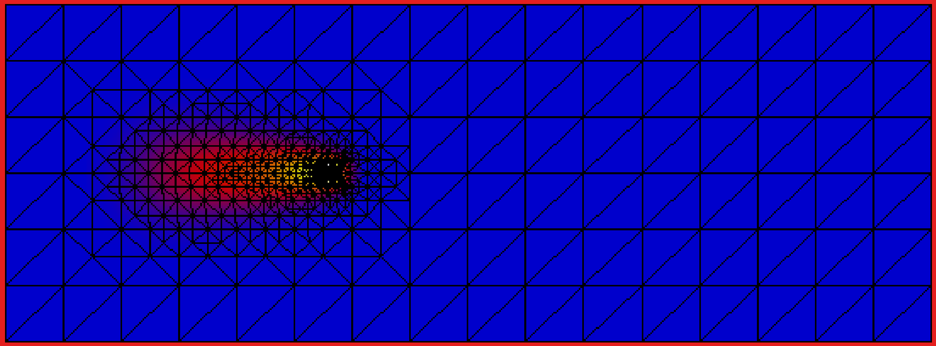
Bremer Institut für
angewandte Strahltechnik GmbH

Precise Prediction of Workpiece Distortion during Laser Beam Welding



Komkamol Chongbunwatana

MZH Gebäude, Universität Bremen, 14 July 2009

Outline

Laser Welding Process Overview

Objective

Simulation Model

Work in Progress

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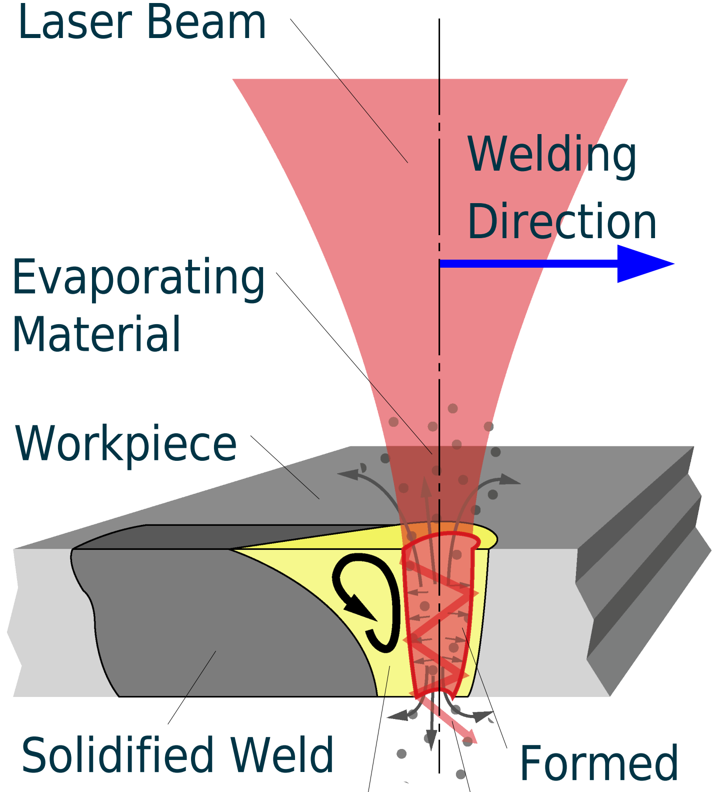
Laser Welding: Deep Penetration Welding Characteristics



Definition: A keyhole fusion welding technique achieved with the very high power density obtained by focusing a beam of laser light to a very fine spot

