Simulation of a Dental Tribological System at a Microscopic Scale

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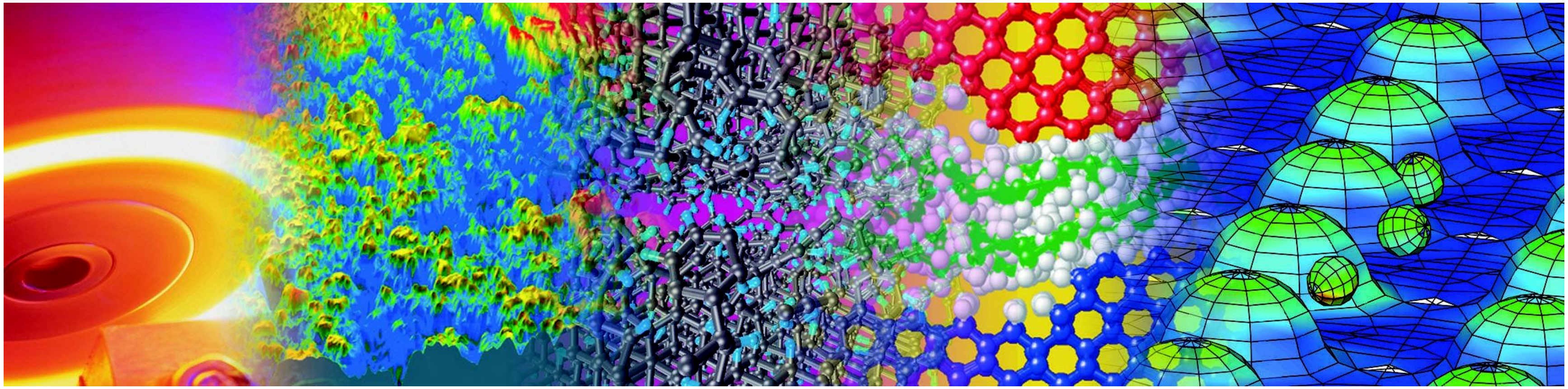

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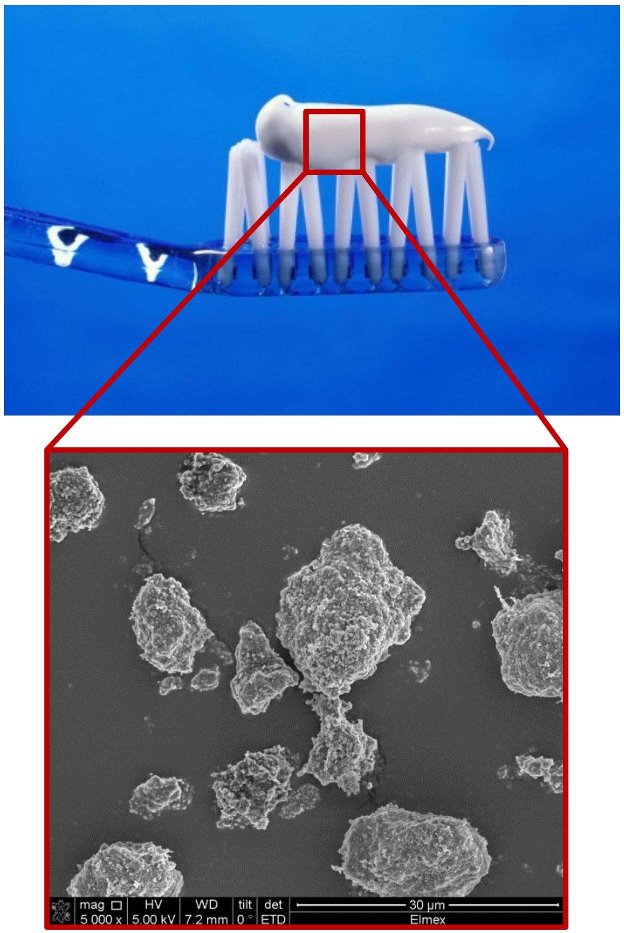
Outline

- Motivation for the investigation of an oral hygiene μ-tribological system
- Experimental and numerical approach
- Testing the parameter space of the „toothbrush – toothpaste – enamel" system
- Comparison between simulations and experiments

Motivation

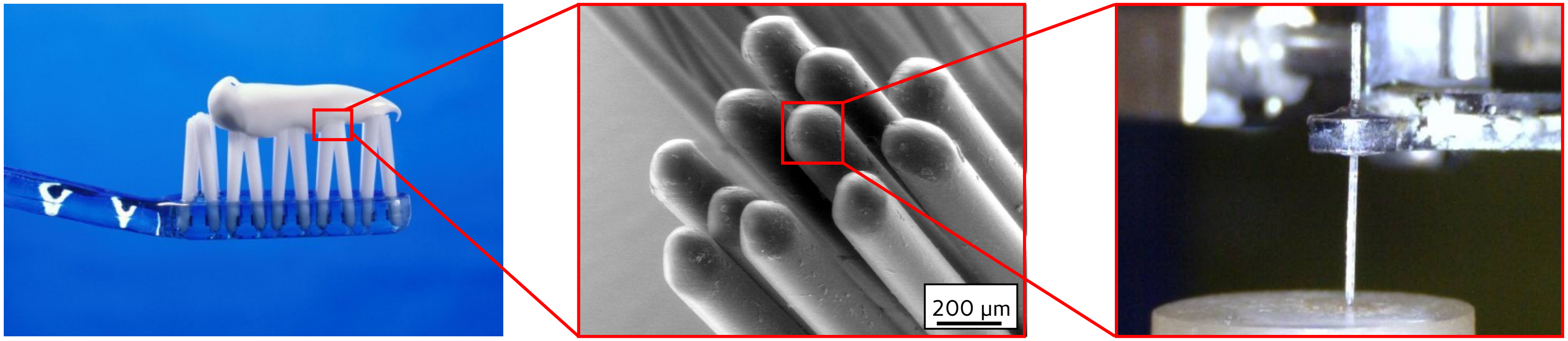


- The abrasive character of toothpaste is dependent on hardness, volume filling factor and size of the abrasive particles (Relative Dentin Abrasion (RDA) value)
- The addition of abrasive particles in the toothpaste is based solely on empirical data.
- Tribological investigations of the cleansing effect of toothpastes on the surface of the enamel are very limited
- The introduction of numerical models with a predictive power for abrasive suspensions could yield an important contribution for the development of dental hygiene products.

