SimuCRACK Phase V

Simulation of Fatigue Crack Growth in Hardmetal at a Mesoscopic Scale

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Estimated costs of project in total:
120.000 €*

Industrial participants:
Hilti Corporation
Ceratizit Luxembourg S.à r.l.
Hyperion Materials & Technologies
Kennametal
Sandvik

History of Simucrack Club Project

2009 – 2010

FP7-NMP-2010-SMALL-4

COLLABORATIVE PROJECT

Proposal full title:

MULTISCALE MODELLING OF FATIGUE CRACK GROWTH IN HARDMETALS

FATIGUELESSHARDMETAL

European Project Proposal

(Stage 1 Pass [16%] / Stage 2 Fail [7%])

"Simu-Crack Phase I"

Consortium Agreement

Issued 16 May 2011

Project:"Simu-Crack Phase II"

Consortium Agreement

Issued 6 March 2013

Project:"SIMU-CRACK Phase III"

Consortium Agreement

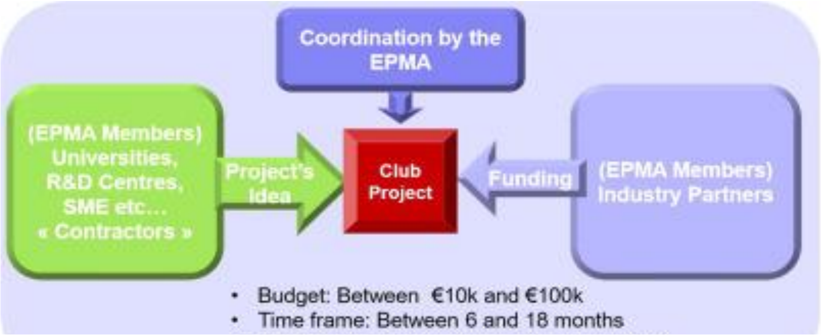
Issued January 2016

"SIMU-CRACK Phase IV"

Consortium Agreement

(2 / 9 /2019)

Leo PRAKASH



"SimuCRACK V"

Consortium Agreement

(28 / 04 / 2022)

"SIMU-CRACK Phase V"

Online Kickoff Meeting

3 November 2022

History of Simucrack Club Project – Phase I

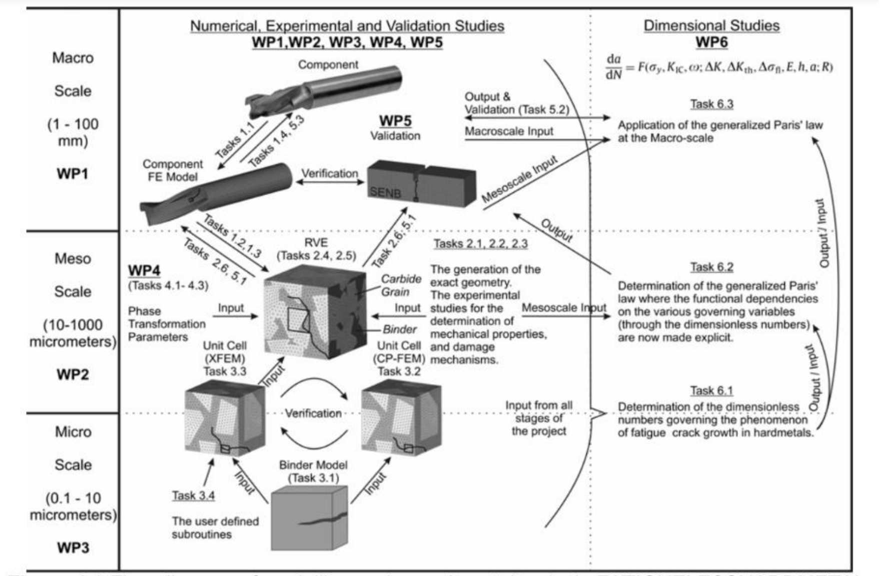


Figure 1.3 Flow diagram of modelling and experimental tasks in FATIGUELESSHARDMETAL.

