# Practical Comparison between the Finite-Element and Mesh-Free Calculation Methods in the Analysis of Machining Simulations


## Fraunhofer Institute for Manufacturing Engineering and Automation IPA

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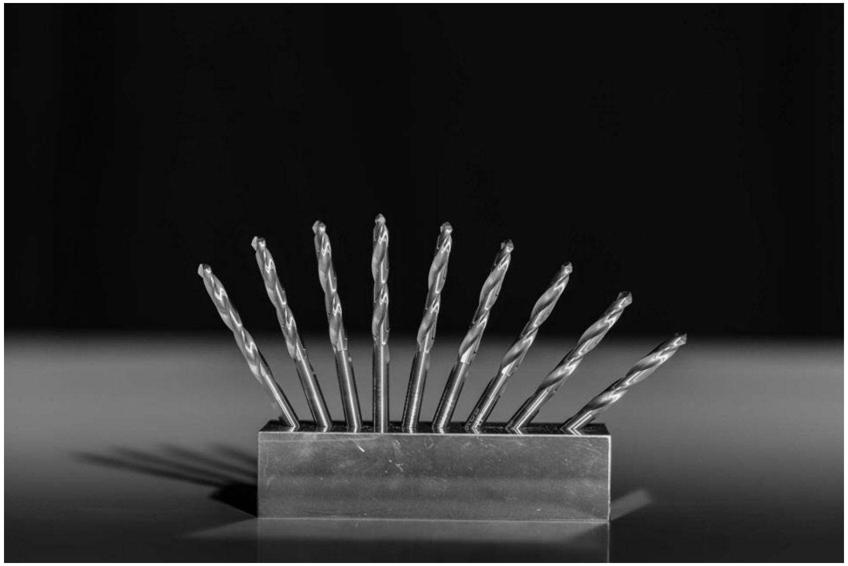
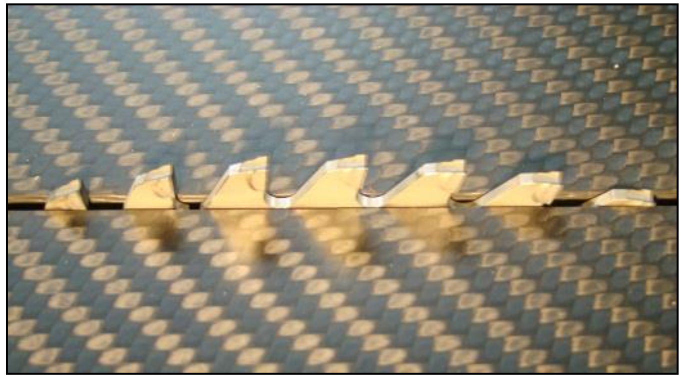
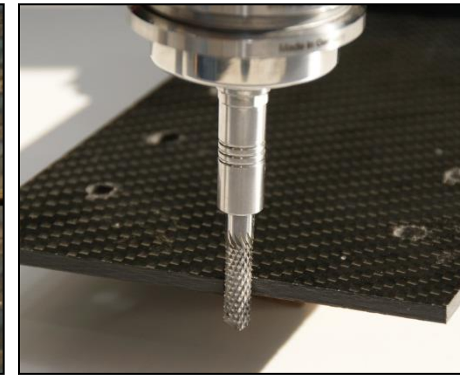