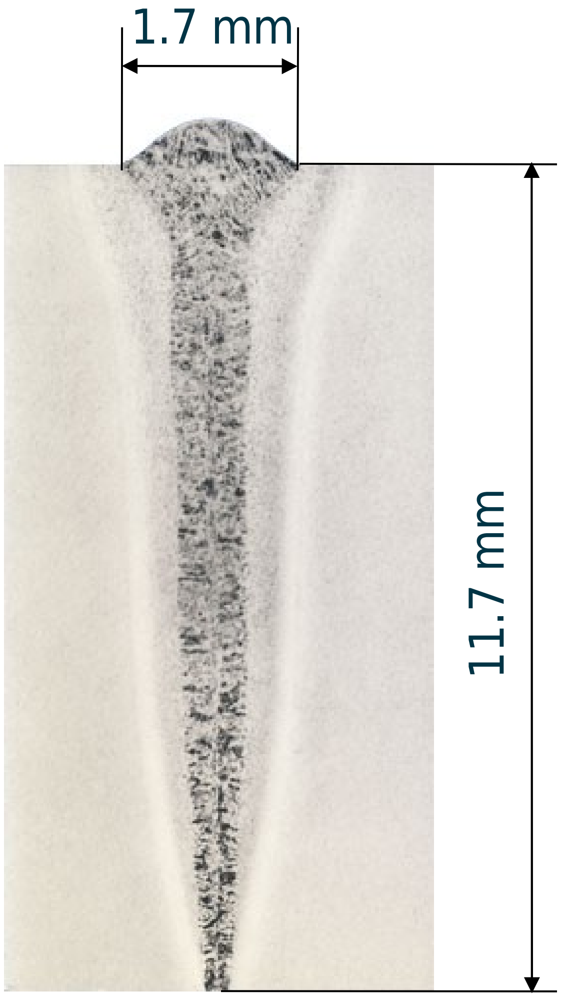
Energy absorption by multiple beam reflection inside the keyhole

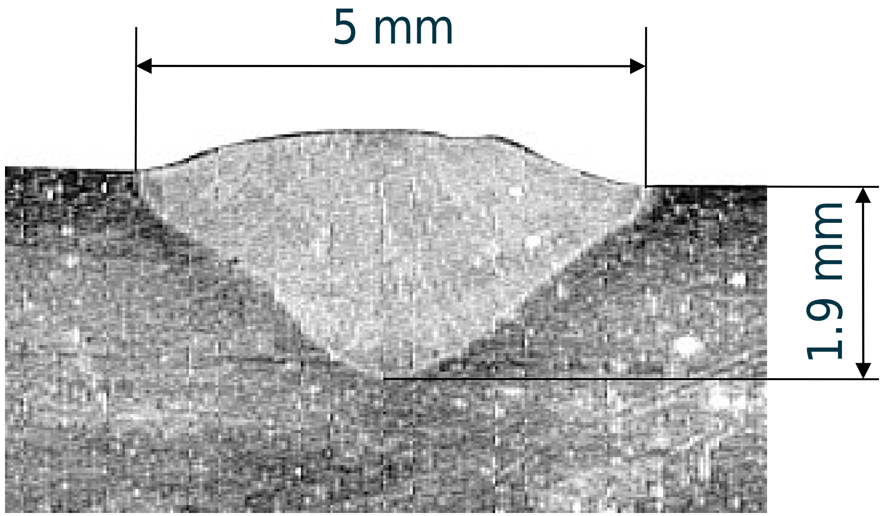
Keyhole held open by the vapour pressure

Laser Welding: Why Laser Welding?

Advantages	Disadvantages
Low heat input - low thermal distortion - reduced metallurgical damage e.g. grain growth	Precise beam joint alignment
High welding speed due to high beam power density - high production rates	Close fitting and clamped joints
High process flexibility - applicable to all welding position	High equipment and operating costs
Welding thick workpiece in one pass - weld penetration depth limited by available laser power (not by conductivity of the workpiece material)	Not portable (workshop-based) due to the large size of the equipments (e.g. power supplies) and compulsarily controlled environment due to safety reasons

