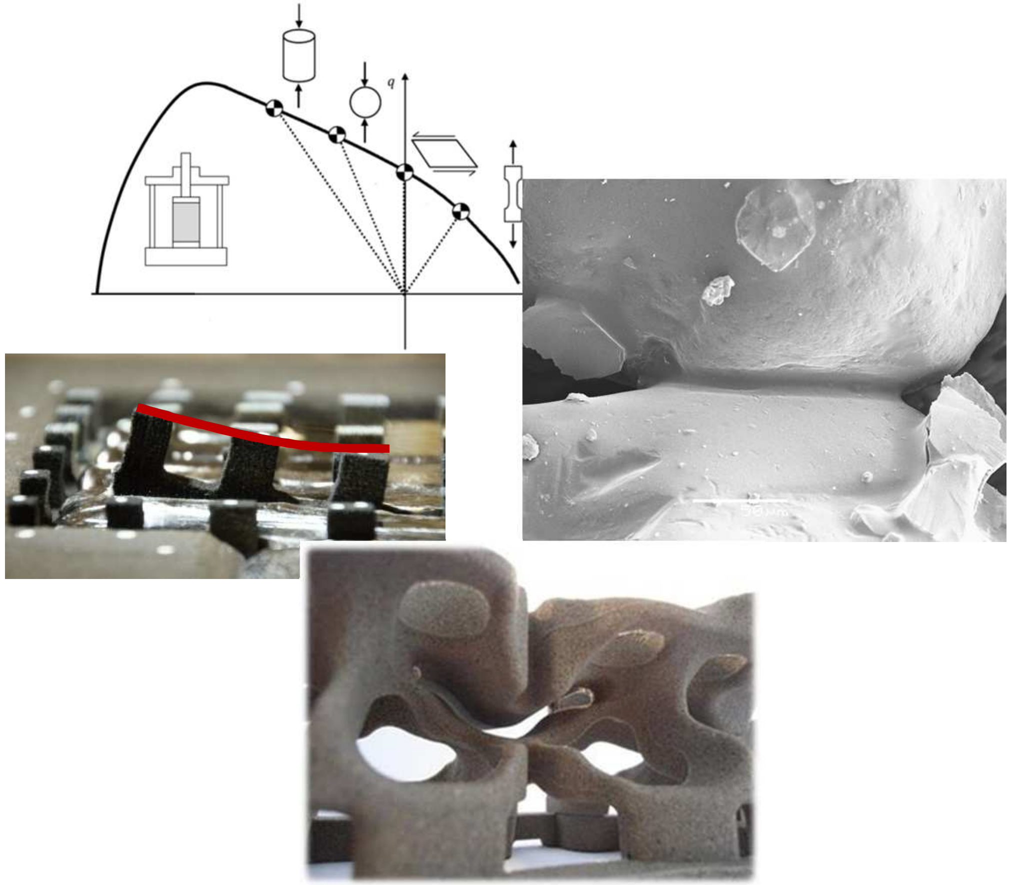
AMAP Project P6

Hot distortion of sand cores

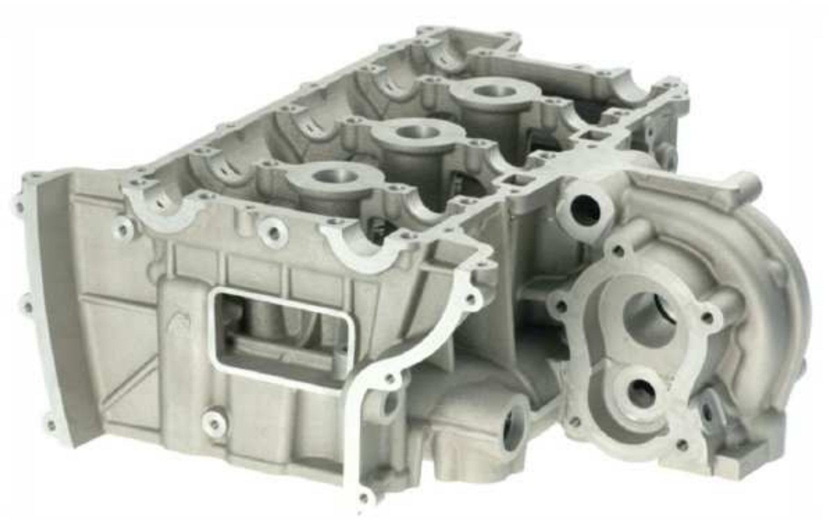


Dr.-Ing. Corinna Thomser
MAGMA GmbH

March 2018

Outline

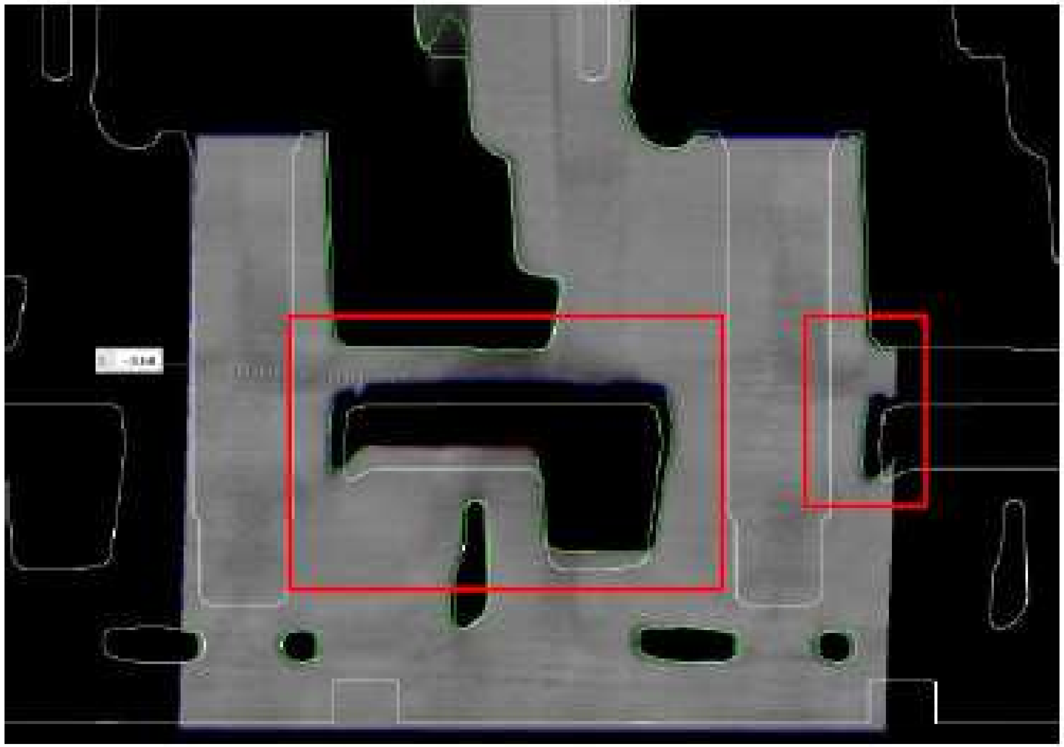
- Motivation
- Demonstrator Experiments
- Sand Measurements and Material Models
- Examples
- Final Remarks