Microtribological investigations

- Reduction of the complex tribological system **toothbrush – toothpaste – enamel** to a microscopic level in order to investigate the interactions between the basic components:
  - Experimental characterisation of the friction and wear behavior
    → µ-tribological investigations

  - Development of smoothed particle hydrodynamic (SPH) simulations for the numerical investigation of the interactions between basic components of the tribosystem

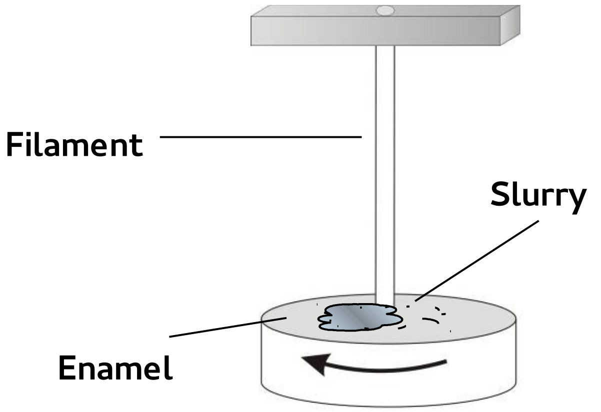


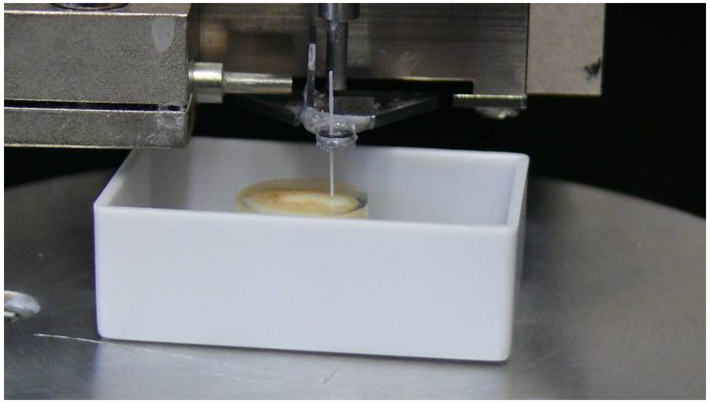
Experimental approach

The Setup

- Experimenta tribological system: **Filament – Toothpaste–Slurry – Enamel**
- For the determination of the coefficient of friction, (µ), a toothbrush filament is mounted on the force transducer of a tribometer (Basalt PT, Tetra) or on a nanoindentor (Nano Indenter G200, Agilent)
- While being forced on a rotatory movement over the enamel, a normal force $F_{n\ [mN]}$ is applied in the vertical direction on the filament
- Determination of the tangential force Ft

$$\mu = \frac{F_t}{F_n}$$



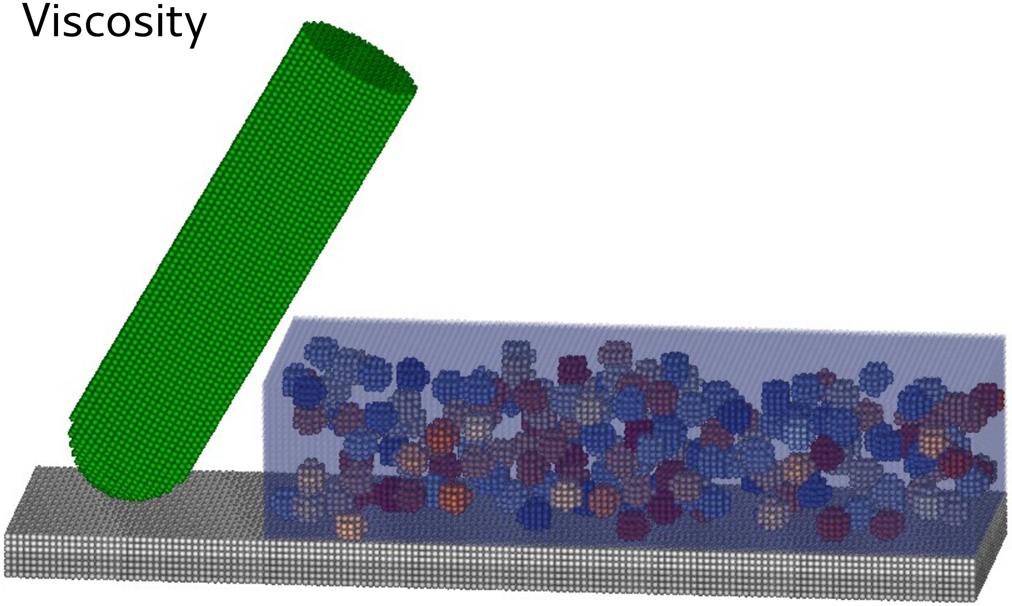


Numerical approach
Parameter space

Suspension:
- Volume filling factor
- Rheologic character of carrier fluid
- Viscosity