# Simulation in the Machining Technology

**Machining processes**

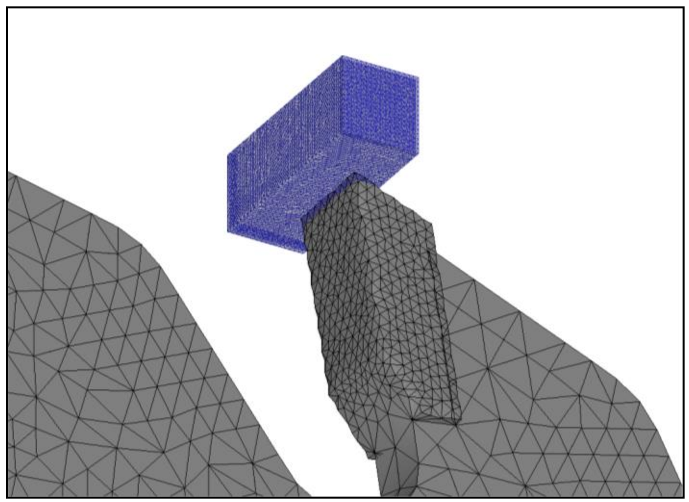
- Turning
- Drilling
- Milling
- Sawing

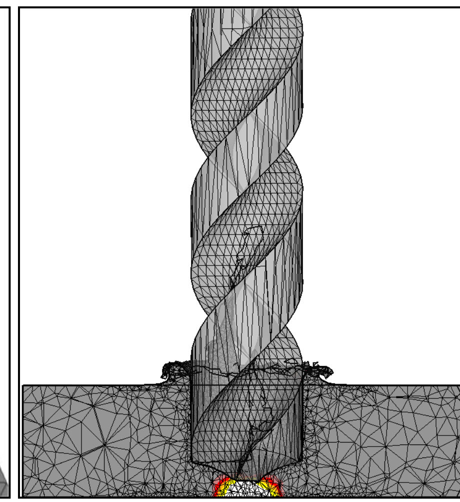




**Analyzed variables**

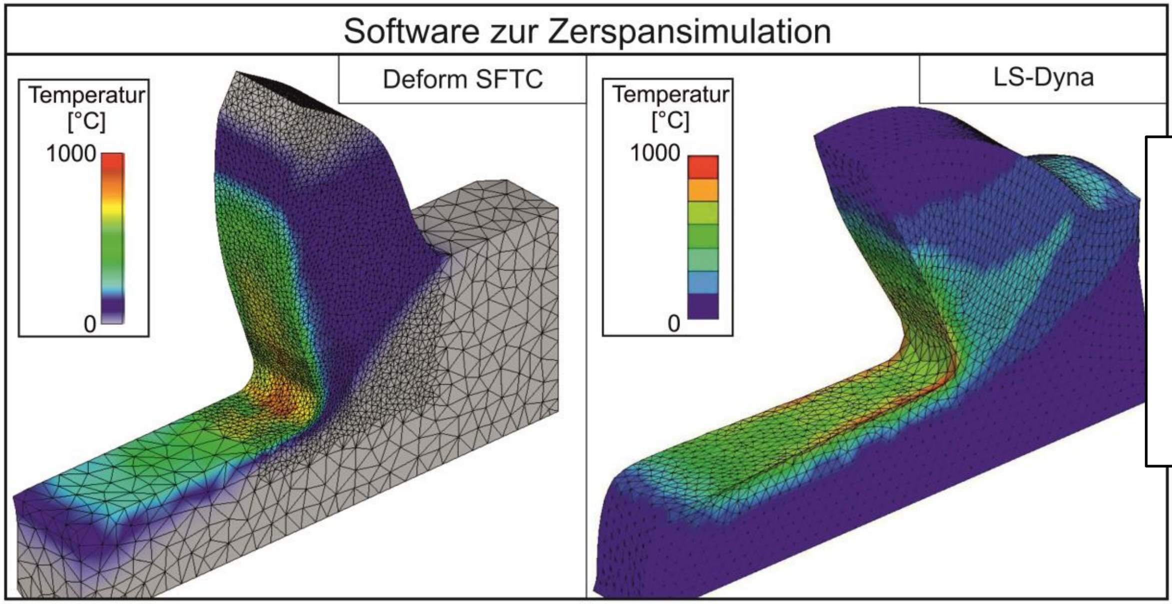
- Cutting forces
- Temperature
- Stress
- Strain
- Chip formation





# Integration of process simulation in the machining technology

- Determination of the relationships between:
  - cutting and process parameters
  - stress, strain and temperature development inside the process




Approximation and close analysis of the high thermo-mechanical loading conditions inside the process

- Tool development through virtual experimentation

# Main requirements in the simulation of machining processes

### Characteristics of machining simulations

- Contact and interaction between several bodies
- High dynamic ($v_c$ > 1 m/s)
- High plastic deformation ($\varepsilon > 0.5$)
- Material separation takes place

### Settings for the simulation

#### Models of material $k_{f\,(\varepsilon,\,\dot{\varepsilon},\,T)}$

- High deformation ($\varepsilon$)
- Effects of strain rate ($\dot{\varepsilon}$)
- Effects of temperature (T)