Aluminium cylinder head

Complex inner cores

Upper water jacket core - Distortion of -3,68 mm



Overview of the AMAP project P6
Hot distortion of sand cores

Companies / Institute:

Nemak, MAGMA, RWTH Foundry Institute

Objectives:

- Selection/Development of appropriate Measurement Methods
- Understand and Minimize Distortion of Sand Cores
- Modeling and Simulation of Core Distortion
- Transfer of Results to Complex Core Geometries (e.g. water jacket)

Process Chain: Casting

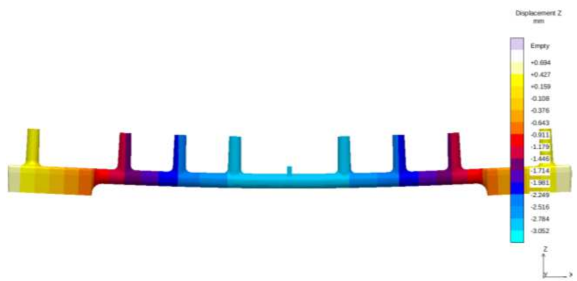
Materials:

Hot-Box/Warm-Box, Cold-Box und Inorganic Cores

Project Term: Start January 2013; term 36 months (+3)

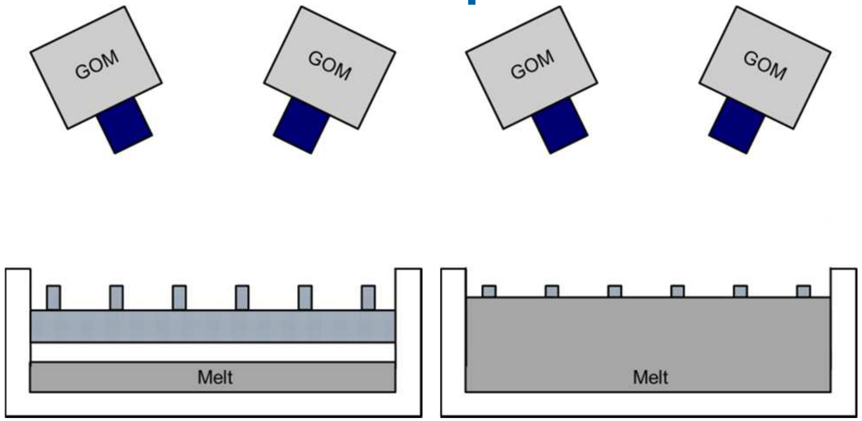
Aluminum cylinder head

Complex inner cores



Prediction by Simulation

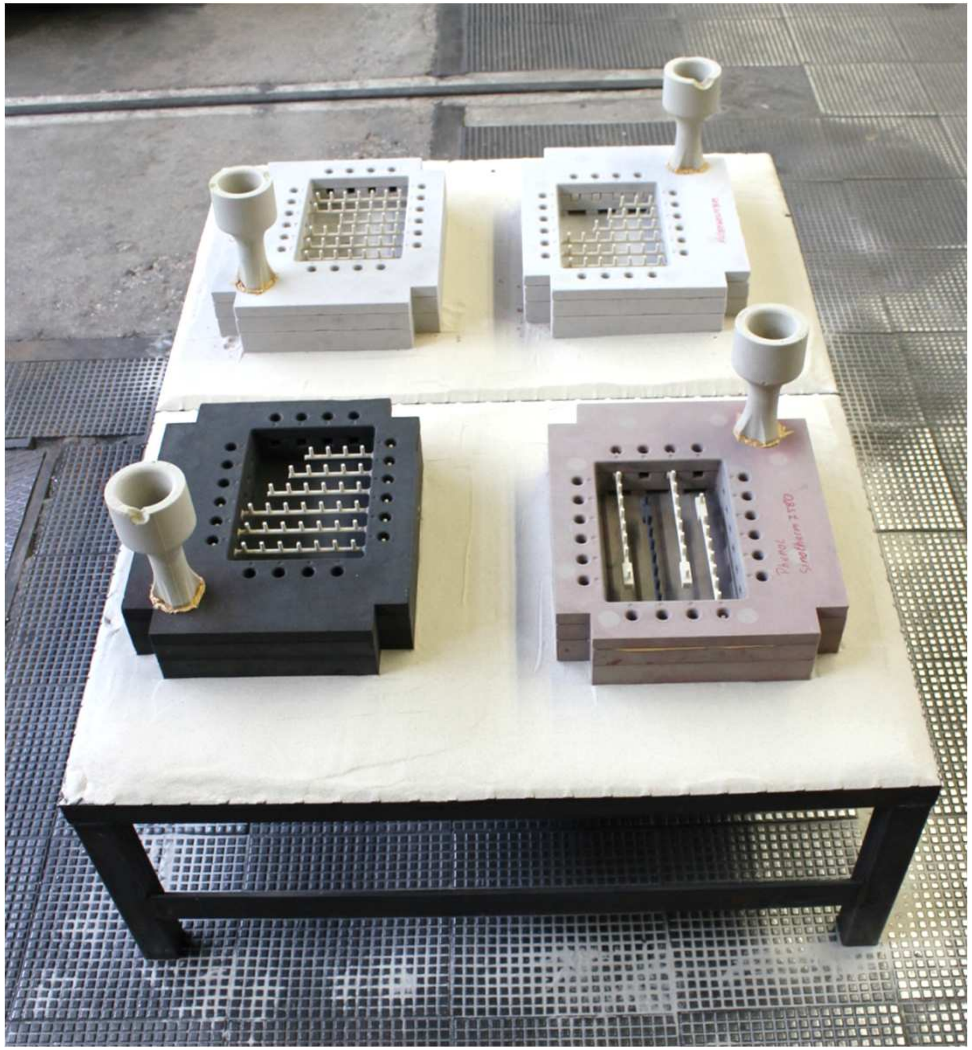
Principle

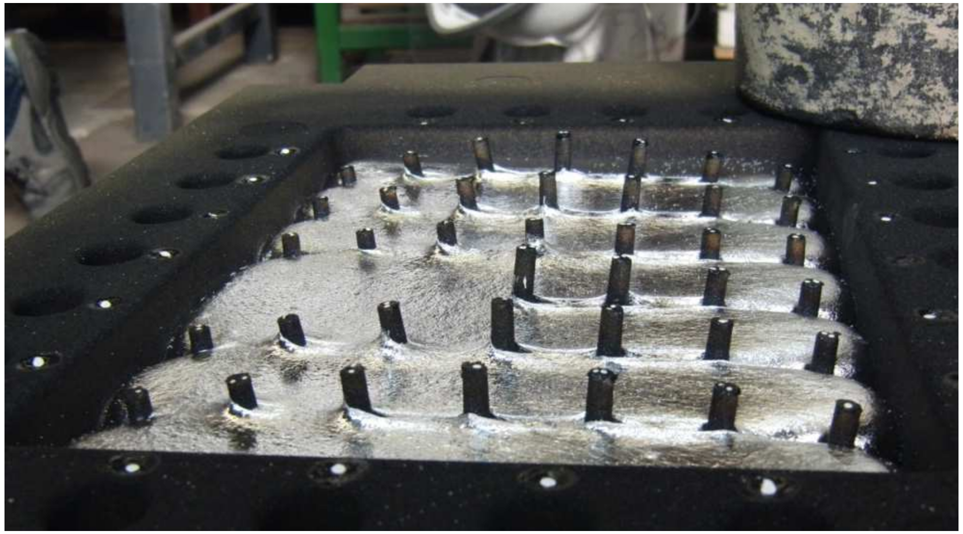


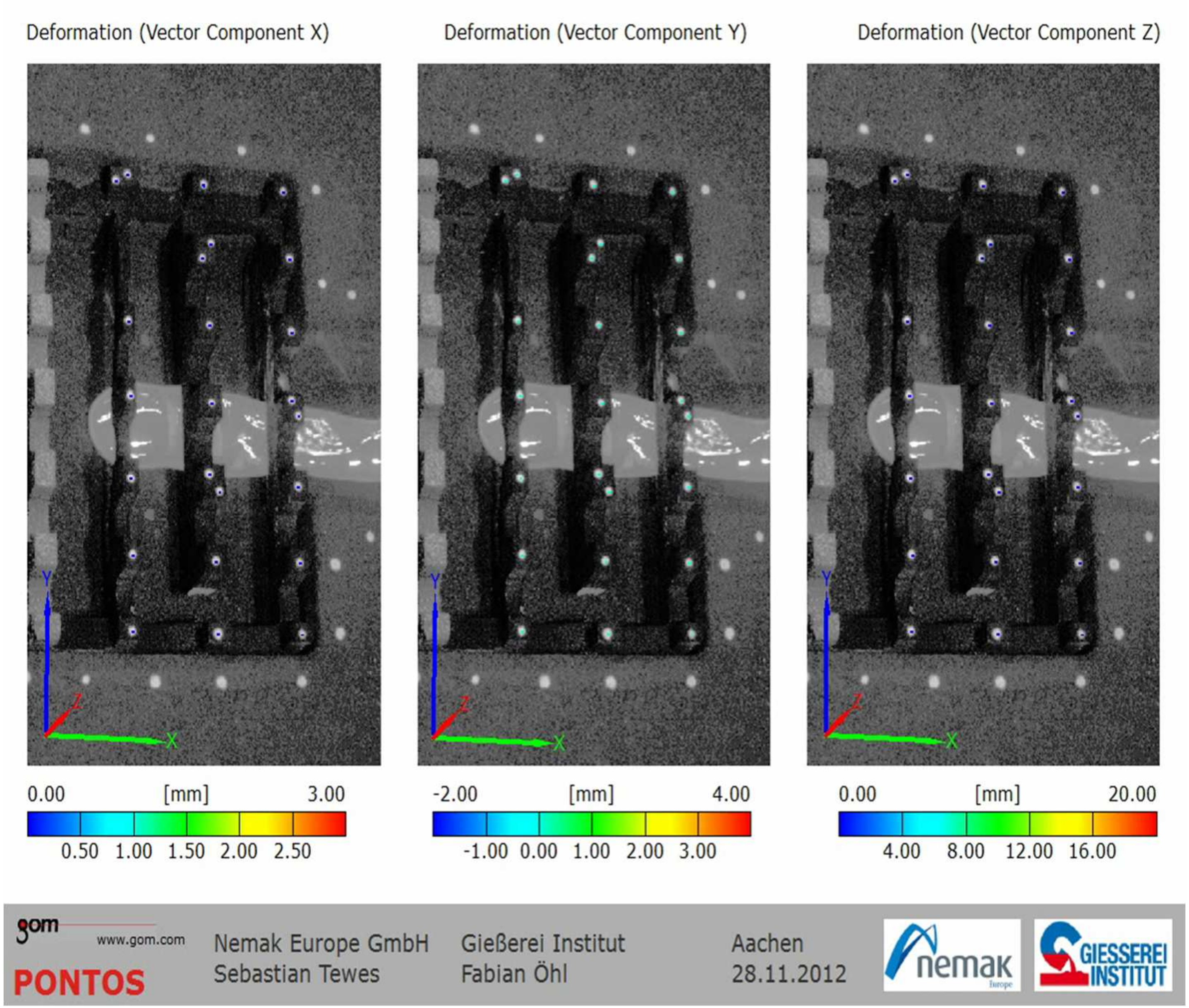
Experiments

Demonstrator cores

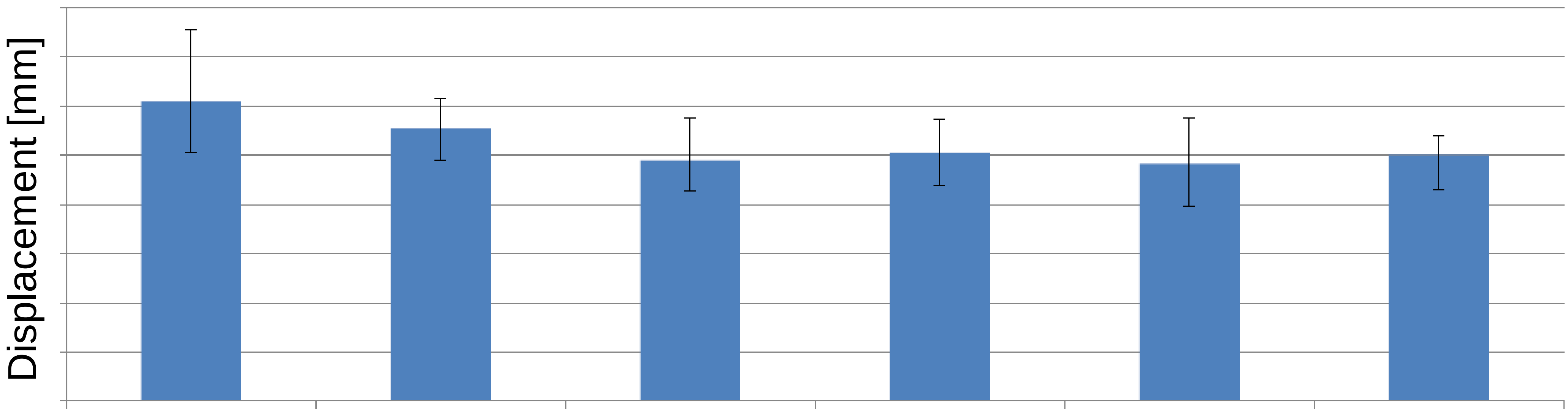
The distortion of sand cores was investigated optically in the casting process.