Abrasive particles:
- Size
- Shape

Filament:
- Shape
- Velocity
- Tilt angle of filament

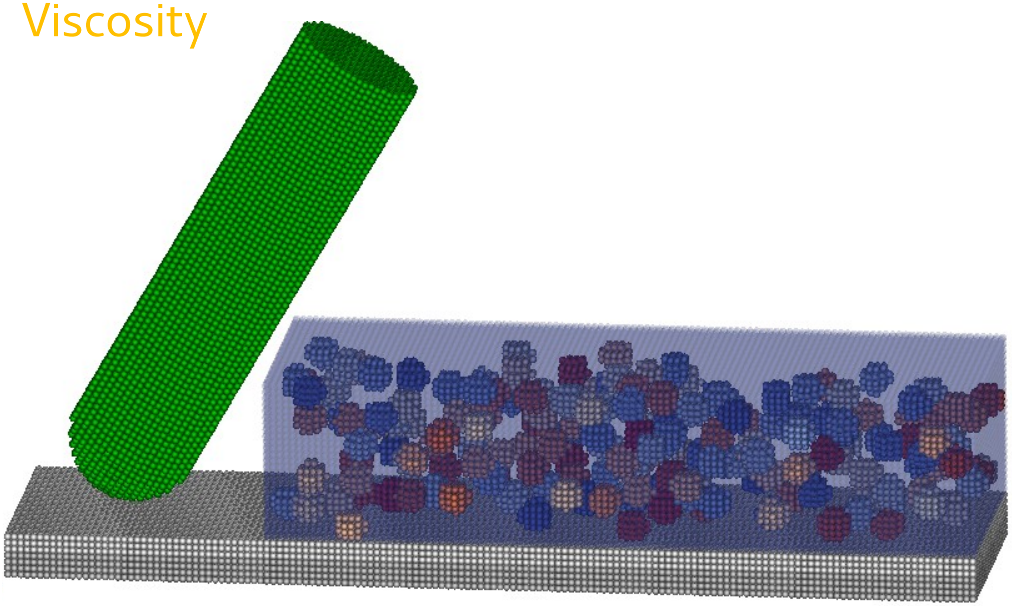


Numerical approach
Parameter space

Suspension:
- Volume filling factor
- Rheology of carrier fluid
- Viscosity

Abrasive particles:
- Size
- Shape

Filament:
- Shape
- Velocity
- Angle between Filament and Enamel



Workpiece:
- Young's modulus:
  - 7.5 kPa
- Poisson's ratio:
  - 0.3

Numerical approach

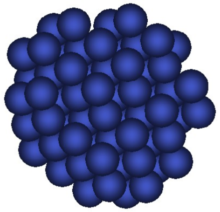
Numerical model – Geometrical setup

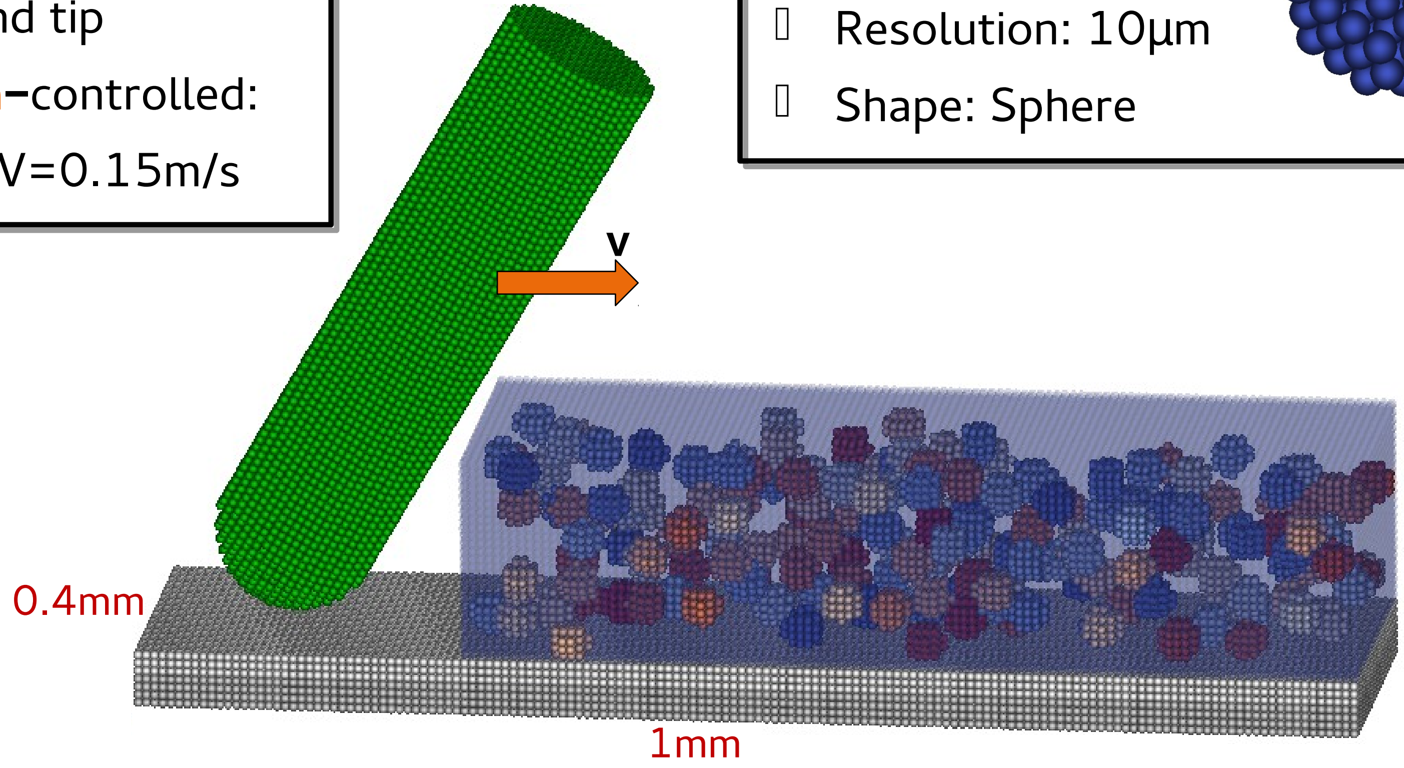
Filament:

- Diameter 200µm
- Round tip
- Path–controlled:
    - V=0.15m/s

Abrasive Particle:

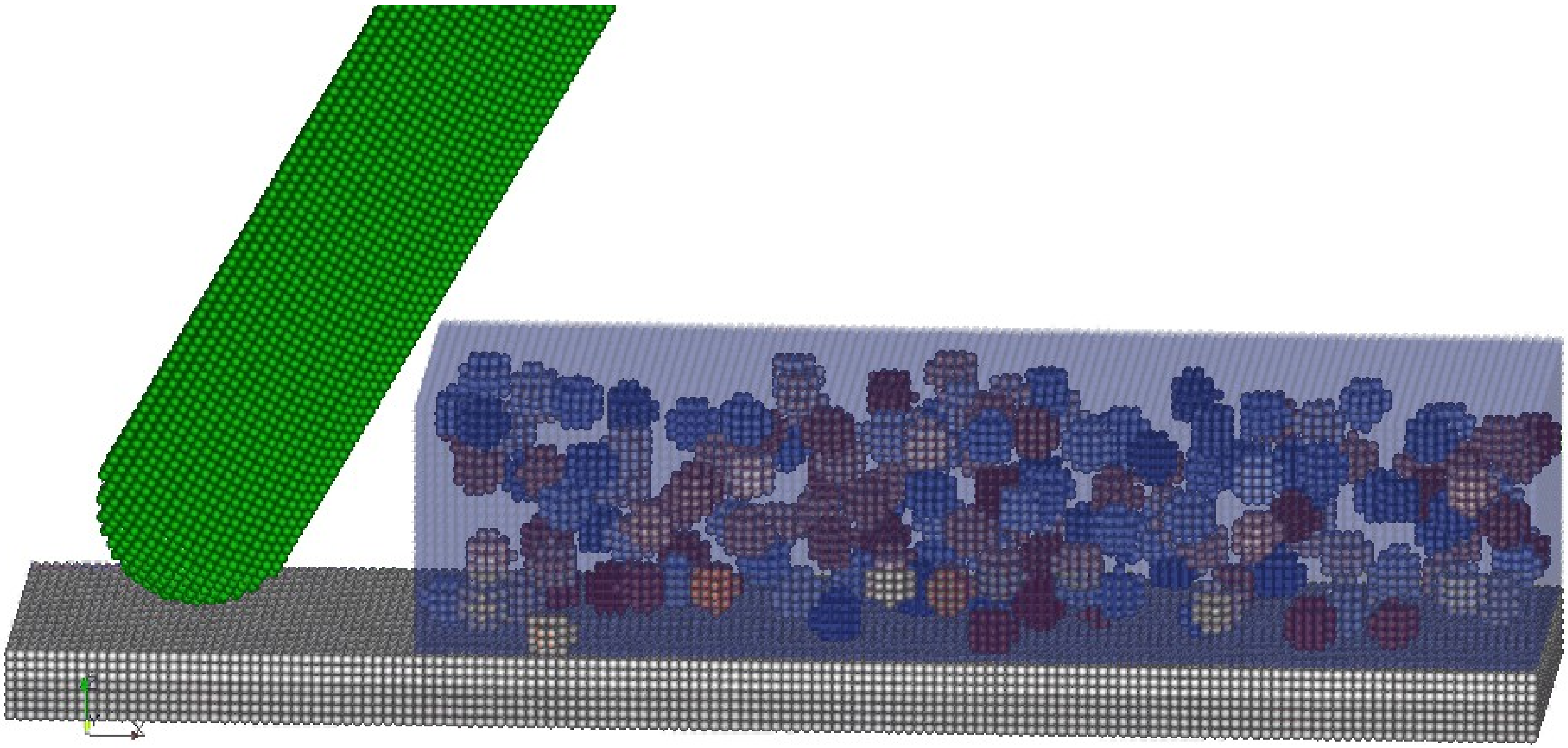
- Diameter 50µm
- Resolution: 10µm
- Shape: Sphere





