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Numerical study on the elastic-plastic contact between rough surfaces

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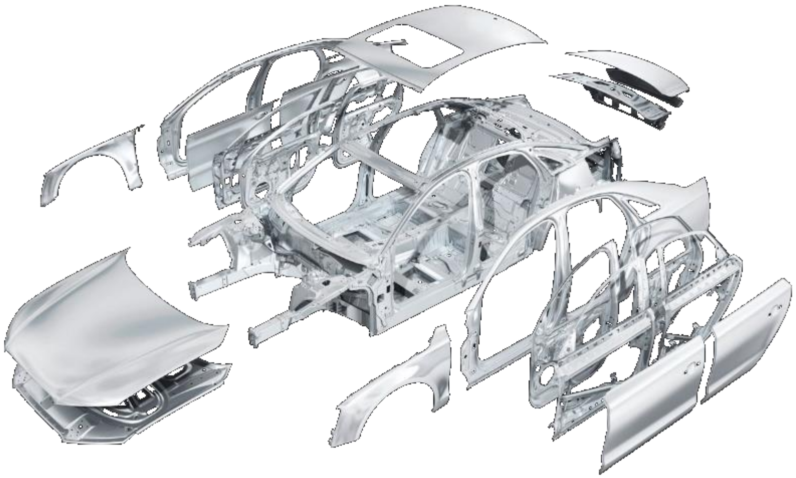
Introduction



Body-in-white

More than 300 sheet metal parts:

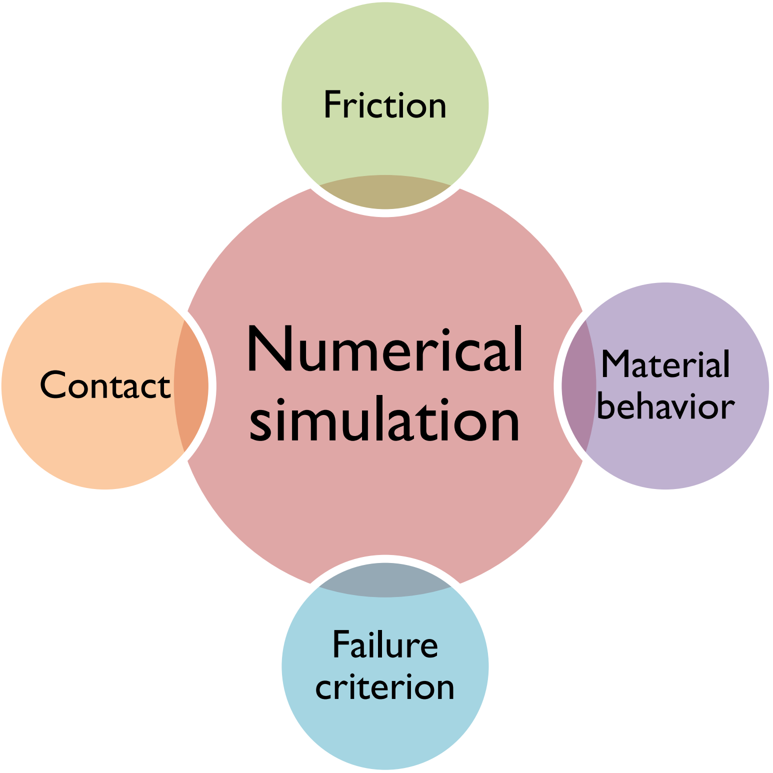
- Closures
- Structural parts
- Reinforcements

Current challenges in the sheet metal forming industry:

- Adoption of new materials (ultra high strength steels, lightweight alloys, etc.)
- Reduced manufacturing cost and lead times
- Shorter product development cycles

Sheet metal forming simulation

- Today the numerical simulation is an **indispensable tool** in the development of new components manufactured by forming
- Simulation is used to **predict formability** issues before going into production



The numerical solution is strongly influenced by the computational models implemented in the FEM code

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Frictional contact

- Frictional contact between the forming tools and the blank
- Typically the friction behavior is modelled by the **Coulomb's law**
- The formability predicted by simulation is significantly influenced by the friction coefficient used in the FE model (difficult to evaluate experimentally)

Existing friction laws are inadequate for the realistic description of local contact conditions

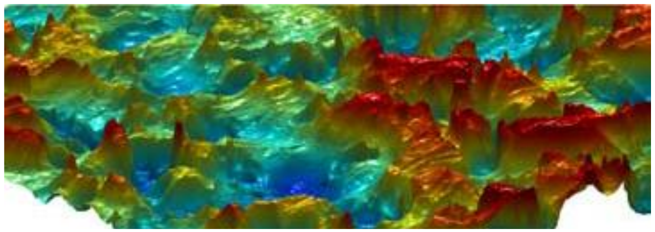
Objective:

Understand the relationship between the **microscopic contact** and the **macroscopic friction forces** generated during sliding contact.

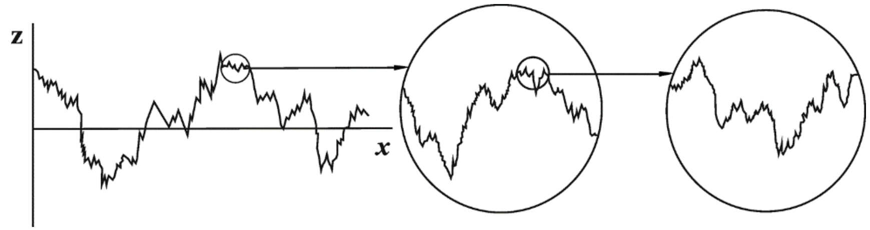
- Finite element simulation of contact between rough surfaces

Surface roughness

- All engineering **surfaces are rough** under certain magnification
- Most of rough surfaces are **fractals**, i.e. self-repeated patterns at every scale