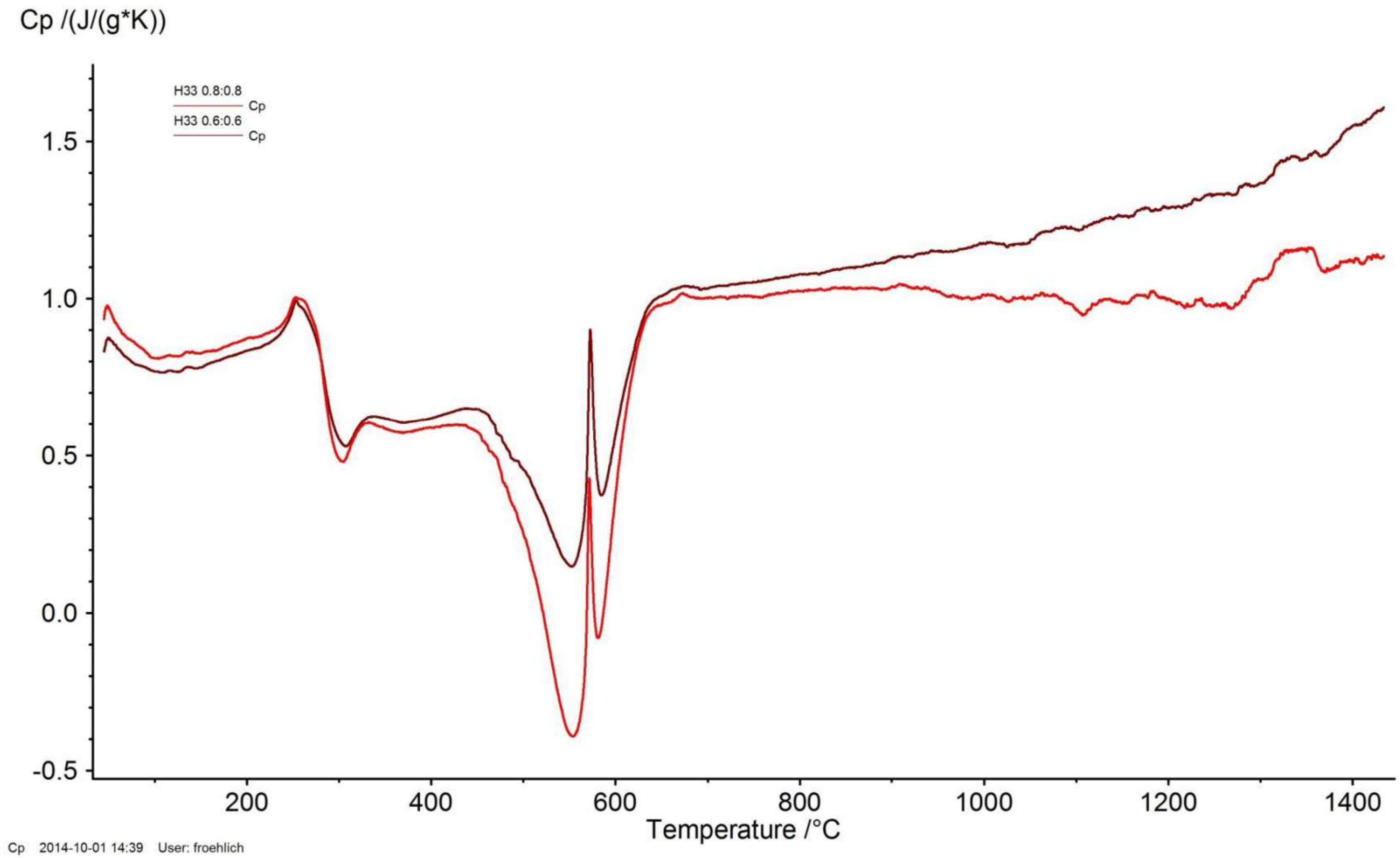


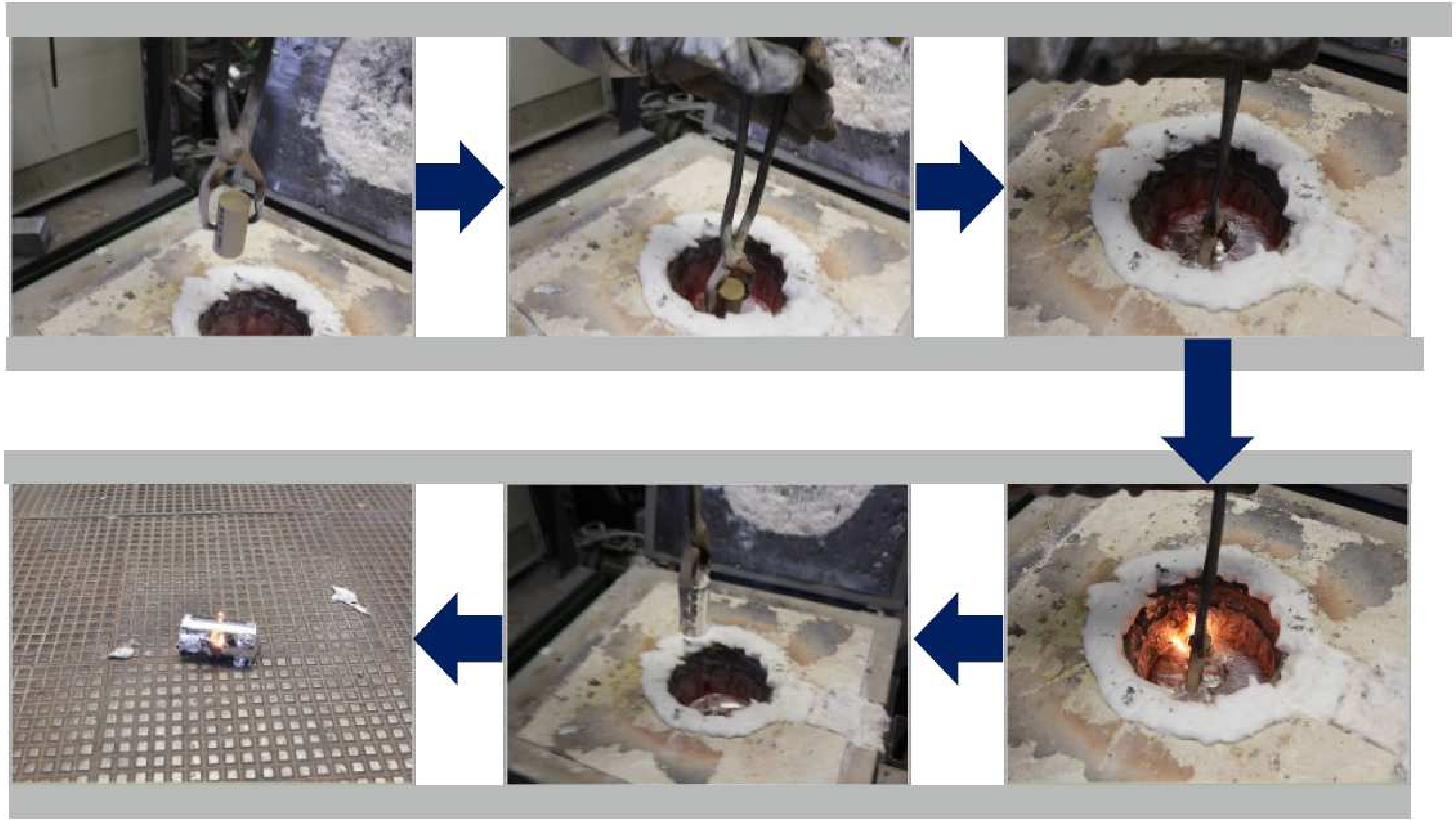

Deformation (Vector Component X)
Deformation (Vector Component Y)
Deformation (Vector Component Z)
0.00 [mm] 3.00
0.50 1.00 1.50 2.00 2.50
-2.00 [mm] 4.00
-1.00 0.00 1.00 2.00 3.00
0.00 [mm] 20.00
4.00 8.00 12.00 16.00
