Modelling and Simulation of the High Frequency Mechanical Impact (HFMI) Treatment of Welded Joints

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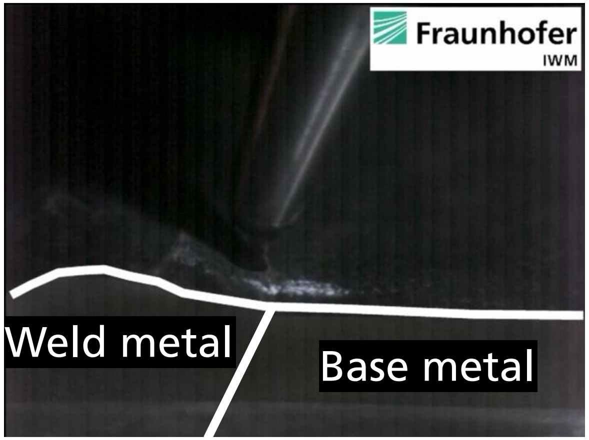
HFMI-Treatment of Welded Joints

Mechanical surface treatment

- The advantages of removing the potential threats of unwanted (tensile) residual stresses and exploiting the **beneficial (compressive) residual stresses by mechanical surface treatments** are already known in welding communities

- In this context, high frequency mechanical impact treatment as a fatigue improvement technique is a statistically proven method to increase the fatigue life of welded joints



➢ During this process, a hardened cylindrical metal pin with a spherical tip impacts the weld toe surface with high frequency and induces local plastic deformation.

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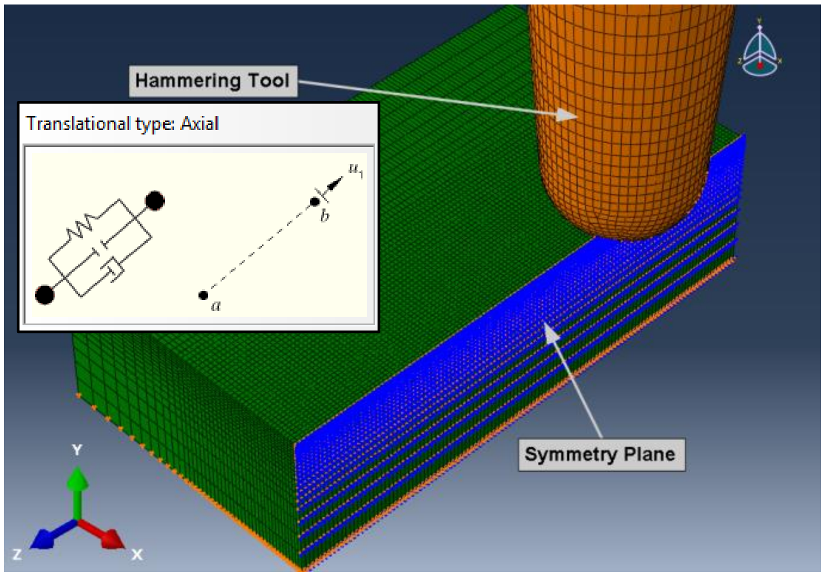
HFMI-Treatment of Welded Joints
Mechanical surface treatment

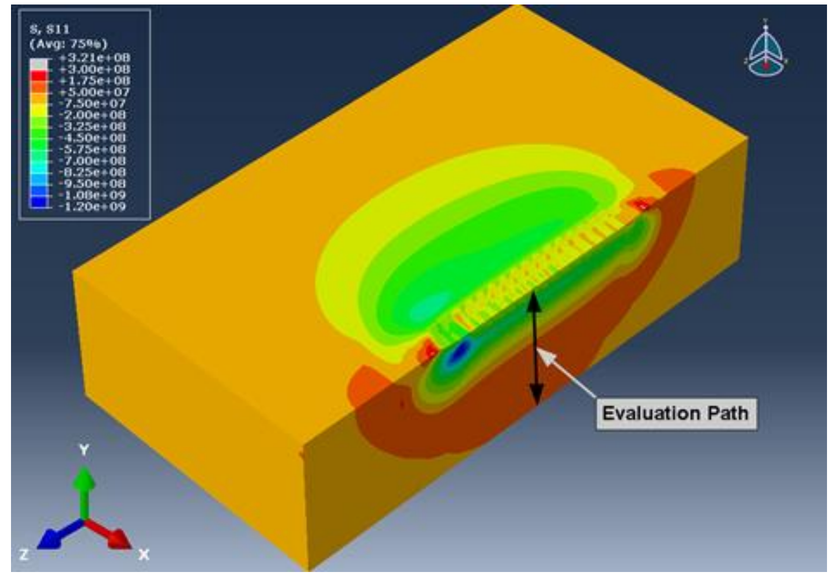
- Main reasons for the **increased fatigue strength**
  - Notch stress concentration at the weld toe is reduced
  - Local hardness is increased (local work hardening of the material)
  - Compressive residual stresses are induced
- Despite the successful practical application, a fundamental description of the governing formation mechanisms of the surface material condition is still missing
  - Thus, it could be assumed that the full potential of this post-treatment technique is not utilized
- Therefore, the goal of the present study was to develop a **computationally efficient approach for determination of the residual stresses** induced by the HFMI process
  - Explicit simulations of the this post treatment process were performed utilizing the software package *ABAQUS*

HFMI-Treatment of Welded Joints

Simulation of mechanical surface treatment

- **Sheet metal plate (specimen) with the dimensions 15*mm* x 4*mm* x 15*mm* and HFMI tool with a diameter of *D*=4*mm* (at the tip)**





- Specimen modelled as elastic-plastic (steel similar to *S355*, σ_0=400*MPa*)
- Hardened HFMI tool (indenter) modelled as rigid
- Hammering tool upgraded using a connector element (contains elastic spring and dashpot); enables the use of force controlled boundary conditions

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Simulation of mechanical surface treatment

- During the simulation, the indenter was moved Δz=6*mm* in the *z*-direction using a stepped amplitude (0.4*mm* infeed per step)
- Indenter oscillates in *y*-direction with constant frequency (*f*=100*Hz*) and amplitude *u*=0.100*mm* (contact with friction coefficient μ=0.15)
  - process:

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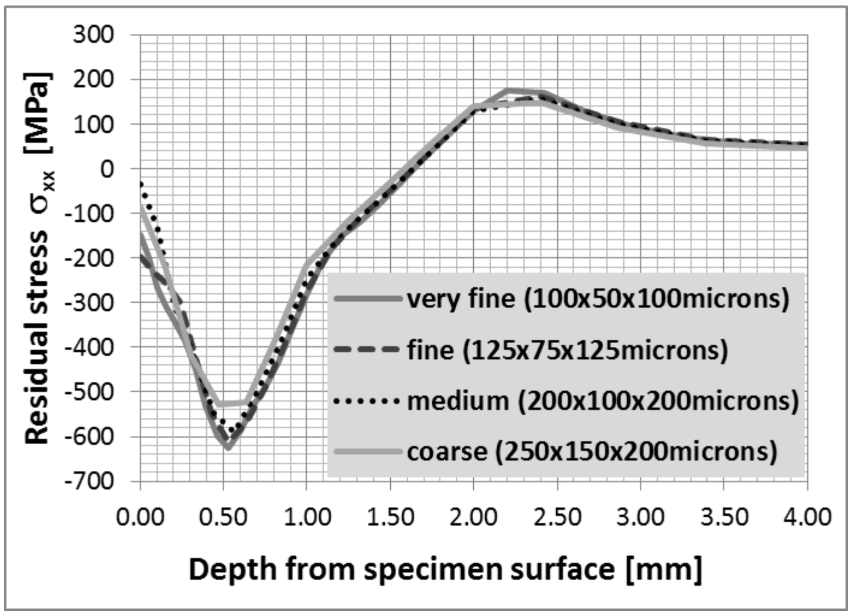
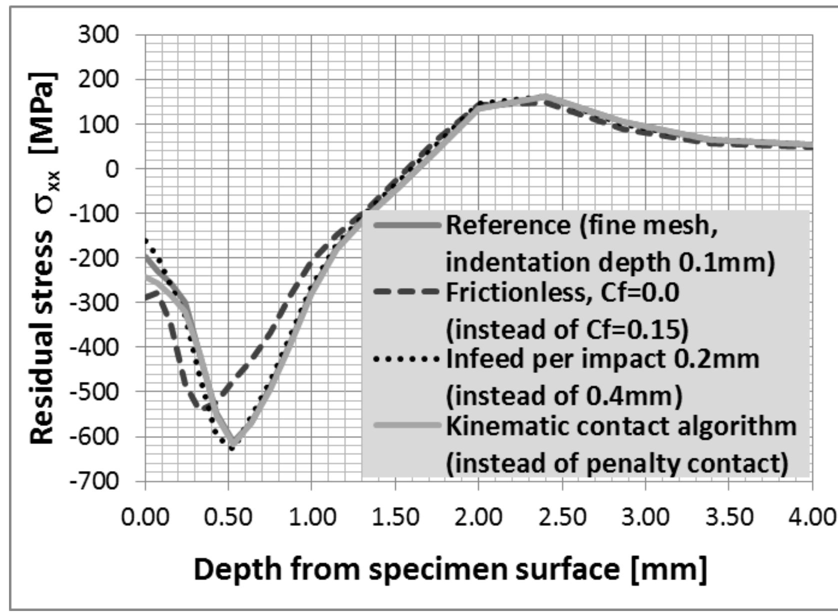
Simulation of mechanical surface treatment

- **Numerical studies**
  - Resulting residual stress depth profiles (σ_{xx}) for different mesh refinements and contact conditions:





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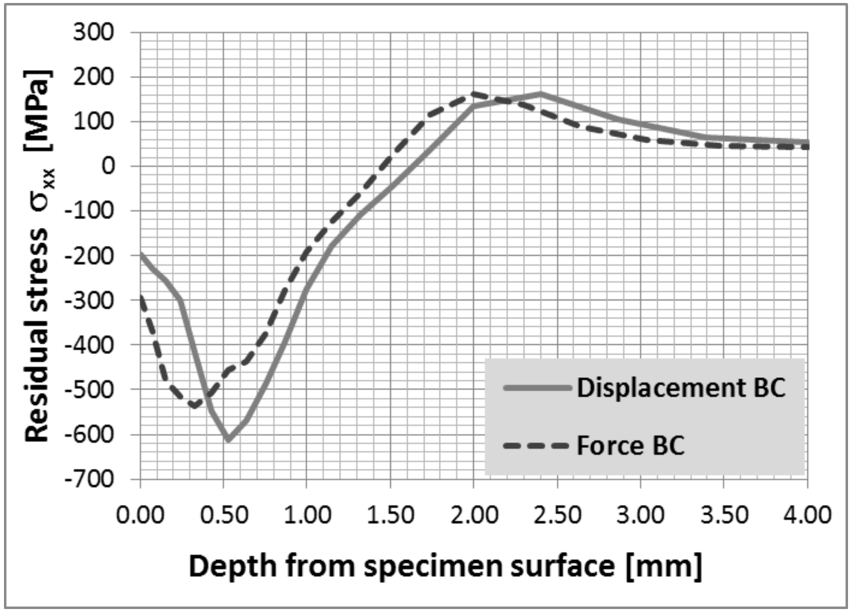
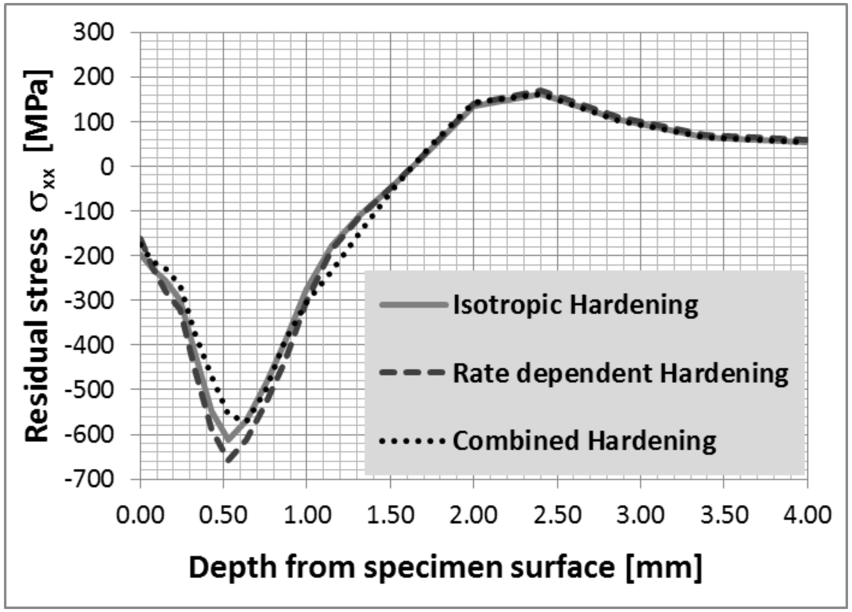
Simulation of mechanical surface treatment

- **Numerical studies**
  - Resulting residual stress depth profiles (σ_{xx}) for different boundary conditions and material models:





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HFMI-Treatment of Welded Joints
Simulation of mechanical surface treatment

- **Numerical studies**
  - Resulting residual stress depth profiles (σ_{xx}) for different numerical features:
    - In general, the plastic deformation induces compressive residual stresses in the peened surface balanced by some tensile stress in the interior ($\sigma_{xx\text{-}max}$= 600*MPa* ; in a depth of approximately *0.50mm*)
    - Fine mesh seems to be a good compromise between accuracy and numerical effort
    - Frictionless contact formulation considerably affects the stress depth profile
    - Displacement BC (given indentation *u*) in general yield a different solution compared to force BC (given accelerating force)
    - Material hardening law features an observable effect on stress depth profile; it mainly influences the peak value of the residual stress