Measured surface roughness

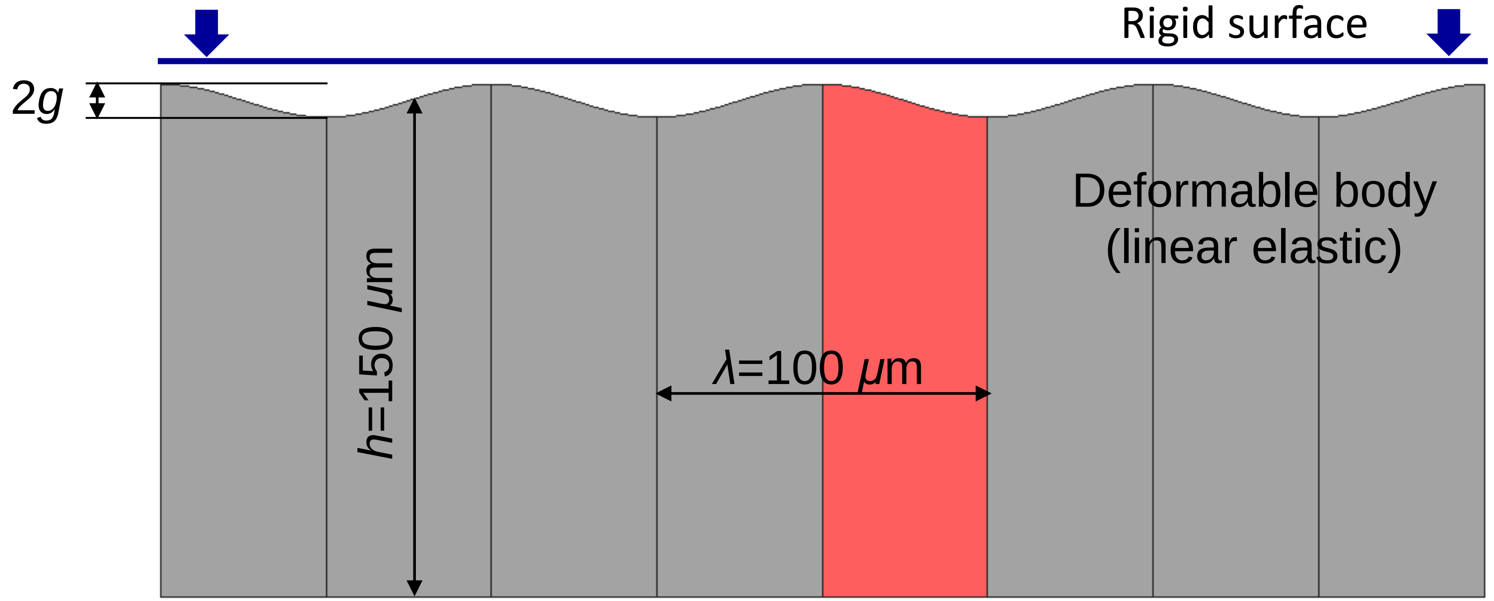


Self-affine surface

- Frictionless contact between two linearly elastic half-spaces is equivalent to contact between an effective **elastic rough half-space and a rigid flat surface**
- **Sinusoidal** rough surface

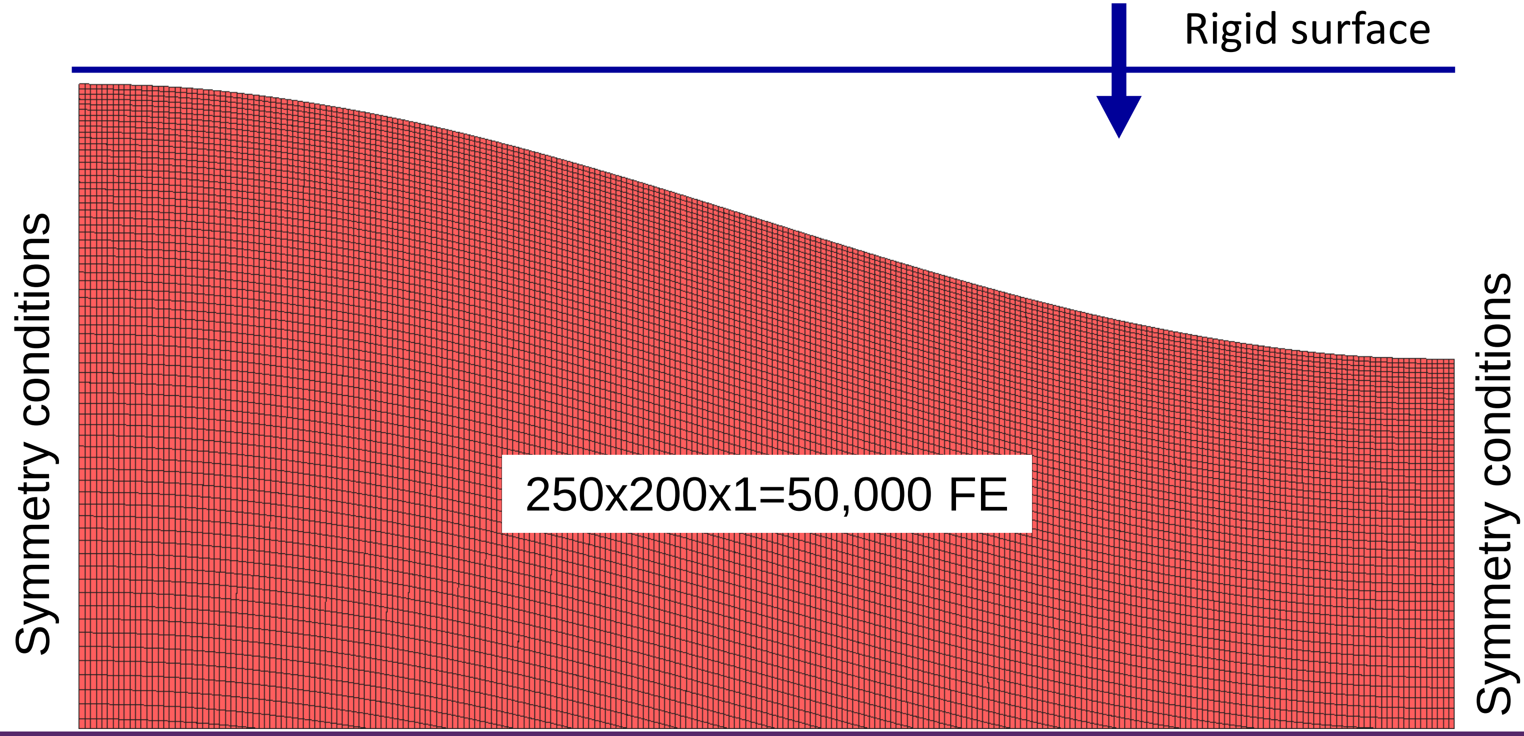
FE model – 1D sinusoidal surface

- Half asperity studied under plane strain conditions
- 2 geometries: asperity height g=1 μm and g=5 μm
- 2 materials: reduced Young modulus E^*=43.9 GPa and E^*=65.9 GPa



