Tribology of Ceramics in Different Environments

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AGENDA

- Short introduction
- Motivation: Application
- Wear analysis in rolling contacts
- Tribological behavior in ceramic cutting tools

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Examples of current research topics

- Ceramics in cold and hot metalforming processes: New materials for improved lifetime and wear resistant components
- Ceramic cutting tools: Towards the understanding of tribological mechanisms in cutting operations

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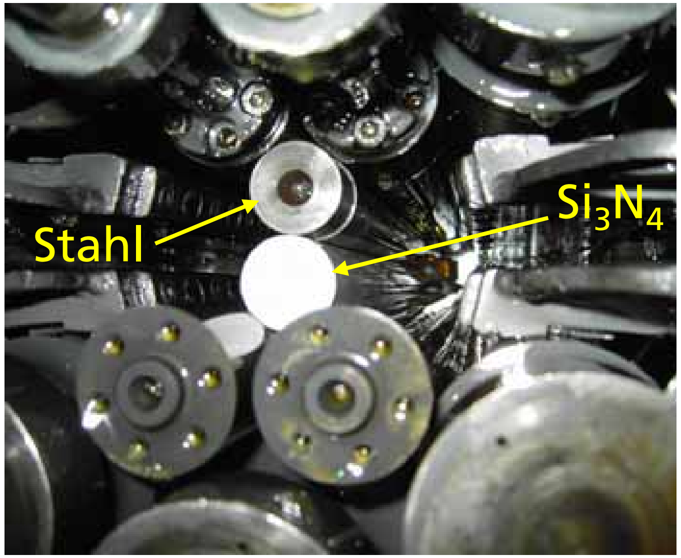
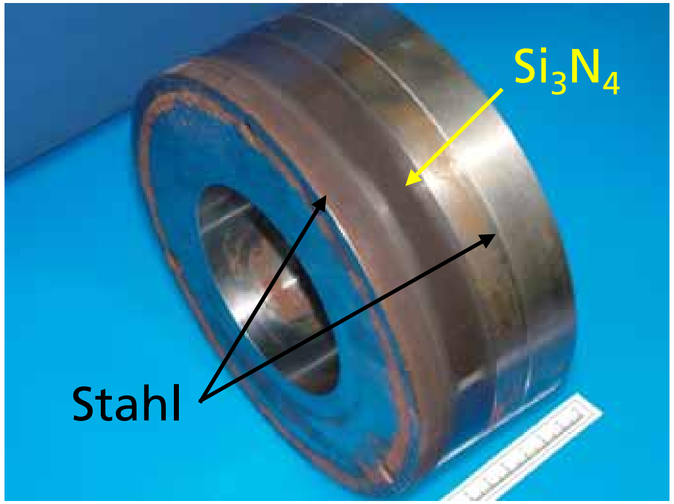
Ceramic rolling tools

- Ceramic tools and components for the fabrication of sheets, foils, wires and profiles
- Assessment of wear resistance and lifetime
- Optimization of surface loading capability
- Simulations (sintering, adhesion)
- Validation in industrial rolling processes

➔ Benchmarks lifetime prolongation were overmatched by a factor ~ 10





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Ceramic materials and components for rolling mills

energy, resources

wear resistance, mechanical and thermal properties

tool lifetime

product quality

cost efficiency

energy consumption

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Ceramic rolling tools

- Ceramic tools and components for the fabrication of sheets, foils, wires, profiles
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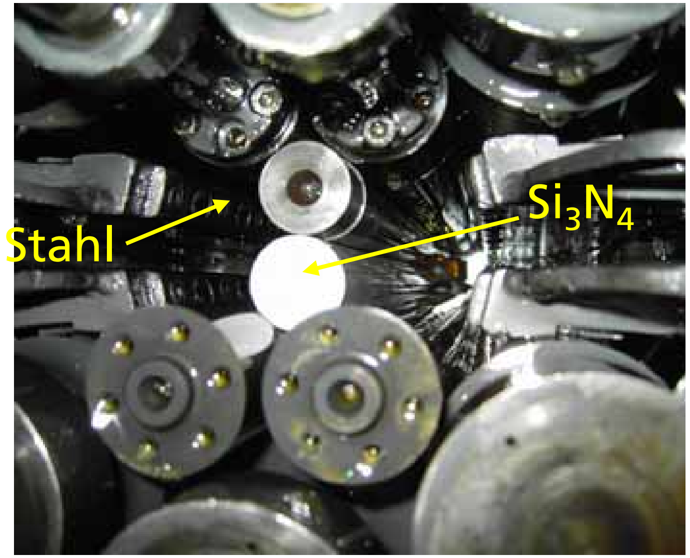
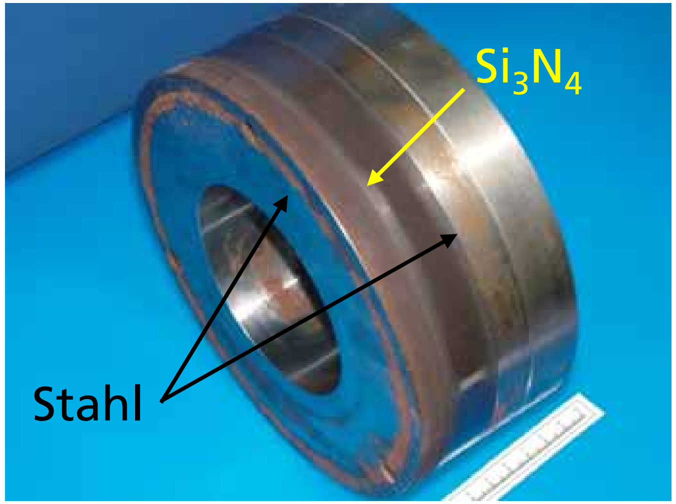
- Simulations (sintering, adhesion)
- Validation in industrial rolling processes

➔ benchmarks for lifetime prolongation were overmatched by factor < 10





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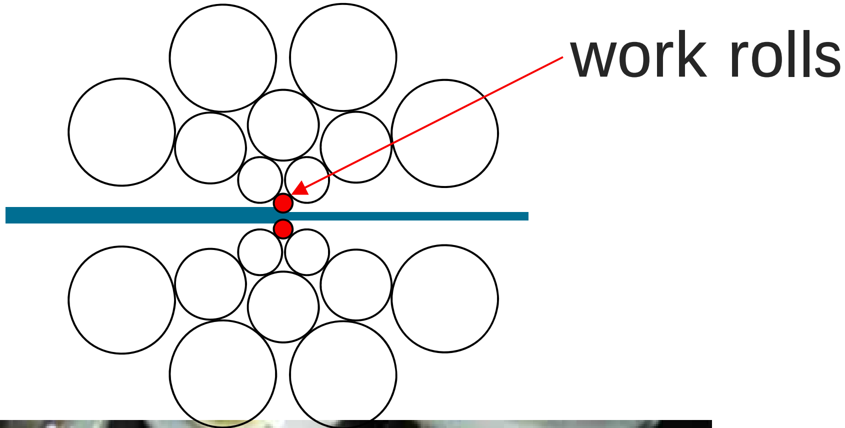
Rolling of metal foils
(Sendzimir mill, MK Metallfolien, Hagen)



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Consortium

- Ceramic Manufacturers
- Machining
- Research institutes
- Industry

...

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Tribological behaviour of new ceramic materials

Aim:

