# High resolution in-situ fatigue damage analysis and extrusion kinetics with ROCS microscopy

**Nadira Hadzic** [1] **M.Sc. Ali Riza Durmaz** [1,2], **Dr. Felix Jünger** [2], **Prof. Dr. Alexander Rohrbach** [2], **Prof. Dr. Chris Eberl** [1,2]
[1] Fraunhofer Institute for Mechanics of Materials (IWM), Freiburg
[2] Department Of Microsystems (IMTEK), University of Freiburg

## INTRODUCTION

For an optimized prediction of the material's lifetime behaviour, two existing setups were combined. The objective was to gain a better knowledge and understanding of the microstructure sensitive damage mechanisms and extrusion kinectics during very high cycle fatigue (VHCF). Current simulative predicition strategies including discrete dislocation dynamics (DDD) and crystal plasticity finite element method (CPFEM) require experimental observations of fatigue processes to validate their underlying models. The multiaxial setup for damage detection [1] was complemented with the rotating coherent scattering (ROCS) microscopy [2] for high resolution in-situ observation under normal air conditions.

## METHODS

The multiaxial setup for damage detection in the VHCF regime by Straub et al. [1] is illustrated in *Figure 1*. In the further miniaturized in-situ ROCS-fatigue setup only one piezo-actuator is used, so fatigue under bending vibrations can be investigated. With a laser and a position sensitive detector the displacement of the sample is controlled over the piezo signal. Experiments run typically with sample resonant frequencies around 2 kHz, so that $10^9$ cycles can be reached in a convenient time.

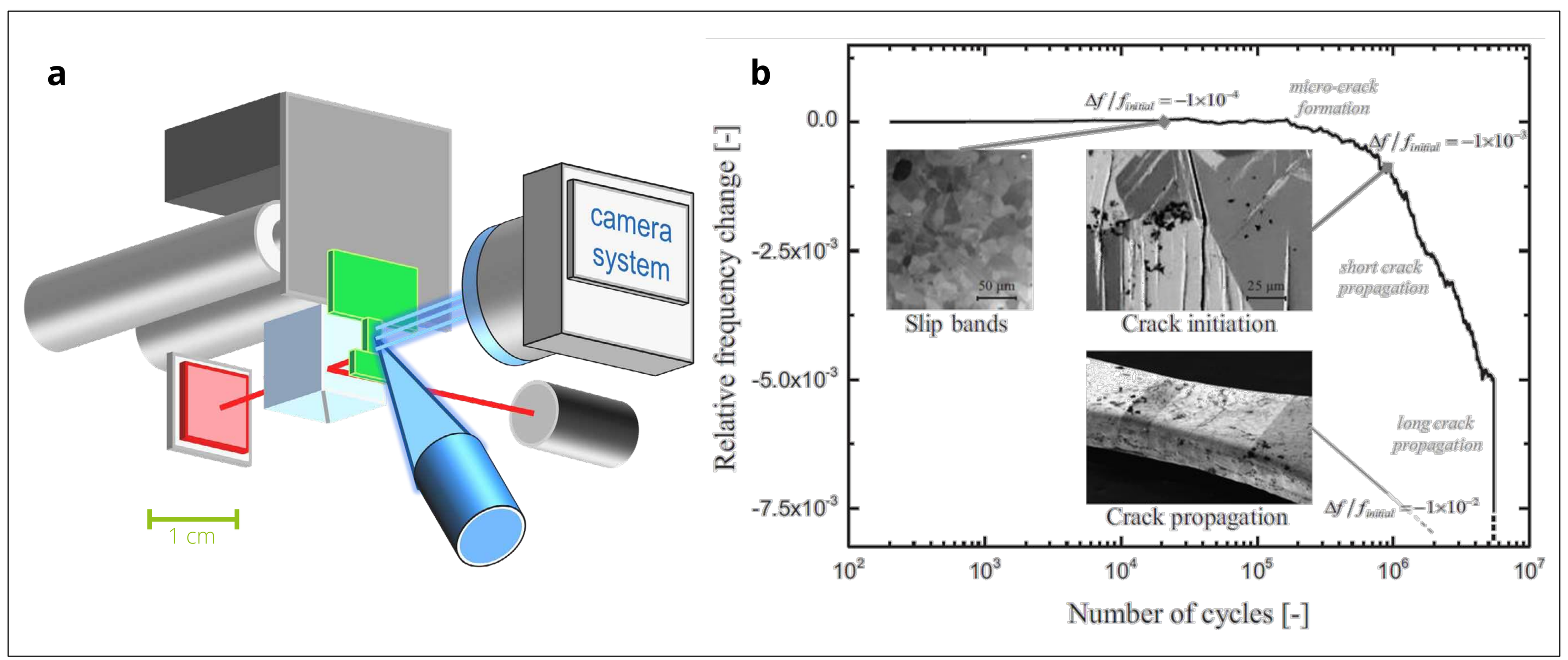


*Figure 1: (a) Scheme of the multiaxial setup for fatigue damage detection. (b) Relative frequency change over the number of cycles showing different decreases during damage and crack initiation.*