FE model – 1D sinusoidal surface

- Vertical displacement of the rigid surface until achieving full contact
- 50000 hexahedral finite elements (half asperity)
- Frictionless contact ($\mu=0$)
- DD3IMP in-house finite element code



Analytical solution for 1D sinusoidal surface

- Some definitions:

$A' = A/A_0$ – ration between real contact area (A) and nominal contact area (A_0)

$\bar{p} = F/A_0 = \dfrac{\pi g E^* \sin^2(\pi A'/2)}{\lambda}$ – average contact pressure

$p_{\mathrm{m}} = F/A = \dfrac{\pi g E^* \sin^2(\pi A'/2)}{\lambda A'}$ – mean contact pressure

F – applied force

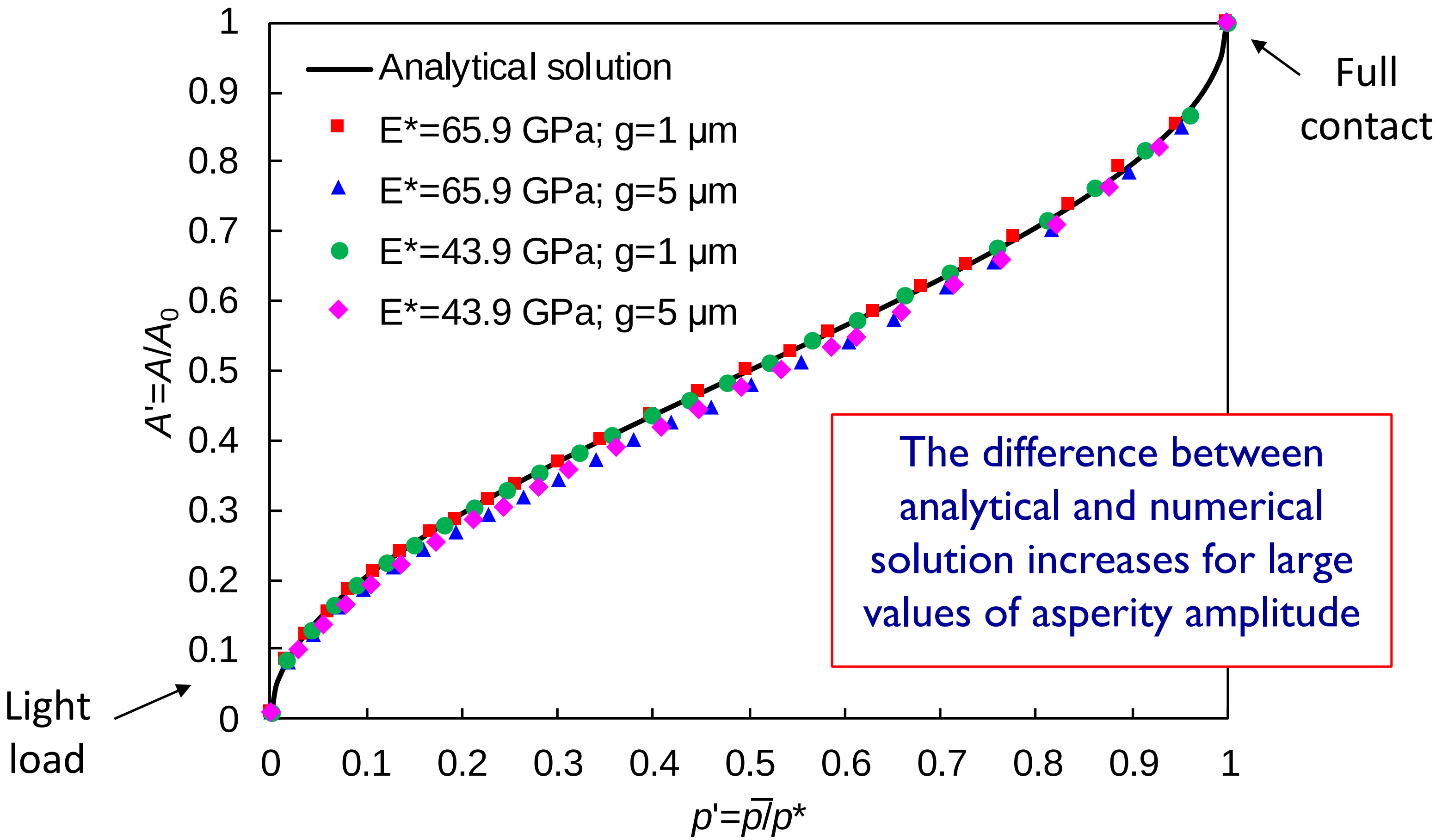
$p^* = \dfrac{\pi g E^*}{\lambda}$ – average contact pressure at full contact

Contact pressure distribution:

$$p(x) = \frac{2\pi g E^* \cos(\pi x/\lambda)}{\lambda}\sqrt{\sin^2(\pi A'/2) - \sin^2(\pi x/\lambda)}$$