Results

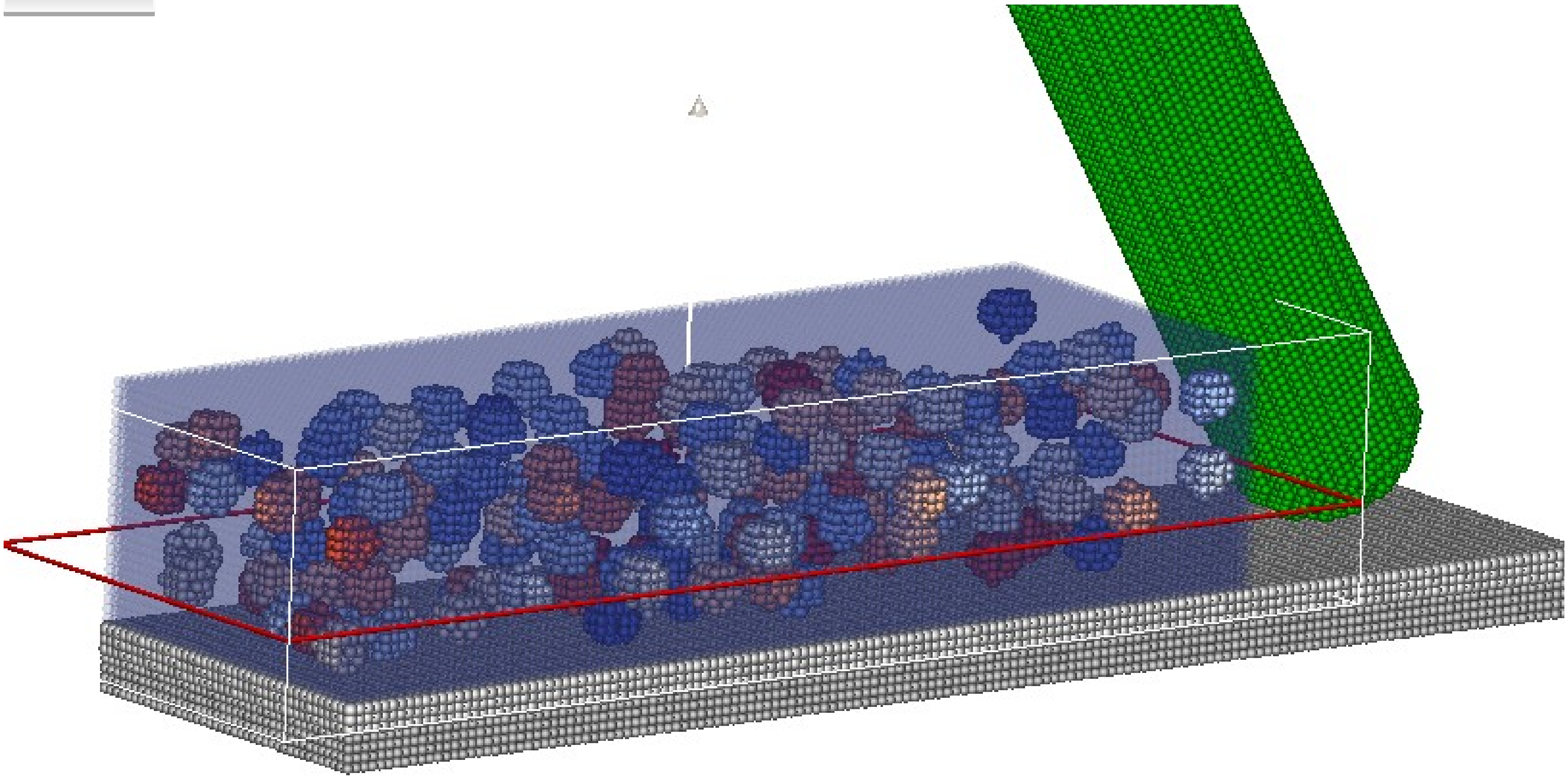
Displaying all components



Results – Stress distribution

Parameter study: viscosity

1mPas

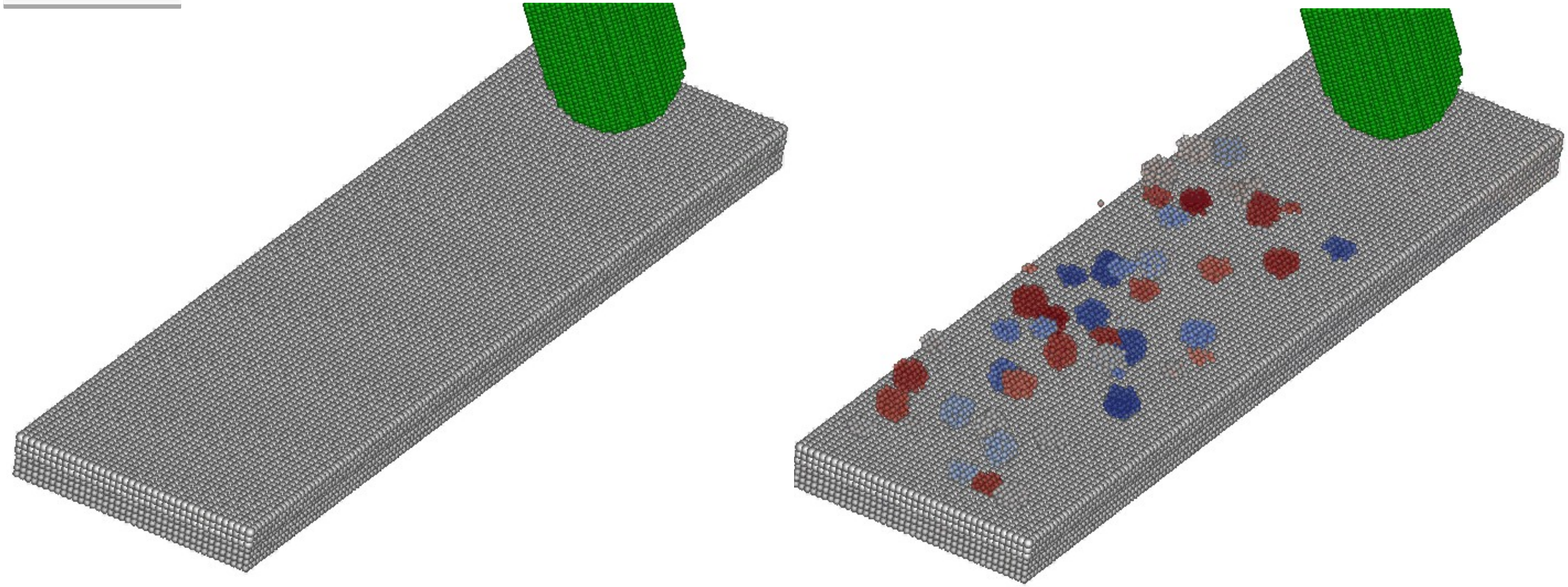


Results – Stress distribution

Parameter study: viscosity

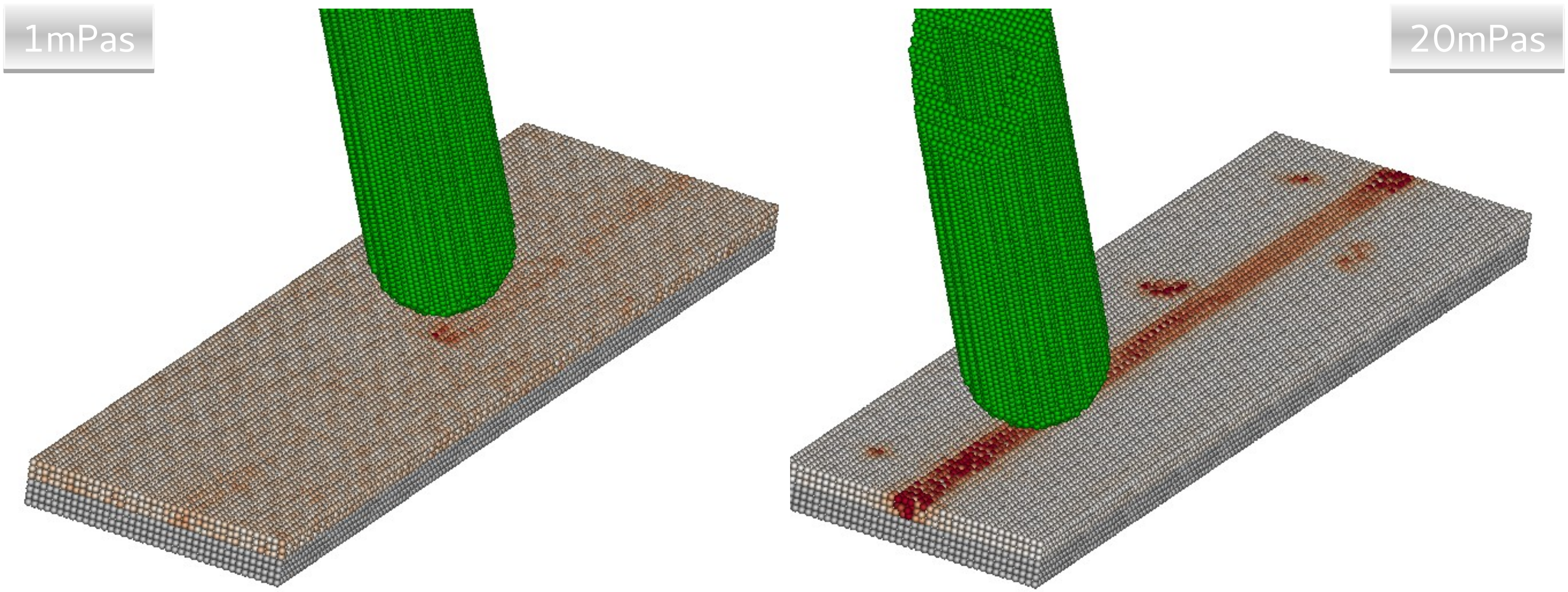
Higher viscosity:

20mPas



Results – Stress distribution

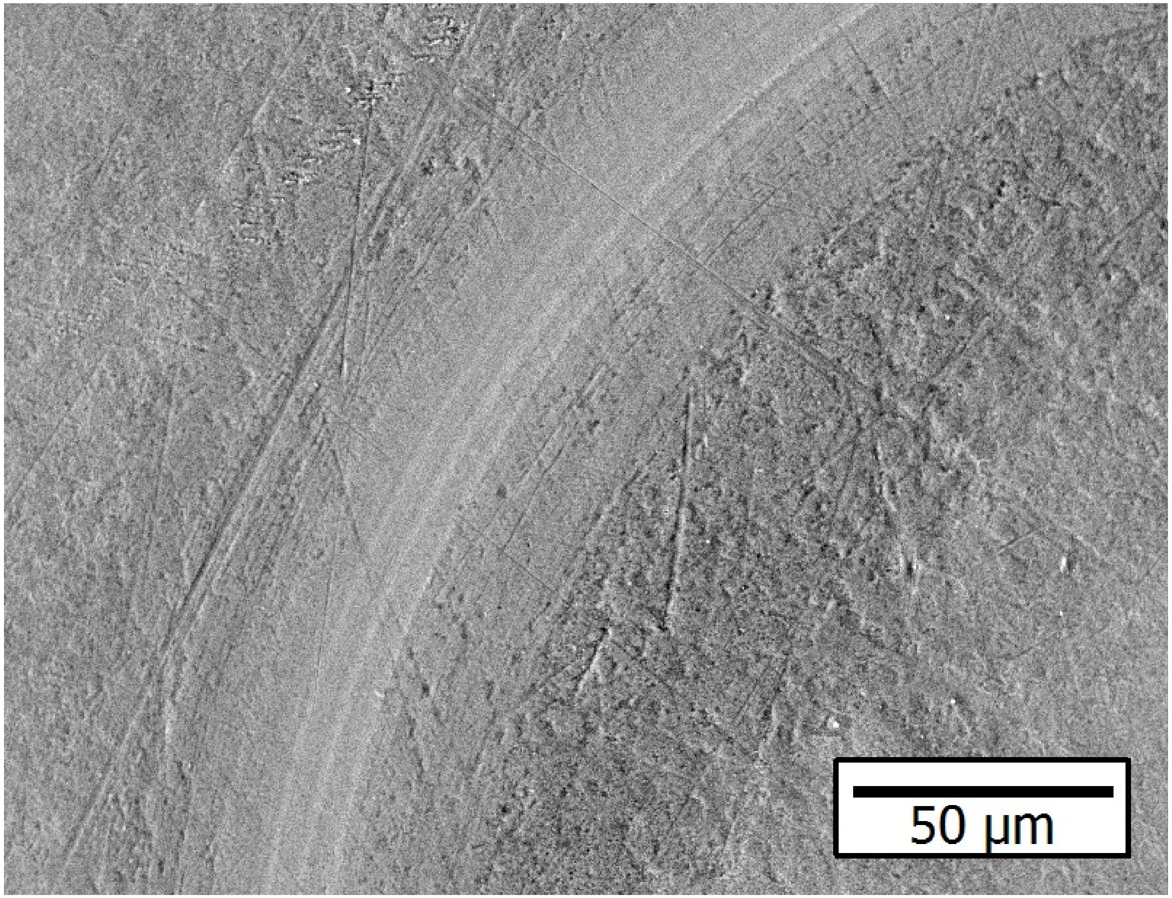
Parameter study: viscosity – Comparison



- **Lower** capture probability of abrasive particles for **lower** viscosities
- **Higher viscosity** yields **larger induced stress** into the enamal by the abrasive particles
- Discrete stress input outside of the sliding wear track

Results

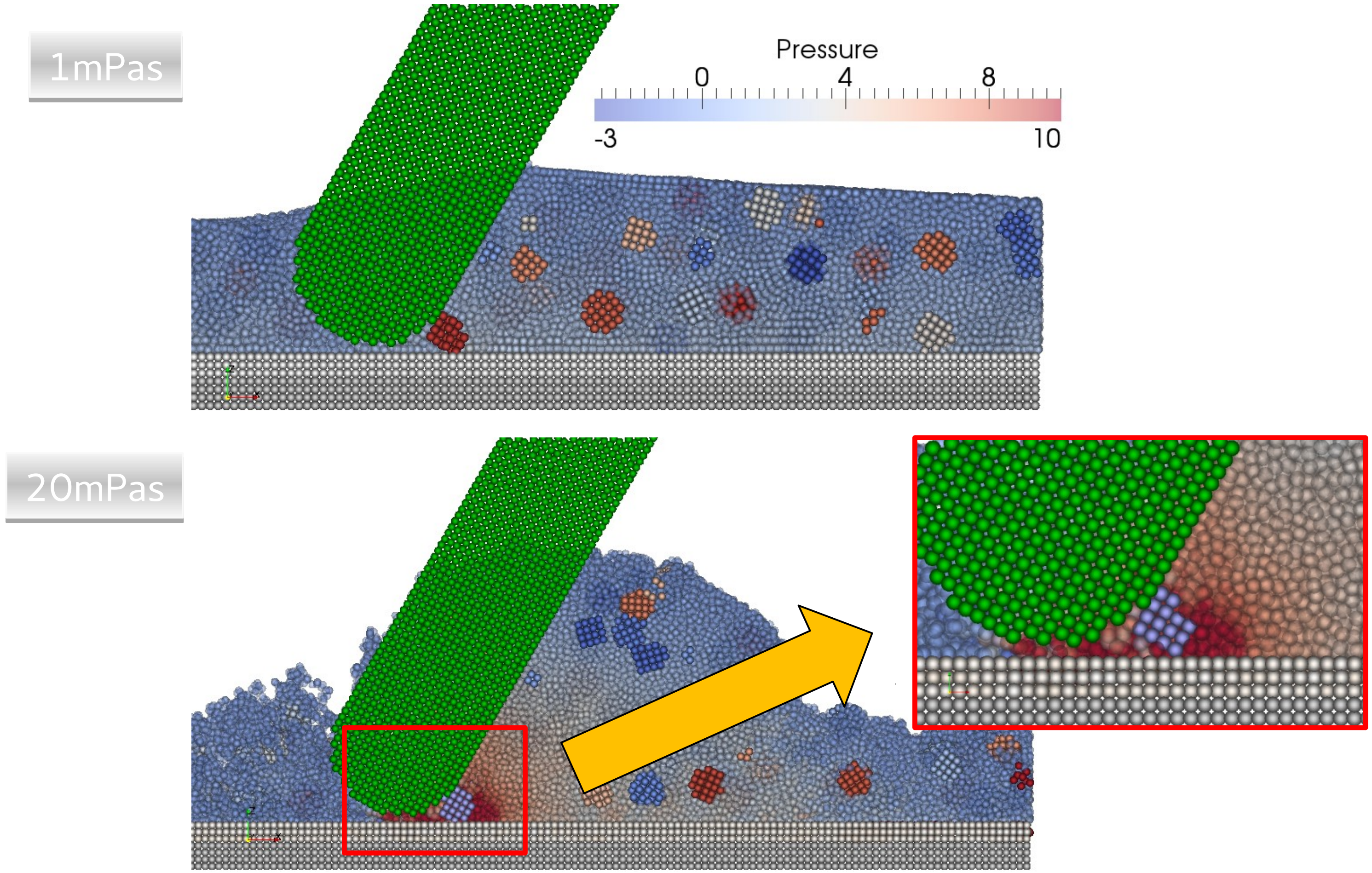
Sliding wear track in the experiment



Wear track after 8000 cycles of a cylindric filament embedded within a toothpaste slurry on the enamel.