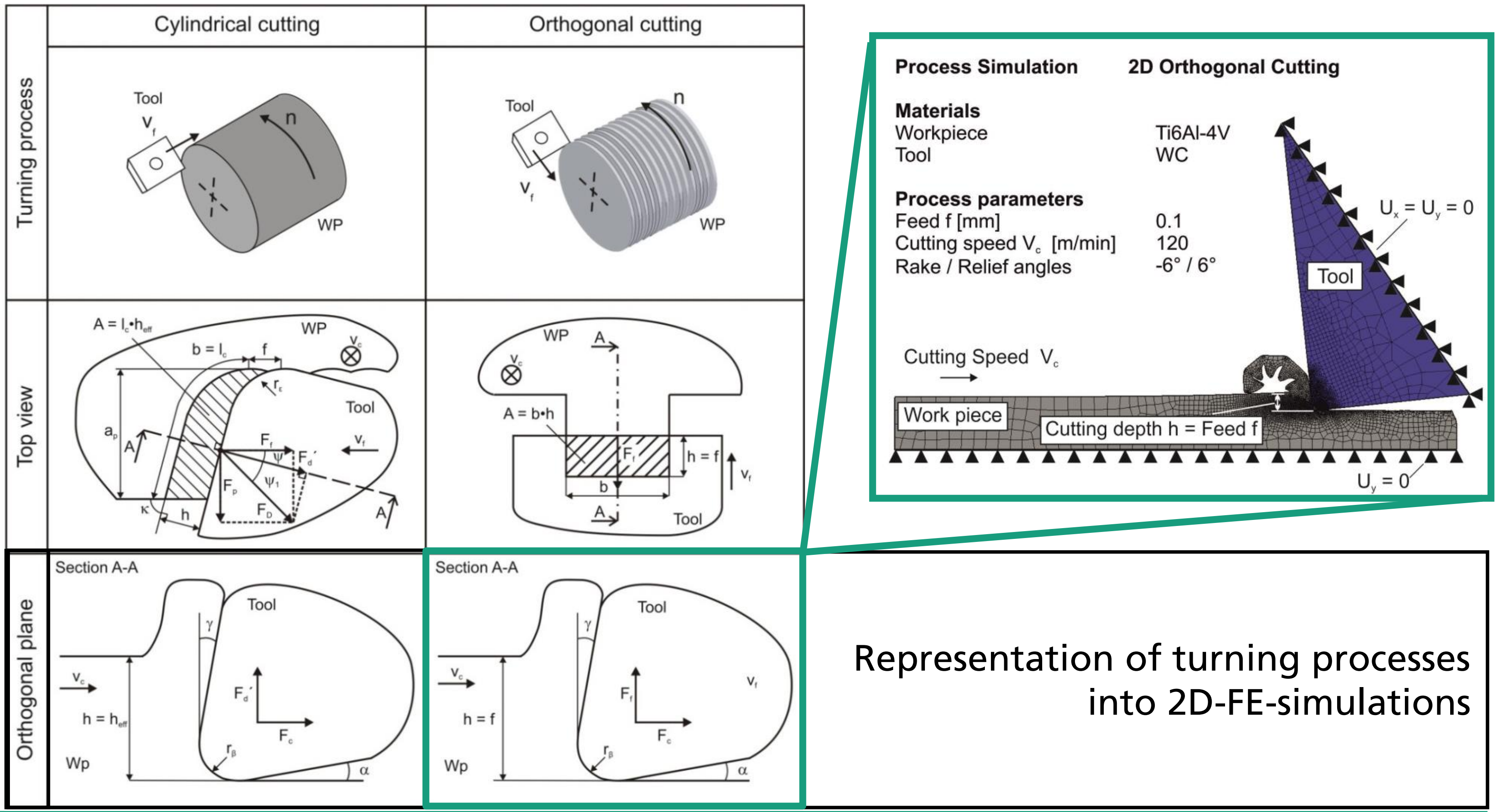
#### Material separation methods

- Node separation
- Elements deletion
- Remeshing
- Mesh-free methods

# Alternative numerical methods in LS-Dyna

| Mesh dependent | Mesh free | | |
|---|---|---|---|
| **FEM**<br>Finite element method<br><br>• Discretization into a grid of finite elements<br><br>• Element based connectivity<br><br>• Requires additional separation or fracture formulations | **SPH**<br>Smoothed particle hydrodynamics<br><br>• Discretization through SPH-particles<br><br>• Absence of an interconnected grid<br><br>• A smoothing function defines an influence length and interaction strength between particles<br><br>• Allows the modeling of solid and fluids | **EFG**<br>Element free Galerkin<br><br>• Mesh free principle<br><br>• Weak formulation of the method has a higher order<br><br>• Mesh supports contact and boundary conditions<br><br>• The user interface in LS-Dyna for EFG is not fully implemented | **DEM**<br>… |