Laser Welding: Weld Cross Section

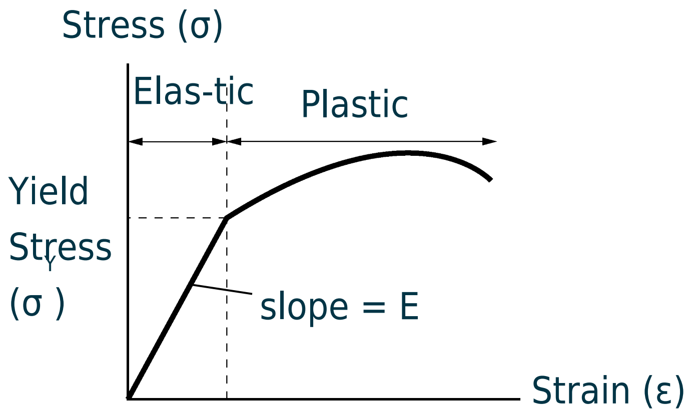


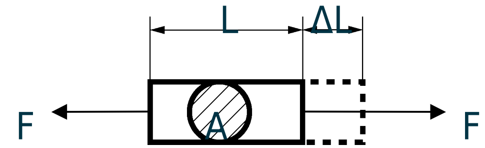


2. Metal Arc Welding (D/H = 2.6)

Laser Welding: Cause of Distortion in Welding

Stress-Strain Diagram

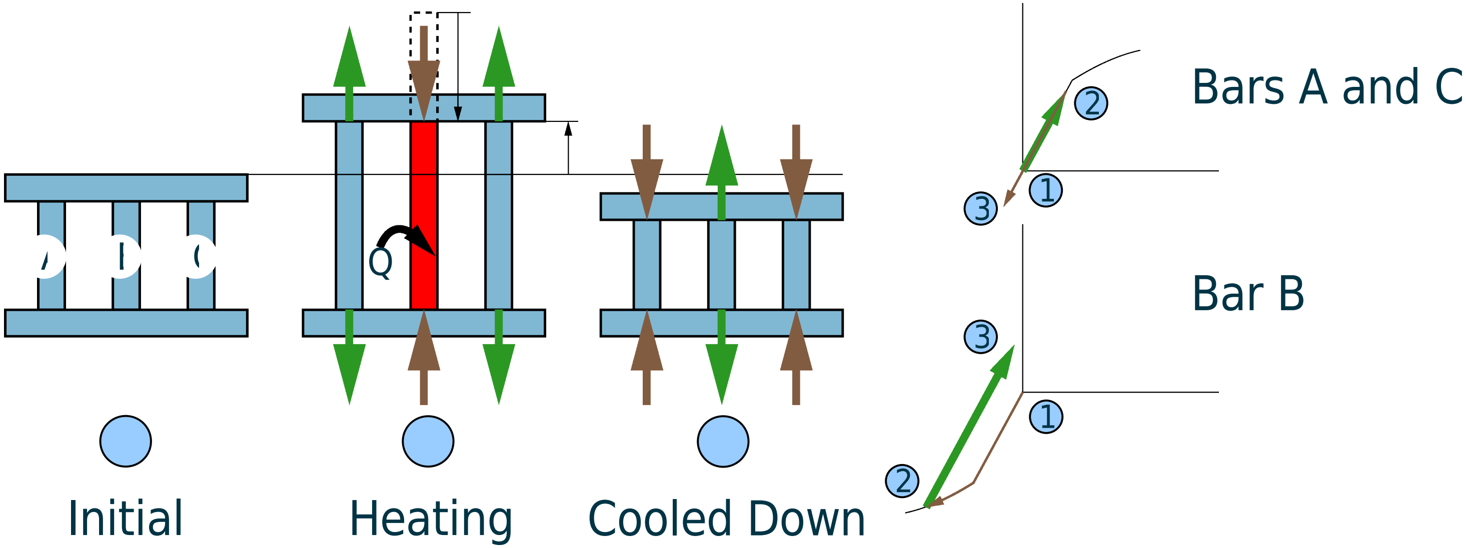




$$\sigma = \frac{F}{A}$$

$$\varepsilon = \frac{\Delta L}{L}$$

Distortion Caused by Inhomogeneous Temperature Distribution



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Objective

Developing a precise simulation model for workpiece distortion prediction

Determination of relationship between weld geometry and degree of workpiece deformation

Solution:

„Coupling of fluid dynamics simulation (accurate heat source) and solid structure simulation (calculating workpiece distortion)"

Outline

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Laser Welding Process Overview