The different damaging stages can be tracked by the relative frequency change over the number of cycles. Additionally, in a prior work, the multiaxial fatigue setup [1] was extended with a camera system and LED spot lights to aquire not only global but also local information. Due to the objective to get statistical data of the whole sample, this imaging system does not provide the spatial resolution needed to resolve single extrusion formation dynamics. Therefore, ROCS microscopy was used as an alternative imaging system with a high spatial resolution, but at the cost of a reduced field of view.

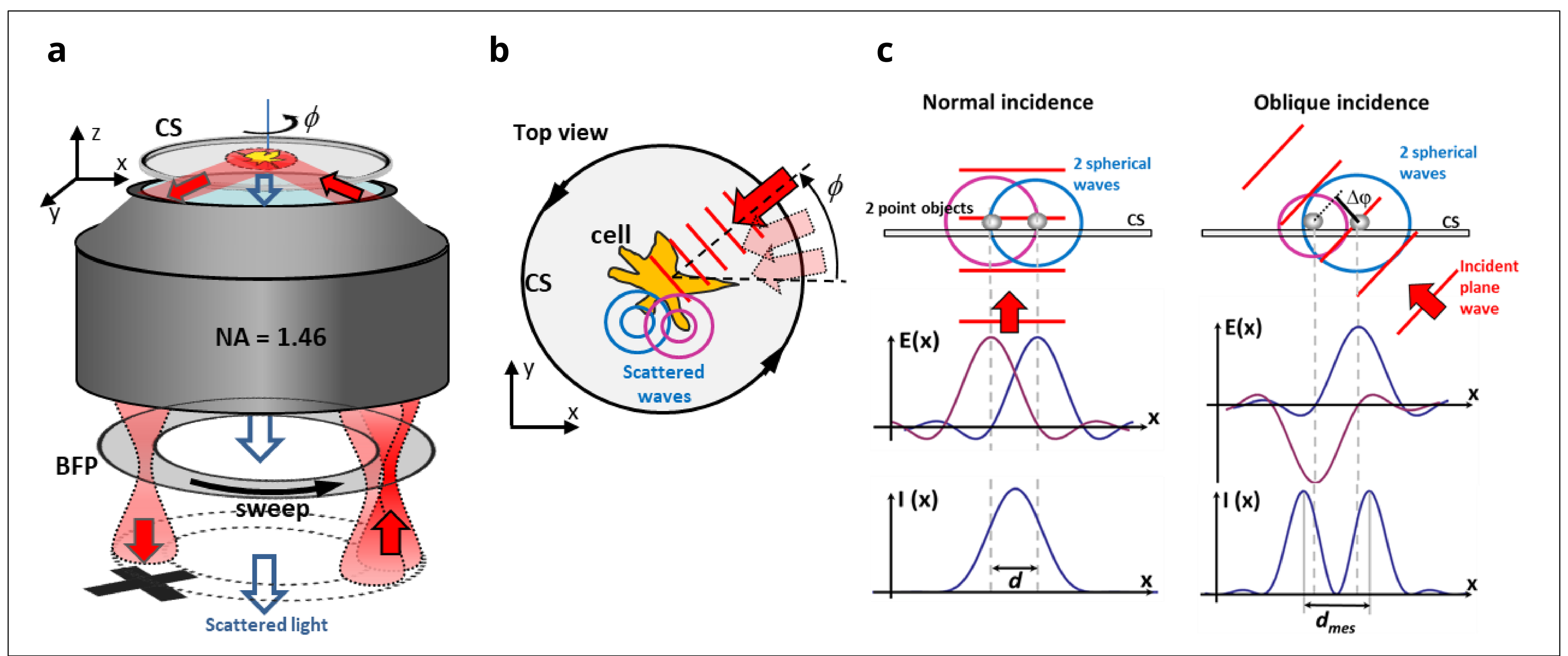


*Figure 2: ROCS microscopy – experimental setup and operation principle.*

ROCS microscopy [2] was developed for high resolution and fast imaging of cells. A laser rotates in the back focal plane (BFP) of the objective and illuminates the sample from different azimuthal angles (*Figure 2a*). The surface structure of the sample leads to various scattering generating interference patterns. Further, the resolution is improved by oblique illumination (explained in *Figure 2c*).

For the fatigue experiments micro samples of 50CrMo4 steel with a hardness of 29 HRC were used. The material was austenized at 860°C, quenched in oil and tempered at 650°C for 90 minutes.