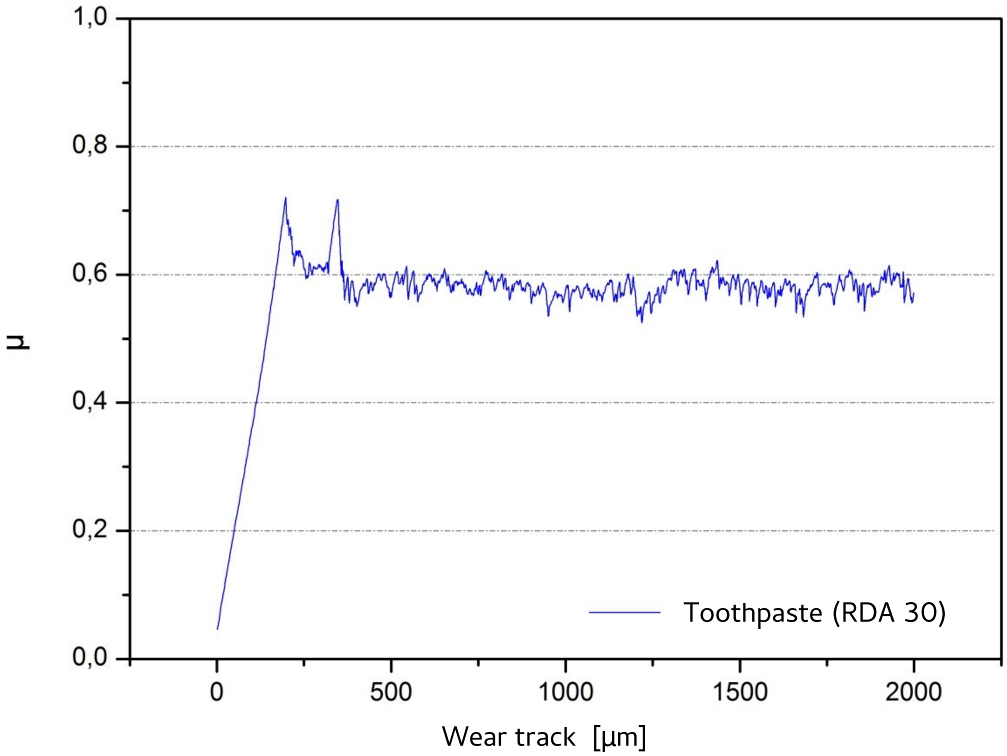
Results

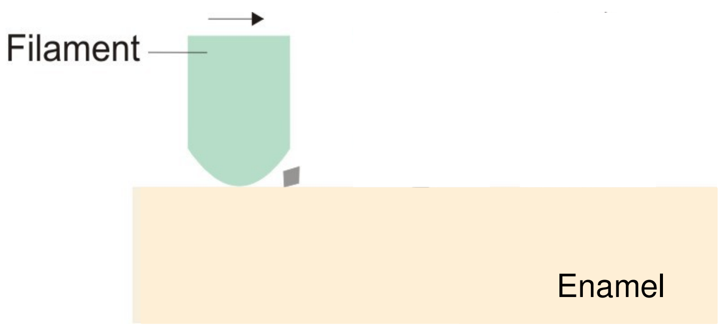
Viscosity dependend pressure distribution



Experimental results

Are there stick-slip effects?

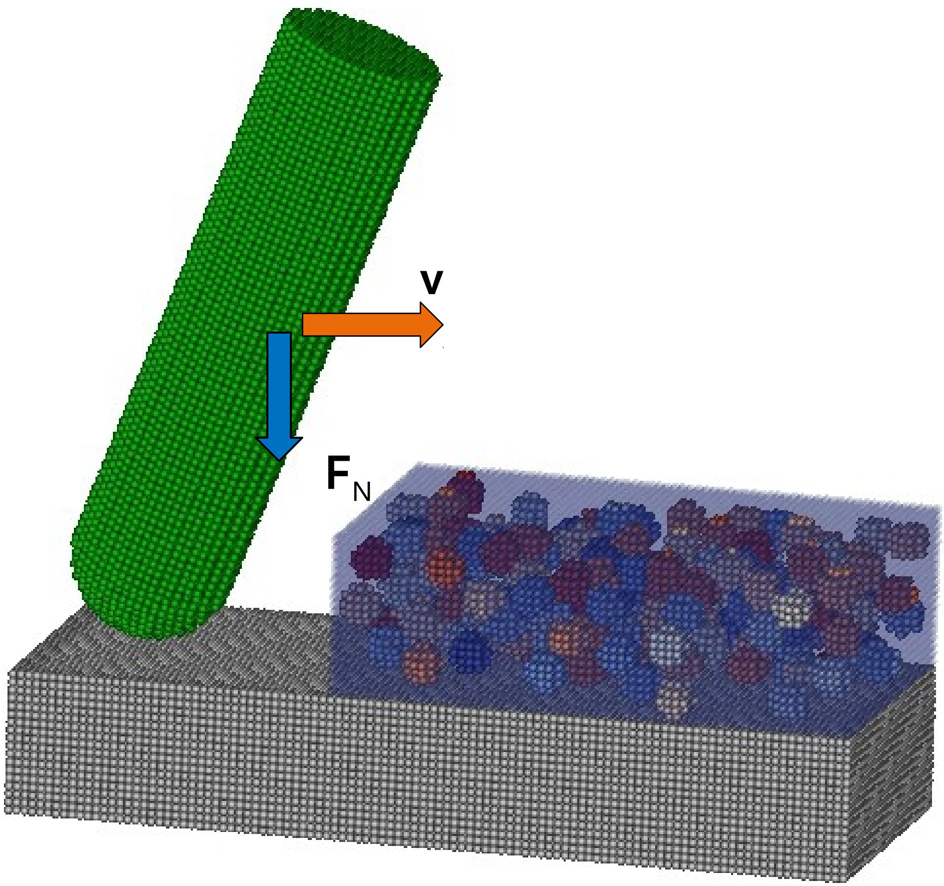




stick-slip effect

Results

Geometrical setup – new model



Improved model:

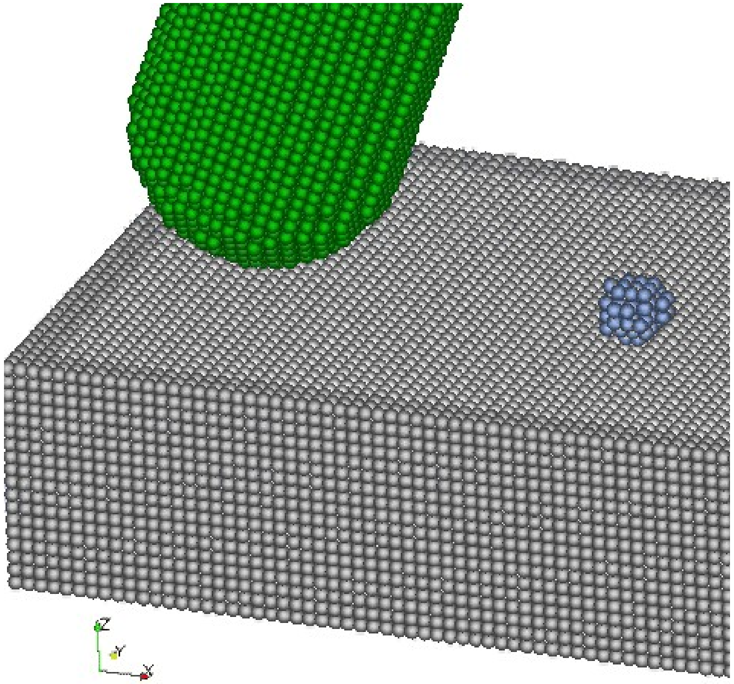
- Geometrical shape of enamel:
  - (600x450x200)µm
- Filament movement:
  - Force–Path-controlled