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Simulation Model
Coupling Principle
Solid Structure Simulation
Fluid Flow Simulation
Alberta Implementation

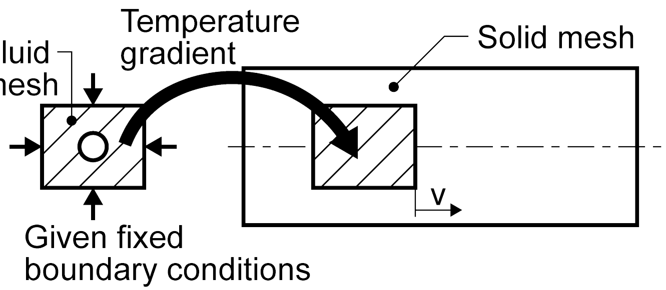
Work in Progress

Coupling Principle

Stationary Heat Source:

Fluid flow simulation with given constant boudary conditions

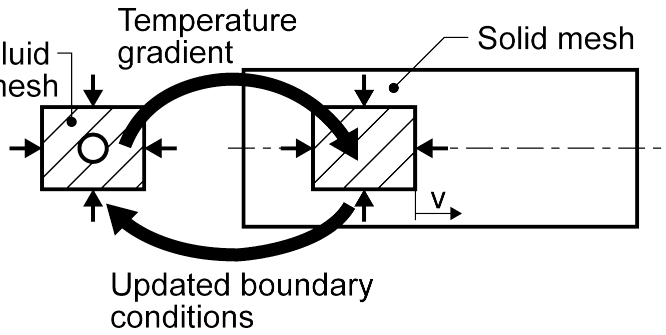
Solid structure simulation with the temperature gradient gained from the fluid f



Fluid flow simulation with current timestep boundary conditions from the solid s

Dynamic Heat Source:

Solid structure simulation with the temperature gradient gained from the fluid f



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Solid Structure Simulation: Thermal Calculation

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Heat Equation

$$\frac{\partial T}{\partial t} - \nabla \cdot \left(\frac{k(T)}{\rho(T) c_p(T)} \cdot \nabla T\right) = 0 \qquad on\ \Omega \times (0, \tau)$$

$$T = T_{source} \qquad on\ \Gamma_D \times (0, \tau)$$

$$-(k(T) \cdot \nabla T) \cdot n = h(T) \cdot (T - T_0) \qquad on\ \Gamma_N \times (0, \tau)$$

$$T(x, 0) = T_0 \qquad on\ \Omega$$

- T : Temperature [°C]
- $\rho(T)$: Temperature-dependent density [kg/mm^3]
- $k(T)$: Temperature-dependent thermal conductivity [W/mm°C]
- $h(T)$: Temperature-dependent thermal transfer coefficient (air) [W/mm^2°C]
- $c_p(T)$: Temperature-dependent specific heat [J/kg°C]
- T_0 : Room temperature [°C]

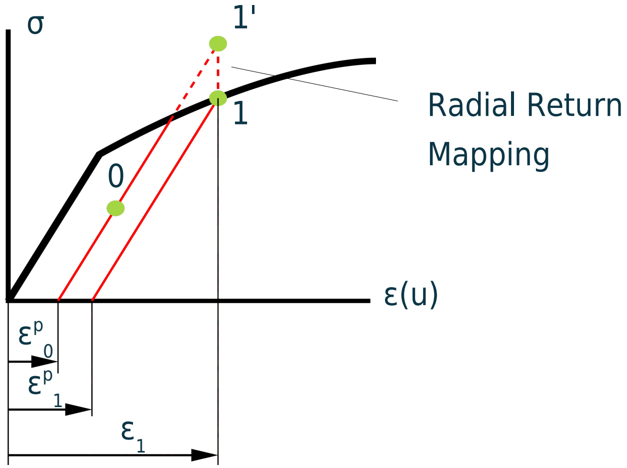
Solid Structure Simulation: Mechanical Calculation