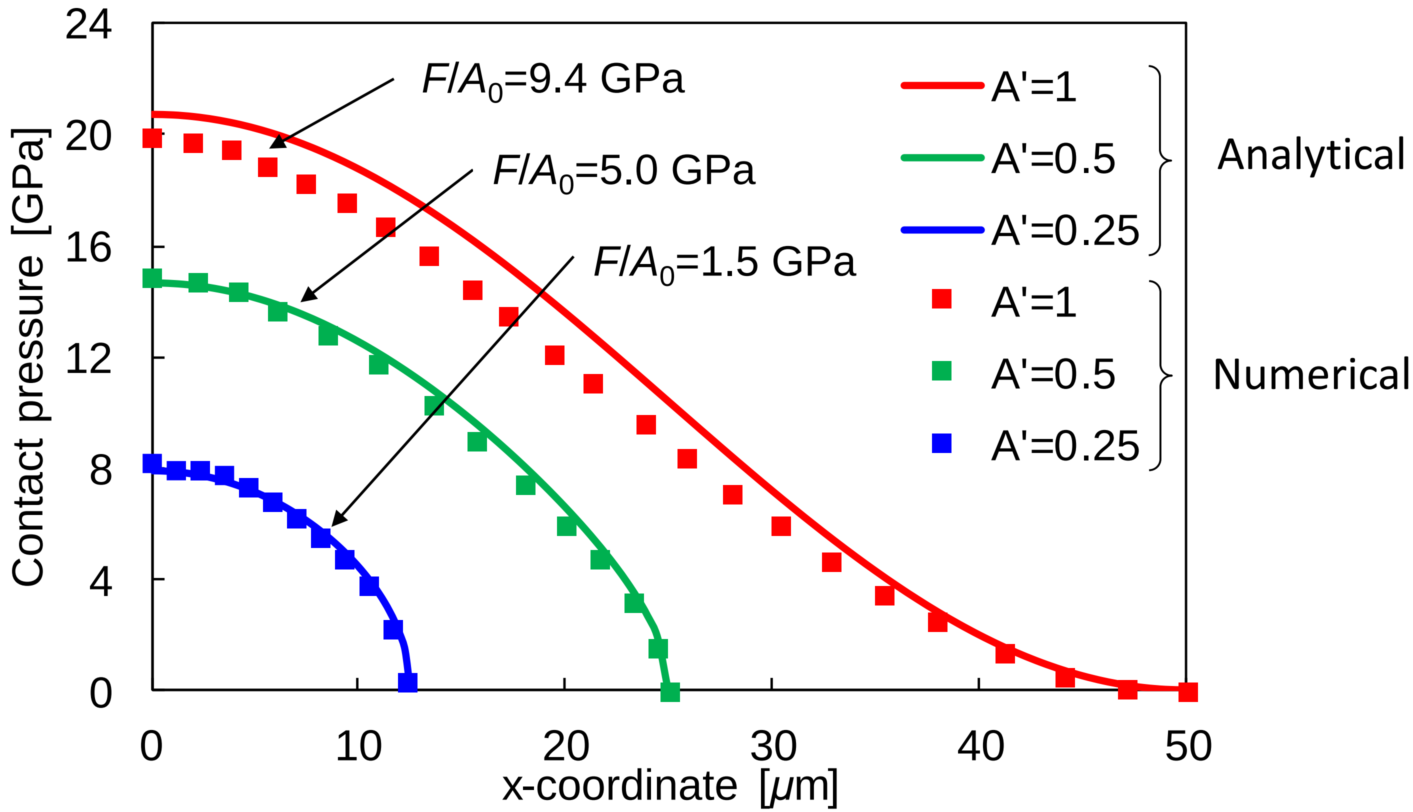
Real contact area (analytical vs simulation)

- Evolution of the real contact area for 2 materials and 2 geometries of asperity
- Numerical results in very good agreement with the analytical solution



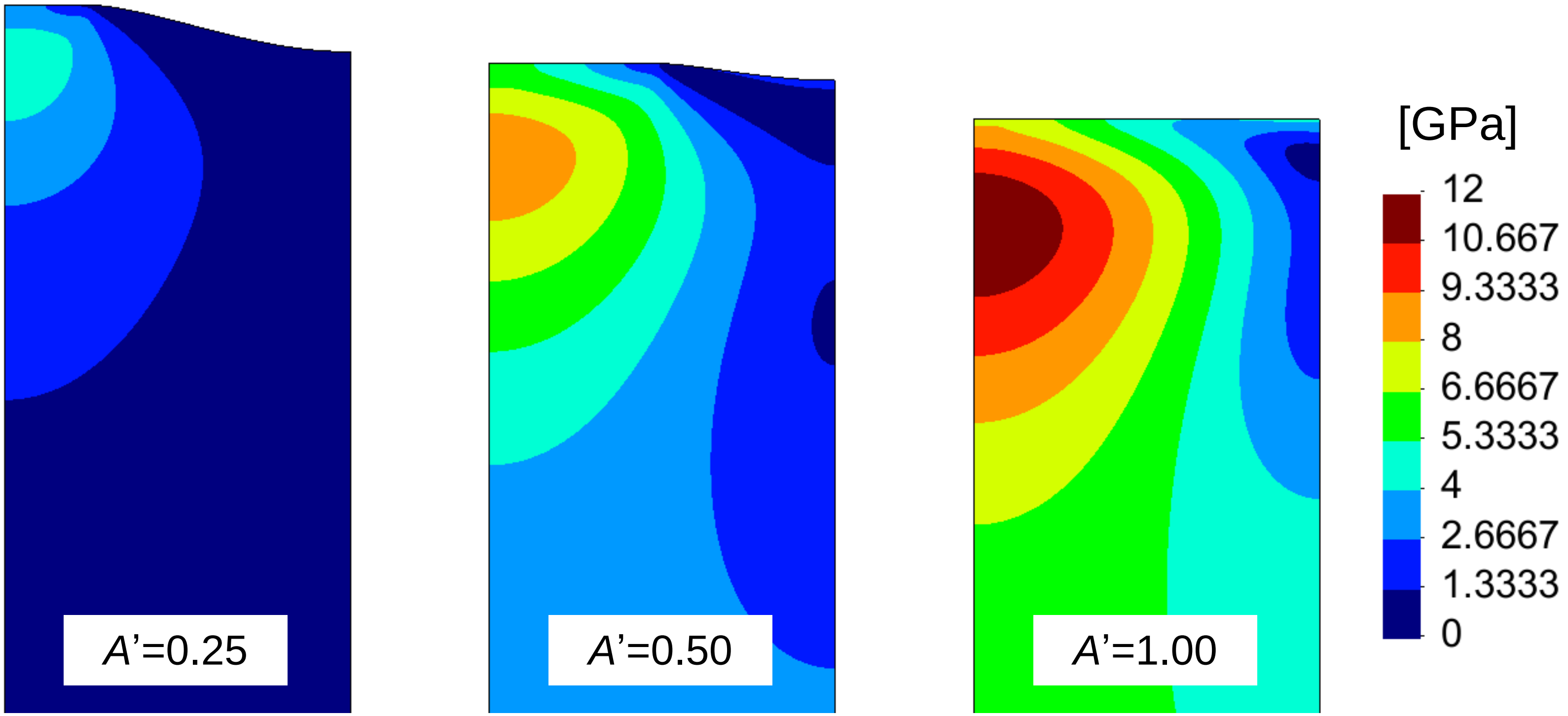
Contact pressure distribution (analytical vs simulation)