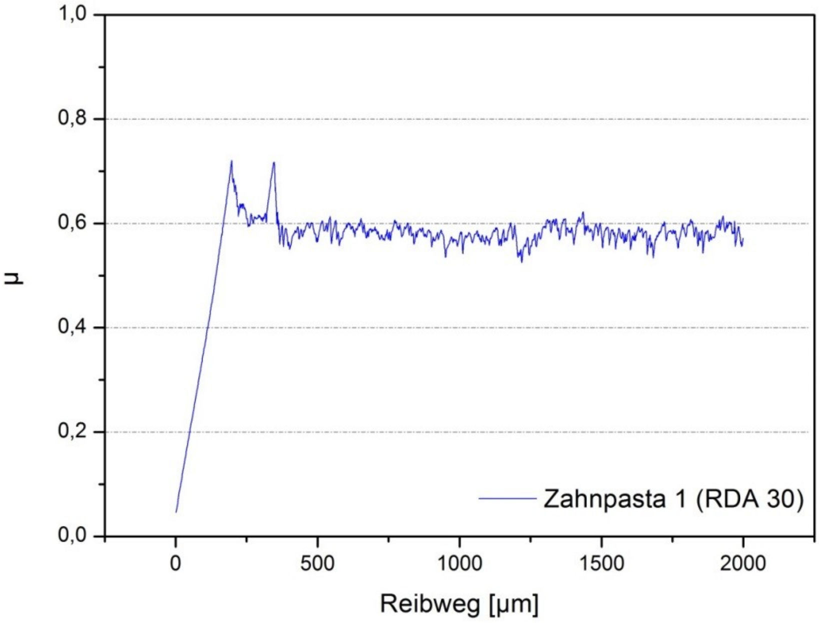
Suspension:

- Volume fraction of abrasive particles: 20%
- Ø = 50µm
- Viscosity: 1mPas

Results

stick-slip effect in the simulations

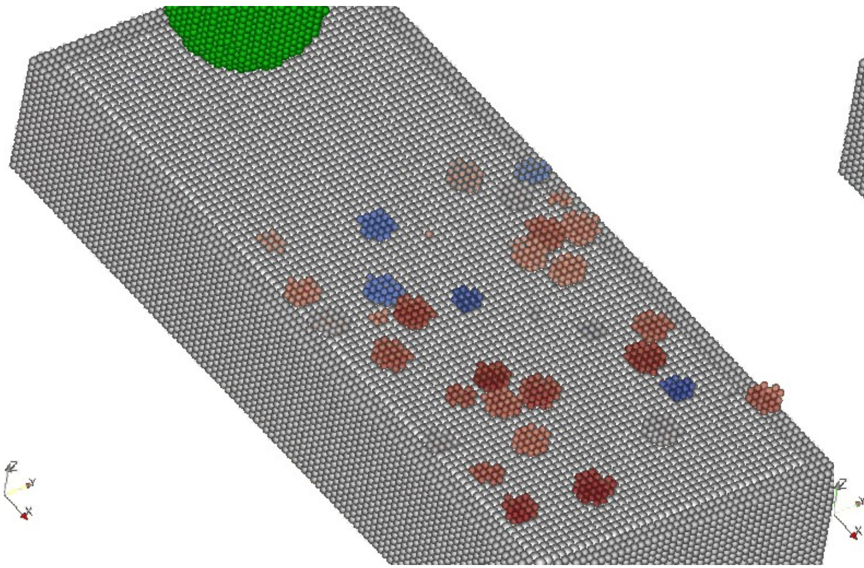




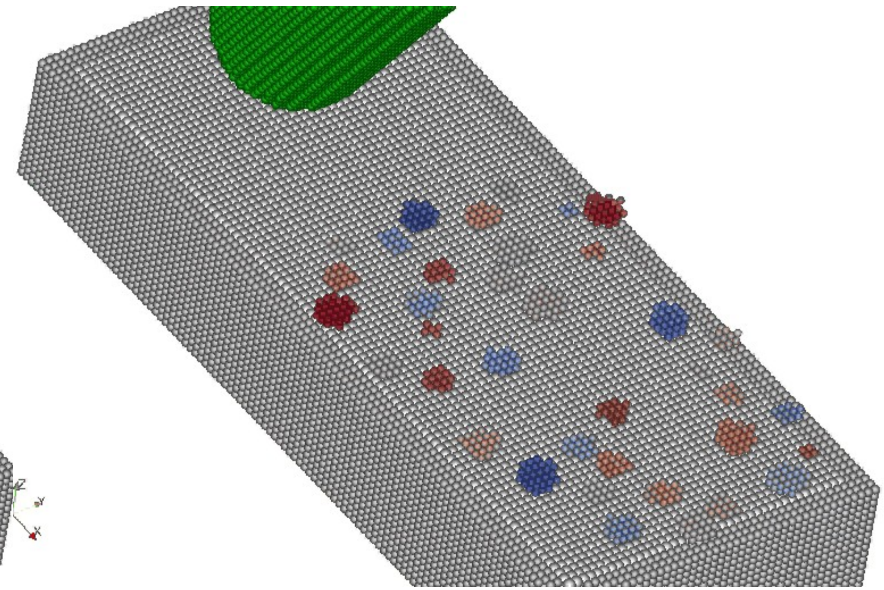
Results

Variation of tilt angle

0°



30°



- **Inclined filament** possesses **higher capture probabilit**y of abrasive particles and hence higher risk of abrasive processes on the enamel

Summary

- Improved knowledge about the fluid mechanical mechanisms in toothpaste slurrys due to the comparsion of experimental and numerical investigations
- Gained insight due to microscopical simulations and experiments:
  - Higher viscosities of the toothpaste slurry raises the induced stress into the enamel by the abrasive particles
  - Numerical investigations support the idea about a broad stress distribution across the wear track
  - Larger tilt angle raises capture probability of abrasive particles by the filament and hence increases abrasion
  - Suggested stick-slip effects seen in experiments is supported by the numerical investigations