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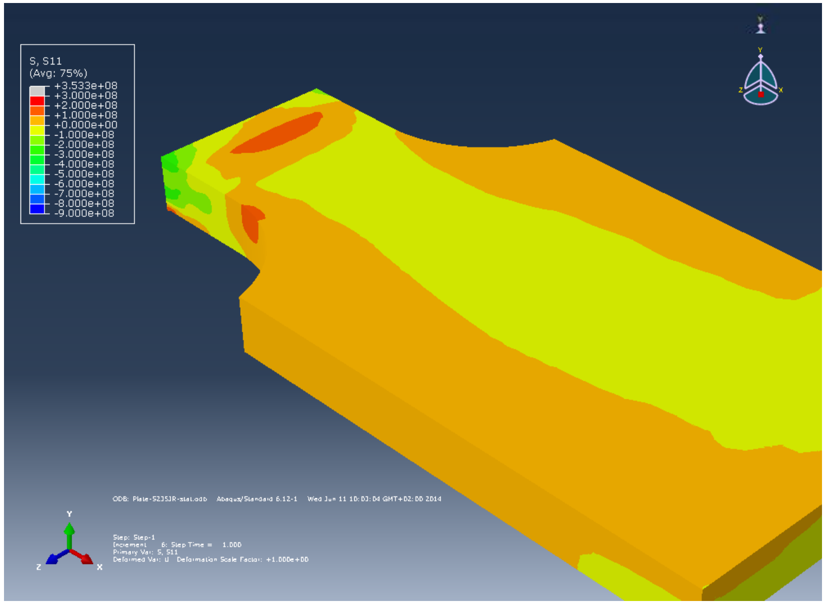
Consideration of residual stresses from welding

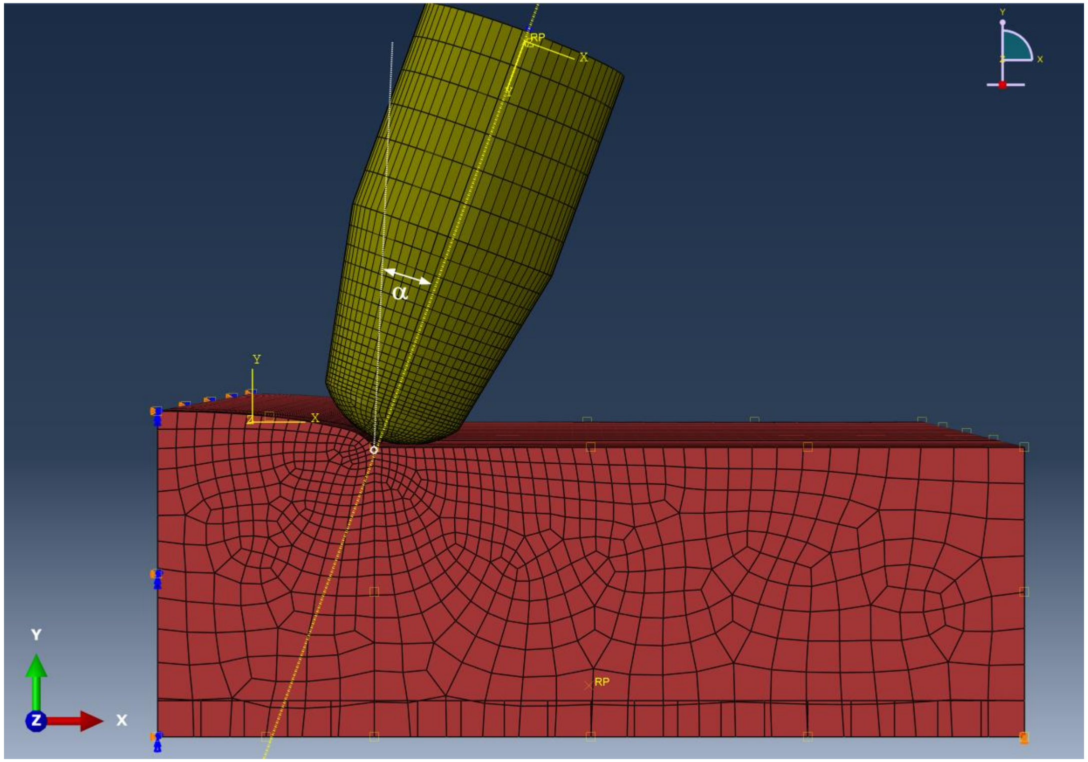
- **Welding simulation**
  - Plate with length 300*mm*, width 240*mm* and thickness 9.0*mm*
  - Non-linear thermal analysis was performed
  - Weld modeled using the element birth technique (activation of weld-line elements sequentially during welding process)
  - After simulation of welding process, a specimen was cut out of the welded plate and HFMI-treated afterwards



HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **General Information**
  - Hammering tool:
    D=3…4…5mm
  - Indentation (y-direction):
    u=0.050…0.10…0.150mm
  - Translation in z-direction
    via given displacement:
    Δz=20mm (Δx=0mm)
    - 0.4mm/indentation
  - Working angle:
    α=0…30°
  - Friction coefficient:
    μ=0…0.20



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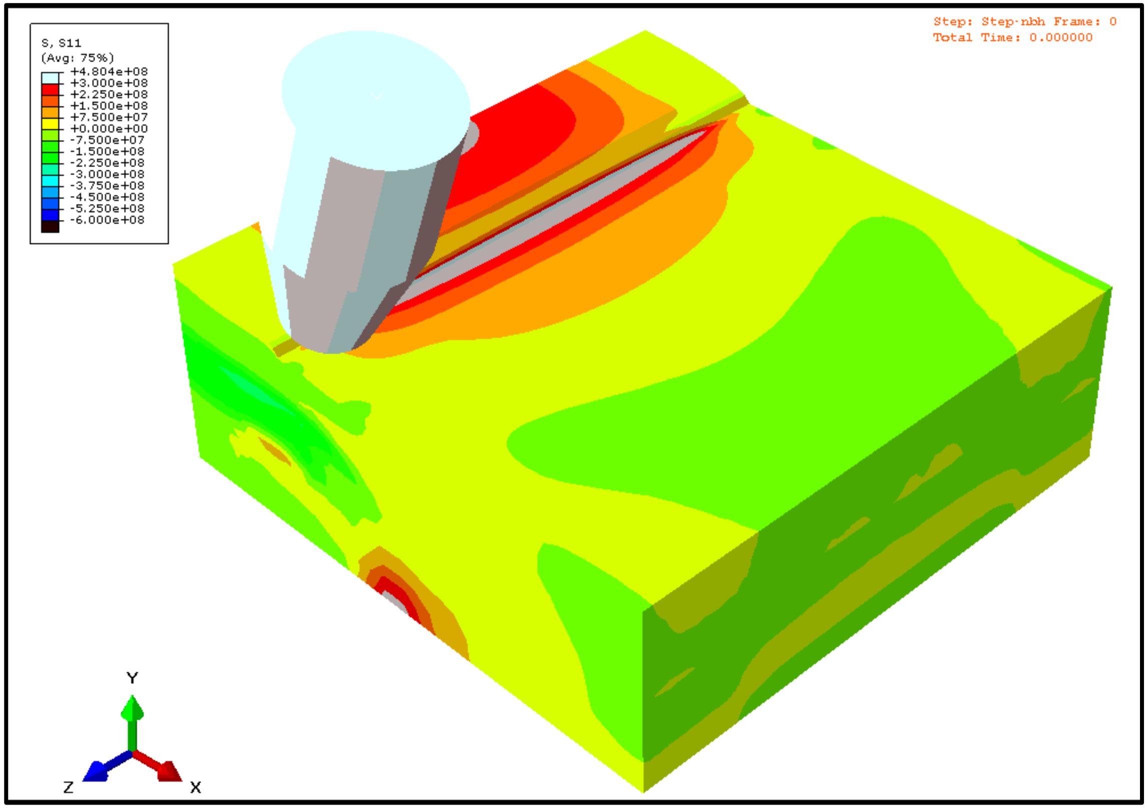
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Process:**