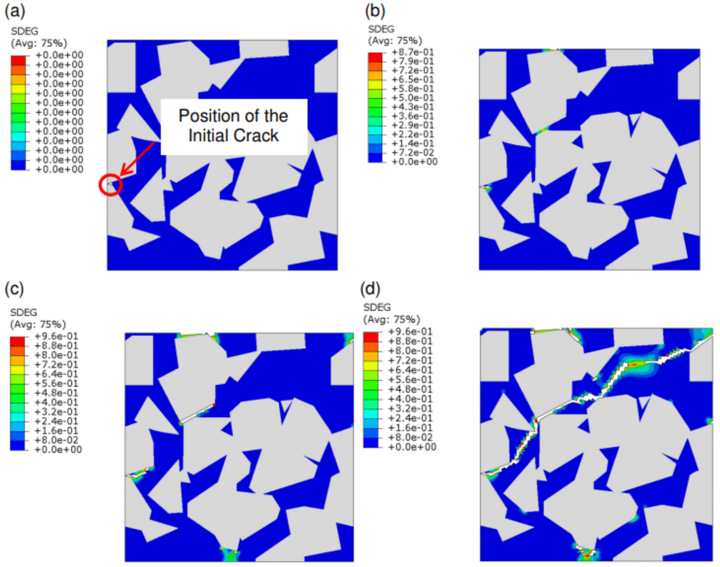


Figure 12. The fatigue crack propagation under R = -0.5 at (a) Cycle 0 (b) Cycle 100 (c) Cycle 105 and (d) Cycle 118 for 75 % W_{WC} WC/Co. SDEG = Stiffness Degradation.

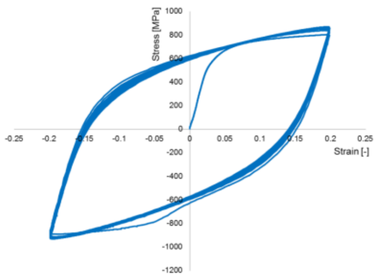
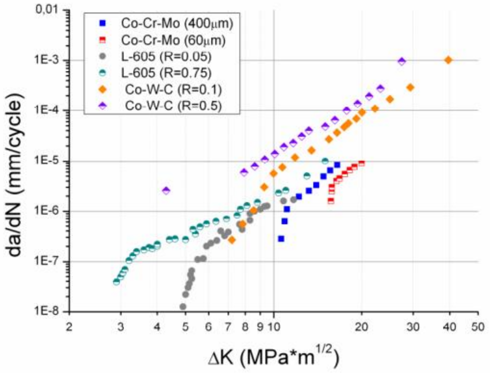
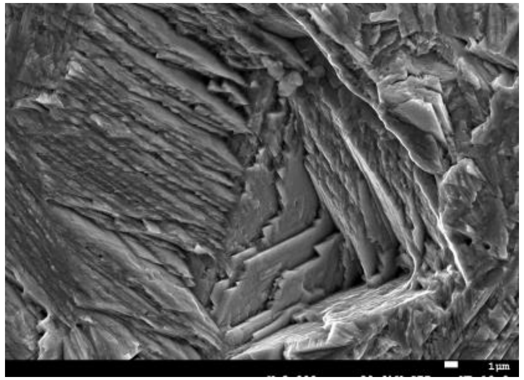


Figure 24. Hysteresis diagram for the representative binder alloy.

Utku ÖZDEN (Phases I and II)
Nowadays Lead Specialist in Simulation Technology - Advanced Material Technology, Velux A/S





History of Simucrack Club Project – Phase II

SIMU-CRACK II project Meeting in Barcelona, October 2013

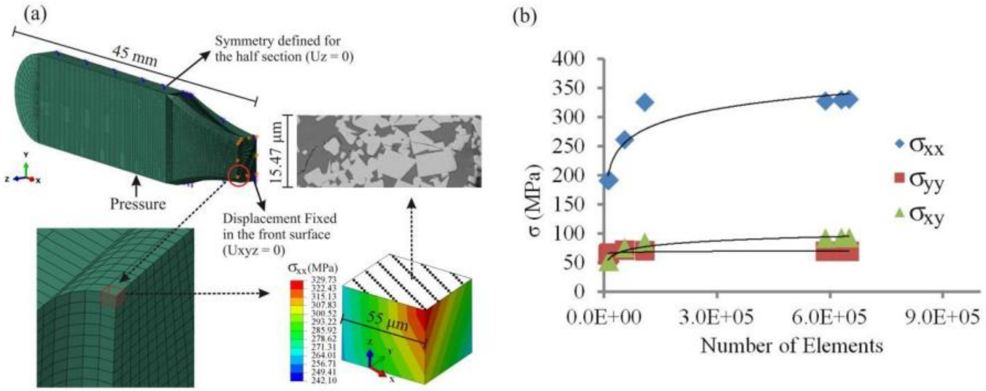


Fig. 1. (a) macroscopic FEM model and its relation to the microstructural model; (b) results of the convergence study.