# Schematic representation of a turning process simulation



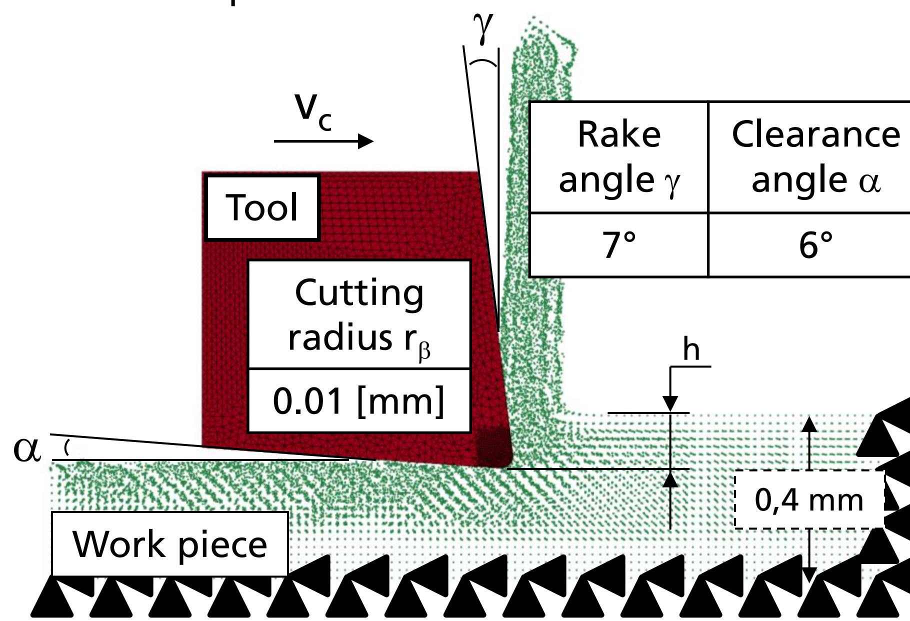

Representation of turning processes into 2D-FE-simulations

# Design of a turning process simulation

## Mechanical 3D-Simulation

- Calculation methods: FEM / SPH / EFG
  - Software: LS-Dyna, version 7.1.1
- Process : Orthogonal turning
  - Cutting distance:  0.85 [mm]
  - Termination time: 0.17 [ms]
- Cutting tool
  - Material: Tungsten carbide (WC)
  - Element type: rigid shell elements
  - Number of elements: 16,500
  - Smallest element size: 3 µm
- Work piece
  - Material:  Al7075
  - Material model: Plastic kinematic (MAT_003)

- Process parameters

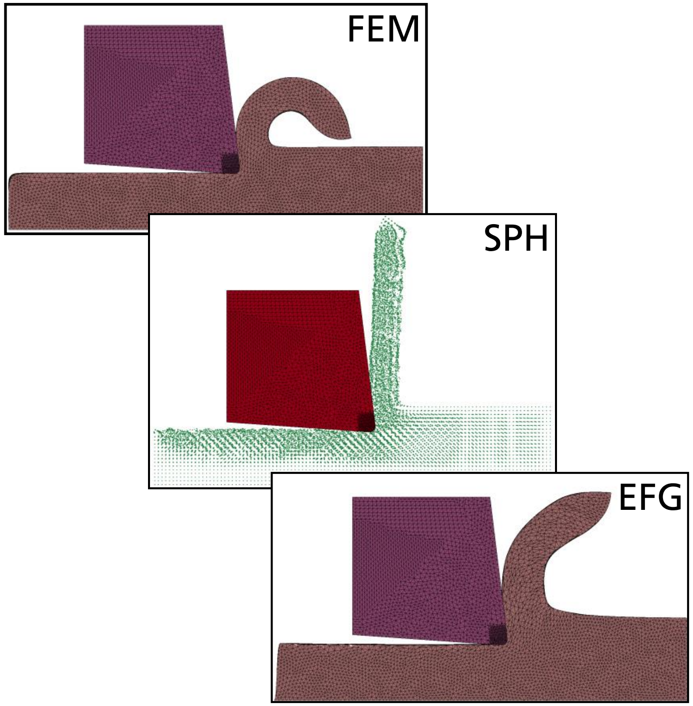



| Rake angle $\gamma$ | Clearance angle $\alpha$ |
|---|---|
| 7° | 6° |

| Cutting speed $v_c$ | Cutting width b | Cutting depth h |
|---|---|---|
| 300 [m/min] | 0.25 [mm] | 0.1 [mm] |