Improve wear resistance and high temperature strength

- New material variations
- Influence of cooling lubricants

R_a: 0,08 µm, R_z: 0,15-0,2 µm

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Wire rolls

Hot Rolling of Copper

Wire temperature ~840°C,
Velocity ~2 m/s, cooling lubricant

Hot rolling of steel and Ni-base alloys

Wire temperature ca. 1050°C,
velocity ~10 m/s, cooling lubricant

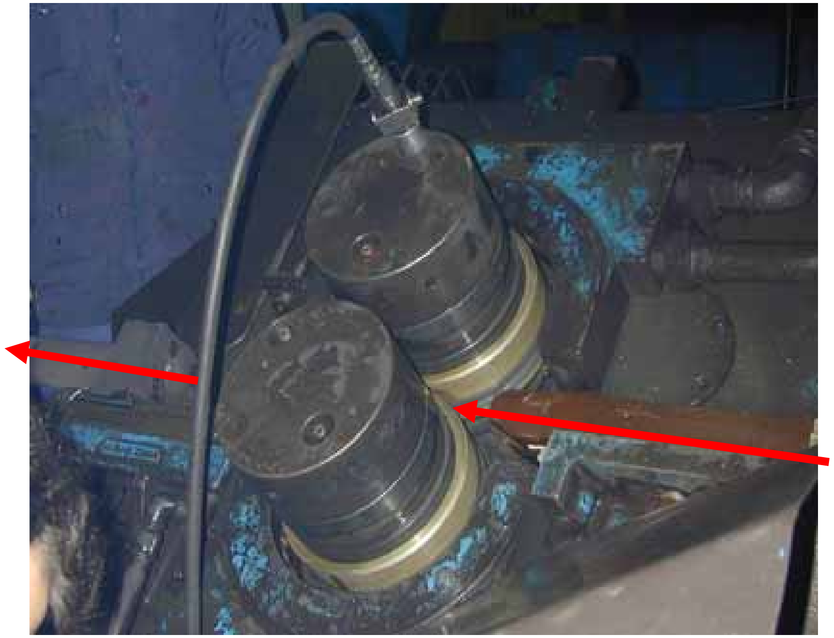

Bild: Böhler Edelstahl

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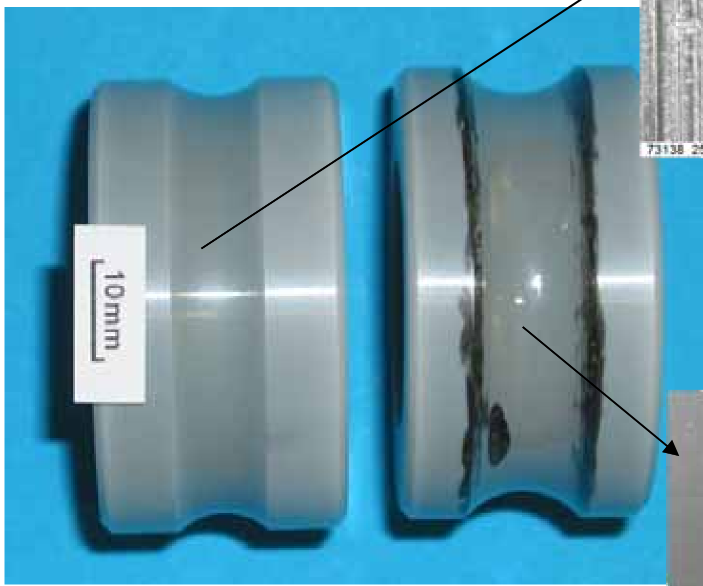
Ceramic guiding rolls

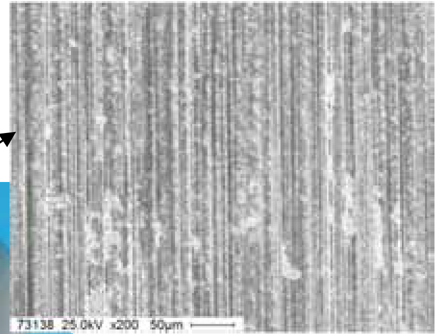
Surface smoothening

10 times higher lifetime

Steel rolls: 60 t wire

Ceramic rolls: **> 600 t**






new after service

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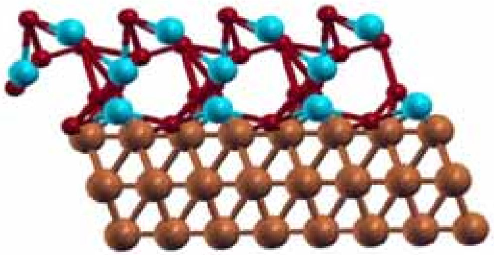
Tribochemical wear: Copper wire rolling

(A. Hashibon, J.-M. Albina, FhG IWM)

System	Work of separation (W_{sep}) [J/m²]
Cu (111) / γ-Fe (111)	**4.00**
Cu (111) / β-Si_3N_4 (0001)	2.72
Cu (111) / α-SiO_2 (0001)	**4.10**
Cu (111) / [Cu ML , γ-Fe (111)]	3.30
Cu (111) / Cu (111)	3.08



Cu / α-SiO_2

ML: monolayer

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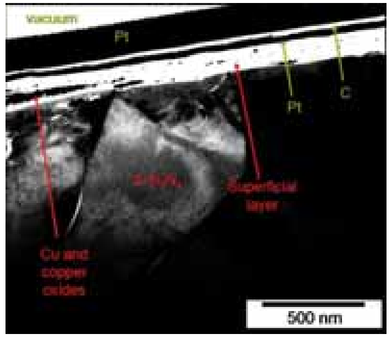
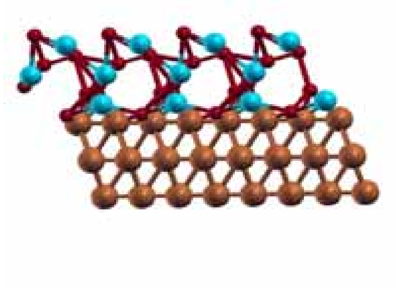
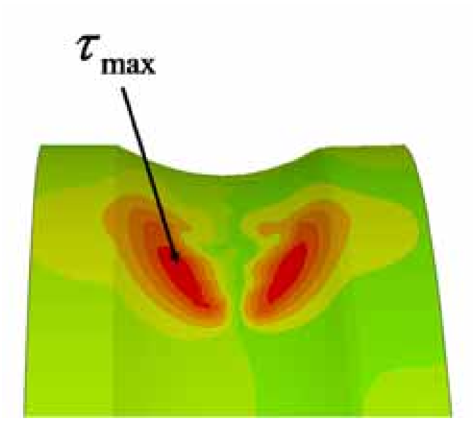
Tribochemical wear: Copper wire rolling

Si_3N_4 → High T, P + Sliding → SiO_2



SiO_2 ↔ High adhesion affinity ↔ Cu





Tribological contact →

Delamination of low shear-strength oxide layers

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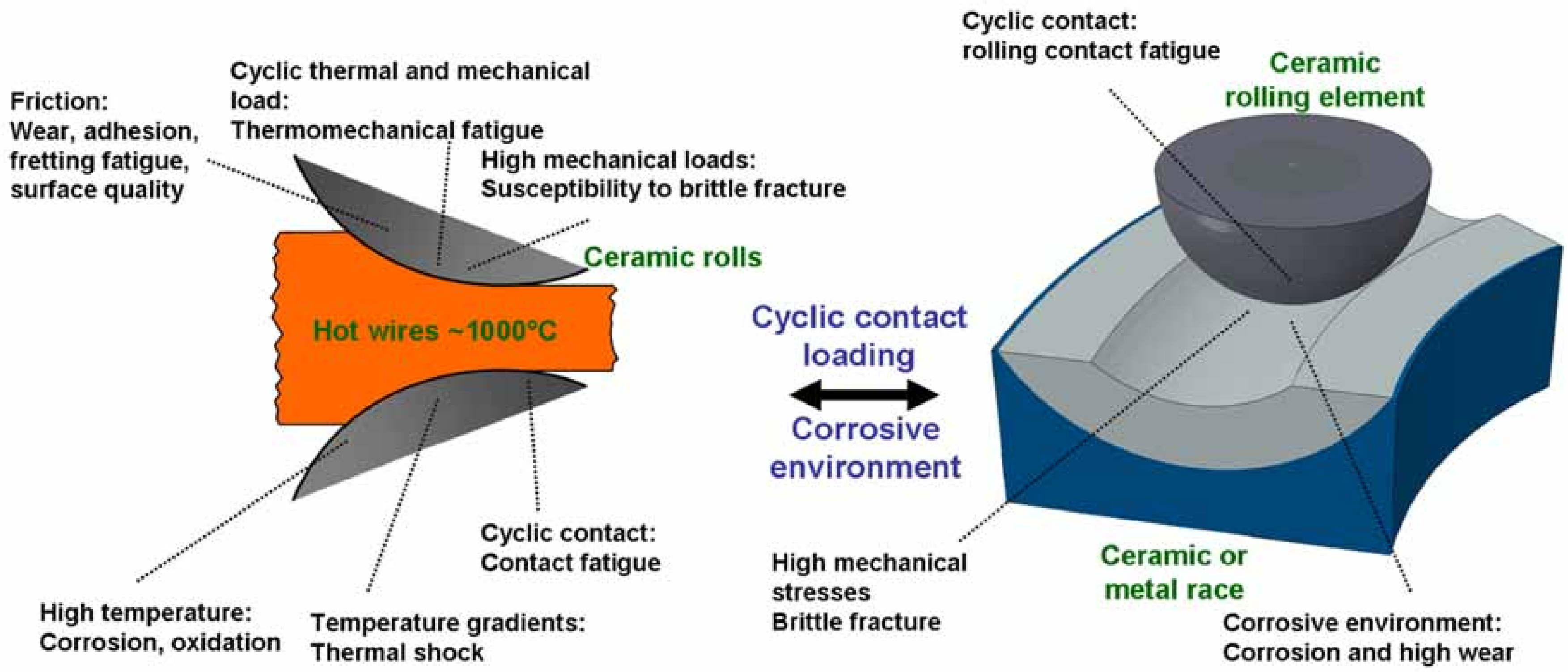
Multiscale simulation to model degradation in ceramic components

EU-Project (2011 – 2014): IWM, KIT, IPM, ISFK, SKF, Böhler Edelstahl, FCT



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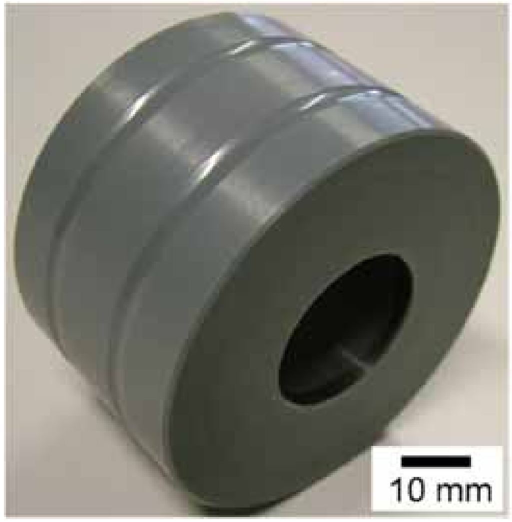
Component testing: Wire rolling test rig



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Tribochemical wear and wire rolling