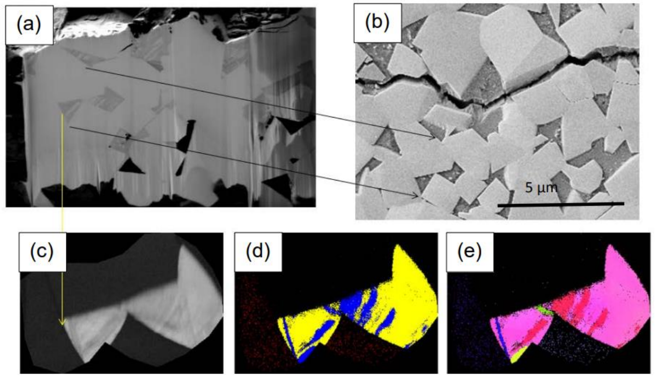


Figure 28. Examination of fatigued 11% Co hardmetal shown in **Figure 27**: a) secondary electron image of ion beam milled material from the same region shown in b) of the lower half of the fracture sample; c) image quality EBSD map of region shown by arrow, d) EBSD map of FCC (yellow), and HCP (blue), e) EBSD map of orientations of Co phase.

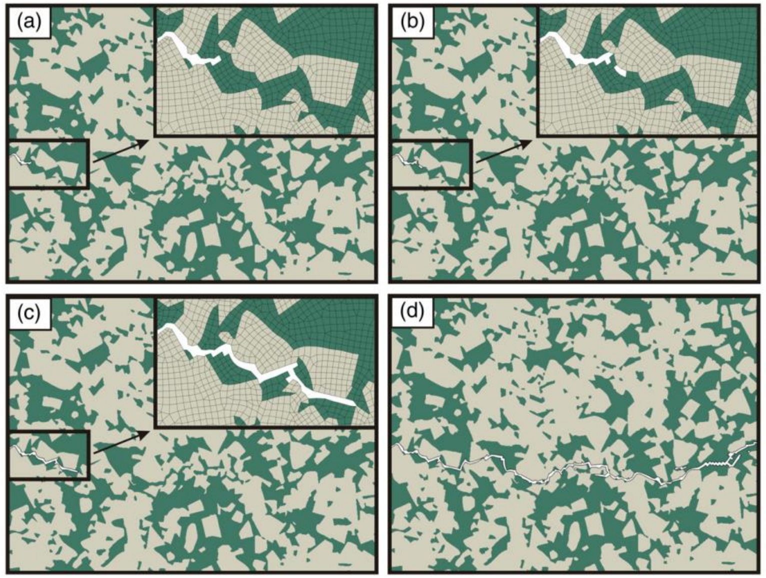


Fig. 6. Evolution of damage in the mesoscale FE model at (a) 50 cycles; (b) 117 cycles; (c) 244 cycles; (d) 245 cycles.

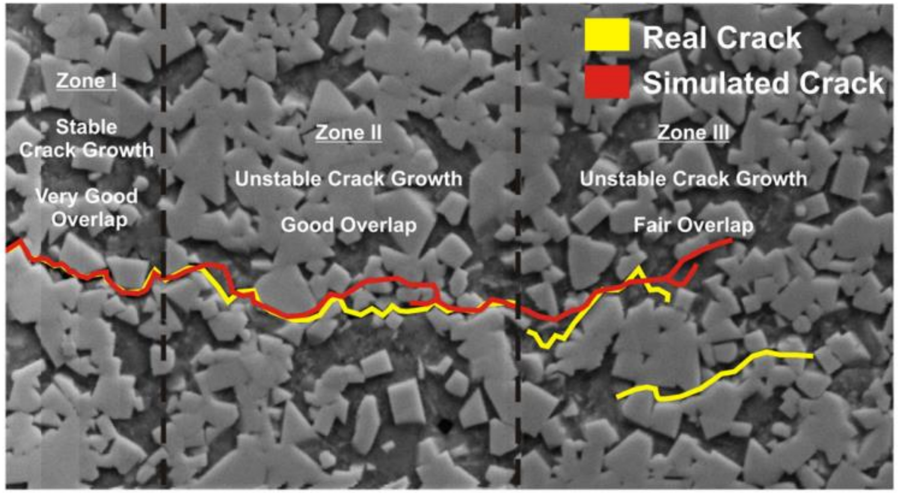


Fig. 7. Comparison between the real and simulated crack patterns.

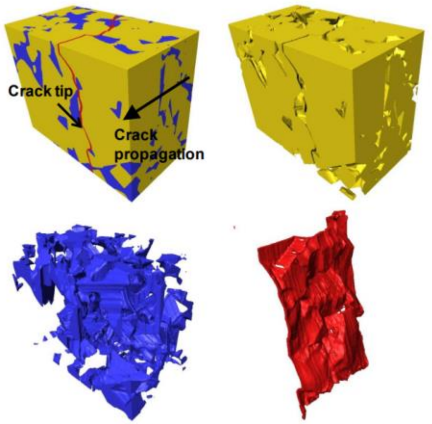


Figure 21. 3D reconstruction of process zone for stable crack growth under cyclic loading. Yellow correspond to the WC skeleton; blue to the Cobalt phase; and red represents the cracked region.