gom www.gom.com
PONTOS
Nemak Europe GmbH
Sebastian Tewes
Gießerei Institut
Fabian Öhl
Aachen
28.11.2012
nemak
GIESSEREI INSTITUT

Results for the 6mm Coldbox cores



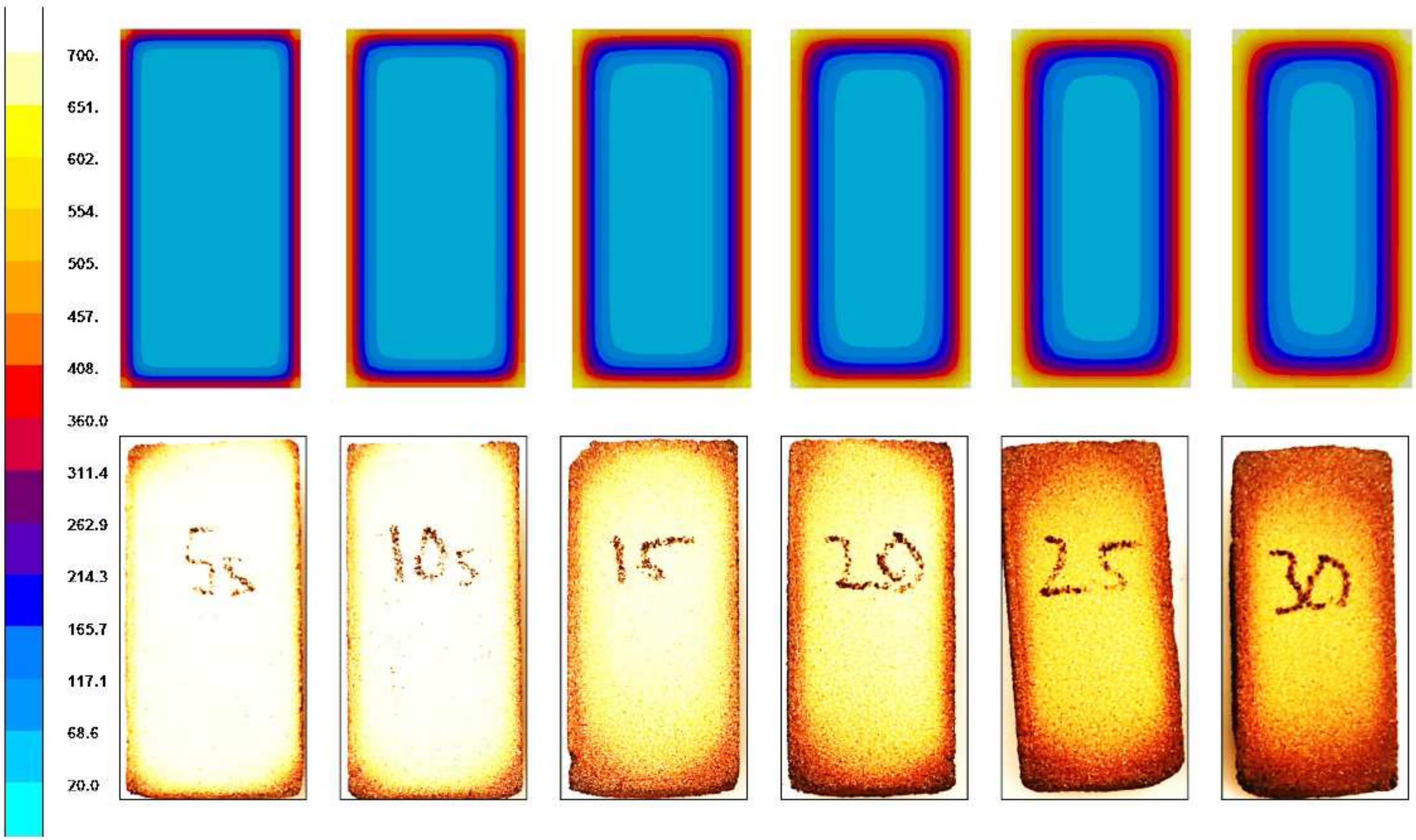
Thermo physical material properties were measured for different sand/binder systems.





