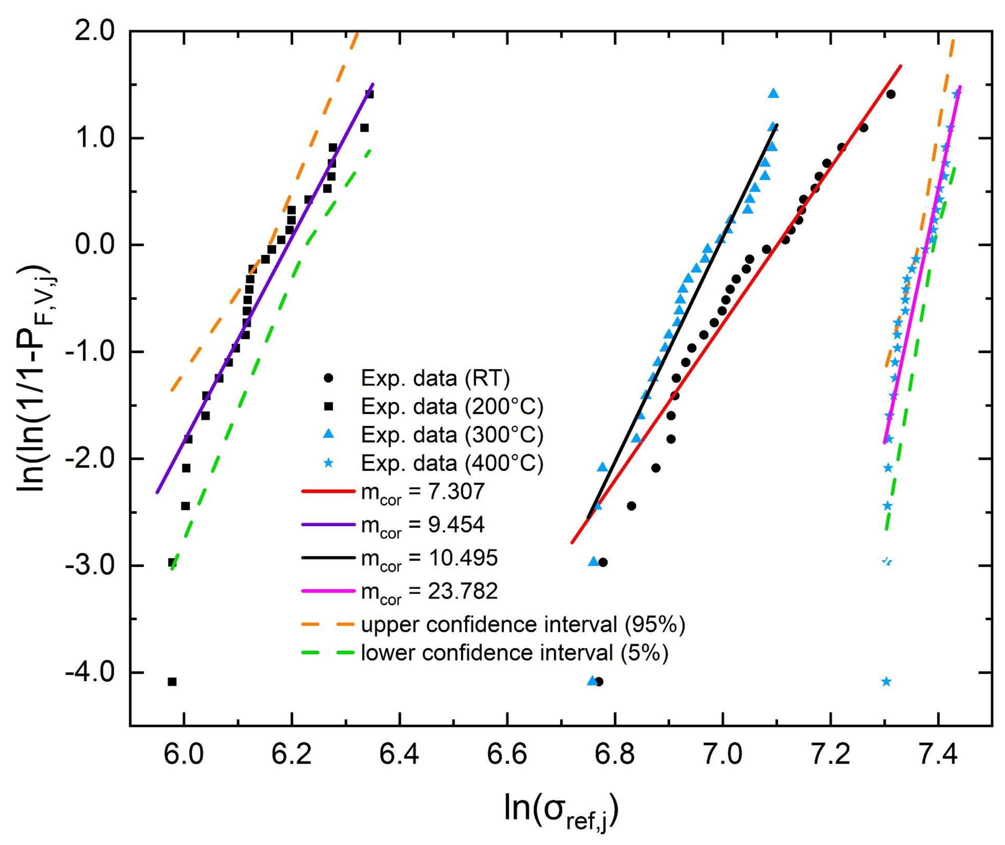
- Weakest-link theory with a two parameters Weibull distribution
- Brittle behavior characterized by Weibull model:

$$P_{F,V} = 1 - \exp\left[-\left(\frac{\sigma_{ref}}{b}\right)^m\right] \qquad \sigma_0 = b\left(\frac{V_{eff}}{V_0}\right)^{\frac{1}{m}}$$

- Lower shelf (onset of plasticity) by Beremin model:

$$P_{F,V} = 1 - exp\left[-\left(\frac{\sigma_W}{\sigma_u}\right)^m\right] \qquad \sigma_W = \sqrt[m]{\sum_j (\sigma_1^j)^m * \frac{V_j}{V_0}}$$

- Determination of requires sufficient number ($N \geq 30$) of tests



- Weibull analysis:

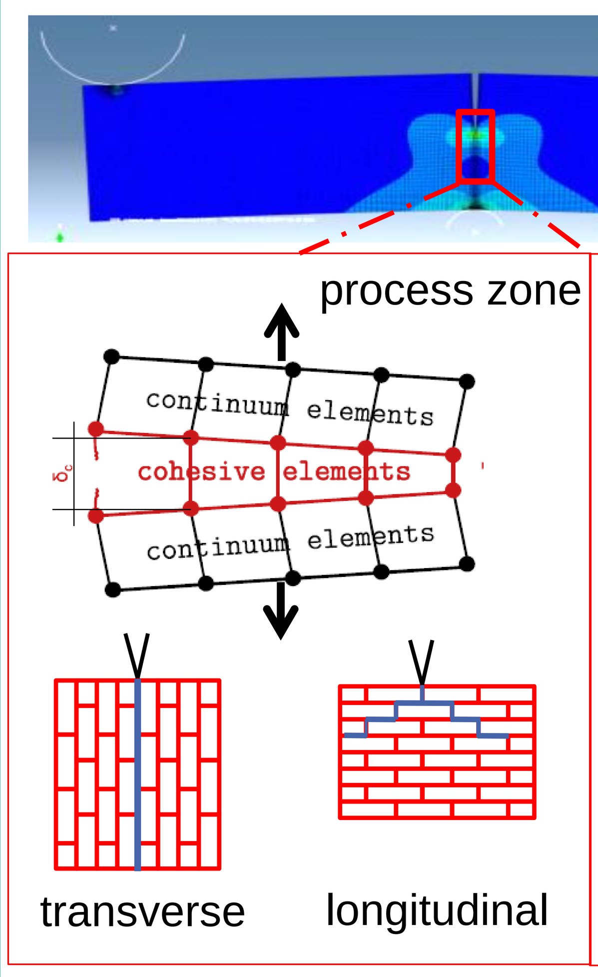
	RT	200 °C
$\hat{m}_{cor}$ [-]	7.307	9.545
σ_0 [MPa]	1290.27	869.35

- Beremin analysis:

	300°C	400 °C
$\hat{m}_{cor}$ [-]	10.495	23.782
$\hat{\sigma}_u$ [MPa]	1089.04	1599.97

Fracture mechanical simulation

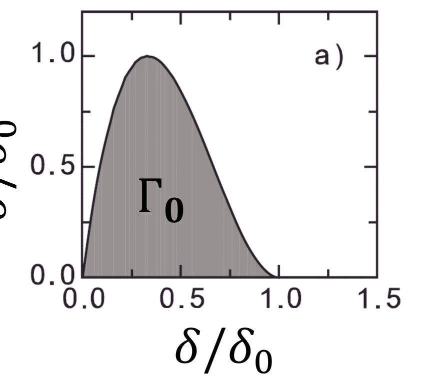
- Crack propagation modelling with Cohesive Zone Elements (CZE) in-between the continuum elements



σ_{Coh}: cohesive strength → σ_f (4PB)

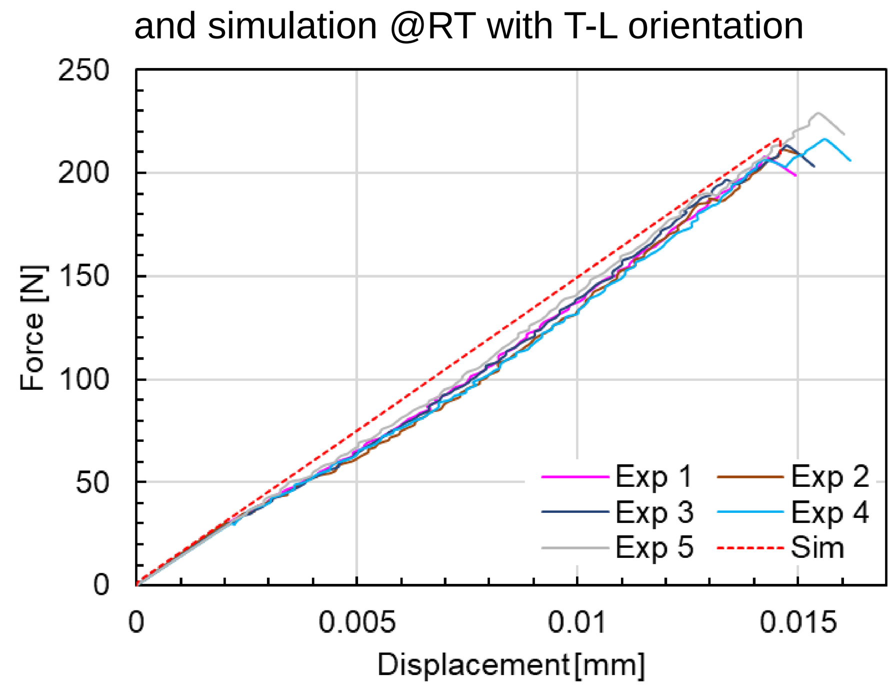
Γ_{Coh}: cohesive energy → FM test (K_{IC})