History of Simucrack Club Project – Phase III

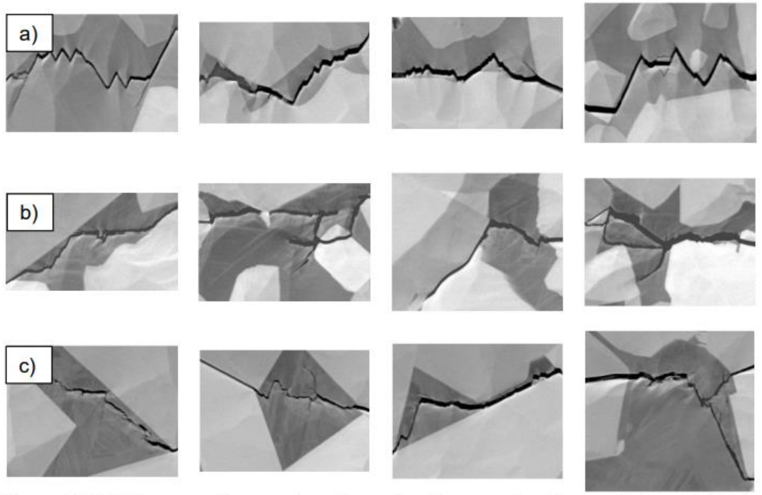
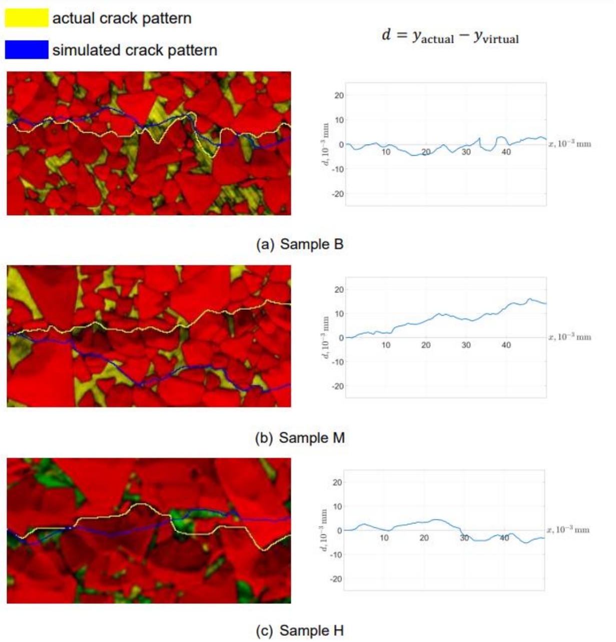


Figure 12 SEM images of example regions of surface crack path growth through binder regions of a) (top row) B, b) (centre row) M, and c) (bottom row) H samples. Each field of view 6.25 µm wide



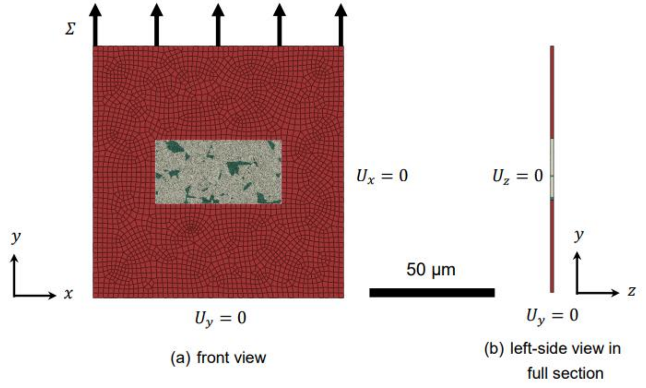
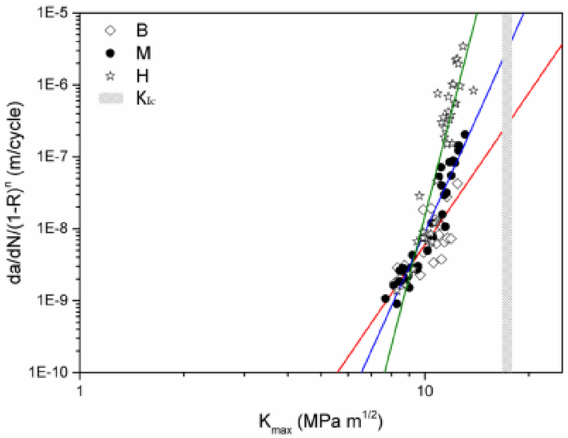
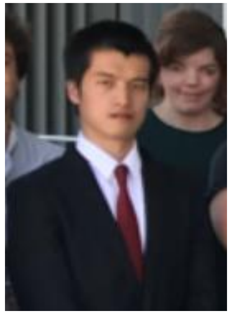