Momentum Equation (Displacement Calculation)

$$
\begin{aligned}
-\nabla\cdot\sigma &= 0 \quad on\ \Omega\times(0,\tau) \qquad ;\ \sigma = \sigma(u,T,\epsilon^{p})\\
u &= 0 \quad on\ \Gamma_D\times(0,\tau)\\
\sigma\cdot n &= 0 \quad on\ \Gamma_N\times(0,\tau)
\end{aligned}
$$

σ: stress [N/mm], u: displacement [mm], ε^p: plastic strain [-]

Plasticity Theory (Stress and Plastic Strain Calculation)



Isotropic strain hardening employed

Radial return mapping employed

Outline

Fluid Flow Simulation (Research State)

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Alberta Implementation

ALBERTA Concept

- Adaptive Finite Element Toolbox (simplex elements)
- Refinement technique: Bisectioning
- Error estimator type: Residual error estimator

Applied Refinement and Coarsening Strategy (Solid Struture)

- Strategy: Implicit (time step control) and equidistribution (element size control) strategy
- Error estimator: Based solely on the heat equation

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Work in Progress: Project Status

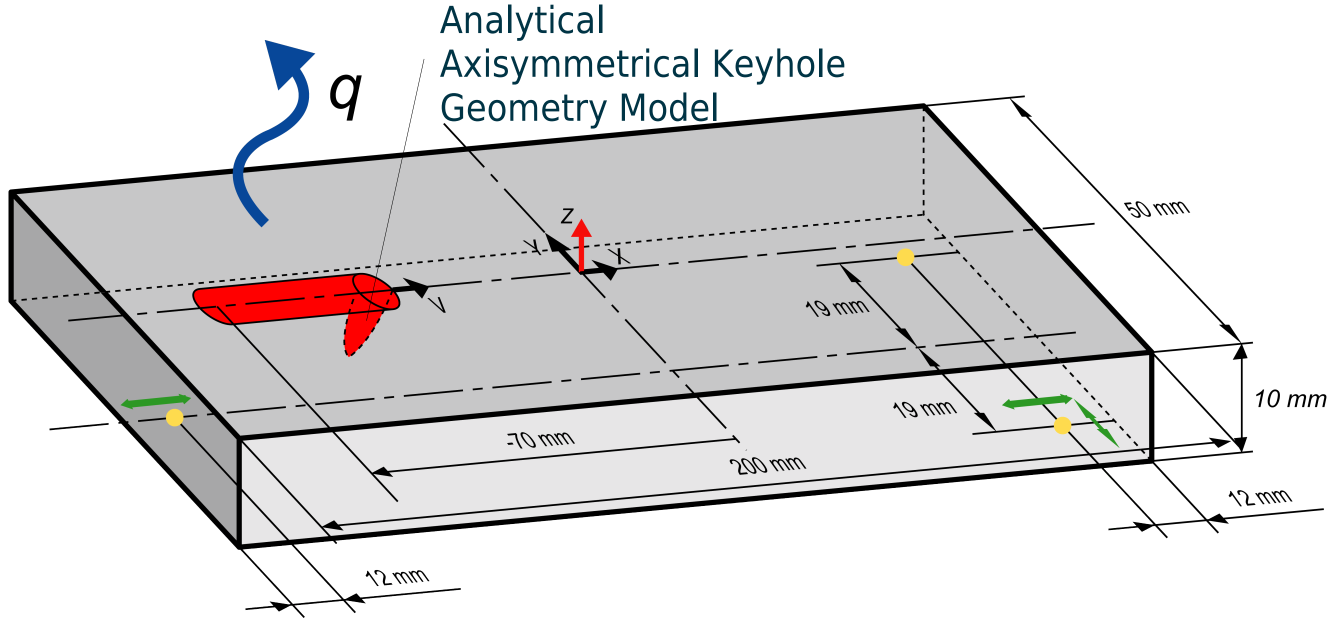
Modified solid structure simulation model from the forerunner project obtained with a simplified analytical keyhole model (calculated keyhole geometry)

Fluid flow simulation model not yet created (research stage)