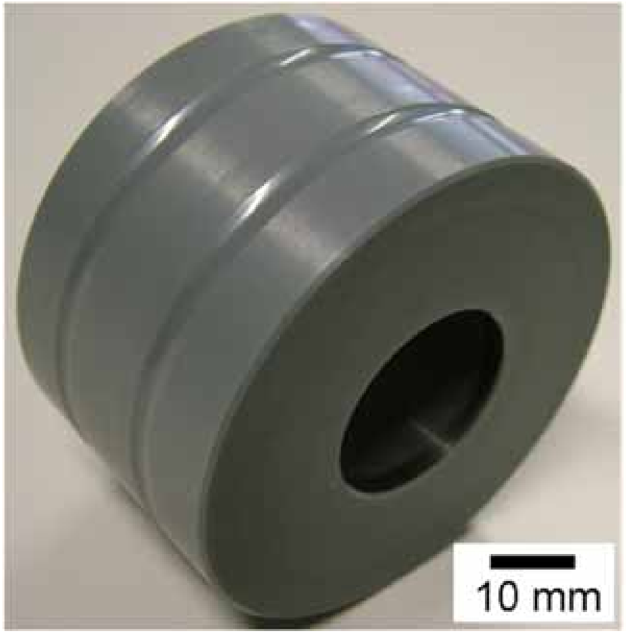
Ceramic rolls: Si_3N_4 - SL200 BG (oval-profile caliber)

Wire: Steel 1.4310

Rolling temperature: ~900°C

Reduction: 0.3

Lubrication: Cooling lubricant (5% emulsion in water)



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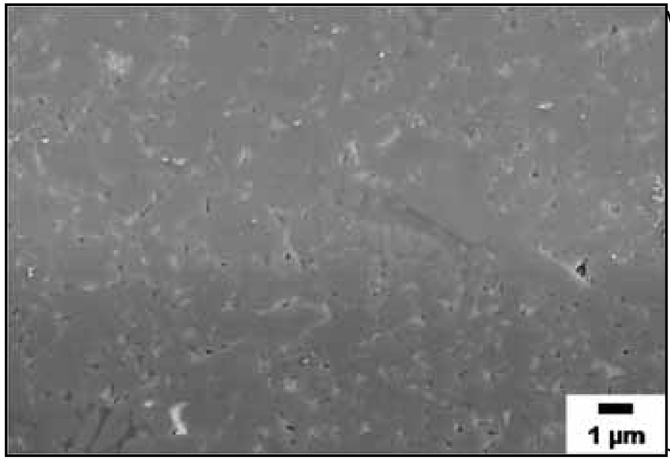
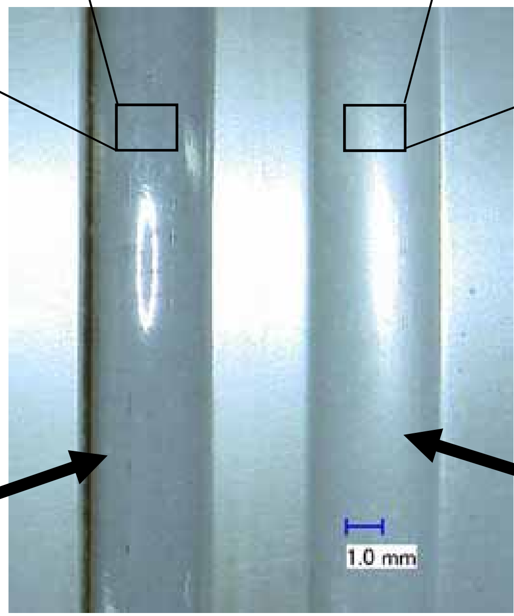
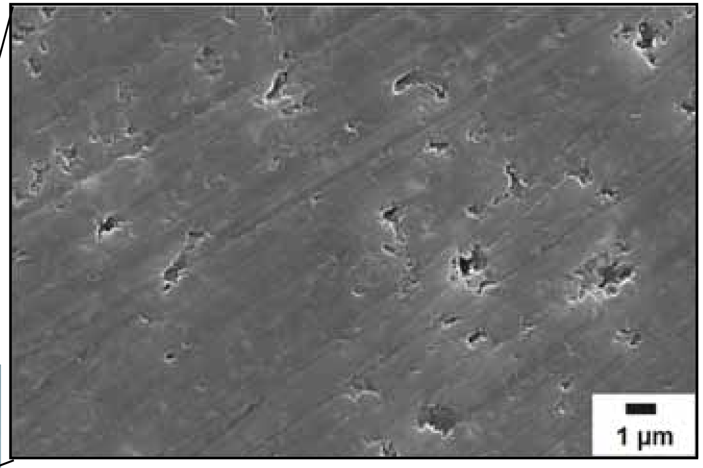
Tribochemical wear: Hot rolling of high strength steel



SL200 BG





R_a = 0,04 ± 0,01 µm

R_z = 0,11 ± 0,05 µm

Polished surface
After 3000m at 900°C

R_a = 0,12 ± 0,02 µm

R_z = 0.90 ± 0,10 µm

Virgin state

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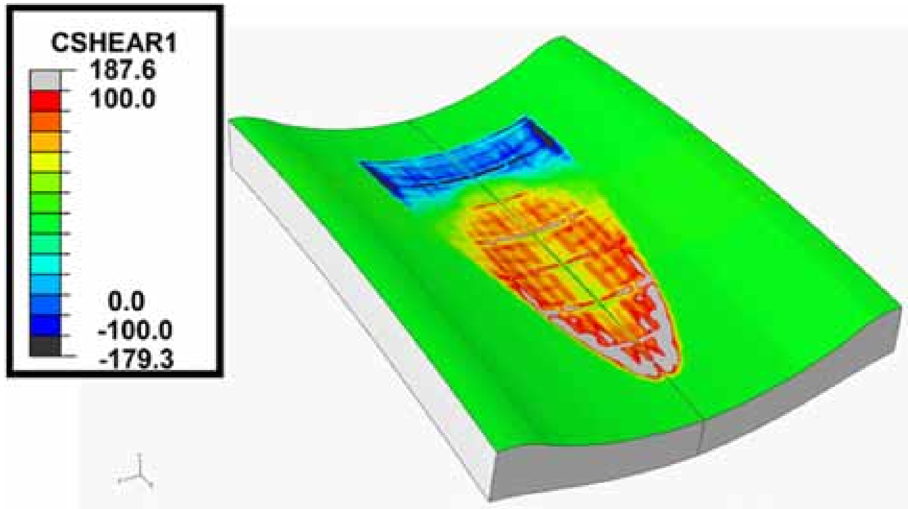
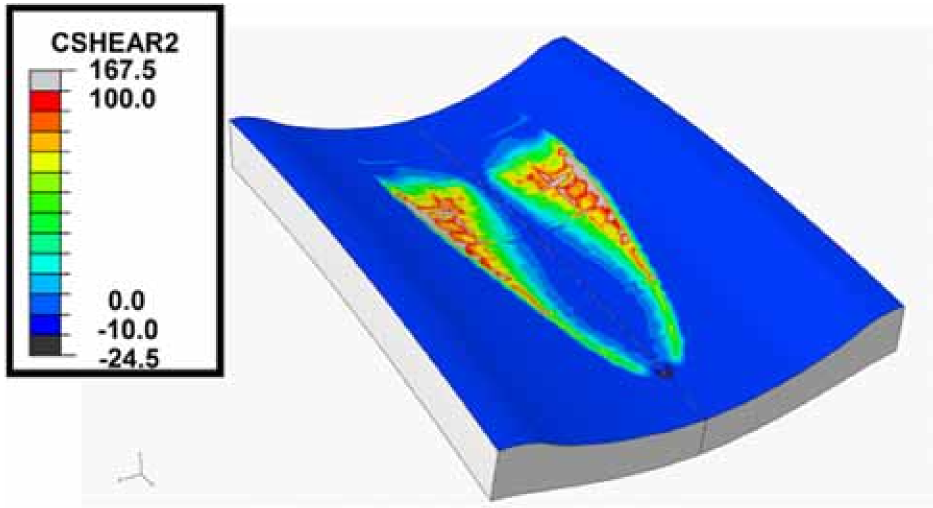
Hot rolling of high strength steel