Dipping tests are done in order to determine heat transfer coefficients.

Temperature prediction in MAGMASOFT®



Dipping tests are done in order to determine heat transfer coefficients.

Deformation of bonded sand cores
Mechanical material behavior

Mechanical performance during casting depends on

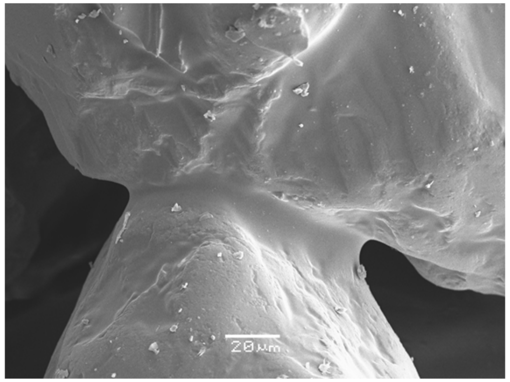
- Binder system
- Sand type and grain size distribution
- Initial density
- Temperature
- Time, curing and degradation of binder
- Stress state
- Buoyancy forces

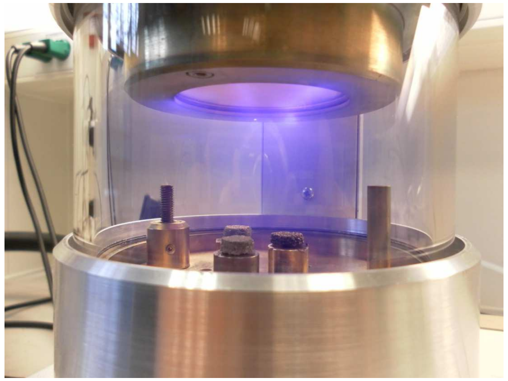
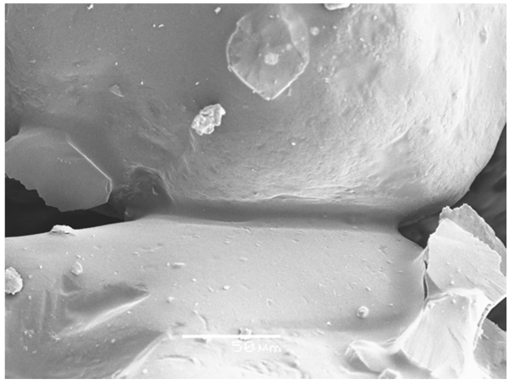
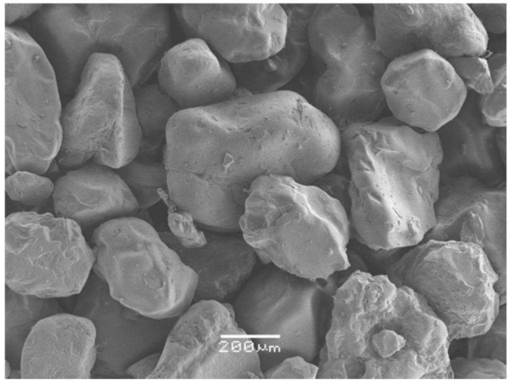
Large effects of the sample size and spread in measured data are observed.

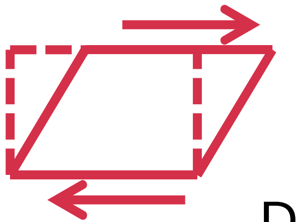
Consequence of elevated temperatures

- Degradation/burning off the binder
- Vapor due to drying of the surface
- Transport of gasses from the surface to condensation zones in the inner regions of the core => sub surface swelling
- The cores transform from a bonded material to a granular material
- Phase transformation of silica at 573 °C
- Large variation through the thickness

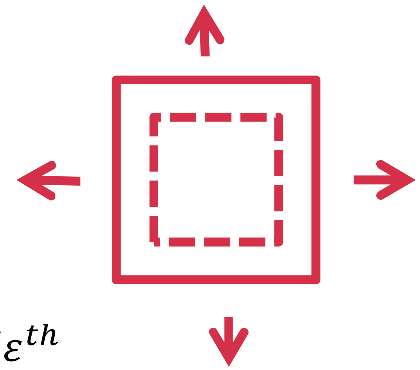
SEM – resin bonded sand





$$\sigma_{ij} = s_{ij} + \delta_{ij}\sigma_m$$



Deviatoric system

$$\sigma_e = \sqrt{\frac{3}{2} s_{ij} s_{ij}}$$

Volumetric system

$$\sigma_m = K\varepsilon_{kk} - 3K\varepsilon^{th}$$

Both elastic and plastic system (porous material)