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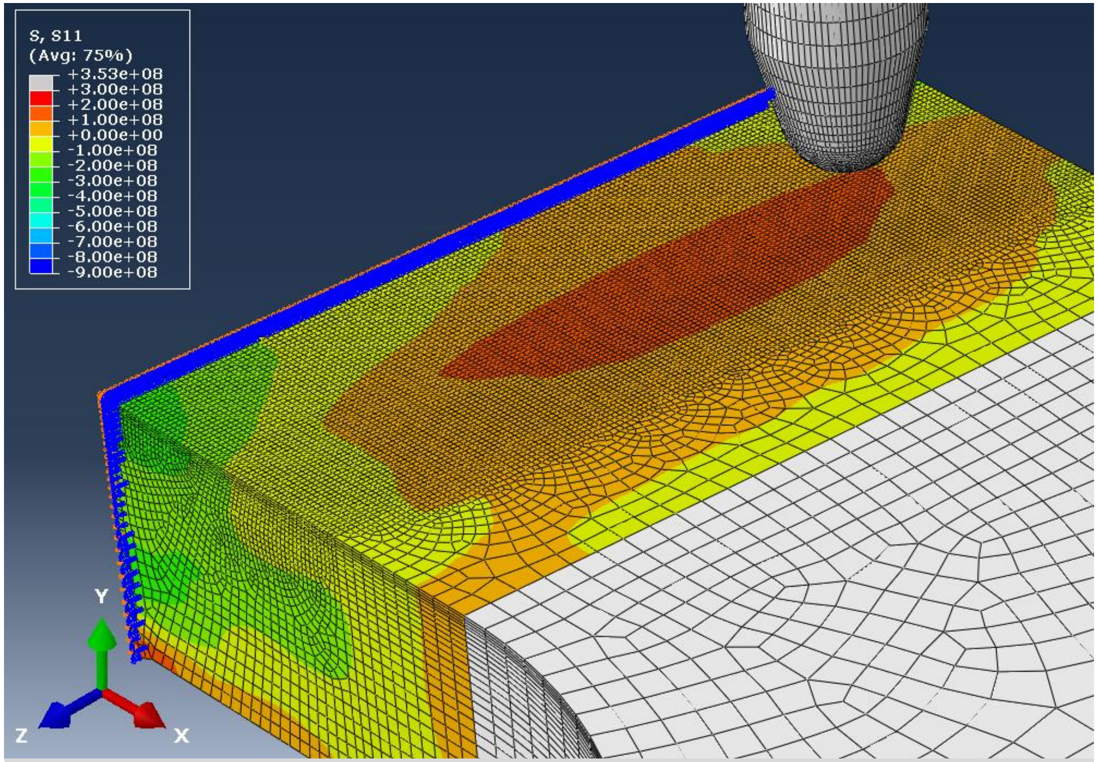
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

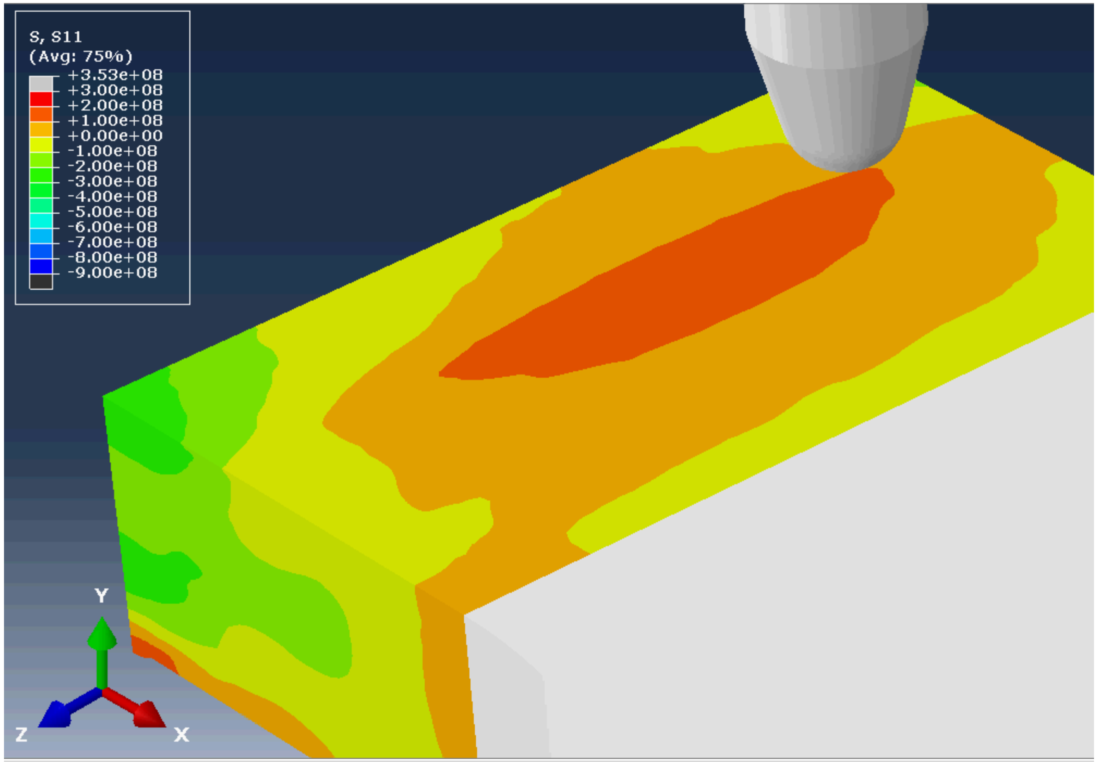
- **Example 1**
  - Hammering tool:
    D=4*mm*
  - Indentation (*y*-direction):
    u=0.075…0.10…0.125*mm*
  - Translation in *z*-direction
    via given displacement:
    Δz=20*mm* (Δx=0*mm*)
    - 0.4*mm*/indentation
  - Working angle:
    α=0°
  - Friction cofficient:
    μ=0.15



Half symmetrical model of the weld specimen

HFMI-Treatment of Welded Joints
Simulation of HFMI-treatment of welded joints

- **Example 1**
  - Hammering tool:
    D=4mm
  - Indentation (*y*-direction): *u*=0.075…0.10…0.125*mm*
  - Translation in *z*-direction
    via given displacement:
    Δz=20*mm* (Δx=0*mm*)
    - 0.4*mm*/indentation
  - Working angle:
    α=0°
  - Friction cofficient:
    μ=0.15