Surface shear stresses in wire rolling





Complex sliding contact conditions in the deformaiton zone

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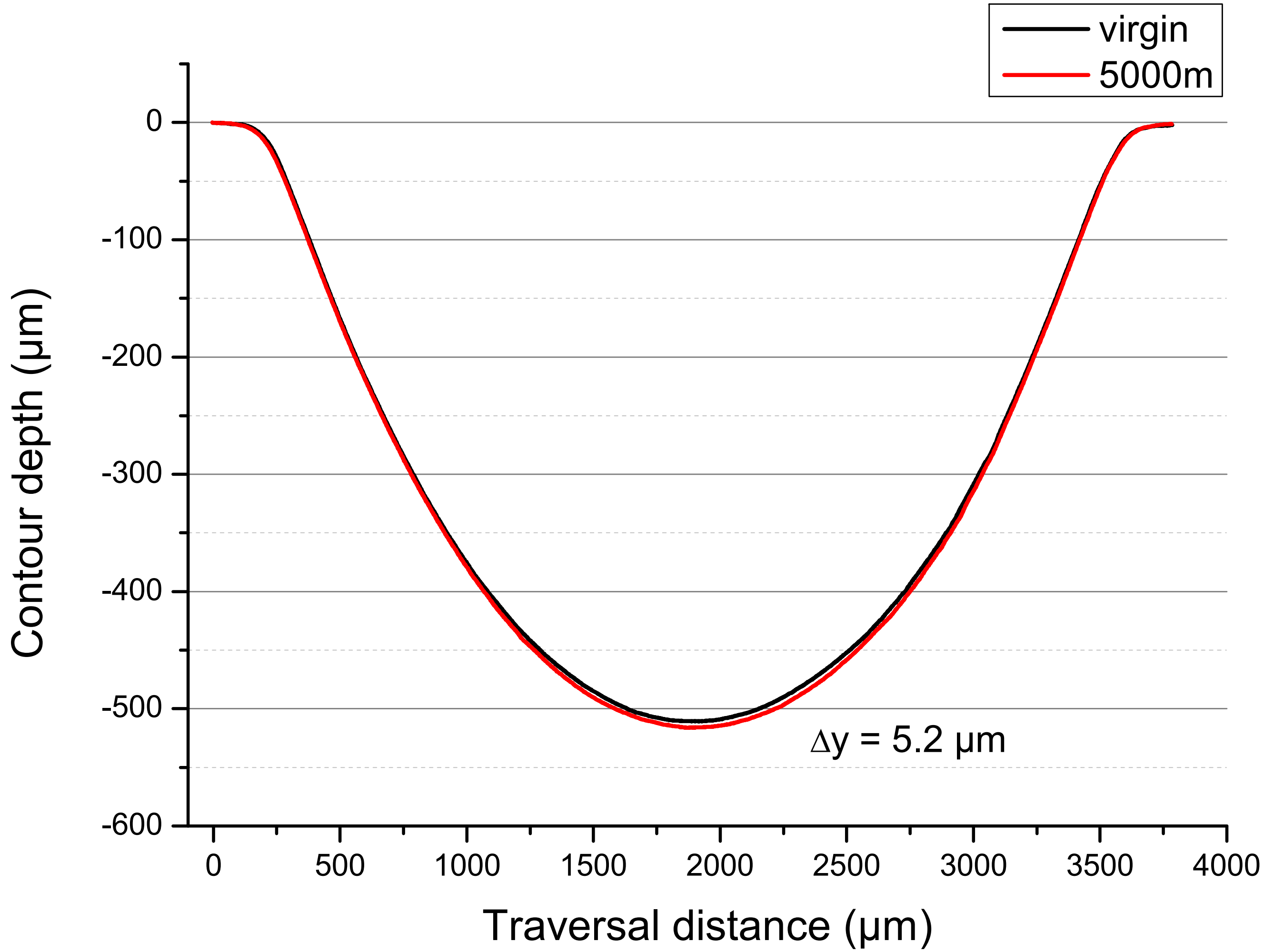
Hot rolling of high strength steel



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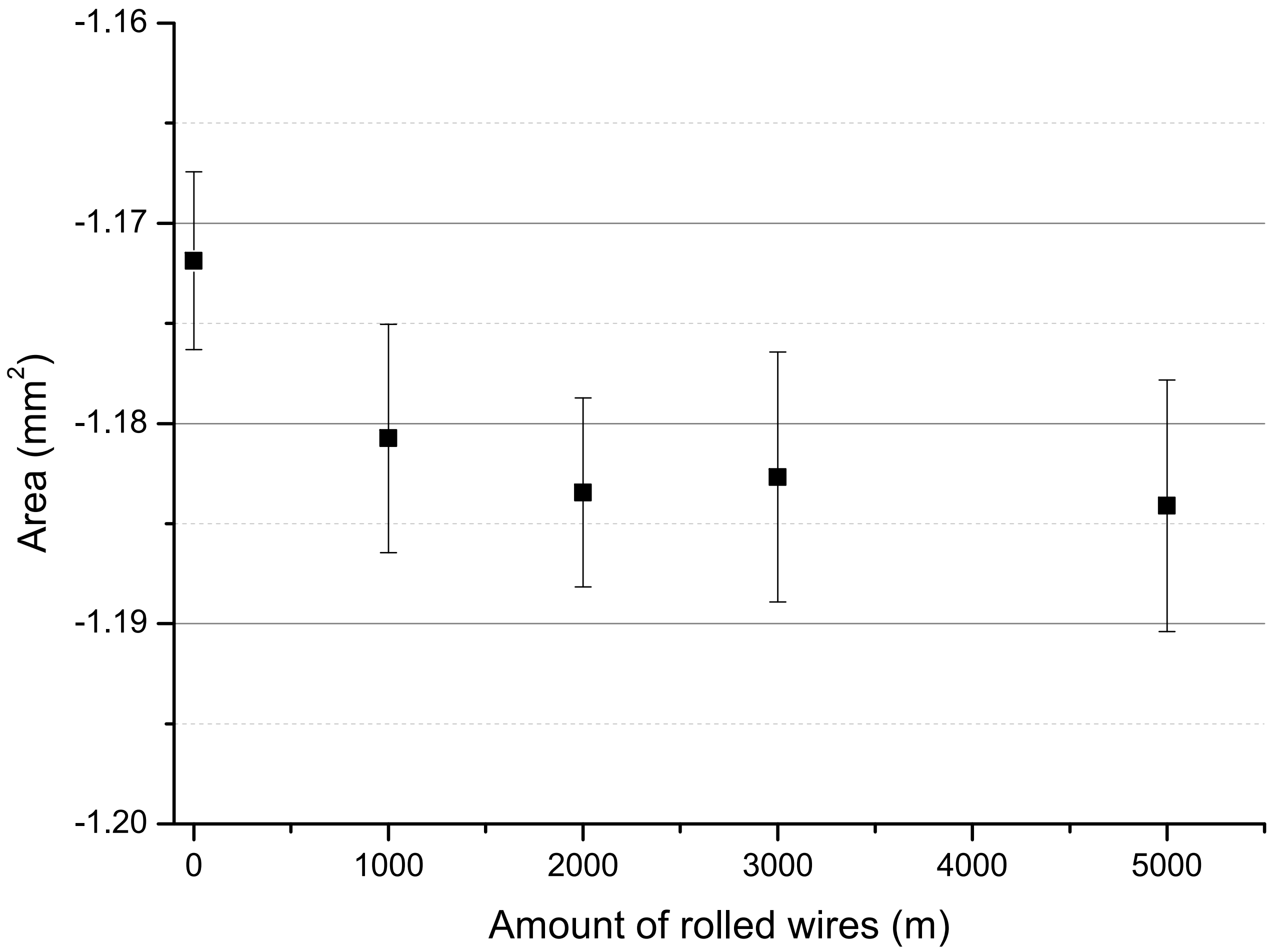
Hot rolling of high strength steel



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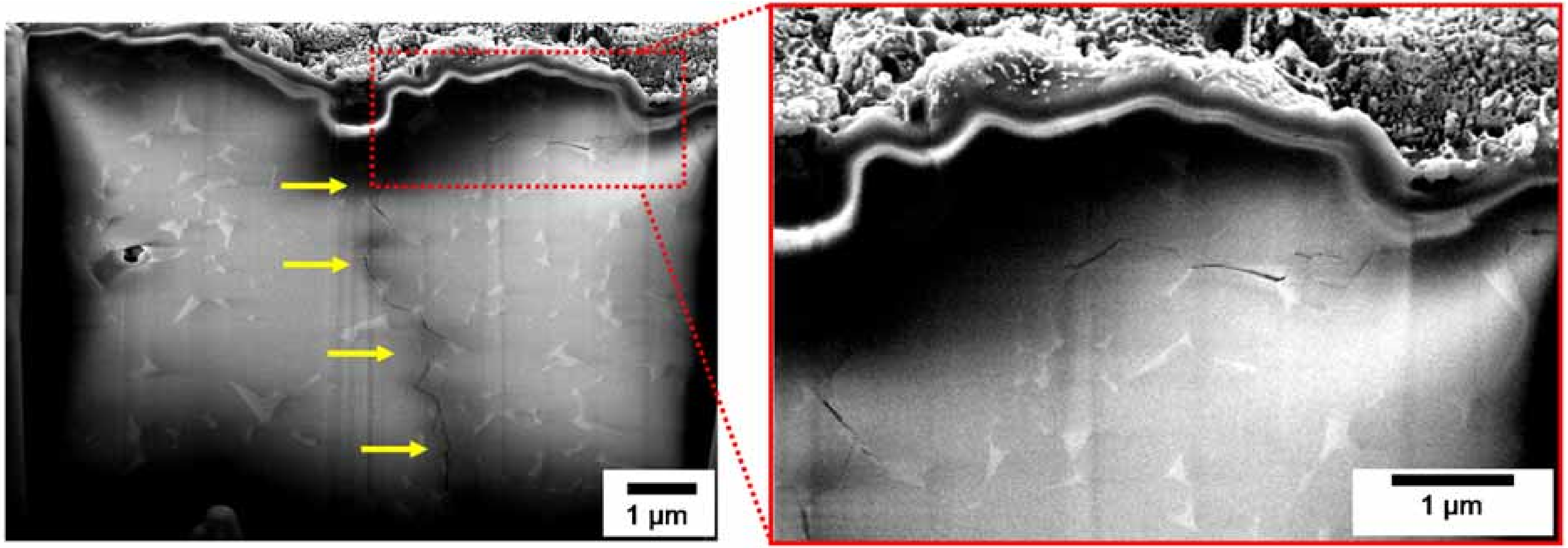
Damage Characteristics → Reliability