- Material: E^*=65.9 GPa; asperity geometry: g=5 μm (largest amplitude)
- Contact pressure slightly overestimated by the analytical solution



Stress distribution (E^*=65.9 GPa and g=5 μm)

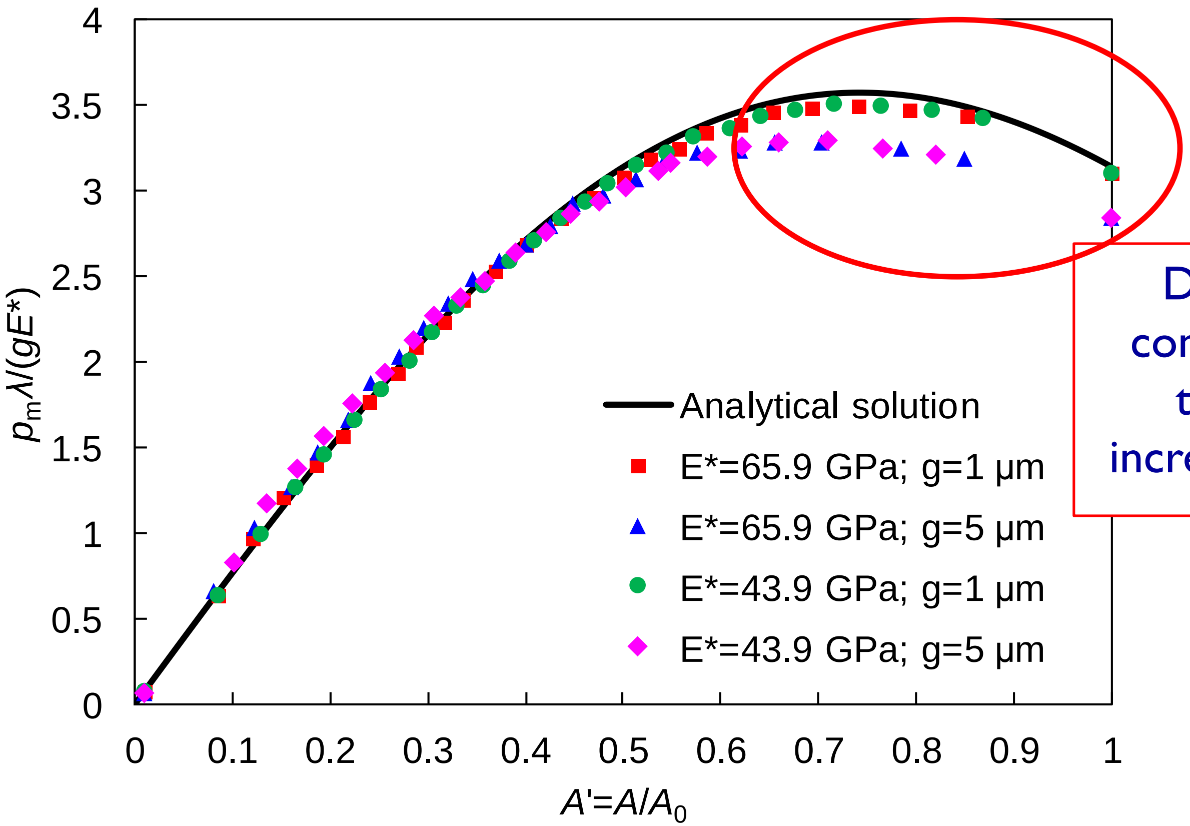
- von Mises stress distribution on half asperity, for 3 values of real contact area
- Maximum value of von Mises stress lies in the asperity interior (like in the Hertz solution)



$\bar{p}=F/A_0$=1.5 GPa $\bar{p}=F/A_0$=5.0 GPa $\bar{p}=F/A_0$=9.4 GPa

Mean contact pressure evolution (analytical vs simulation)

- Evolution of the mean contact pressure for 2 materials and 2 geometries
- The difference between analytical and numerical solution increases for large values of asperity amplitude



Decrease of the mean contact pressure because the real contact area increases quickly at the end