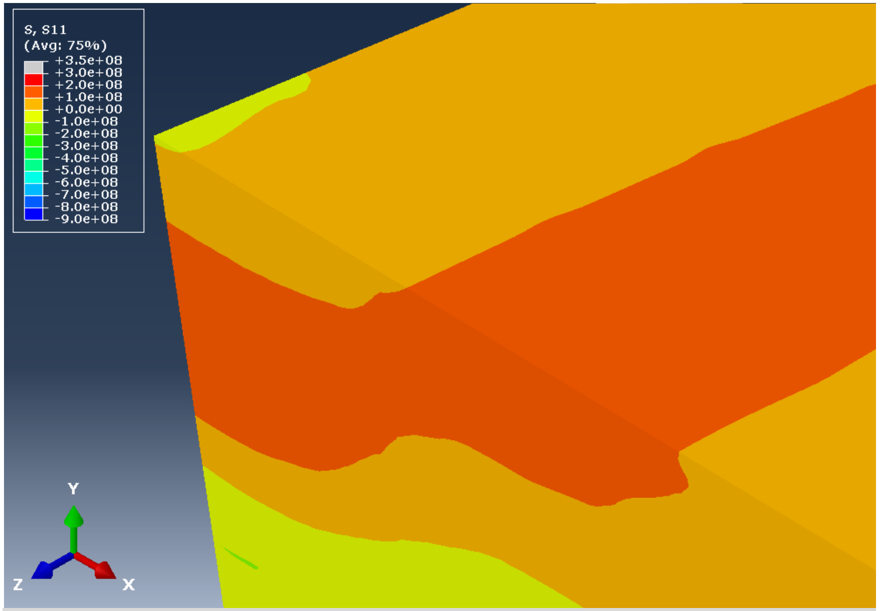


Half symmetrical model of the weld specimen

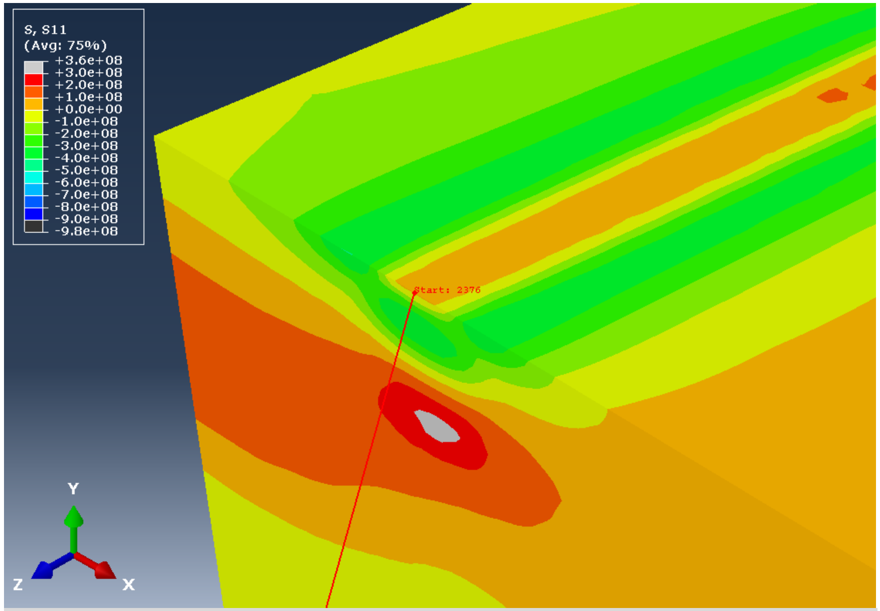
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 1**
  - Resulting residual stress (σ_{xx}) :



As welded



After HFMI-treatment

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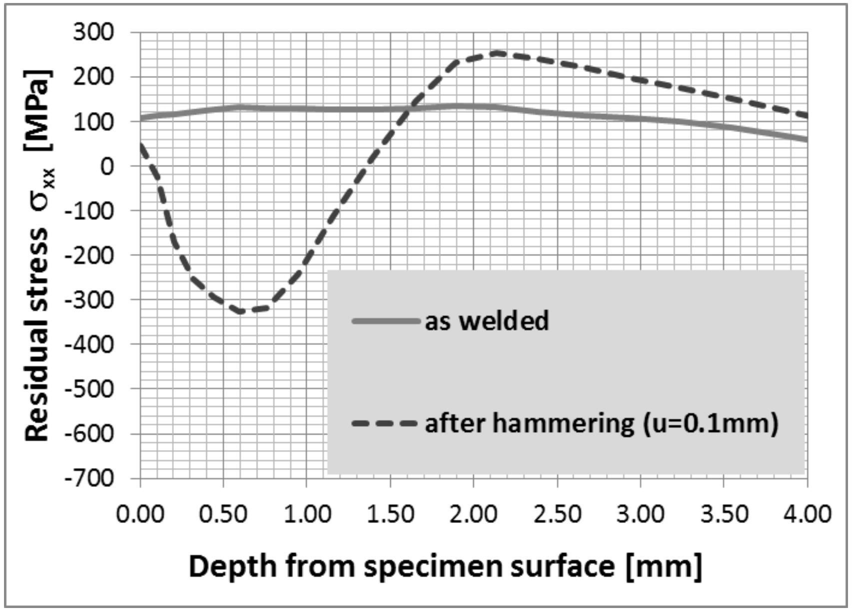
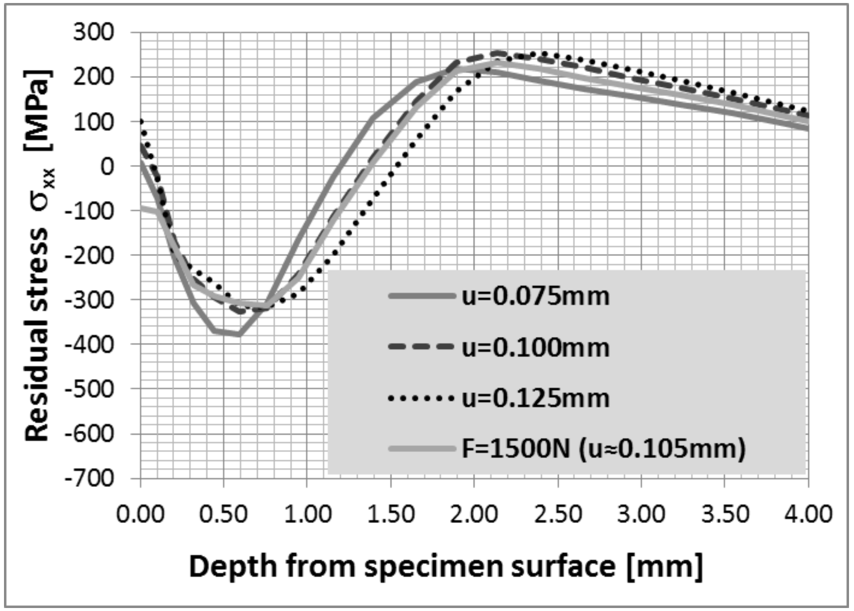
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 1**
  - Resulting residual stress depth profiles (σ_{xx}) for different indentation depths *u*:





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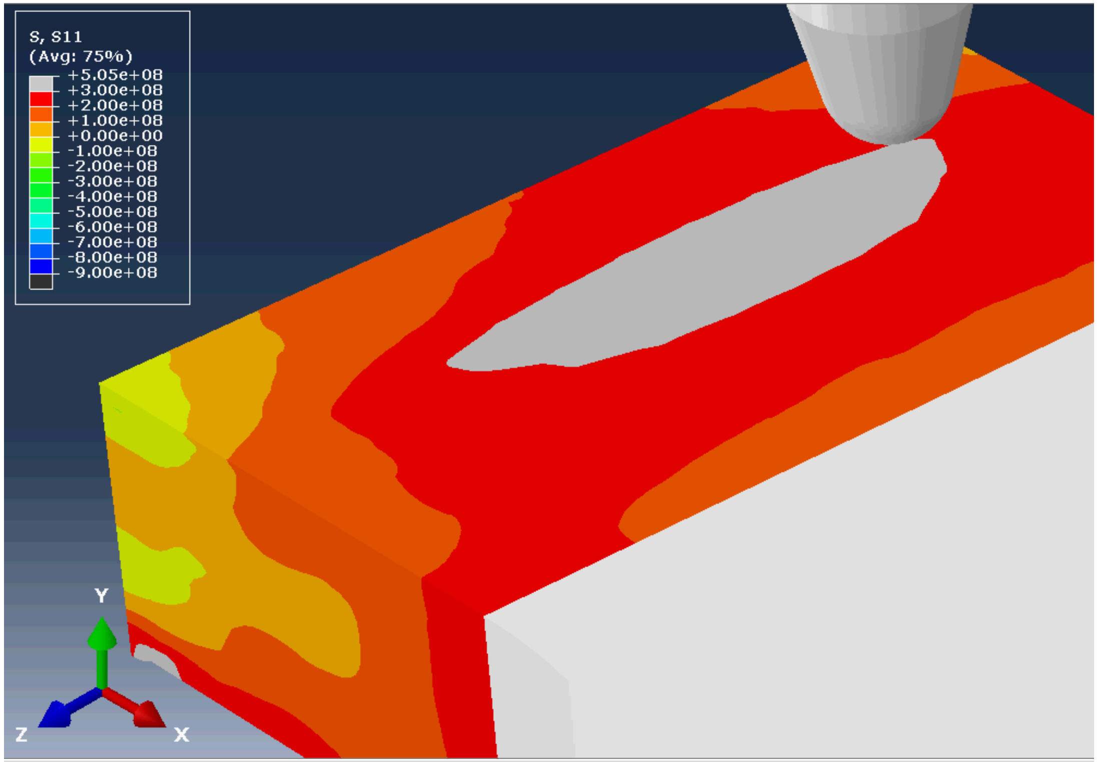
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 2 (stress peening)**
  - Hammering tool:
    D=4*mm*
  - Indentation (*y*-direction):
    u=0.100*mm*
  - Translation in *z*-direction
    via given displacement:
    Δz=20*mm* (Δx=0*mm*)
    - 0.4*mm*/indentation
  - Working angle:
    α=0°
  - Friction cofficient:
    μ=0.15



Half symmetrical model of the weld specimen – loaded with $\sigma_{xx\text{-load}}$=200*MPa*

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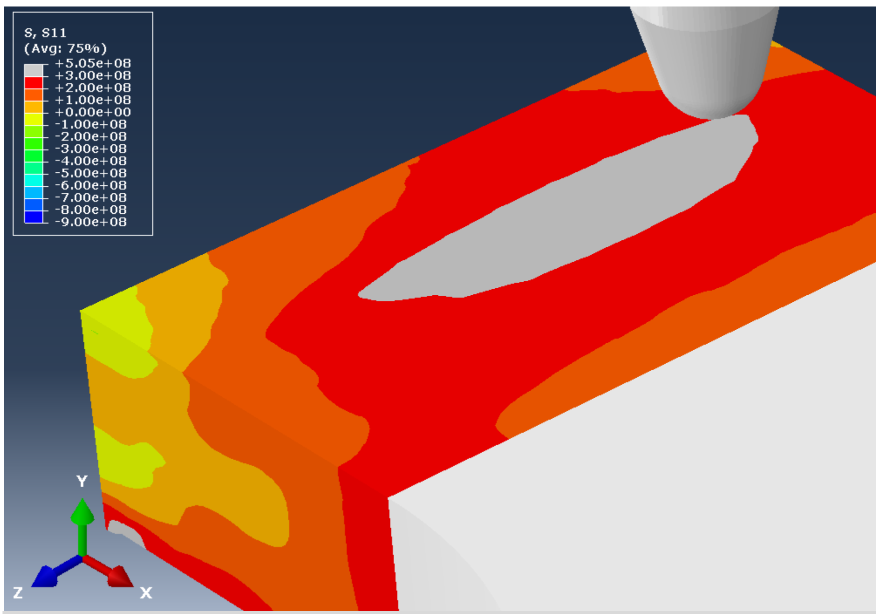
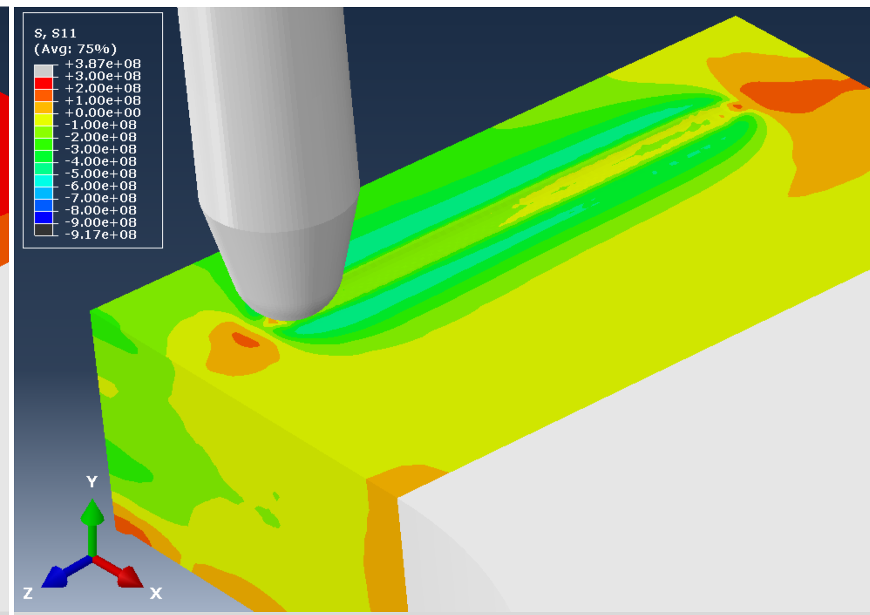
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 2 (stress peening)**
  - Resulting residual stress (σ_{xx}) :



As welded + additional load



After HFMI-treatment (unloaded)