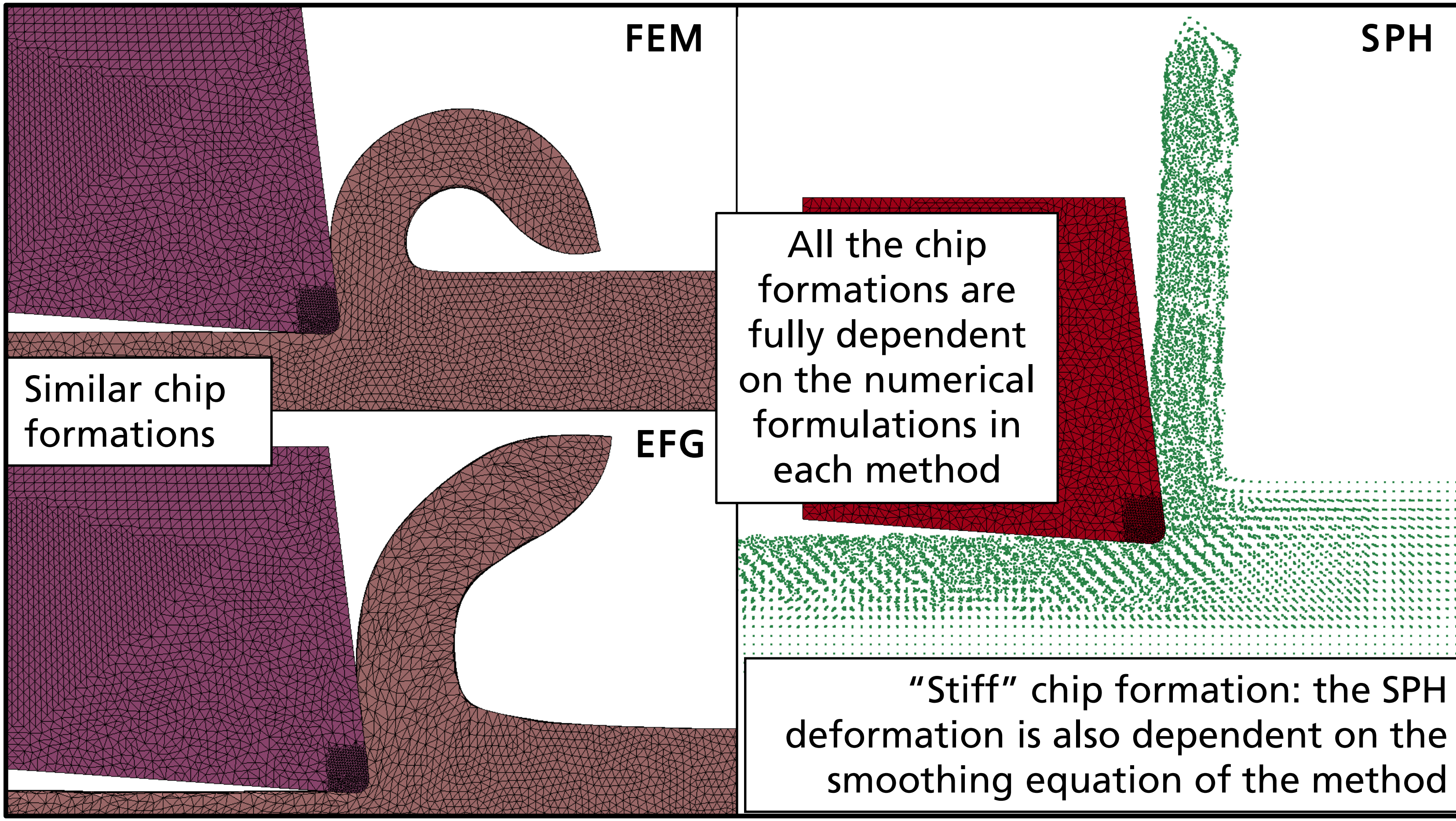
# Design of a turning process simulation
## Simulation parameters

- Parameters of the **FEM** simulations
  - Element types: tetrahedral volume elements
  - Number of elements//nodes: 30,000//50,000
  - Smallest element size: 9 [µm]
  - Separation: Adaptive remeshing
- Parameters of the **SPH** simulations
  - Element types: SPH
  - Number of particles: 40,000
  - Separation: -none-
- Parameters of the **EFG** simulations
  - Number of elements//nodes: 30,000//50,000
  - Smallest element size: 9 [µm]
  - Separation: Adaptive remeshing
- Interface properties
  - Contact: nodes to surface
  - Sliding friction coefficient: µ = 0.1