Mechanical material behavior

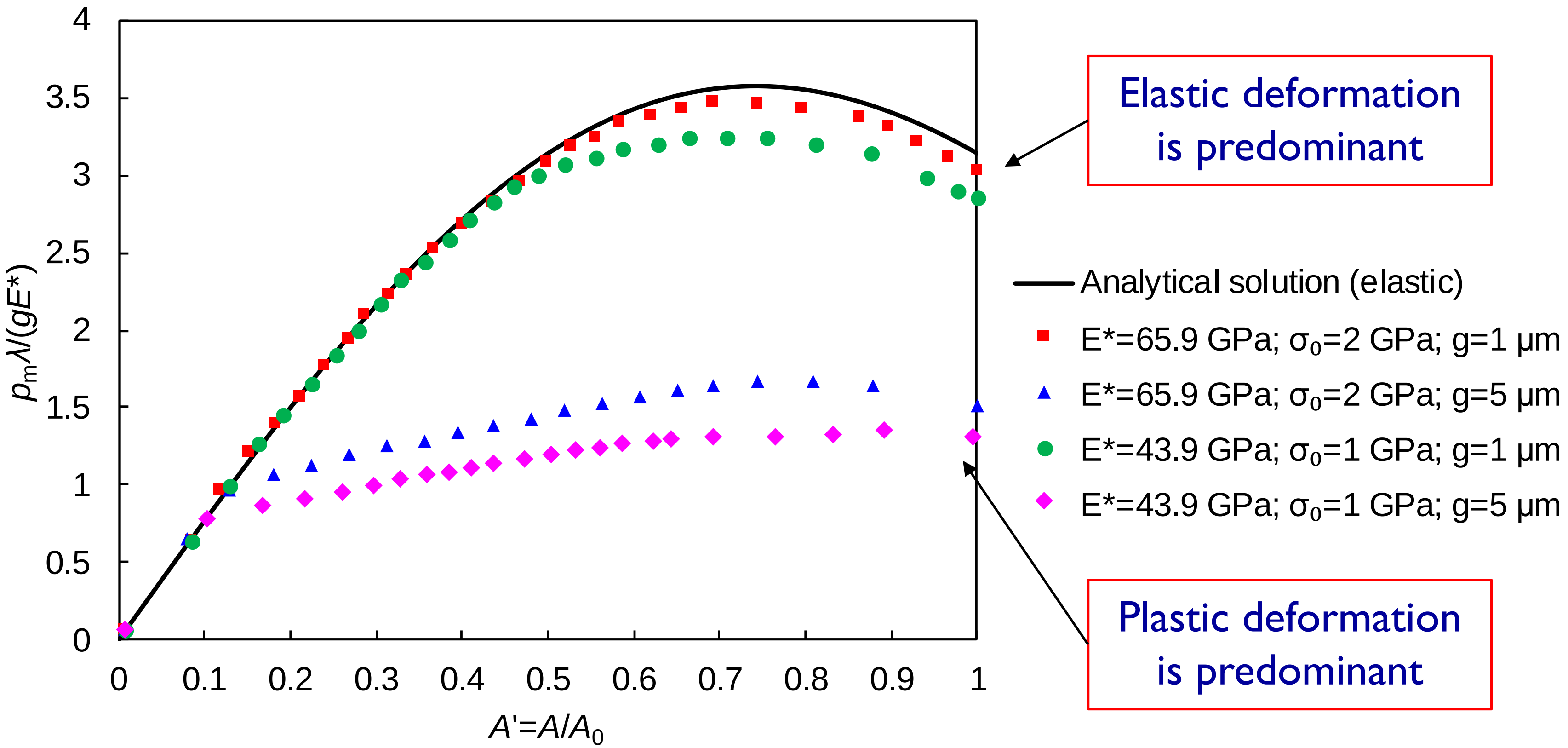
- The results previously presented consider **linear elastic material** behaviour
- Very good agreement between numerical and analytical solutions

New analysis

- **Elastic-perfectly plastic** material behaviour
- Elastic and plastic properties: E^*=43.9 GPa and σ_y=1 GPa
- Elastic and plastic properties: E^*=65.9 GPa and σ_y=2 GPa
- 2 geometries: asperity height g=1 μm and g=5 μm

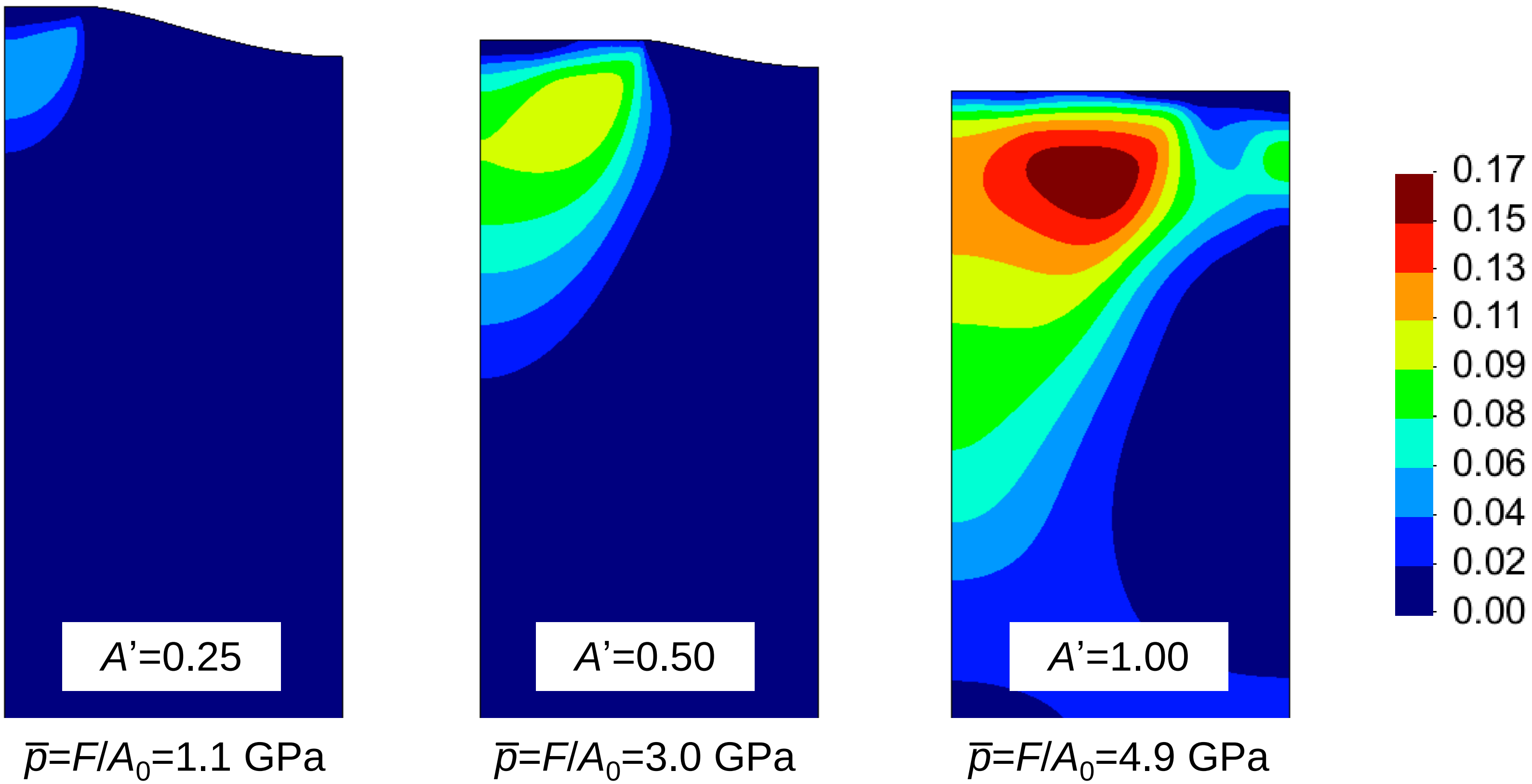
Mean contact pressure evolution (elastic-perfectly plastic)