Coupling not yet researched

Work in Progress: Experiment and Simulation Setup

Simulation Setup



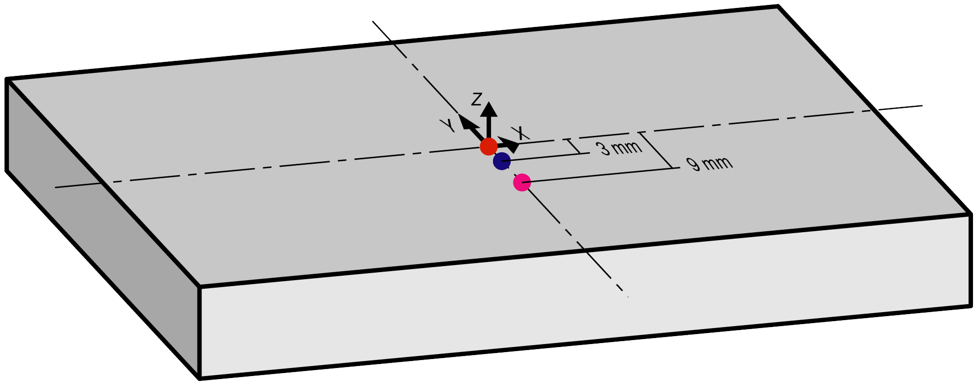
Workpiece: 200x50x10 mm
Welding Speed: 50 mm/s
Laser Power: 3000 W
Weld Length: 140 mm
Cooling Time: 12 s

Keyhole Model: Jüptner
Thermal BCs:
- 3000 °C (vapour) inside keyhole
- Radiation and convection