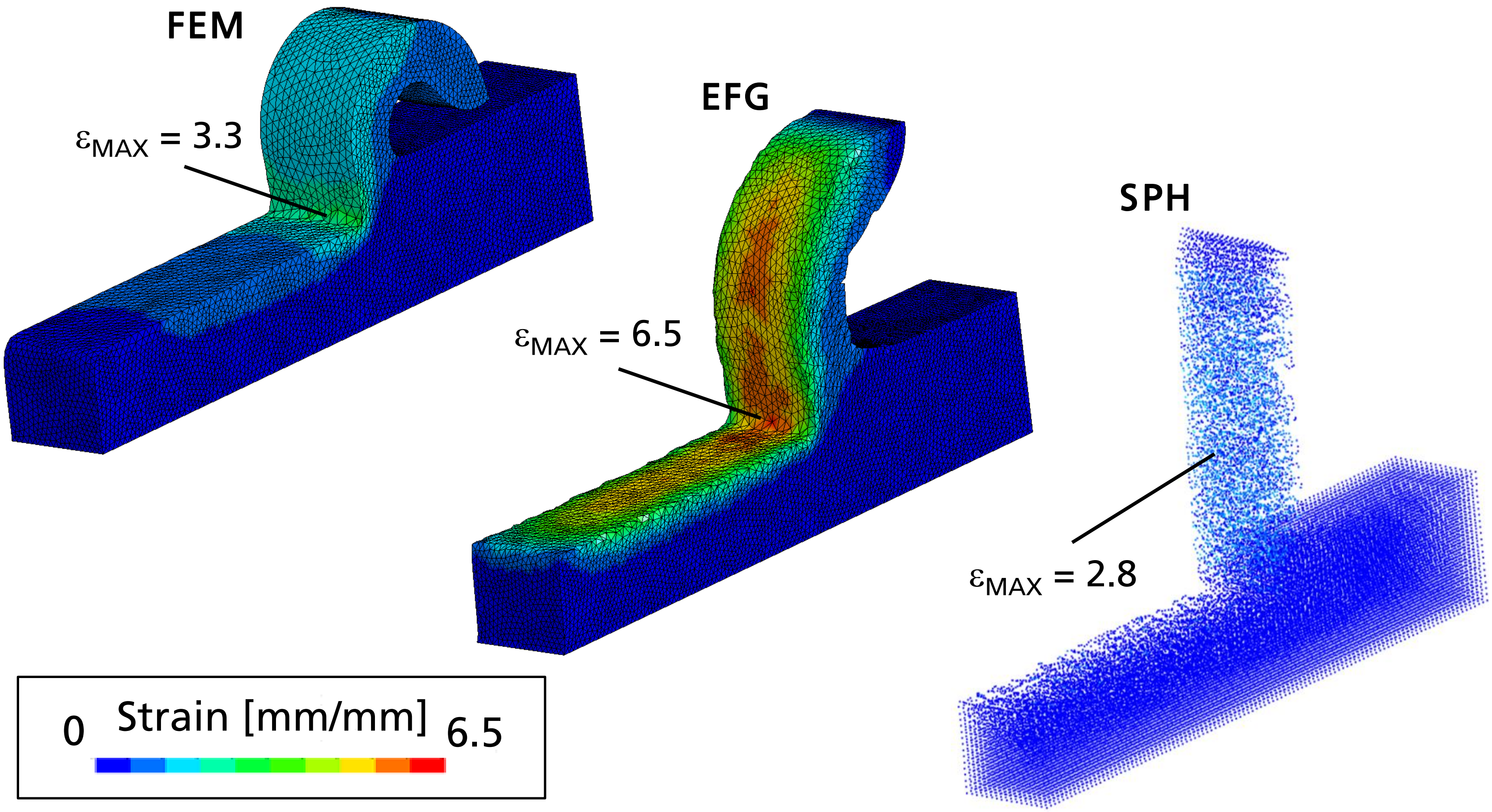
# Comparison between FEM, EFG and SPH

## Chip formation



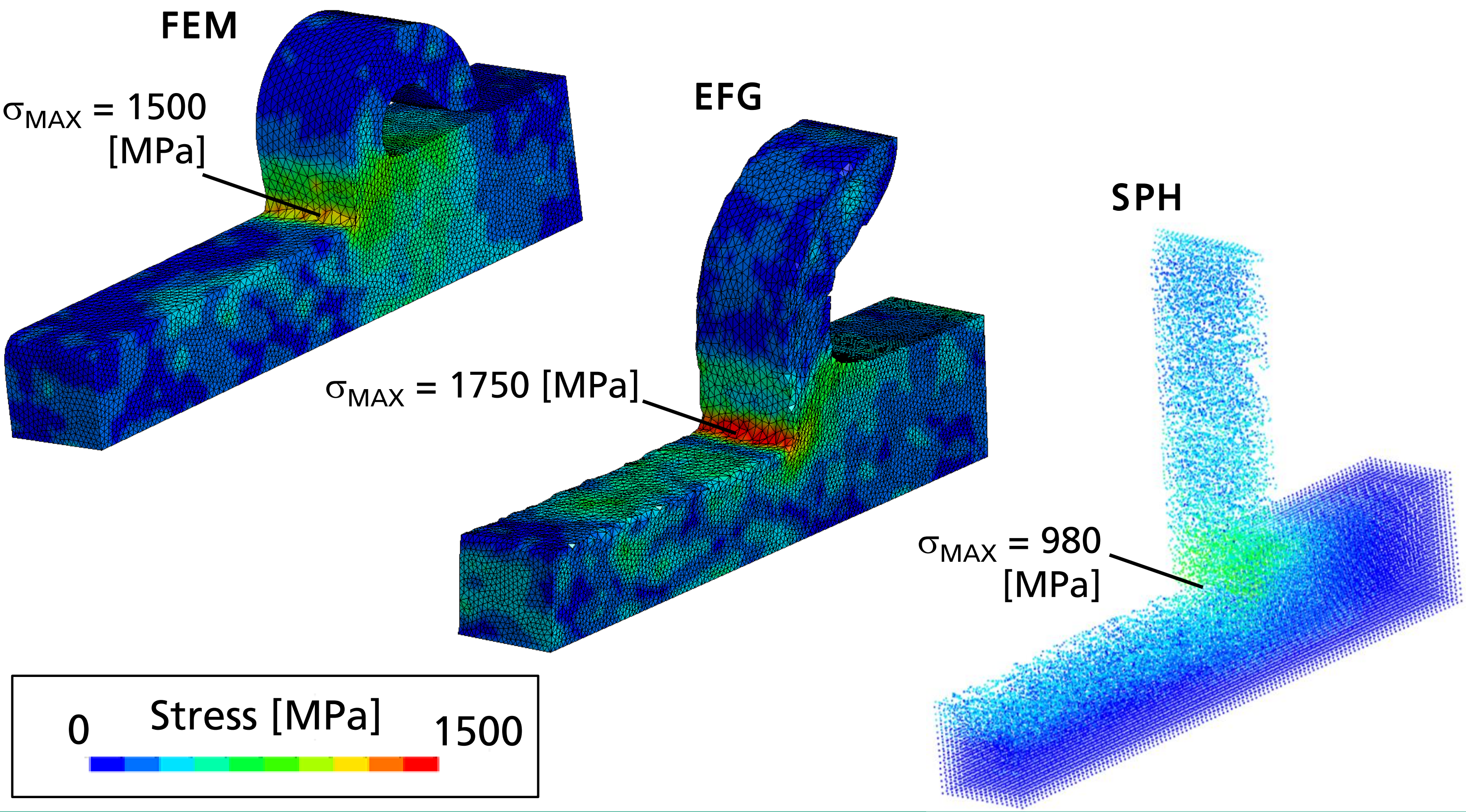
# Comparison between FEM, EFG and SPH

## Strain



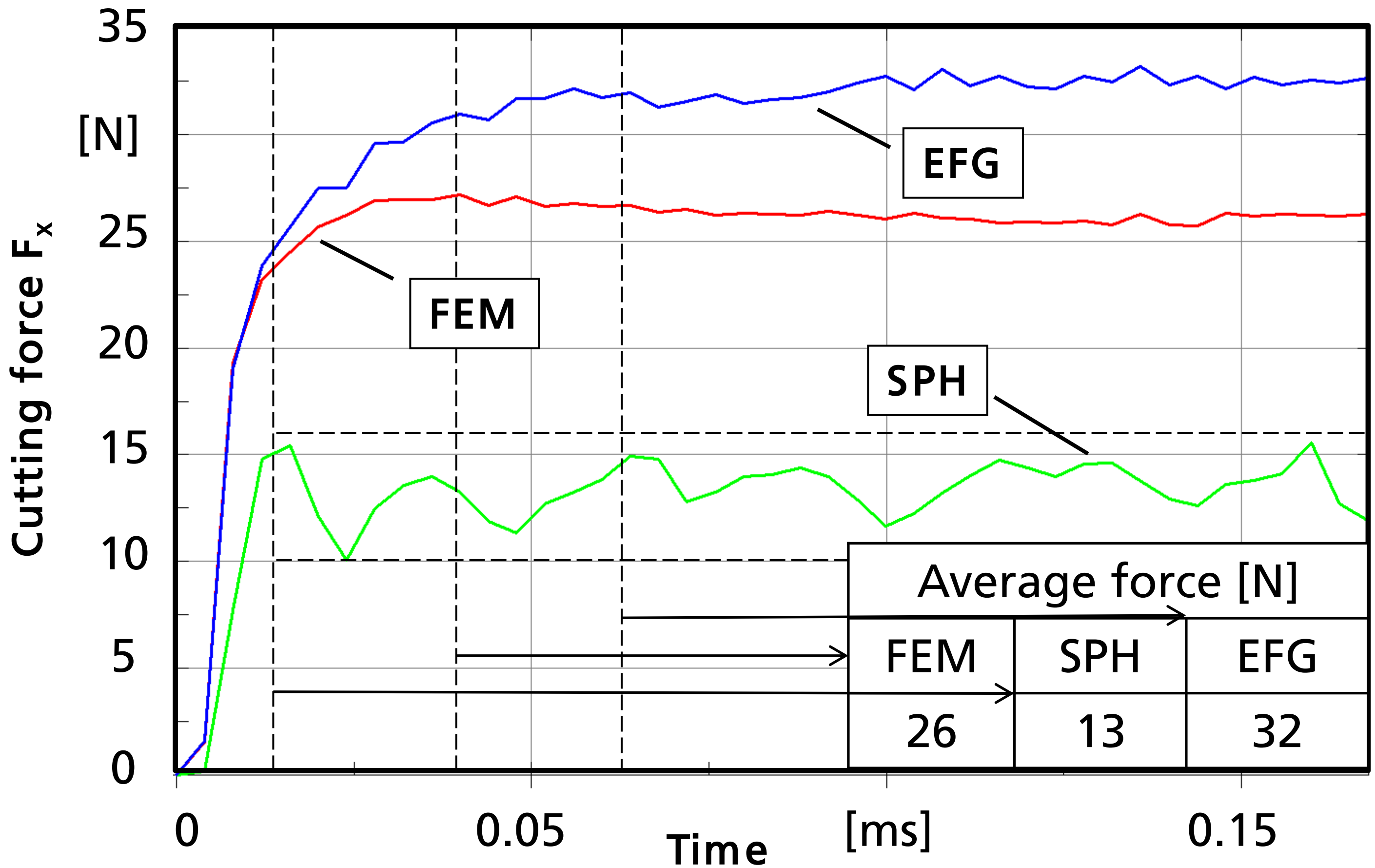
# Comparison between FEM, EFG and SPH

## Stress



# Comparison between FEM, EFG and SPH

## Cutting force $F_x$



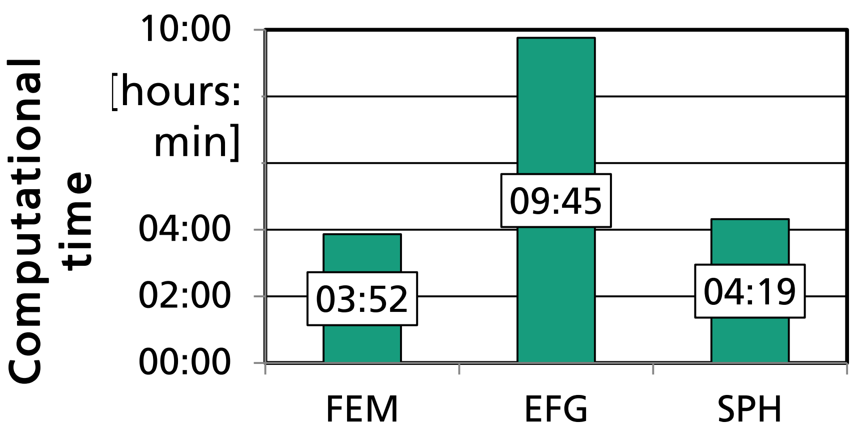

| Average force [N] | | |
|---|---|---|
| FEM | SPH | EFG |
| 26 | 13 | 32 |

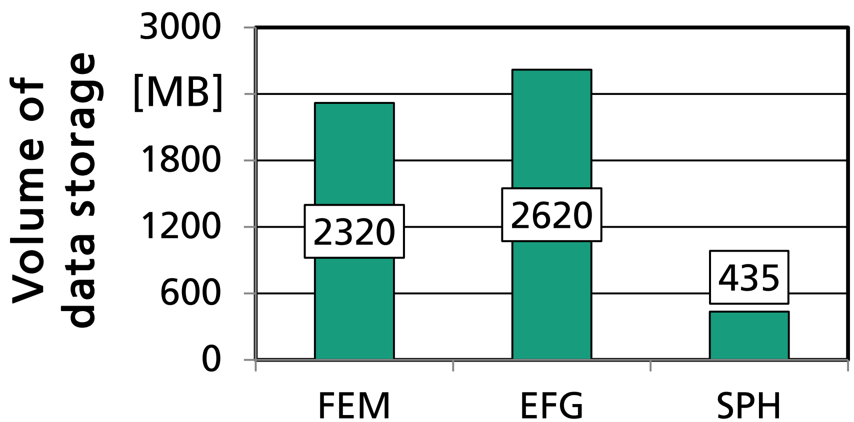
Methods with lowest fluctuations

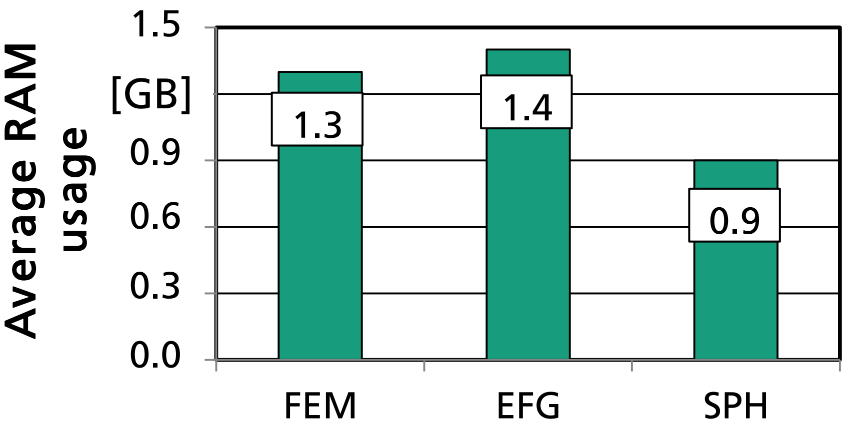
An increase of the particles number may reduce the high fluctuation

# Comparison between FEM, EFG and SPH

## Calculation time und memory usage

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# Comparison between FEM, EFG and SPH

## Conclusions

| | |
|---|---|
| Green face | Good properties |
| Yellow face | Manageable environment |
| Red face | Rough environment |

| | Stability # error reports | Manageability # configuration steps and cards | Theoretical precision | Field of application |
|---|---|---|---|---|
| FEM | Manageable environment | Manageable environment | Manageable environment | General applications |
| EFG | Manageable environment | Rough environment | Good properties | Analyses of deformation (chip formation) |
| SPH | Good properties | Good properties | Rough environment | Introductory process analysis |

Numerical error reports take place at the beginning

No need of separation criterion

Formulation equations of higher order

Highest time and memory costs

Lowest calculated values

Setup over the k-file

Dependency on the smoothing function

# Thank you for your attention!

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