Figure 27 Finite element mesh and boundary condition





Keng JIANG, (Phases 2 and 3),
PhD Thesis: “Computational Characterization of Fatigue in WC-Co Hardmetals”, to be defended next November 17, 2023

Simucrack III Project Meeting in Barcelona, June 2018

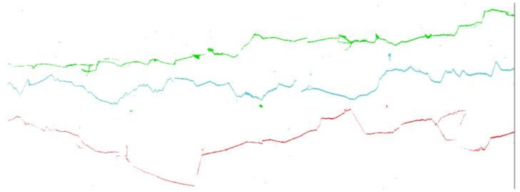


Figure 13 Crack paths close to the crack tip (on left of image) shown with microstructure removed for B (blue, centre line), M (green, top), and H (red, bottom) samples. Image ≈ 81 µm wide

History of Simucrack Club Project – Phase IV

Donat RUDENSKIY
(Phases IV and V)

Alexander BEZOLD
(All phases!)

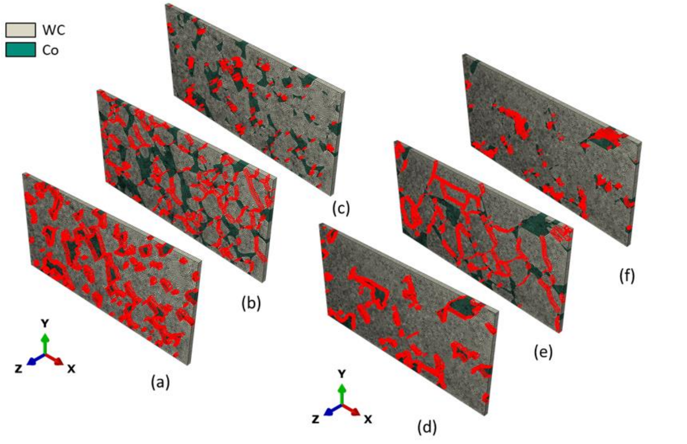


Figure 6 The cohesive elements representing the following interfaces: grade B WC/Co (a), grade B WC/WC (b), grade B Co/Co (c) and grade H WC/Co (d), grade H WC/WC (e), grade B Co/Co (f).

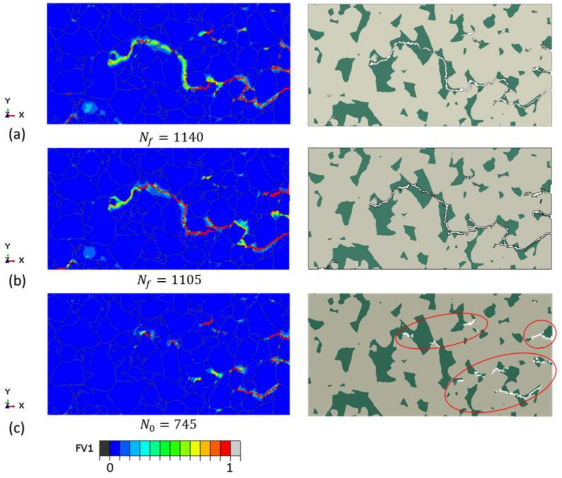


Figure 8 Damage variable $FV1$ plots (left) and crack patterns (right) for grade B model without cohesive elements (a), with cohesive elements at WC/Co interfaces (b) and at all interfaces (c).

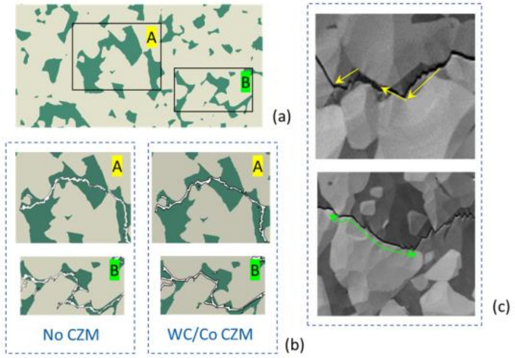


Figure 9 Grade B ROI A and B (a), the comparison of crack paths for no CZM model and WC/Co CZM models (b) and SEM crack pictures from SIMUCRACK III (c).