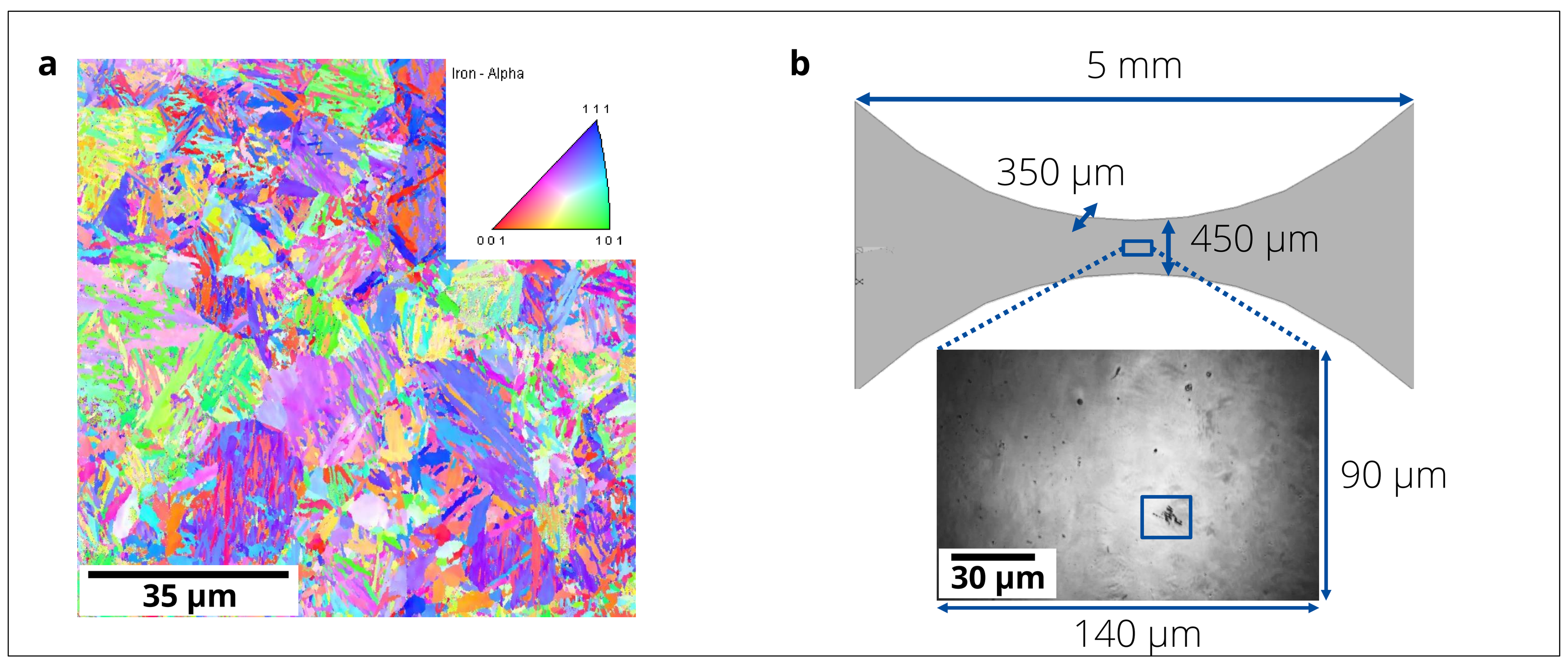


*Figure 3: (a) EBSD scan of the 50CrMo4 material (b) Micro sample geometry and comparison with a ROCS image of a damage location.*

Experimental settings:

- Displacement equivalent to von Mises stress of 310 MPa
- R = -1
- Frequency: 1.8 kHz
- Stopping criterion: $10^7$ cycles