Traction-Separation-Law



Fitting simulation and tests

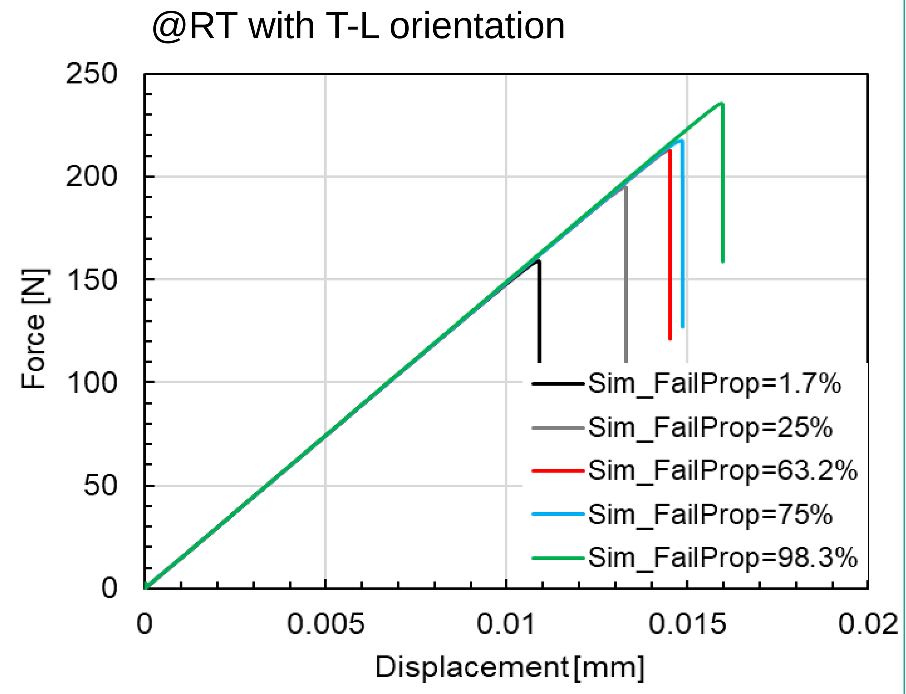
- Fracture mechanical (FM) tests (Exp 1-5) and simulation @RT with T-L orientation



Assumption: $\sigma_{Coh}(P_F) = \sigma_0(P_F)$ or $\sigma_u(P_F)$

Simulations with failure probabilities

- Fracture mechanical (FM) simulations with cohesive stress altered by failure probability @RT with T-L orientation



$$K_Q(P_F) = \frac{F(P_F)*s}{\sqrt{B*B_N}*W^{3/2}} * f\left(\frac{a}{W}\right)$$

- For desired temperatures → $K_Q(P_F, T)$

- Step 1: Keep cohesive stress (σ_{Coh}(63.2 %)) constant and alter cohesive energy (Γ_{Coh}) to fit simulation result to experimental result
- Step 2: Keep obtained energy (Γ_{Coh}) constant and alter cohesive stress ($\sigma_{Coh}(P_F)$) depending on the probability of failure

Conclusion

This method will provide fracture toughness data for design rule against brittle fracture in tungsten and tungsten alloy components considering an allowable probability of failure.

Outlook

- Validation of the method for room temperature
- Focus on further temperatures (up to 400 °C) and grain orientations
- Implementation of brittle fracture assessment post-processing code

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