microcrack formation an growth due to mechanical contact stresses

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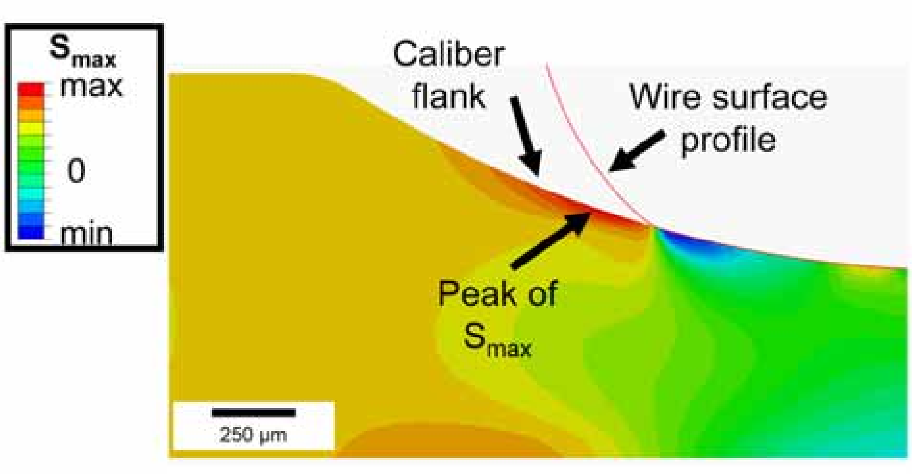
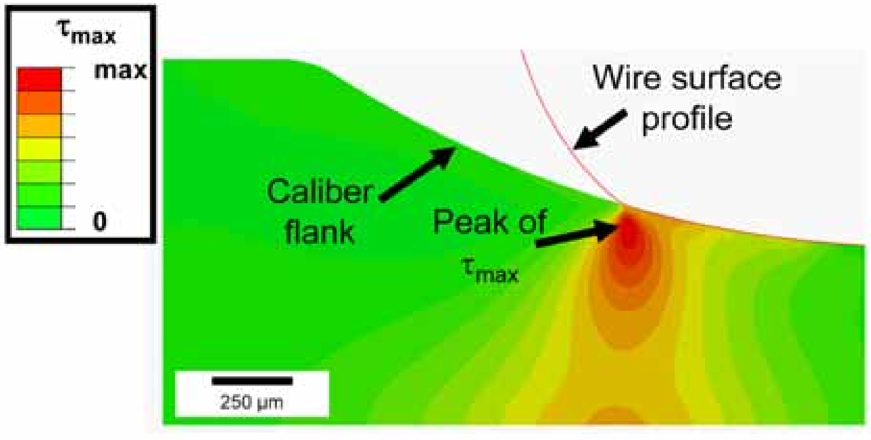
Damage Models

Mechanical stresses



tensile stresses



shear stress

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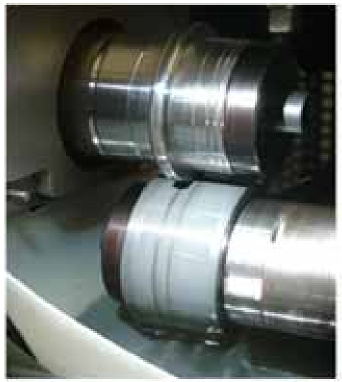
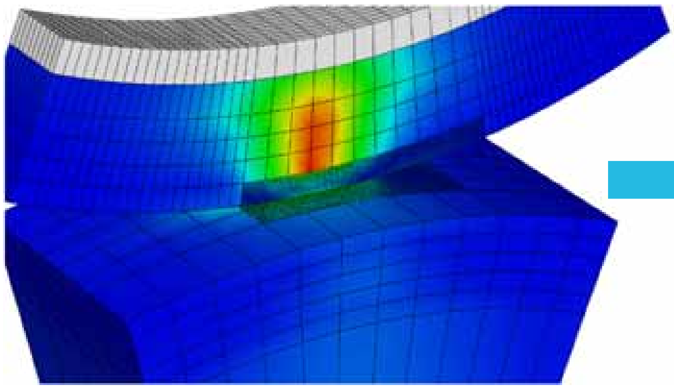
Wear simulations

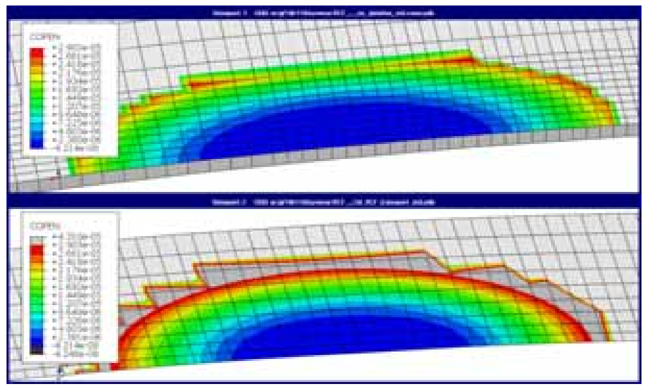
Experiments: Quantification of **wear parameters**

FE-Simulations: **Stress state** corresponding to **modified contact conditions**

Wear parameters → **FEM wear simulation** → Local geometry variations → modified stress state







Contact profile

Experiments Simulations

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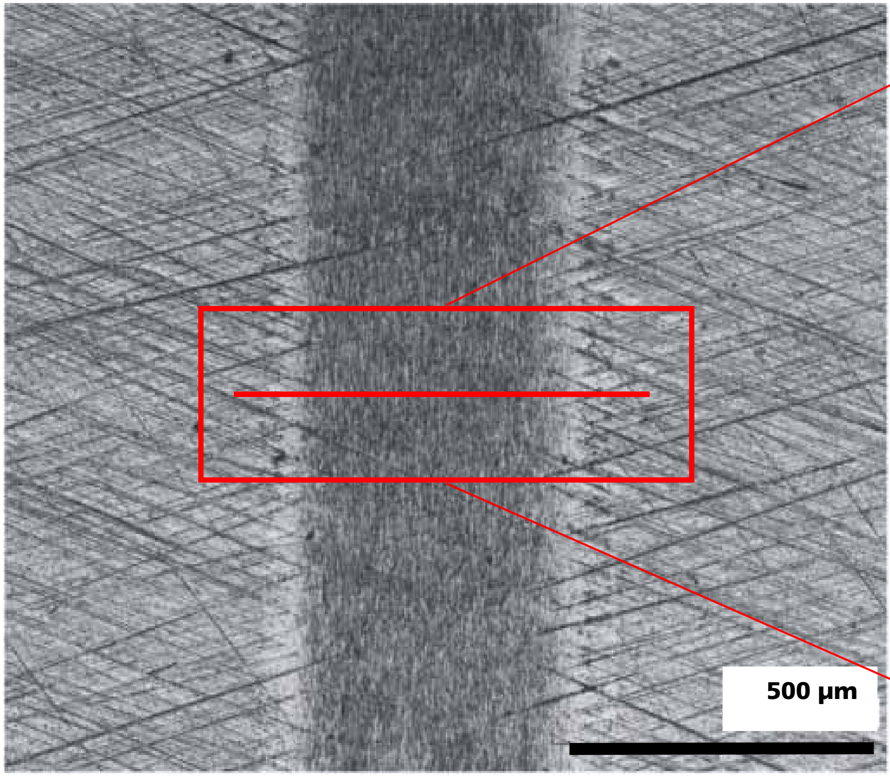
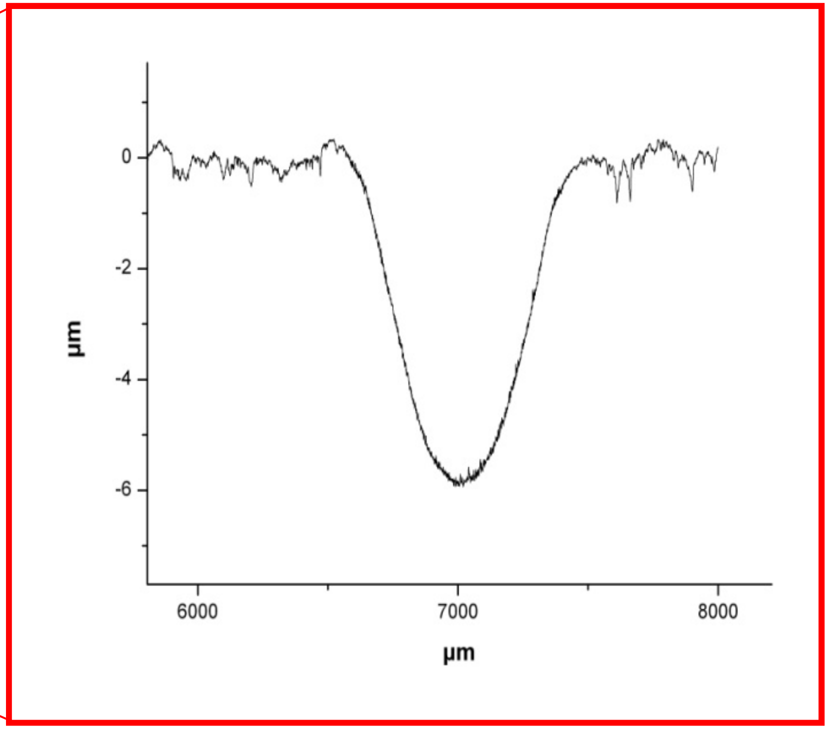
Wear measurement