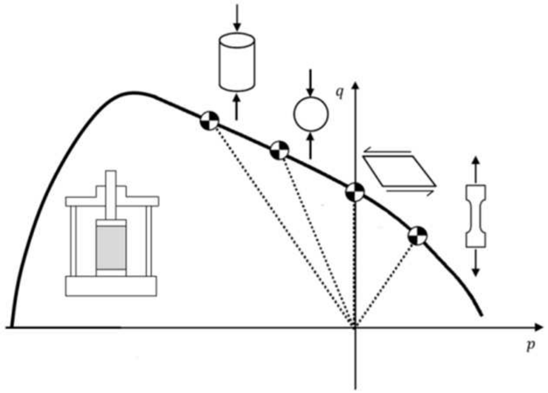
Drucker Prager soil plasticity model used for the sand description

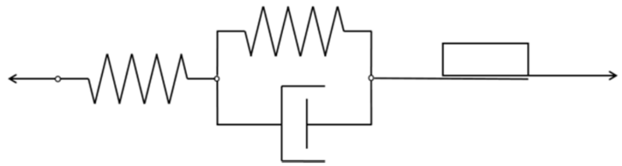
Different behavior in tension and compression

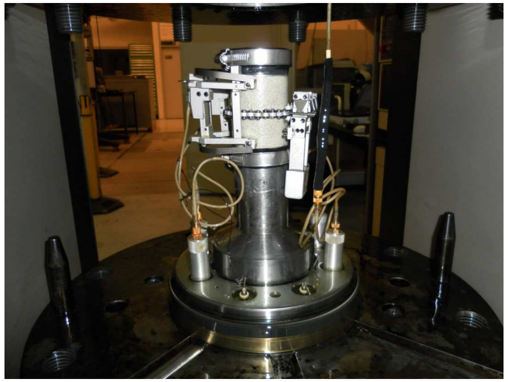
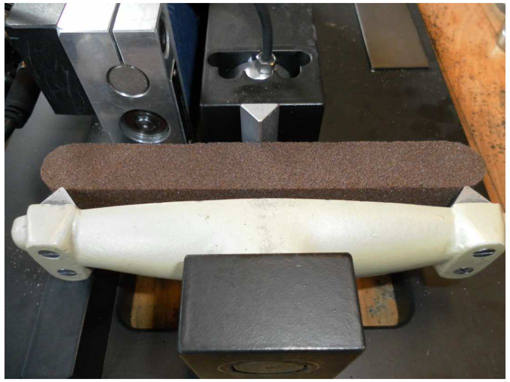
Yield condition

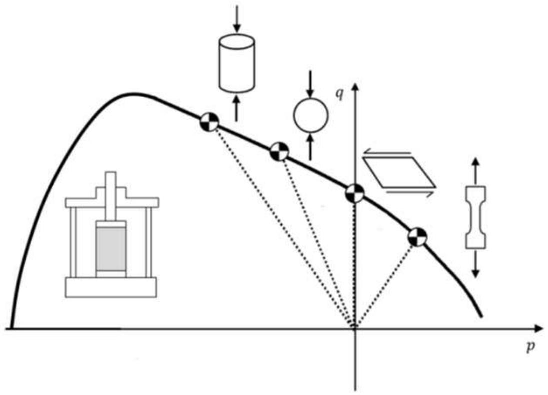
$$f\left(s_{ij}, p, \varepsilon_v^{in}, T\right) = q - p\ tan\beta\ - k = 0$$

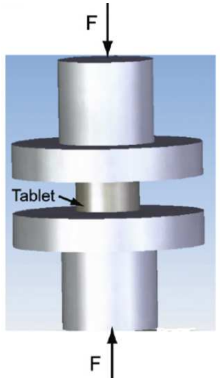
Rheological models to describe the creep behaviour

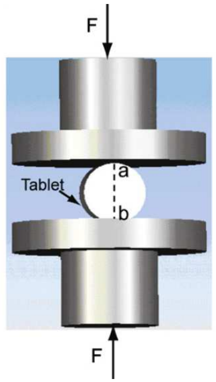


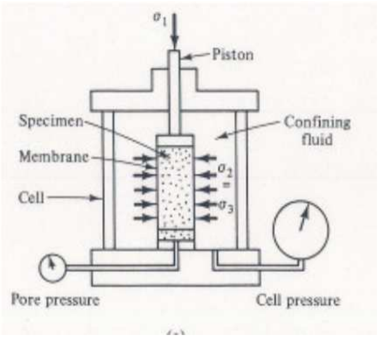


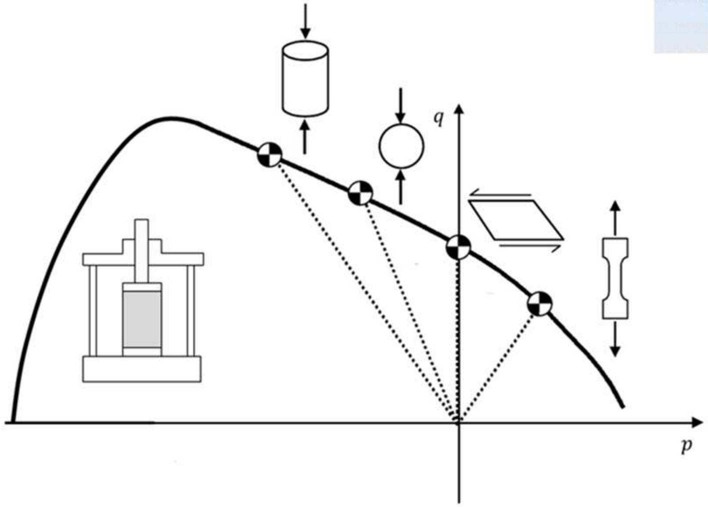
Tri-axial	Indirect tensile test	3 point bending	Compression
			