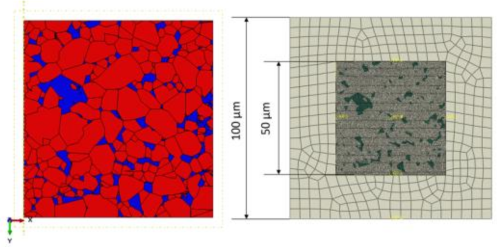


Figure 39 LC specimen Abaqus geometric (left) and meshed model (right).

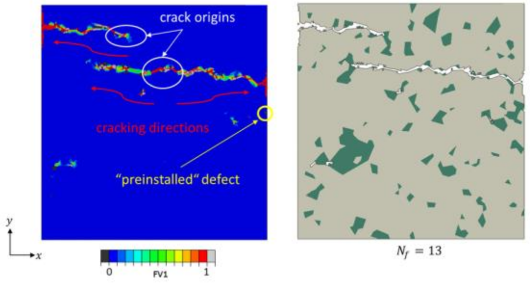


Figure 43 Results of LC specimen under cyclic loading; damage variable contour plot (left) and the final crack pattern (right).

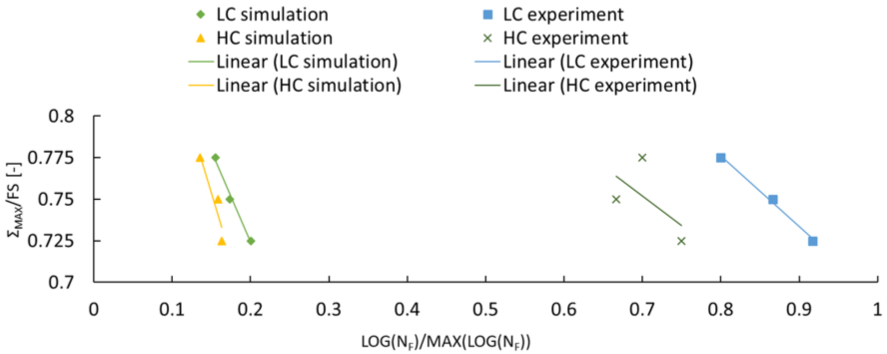


Figure 45 The graphical representation of simulation results and experimental fatigue test results.

SimuCRACK Phase IV – Relevant Outcomes

Experimental insights on FCG mechanism

- FCG mechanisms in low carbon (LC) and high carbon (HC) are not affected by C-content
- Lower fatigue life and higher scatter in HC samples apparently caused by hcp-Co in binder
- Fractography hasn't pointed out a clear distinction between short and long cracks in LC and HC

What does it mean for numerical modelling?

- Mesoscale RVE simulations cover the both stages of crack growth (stable and unstable)
- The model parameters should be adjusted to produce more pronounced main cracks (secondary cracks and crack branching is less relevant)
- An hcp-Co model is required to understand the causes of scatter in experiments

Advances in numerical modelling

- Validation of the numerical model based on SimuCRACK III modelling techniques
- Introducing new features like cohesive zones and orientation dependent damage in WC

SimuCRACK V – Goals

Overarching goal SimuCRACK

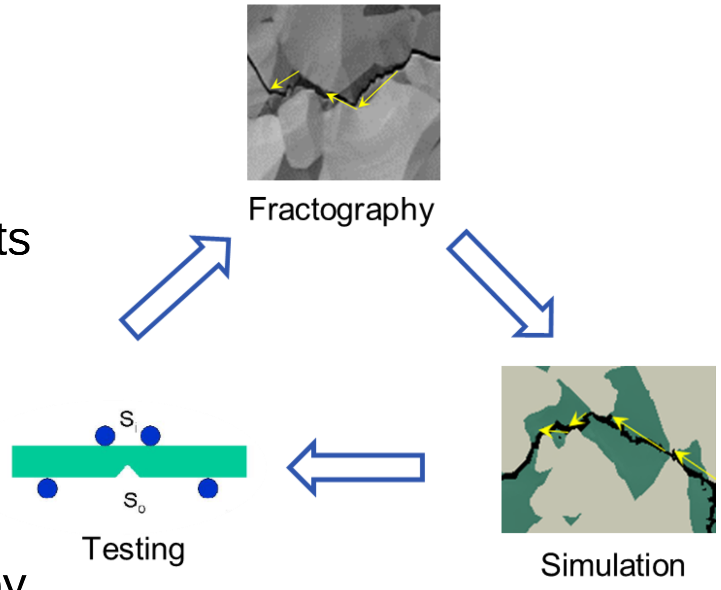
- An all-encompassing simulation-experiment combined methodology for studying, analyzing and understanding FCG behaviour in WC-Co hardmetals.