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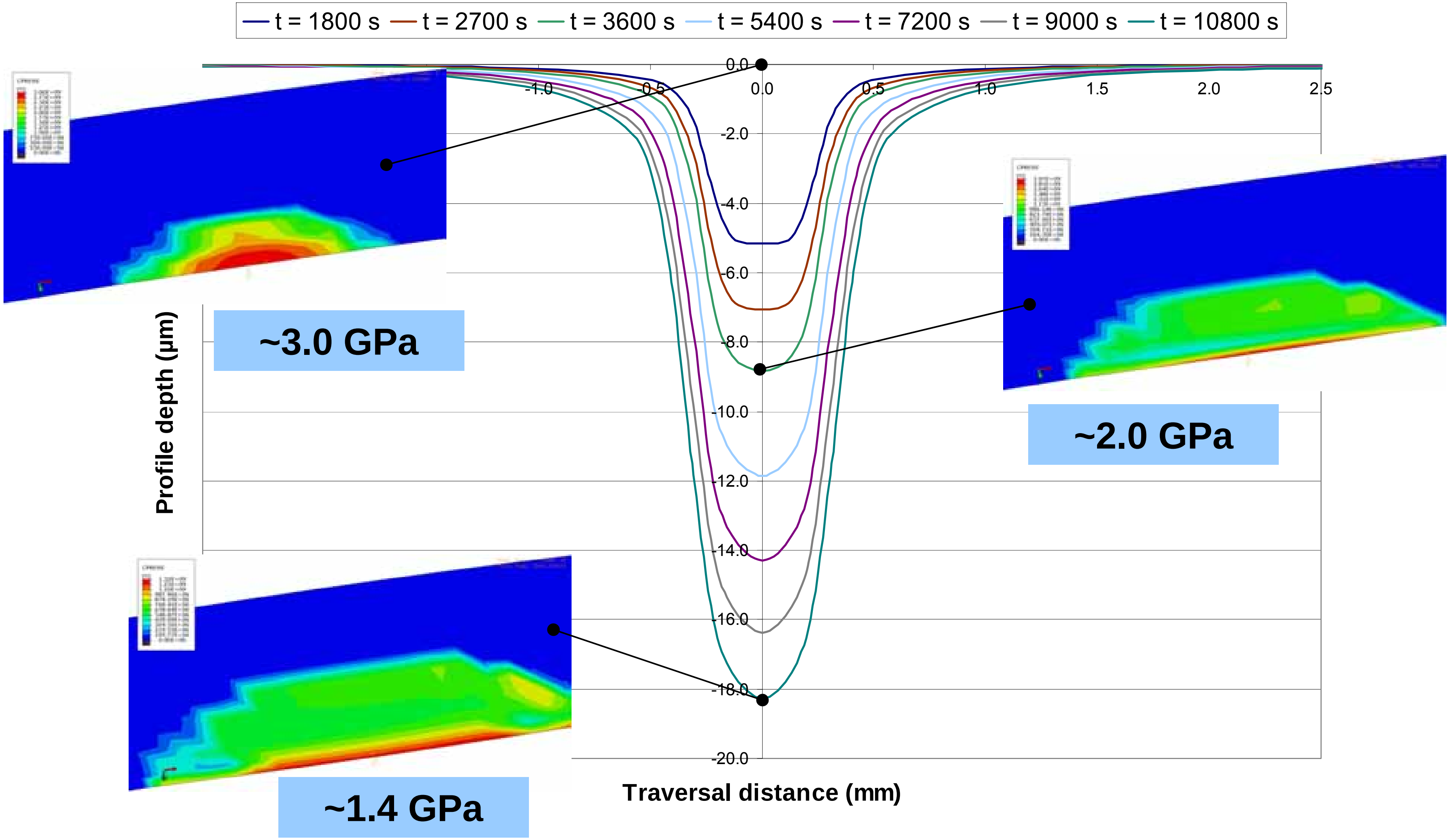
Wear Simulation



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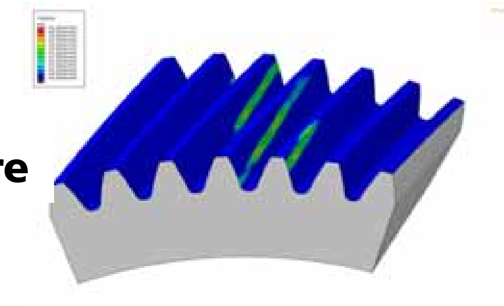
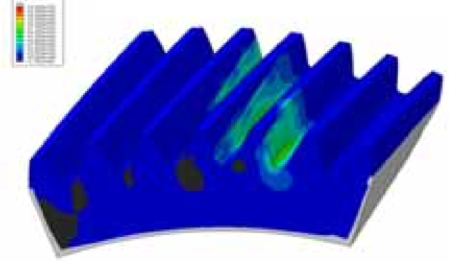
Ceramic Gears

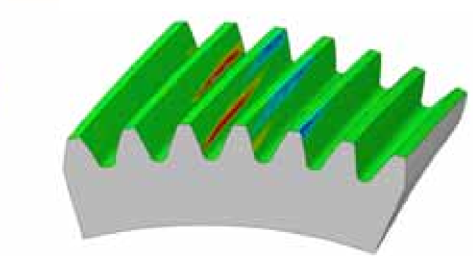
Contact pressure



Tensile stress



Incremental slip



reliability

lifetime

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Ceramics at High Temperature: Wear Mechanisms and Residual Stress Formation in Ceramic Cutting Tools

- Motivation: Understanding the wear mechanisms of ceramic cutting tools
- Examination of degradation mechanisms of ceramic cutting tools
  - Chemical wear
  - Mechanical wear
  - Residual stress formation
- Model experiments
  - High temperature wear analysis

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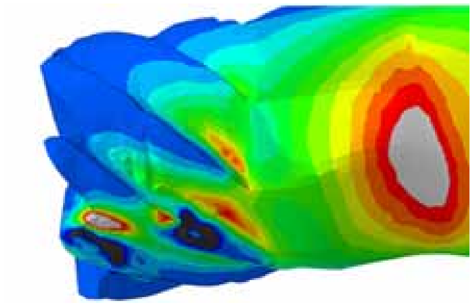
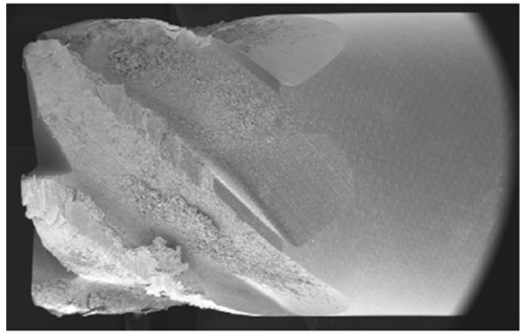
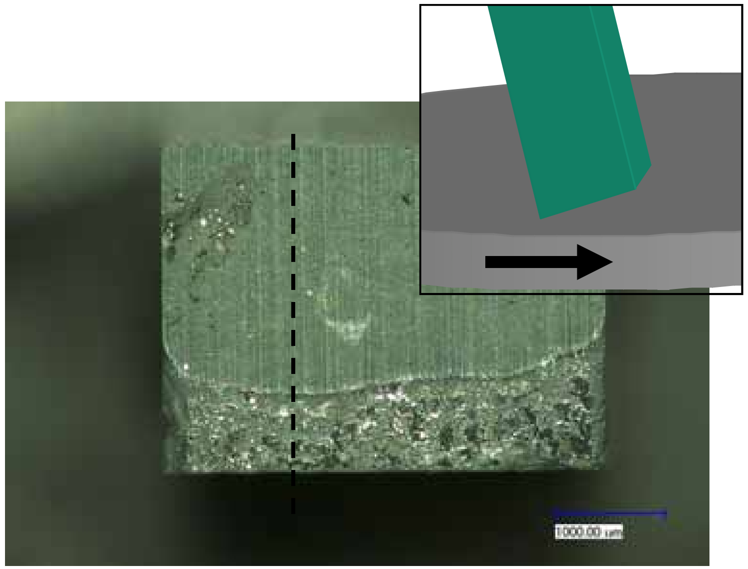
Ceramic Cutting Tools

- Ceramic cutting tools for high-speed-machining of high-temperature alloys
- Cutting speeds ≤ 1000 m/min cause extreme temperatures at cutting edges
- Temperature gradients and cutting forces affect tool wear significantly
- Improved wear resistance by adjustment of material composition and morphology
- Detailed analysis of structural and chemical interface transformations necessary