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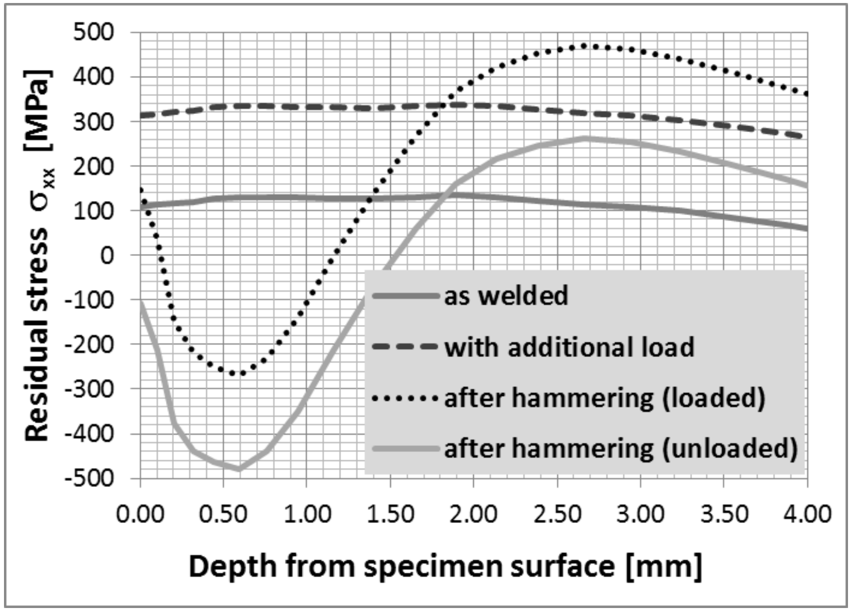
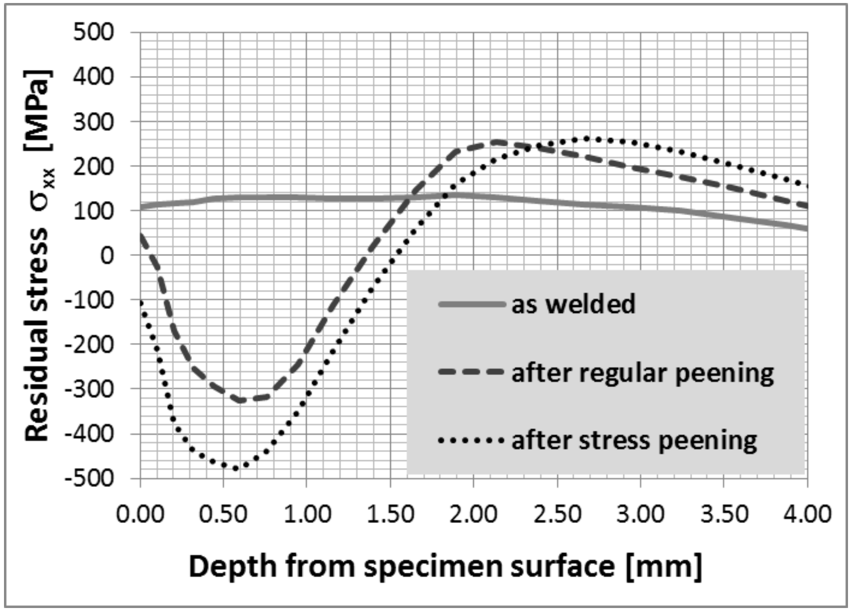
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 2 (stress peening)**
  - Resulting residual stress depth profiles (σ_{xx}) before, during and after the enhanced HFMI-treatment; comparison to regular HFMI:





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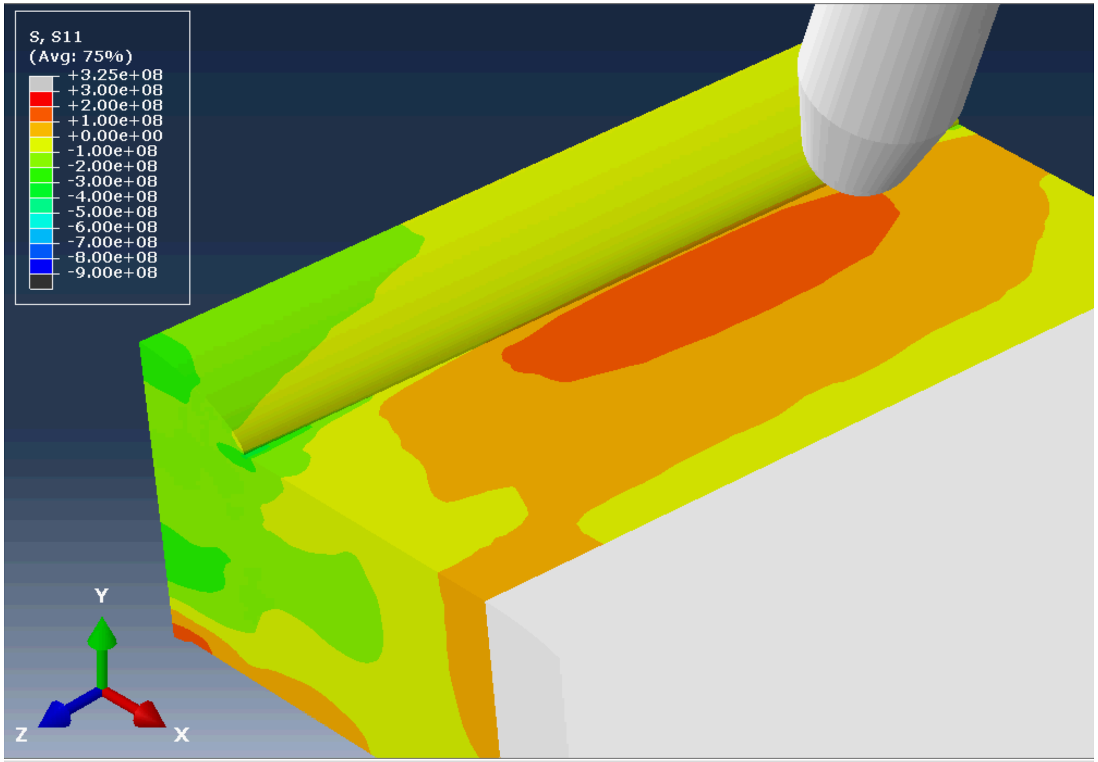
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 3 (HFMI + load cycle)**
  - Hammering tool:
    $D=4mm$
  - Indentation (y-direction):
    $u=0.100mm$
  - Translation in z-direction
    via given displacement:
    $\Delta z=20mm$ ($\Delta x=0mm$)
    - $0.4mm$/indentation
  - Working angle:
    $\alpha=25°$
  - Friction cofficient:
    $\mu=0.15$



Half symmetrical model of the weld specimen – one load cycle after HFMI ($\sigma_{xx\text{-}load} \leq \pm 450MPa$)