- Small increase of the mean contact pressure after onset of plasticity
- Onset of plasticity identified by the deviation of numerical solution from the analytical solution (linear elastic)



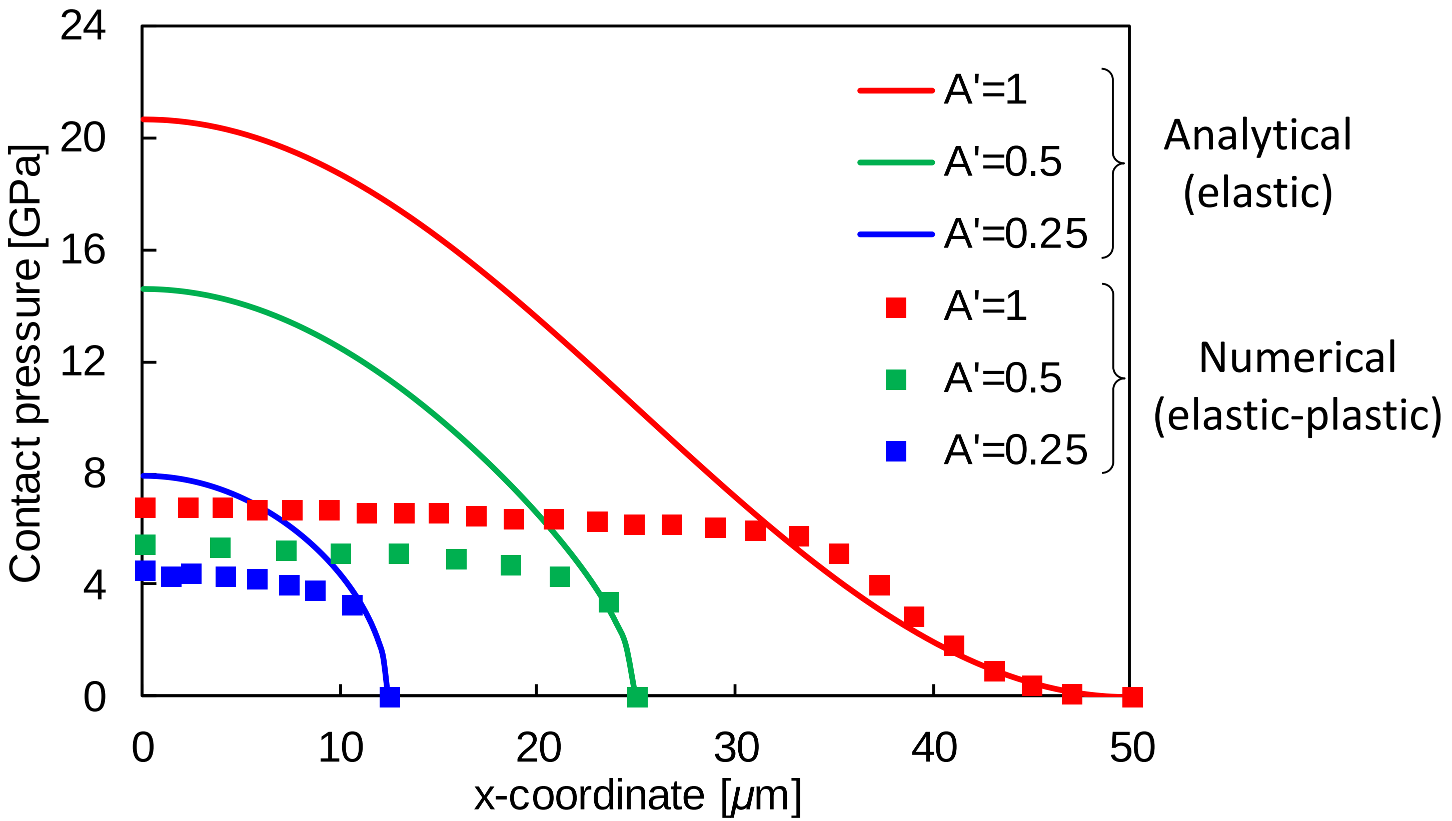
Plastic strain distribution (E^*=65.9 GPa and σ_y=2 GPa)

- Equivalent plastic strain distribution on half asperity (3 different instants)
- Maximum value arises clearly in the asperity interior



Contact pressure distribution

- Material: E^{*}=65.9 GPa and σ_y=2 GPa; asperity geometry: g=5 μm
- Contact pressure approximately constant on the asperity tip
- Slight increase as the applied force rise (real contact area)



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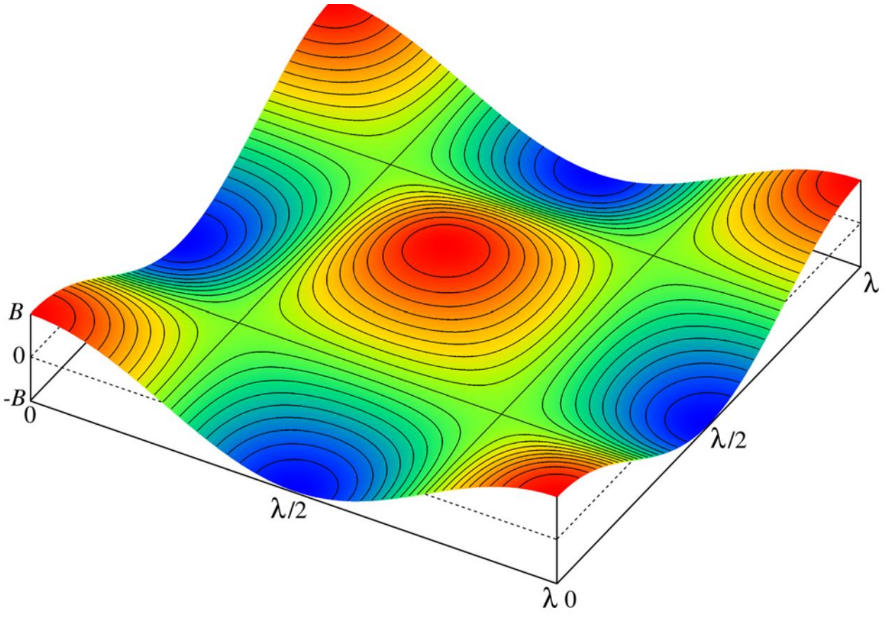
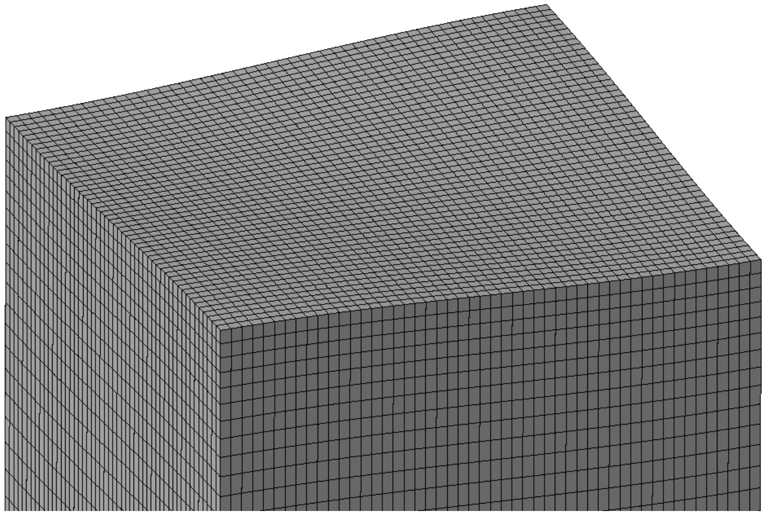
Next steps – 2D sinusoidal surface