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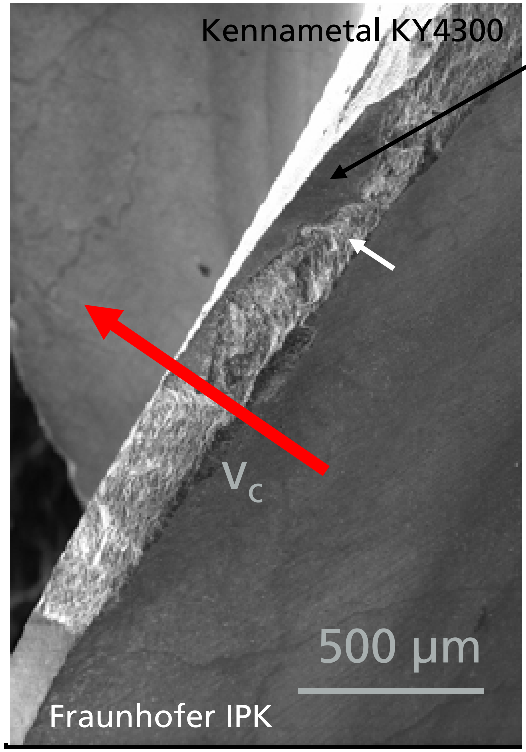
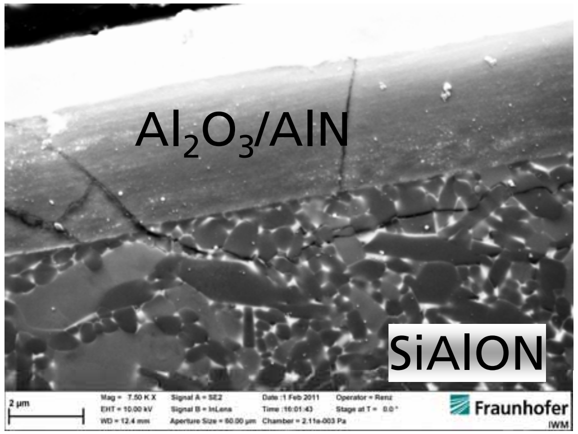
Typical wear marks on used cutting tools

Materials:

Al_2O_3/SiC_w

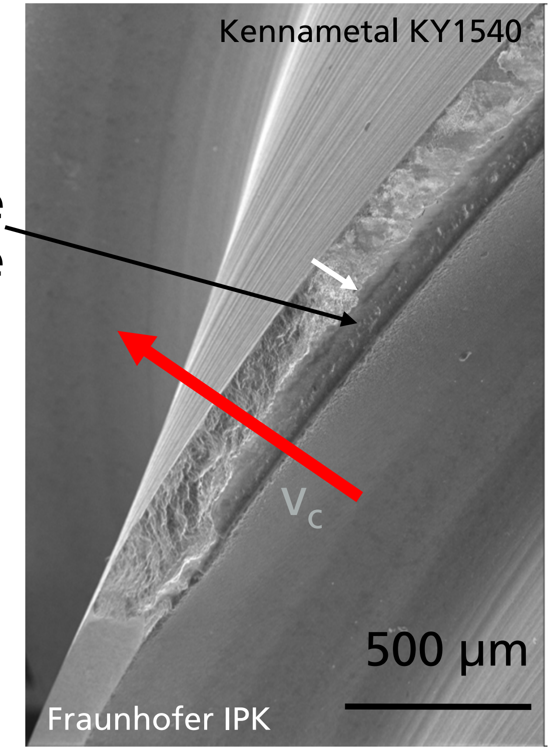


Intact area
at flank



α/β-SiAlON

Built-up phase
at cutting edge



Selective wear of Si_3N_4:
Formation of amorphous Al_2O_3 and AlN layer

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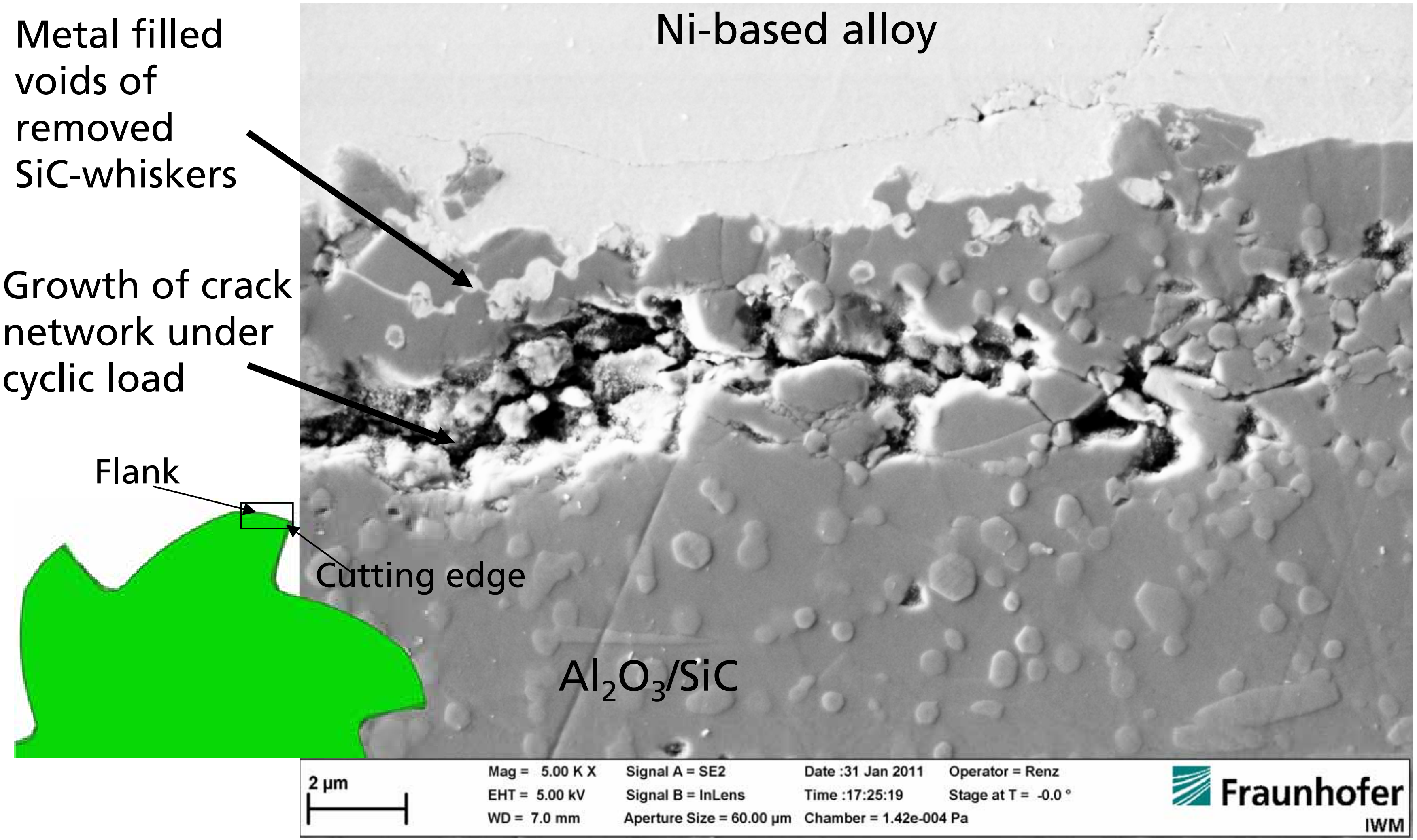
Mechanical wear of Al_2O_3/SiC

Metal filled voids of removed SiC-whiskers

Growth of crack network under cyclic load



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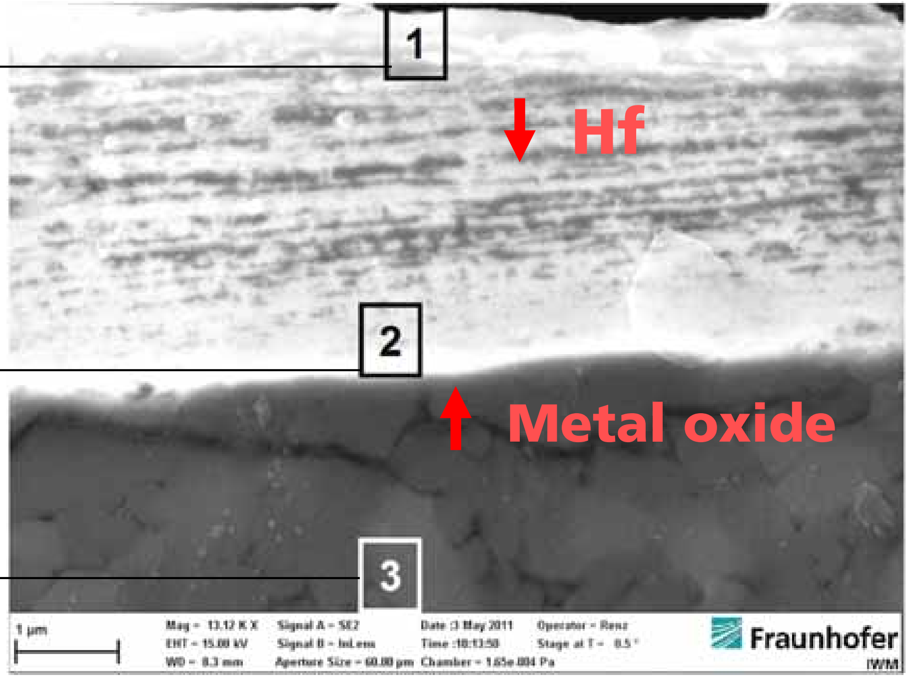
Analysis of built-up layer on SiAlON

N	O	Al	Si	Ni	Hf
2.9	53.8	30.0	0	0.2	13.1
39.1	9.0	6.1	42	0.5	3.3
45.5	4.0	8.4	41.1	0.9	0.2

(in at%)



Assumption:

Hafnia (HfO_2) and Alumina (Al_2O_3) built up on the tool surface by diffusion of alloying Hf and by flow of SiAlON glass phase