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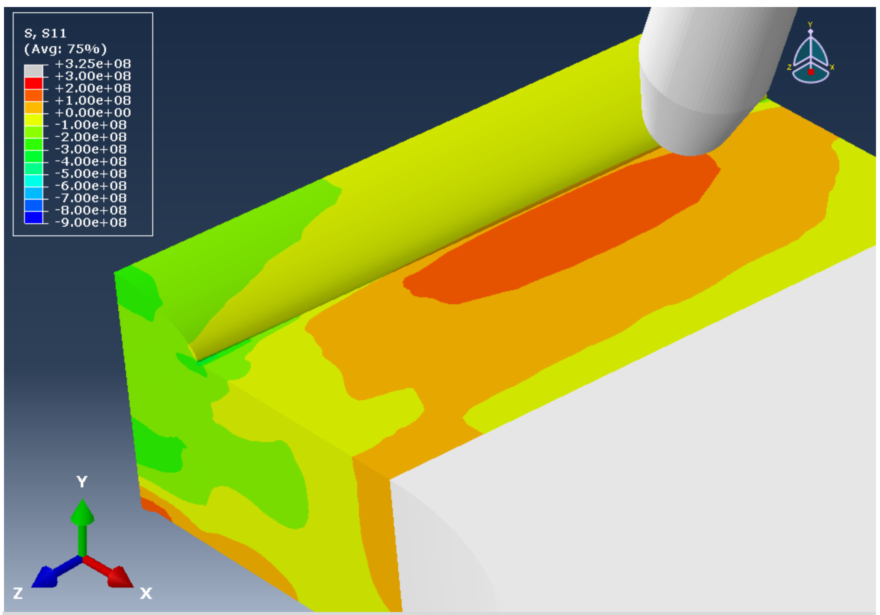
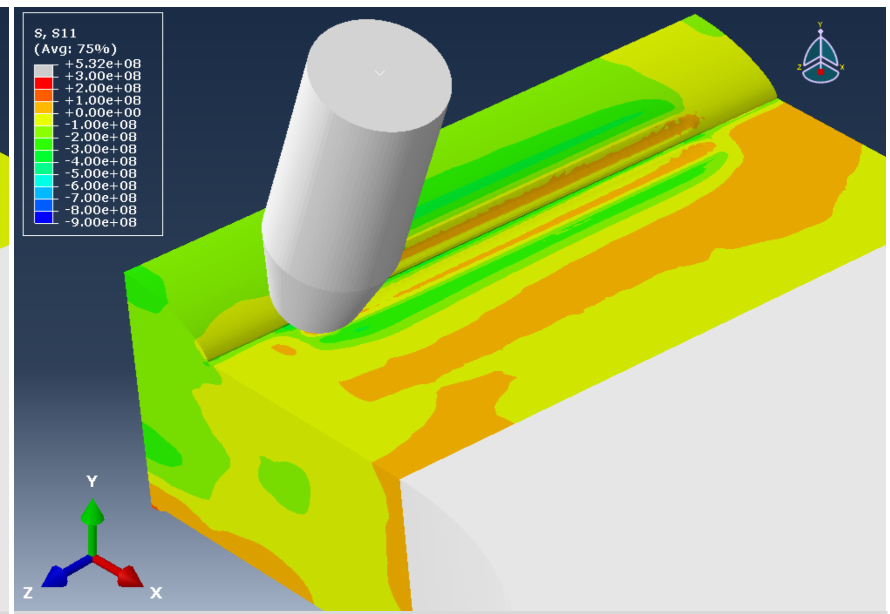
HFMI-Treatment of Welded Joints

Simulation of HFMI-treatment of welded joints

- **Example 3 (HFMI + load cycle)**
  - Resulting residual stress (σ_{xx}) :



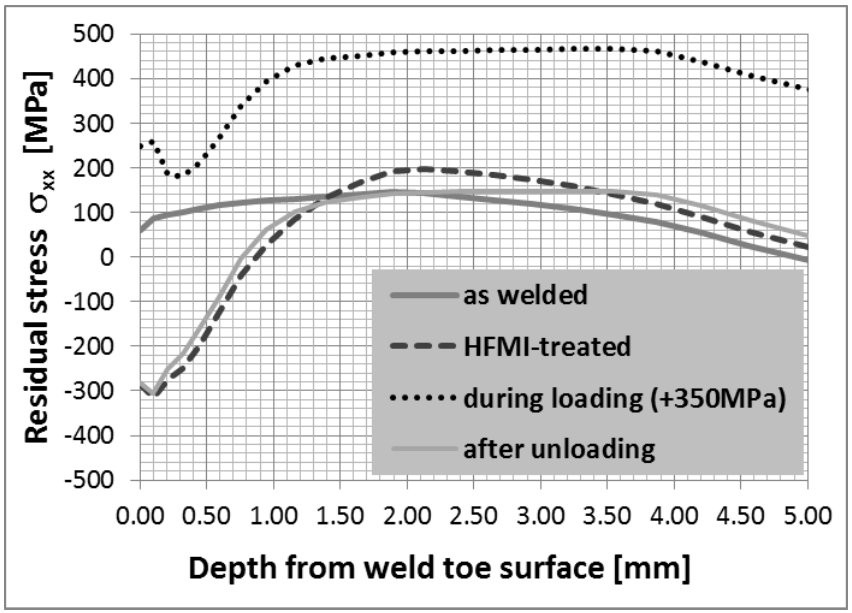
As welded

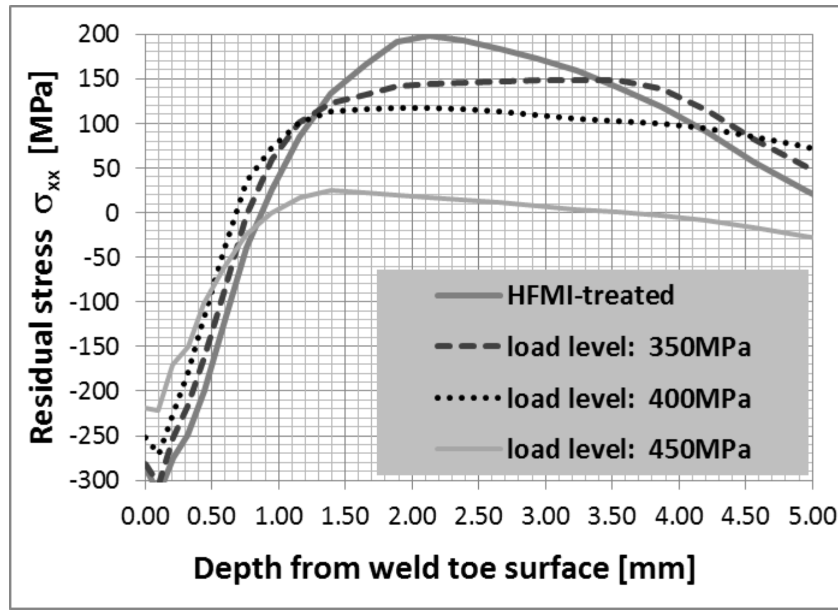


After load cycle ($\sigma_{xx\text{-load}}$=350*MPa*)

HFMI-Treatment of Welded Joints
Simulation of HFMI-treatment of welded joints

- **Example 3 (HFMI + one load cycle)**
  - Resulting residual stress depth profiles (σ_{xx}) before and after HFMI-treatment and during load cycle; comparison of different load levels:





Tensile load

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HFMI-Treatment of Welded Joints
Conclusions

- Explicit simulations of the high frequency hammer peening treatment were performed using the software package *ABAQUS*
- Possible effects of different numerical modelling features (mesh refinement, mesh transition, contact formulation, loading boundary conditions and material model) could be identified
- Implicit simulations of the welding process were performed using the software package *ABAQUS*
- The established modelling technique was successfully applied for the calculation of the residual stress field of a weld specimen after HFMI treatment
- Thus, the simulation technique established within the framework of this study provides the basis for a simulation loop:
  - Structural welding simulation
  - Simulation of the HFMI process
  - Estimation of the fatigue life of the structure

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