## RESULTS

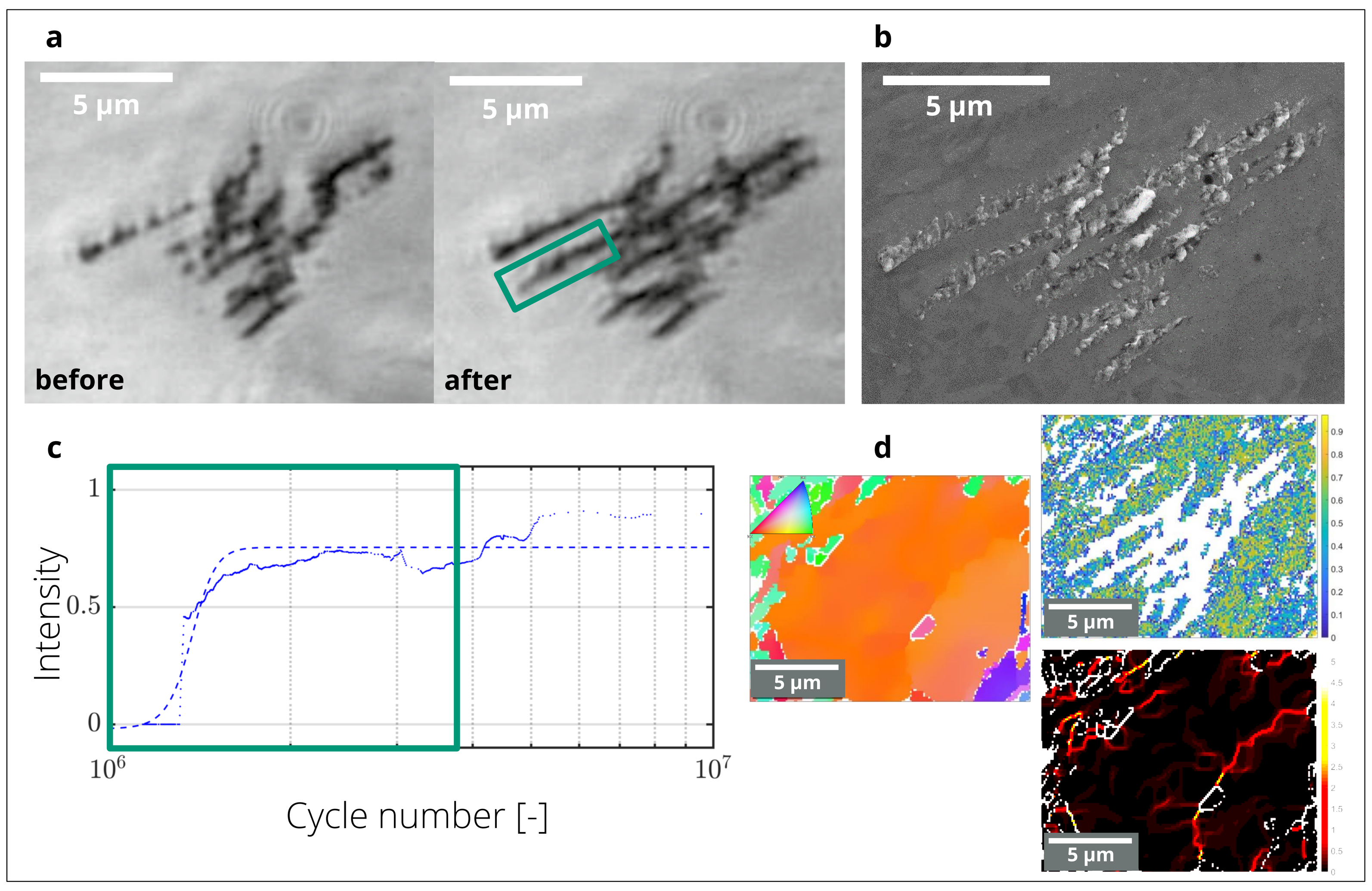


*Figure 4: Results of one fatigue experiment. (a) ROCS images of a damage location before and after the fatigue test. (b) SEM image of the damage location for comparison of the resolvable features and structures. (c) Normalized intensity over the cycle number. Evaluation of the kinetic behaviour of the marked area in figure 4a is shown. (d) EBSD scan maps of the damage location. Orientation map (left) , confidence index (upper right) and kernel average misorientation (lower right).*

- Damage locations mostly appear in greater areas with same orientation
- High confidence index shows presumable ferritic unit cells
- Damage geometry unexpected for martensite laths and for ferritic grains
- Misorientation gradients show on the edges of the damage locations
- Kinetic growth of damage location accessable

## CONCLUSION AND OUTLOOK

A first proof-of-concept study was performed and analyzed. Knowledge about the differences in damage geometry compared with martensite and ferrite microstructure was gained. The kinetic behaviour of extrusion growth is measurable through the intensity of the in-situ images. Further comparison of EBSD data before and after the experiments will help to understand the microstructural influence on the damage formation. The different kinetic growth parameter will be compared to available data from literature.

## REFERENCES

[1] T. Straub et al. „Small-Scale Multiaxial Setup for Damage Detection Into the Very High Cycle Fatigue Regime“. In: Experimental Mechanics 55.7 (2015). PII: 27, S. 1285–1299. issn: 0014-4851. doi: 10.1007/s11340-015-0027-z.

[2] F. Jünger et al. „Fast, label-free superresolution live-cell imaging using rotating coherent scattering (ROCS) microscopy“. eng. In: Scientifc reports 6 (2016). Journal Article Research Support, Non-U.S. Gov't, S. 30393. doi: 10.1038/srep30393. eprint: 27465033.