Expectations towards numerical model

- Improved representation of crack growth kinetics at mesoscale (WP1)
- Mapping the fracture mechanisms instead of merely statistically valid results (WP4)
- Usability and applicability of simulation models in industrial environment (WP5)

Expectations towards deeper experimental understanding

- Extension of reliability assessment approach introduced in Simucrack IV, by taking into consideration service-like induced damage (WP2)
- Assessment of residual strength of hardmetals, as a function of C content, linked to induced damage introduced during previous cyclic loading (WP2)
- Microstructural characterization of service-like damage prior to crack development (WP2 + WP3)



Flowchart SIMUCRACK V

WP0 Sample preparation (industrial partners)

Simucrack IV numerical models

WP2.1 Fracture and fatigue characterization – unnotched specimens (t = 0) (UPC)

WP3.1 Limited fatigue testing of notched specimens (t = 0) (NPL)

WP1 Parametric study of binder properties & final validation of local strength model (IWM)

WP2.2 Residual strength characterization (t = t’, t’’, t’’’) on “damaged” unnotched specimens and fractography (UPC)

WP3.2 SEM/EBSD characterization of damage induced by fatigue on notched specimens (NPL)

WP4 Simulation study of residual strength of notched and unnotched specimens (IWM)

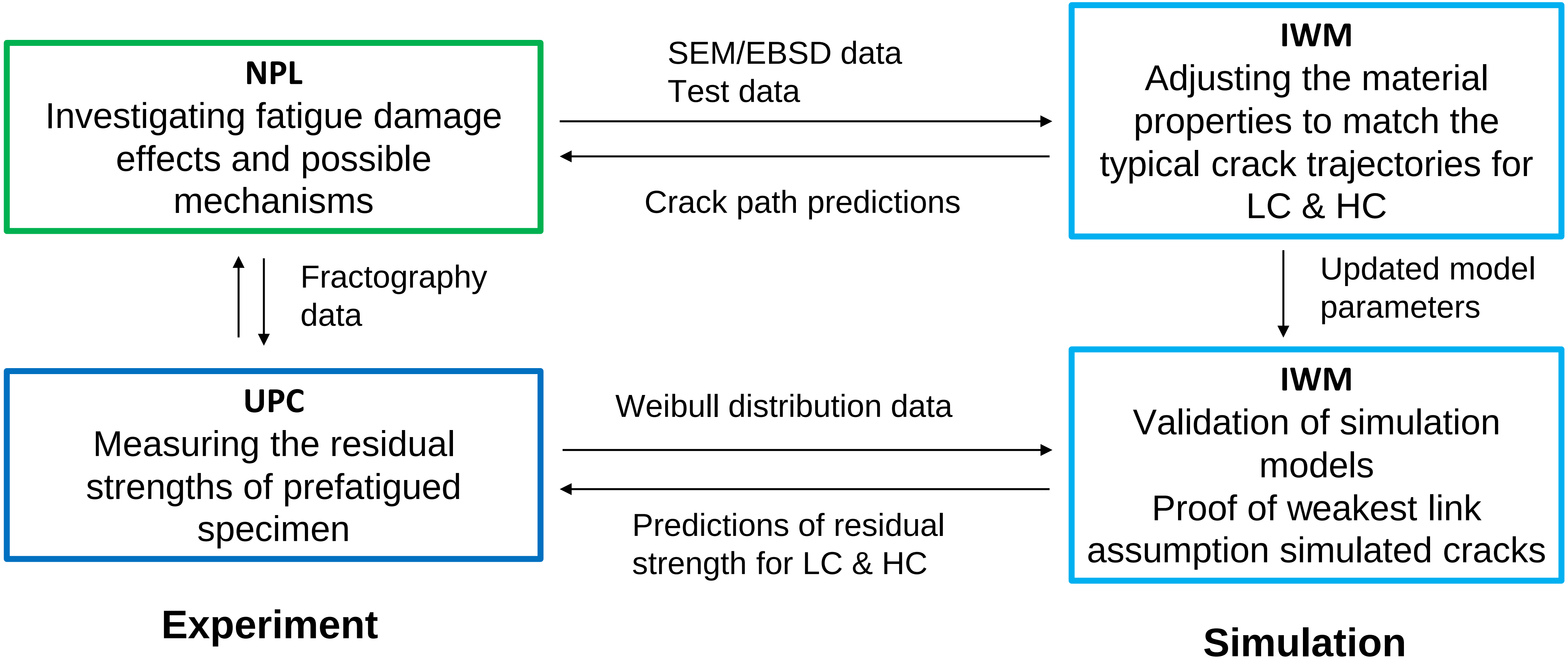
WP2.3 Reliability (Weibull) analysis (t = 0 vs t ≠ 0) (UPC)

WP5 Realization of a modular and extendable numerical model repository (IWM)

WP6 Project management and reporting (EPMA/UPC/NPL/IWM)