→ Depletion of underlying microstructure

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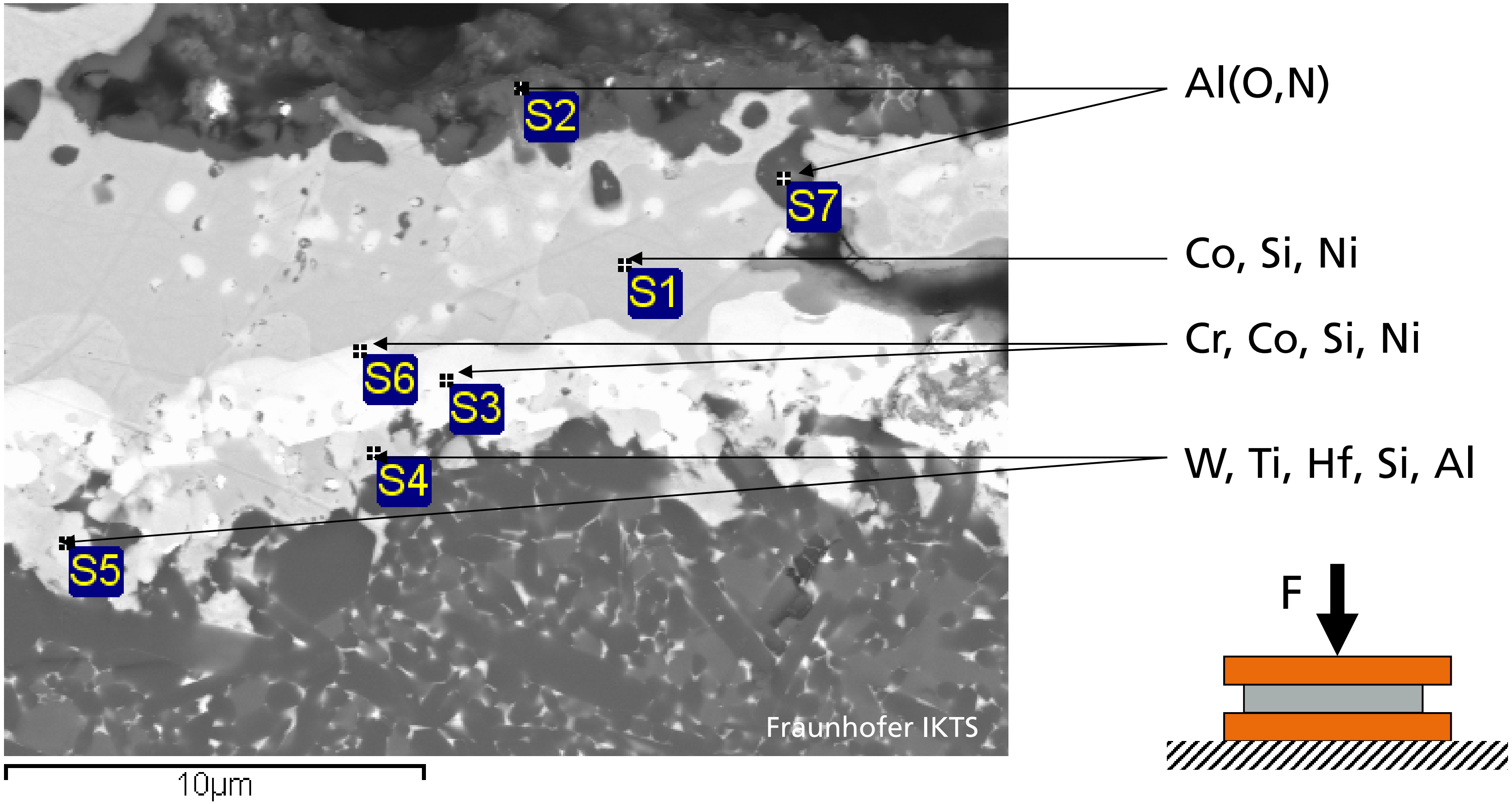
Static interaction couple: Sialon on Ni-base alloy (MAR M247)



Chemical/diffusive surface reactions after 1 h at low contact pressure (17.5 MPa) and high temperature (1300 °C, air)

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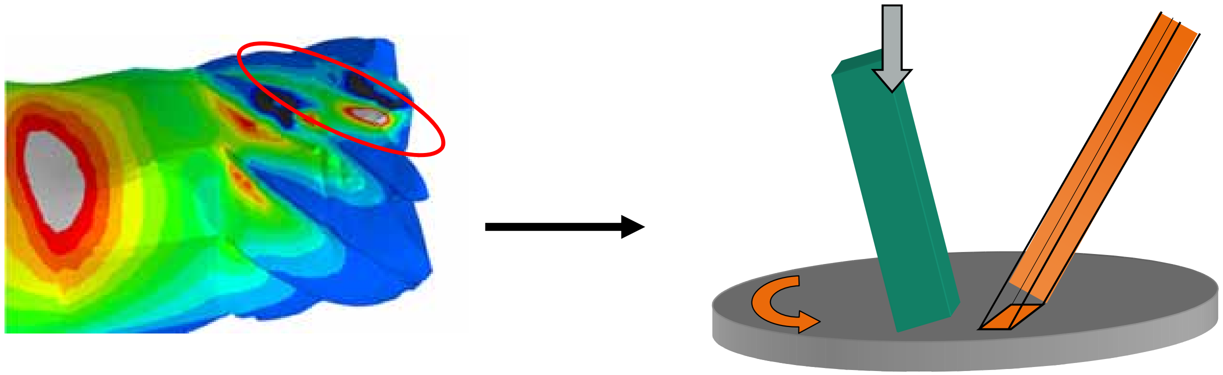
Specimens and experimental setup

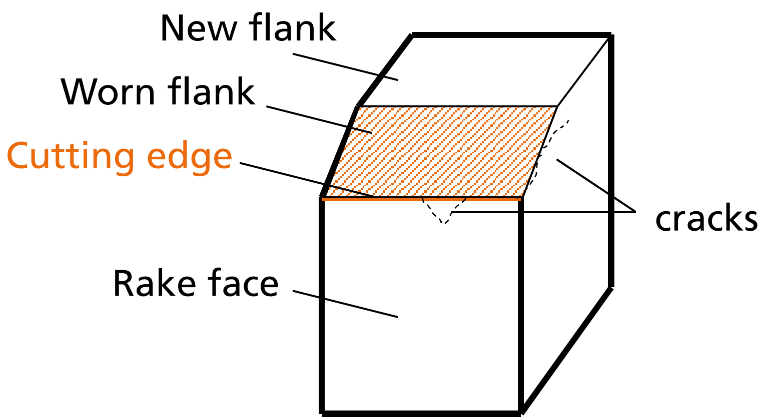
- Simplification of specimen geometry and load situation



- Normal force: $F_N = 50$ N
- controlled Laser heating, T = 800 °C
- Rotation speed: $v_{cut} = 30$ m/min

- Experiment

- Schematic of a worn sample:



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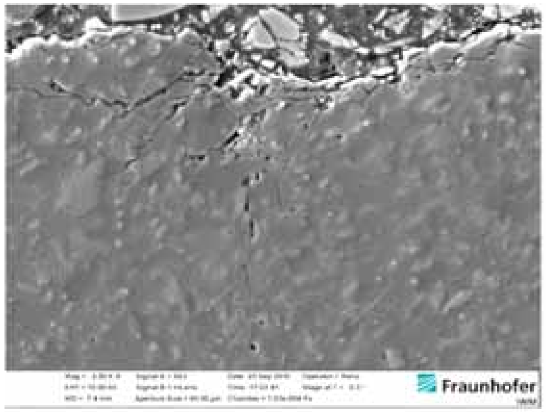
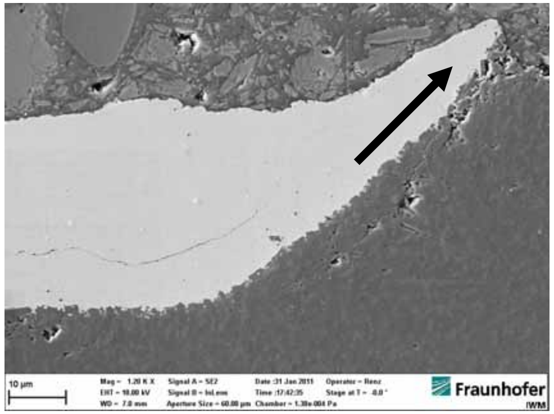
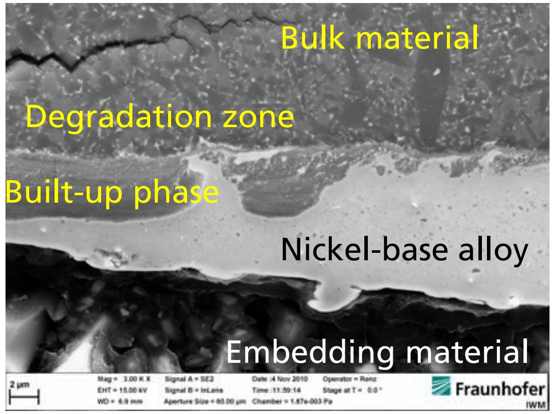
Summary



Surface fatigue and chipping



Adhesive interaction of tool and workpiece material



Tribo-chemical degradation and transformation

- Temperature induced tribochemical wear was observed in both ceramics
- Reactivity of commercial SiAlON with Hf-containing alloys
- Degradation of SiC at high temperatures
- Subsurface layers show fatigue cracks and residual stresses
- Wear rate and coefficient of friction of ceramic tools decrease with rising temperature

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