- Analytical solution unavailable for elastic material behaviour (2D wavy surface)
- Vertical displacement of the rigid surface (frictionless contact)
- Linear elastic material behaviour





50x50x50=125,000 FE

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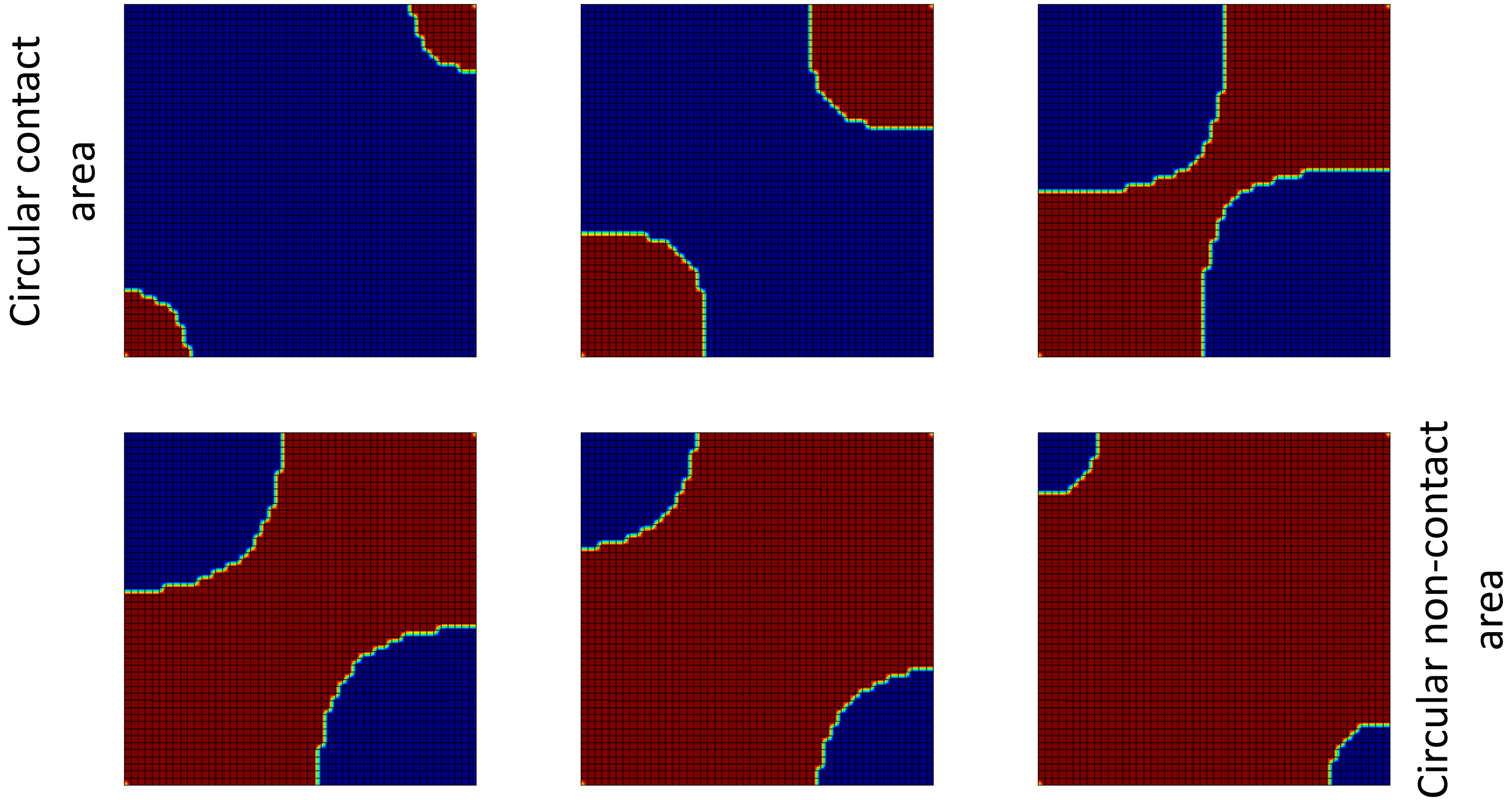
Preliminary results – linear elastic material

- Evolution of the contact area (red) with applied load
- From circular to square-like shape of contact area



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Conclusions

- Finite element simulation of frictionless contact between a deformable sinusoidal asperity and a rigid flat
- Both linear elastic and elastic-perfectly plastic material behaviour
- Roughness described by a sinusoidal function (amplitude and wavelength)

- Very good agreement between numerical and analytical solution considering elastic material and 1D wavy surface
- The increase of the mean contact pressure stabilizes after onset of plasticity
- Contact pressure on the asperity tip is approximately constant when the plastic deformation is predominant
- Study of 2D sinusoidal surfaces is essential to approximate real surfaces

Acknowledgements

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Thank you for your attention!