Experiment / Simulation Interaction

Flow chart describing the data exchange



Current state validated

Model assumptions
- 2.5D geometry model based on EBSD
- Elastic bedding crack-free
- No grain orientations in cobalt
- No phase distinction in cobalt
- No plastic slip in WC
- No interface fatigue

Cobalt material behaviour
- Constitutive model based on Chaboche approach
- CDM based on Lemaitre critical damage

WC material behaviour
- Elastic-anisotropic constitutive model
- Sigma I based damage model

Further developments

Reducing the necessary assumptions

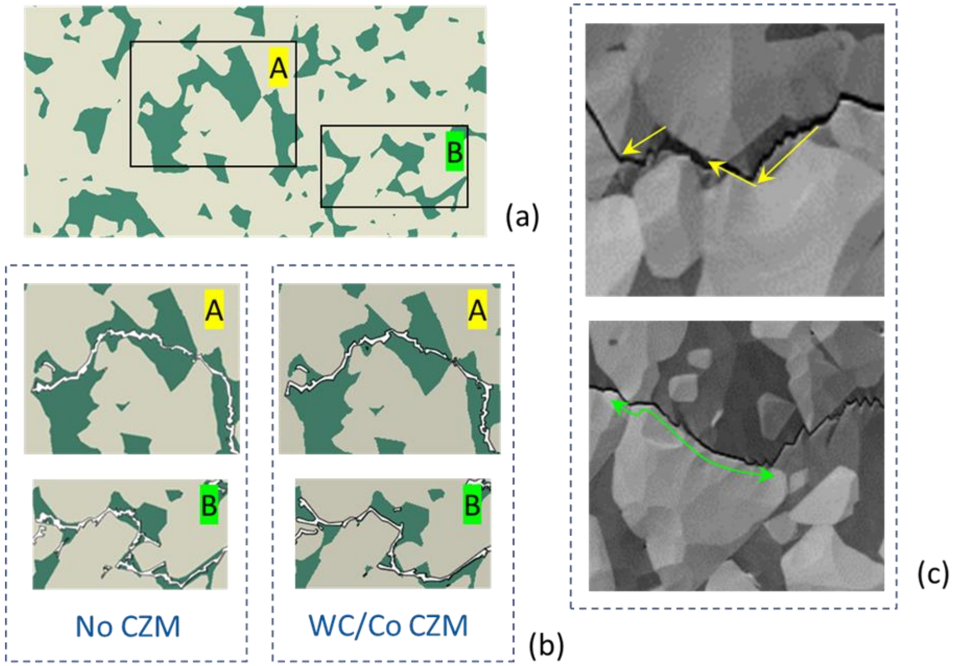
Model assumptions
- 2.5D geometry model based on EBSD
- Elastic bedding crack-free
- No grain orientations in cobalt

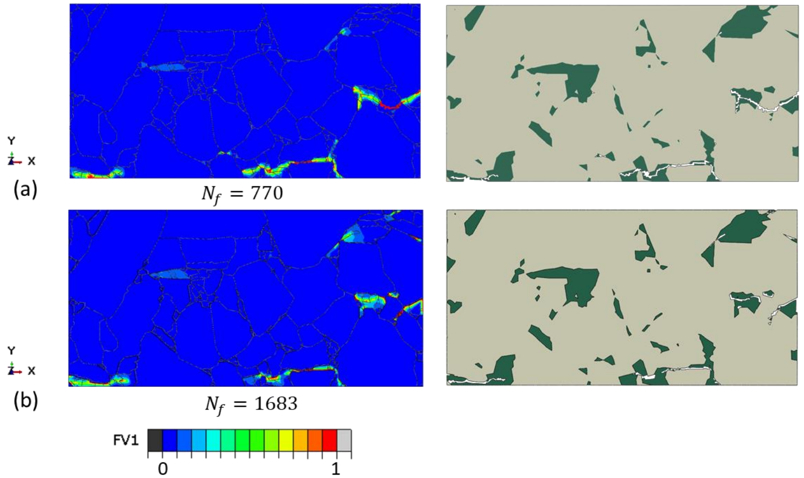
Introducing and verifying new features

Cobalt material behaviour
- Constitutive and damage behaviours for fcc/hcp phases and for low/high carbon

WC material behaviour
- Plastic slip implementation
- Damage accumulation in WC grains

Interface damage & fatigue
- Damage accumulation in WC/Co and WC/WC interfaces





Why do we need model improvements in Simucrack V?

- To capture the binder effects on fatigue cracks more precisely
- To predict the reliability using residual strength approach
- To make the models more stable and fast

*** Design for reliability using the most recent knowledge!**

SimuCRACK V – Timeline