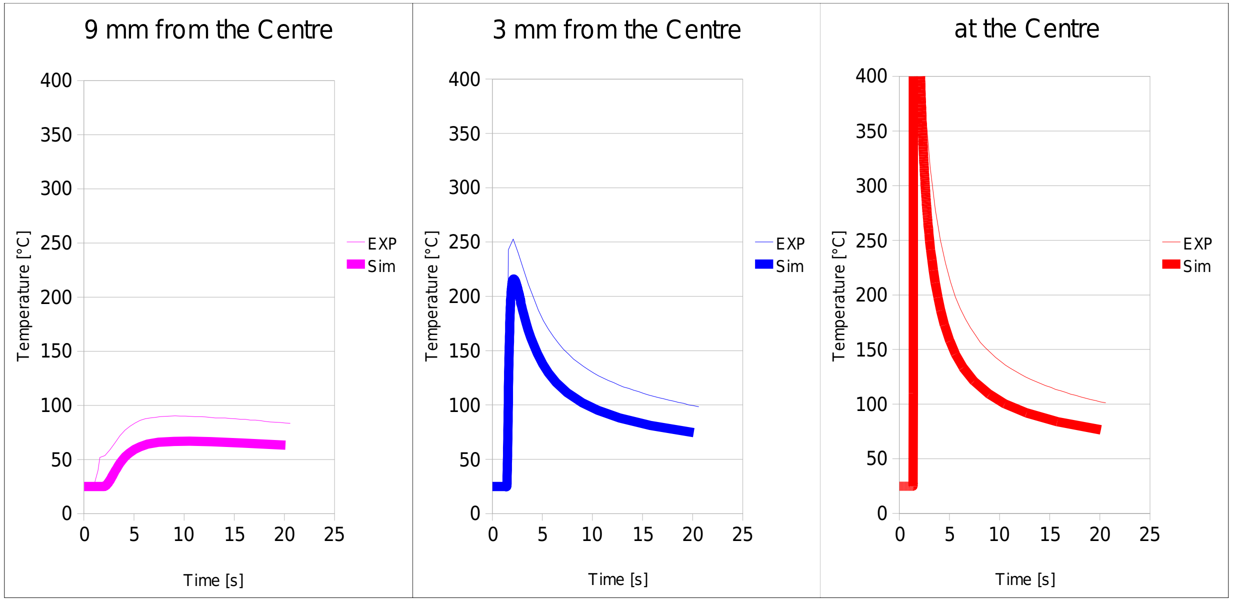
Mechanical BCs: Supports at 3 points

Work in Progress: Simulation Results

Temperature Development

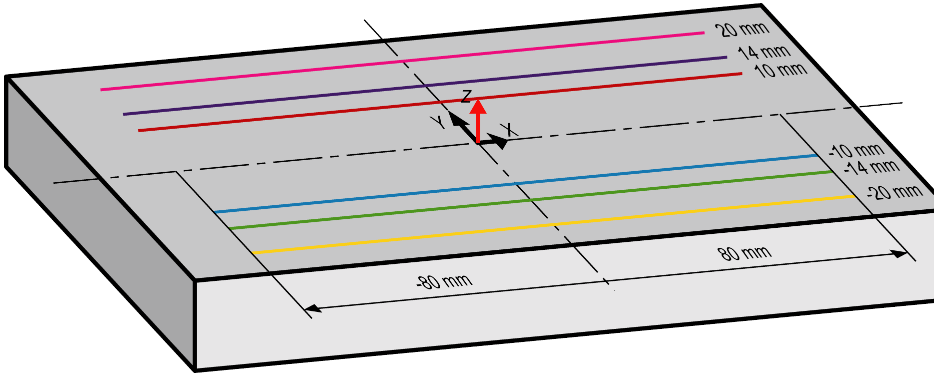


Temperature history of three different points measured on the top surface of the workpiece

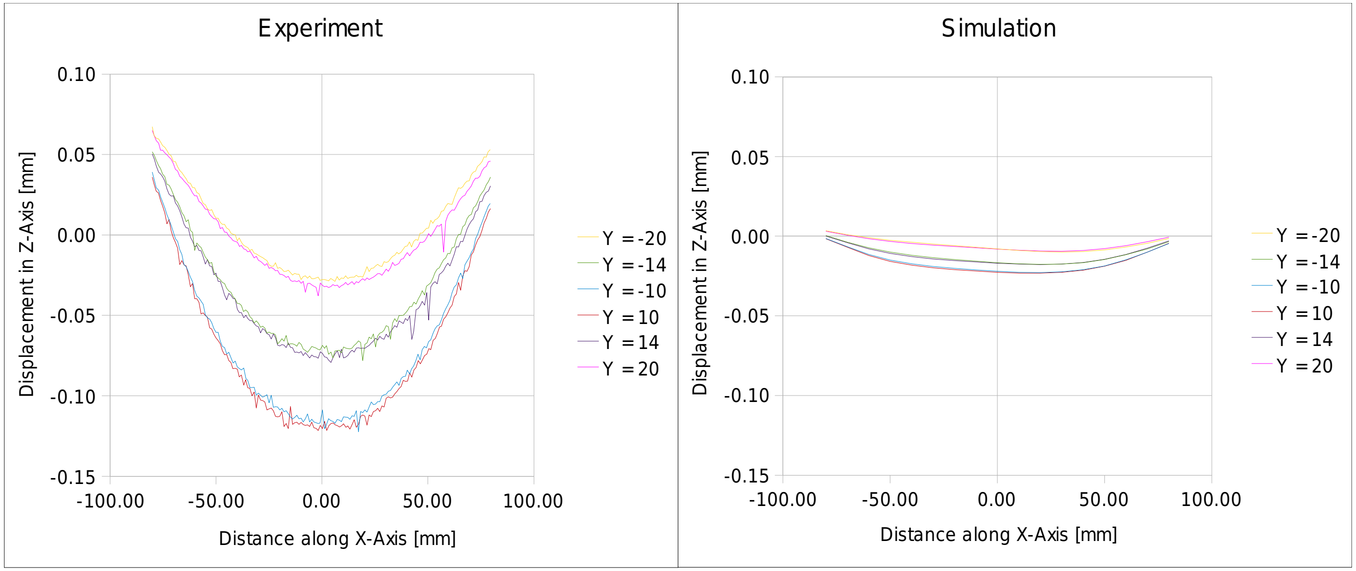


Work in Progress: Simulation Results

Workpiece Deformation



Deformation of the workpiece indicated by the displacement in Z direction measured on the top surface



Thank You for Your Attention