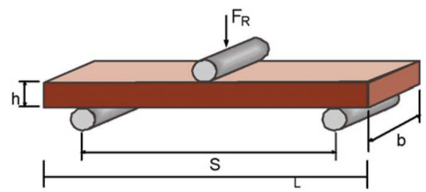




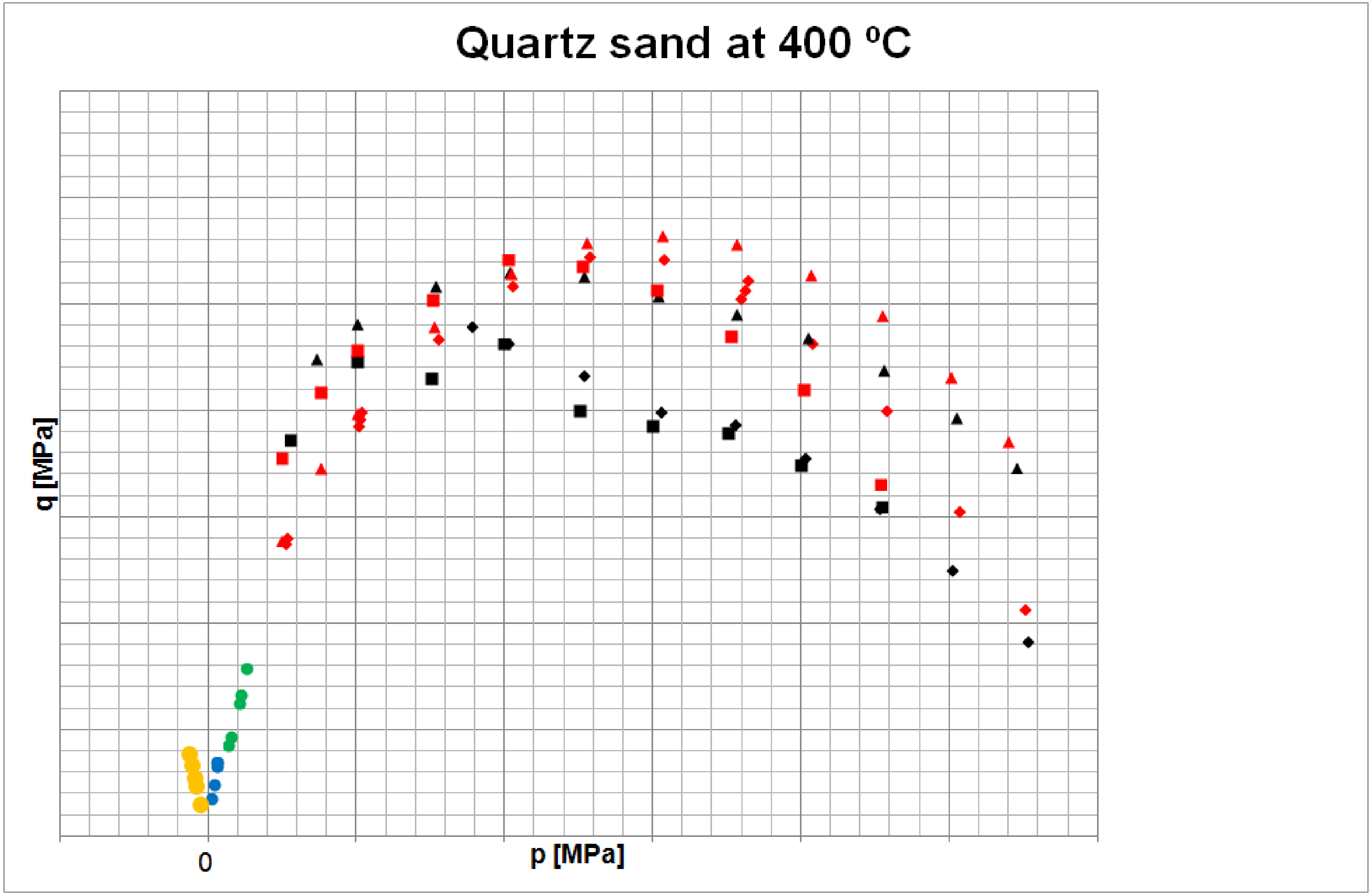




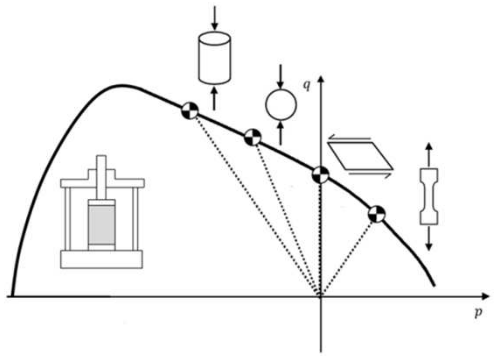




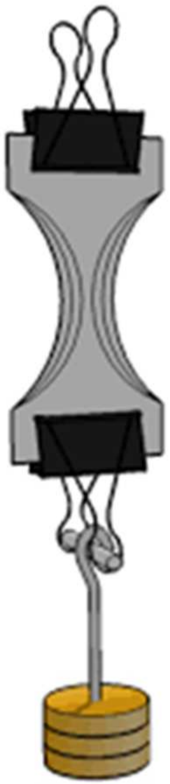
	σ	p	q
Compression	$\frac{4F}{\pi d^2}$	$-\frac{1}{3}\sigma$	σ
Indirect tension	$\frac{2F}{\pi d\, h}$	$-\frac{2}{3}\sigma$	$\sqrt{13}\,\sigma$
3 point bending	$\frac{3F\,L}{2b\,h^2}$	$\frac{1}{3}\sigma$	σ


Quartz sand at 400 °C
q [MPa]
p [MPa]
0

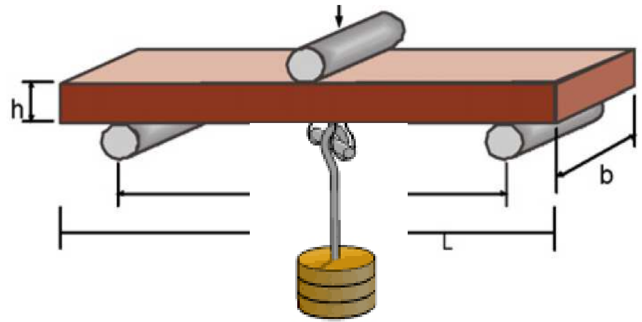
- Deformation of the core when it is surrounded by molten metal
- Buoyancy forces
- Influence of the solidified shell of the melt
- Consider time and temperature influence on the performance of the bonded sand material
- Describe bonding strength as function of curing and binder degradation - softening when the material is damaged
- Different behavior in tension and compression
- Creep behavior of the binder material at elevated temperature



Creep tensile test

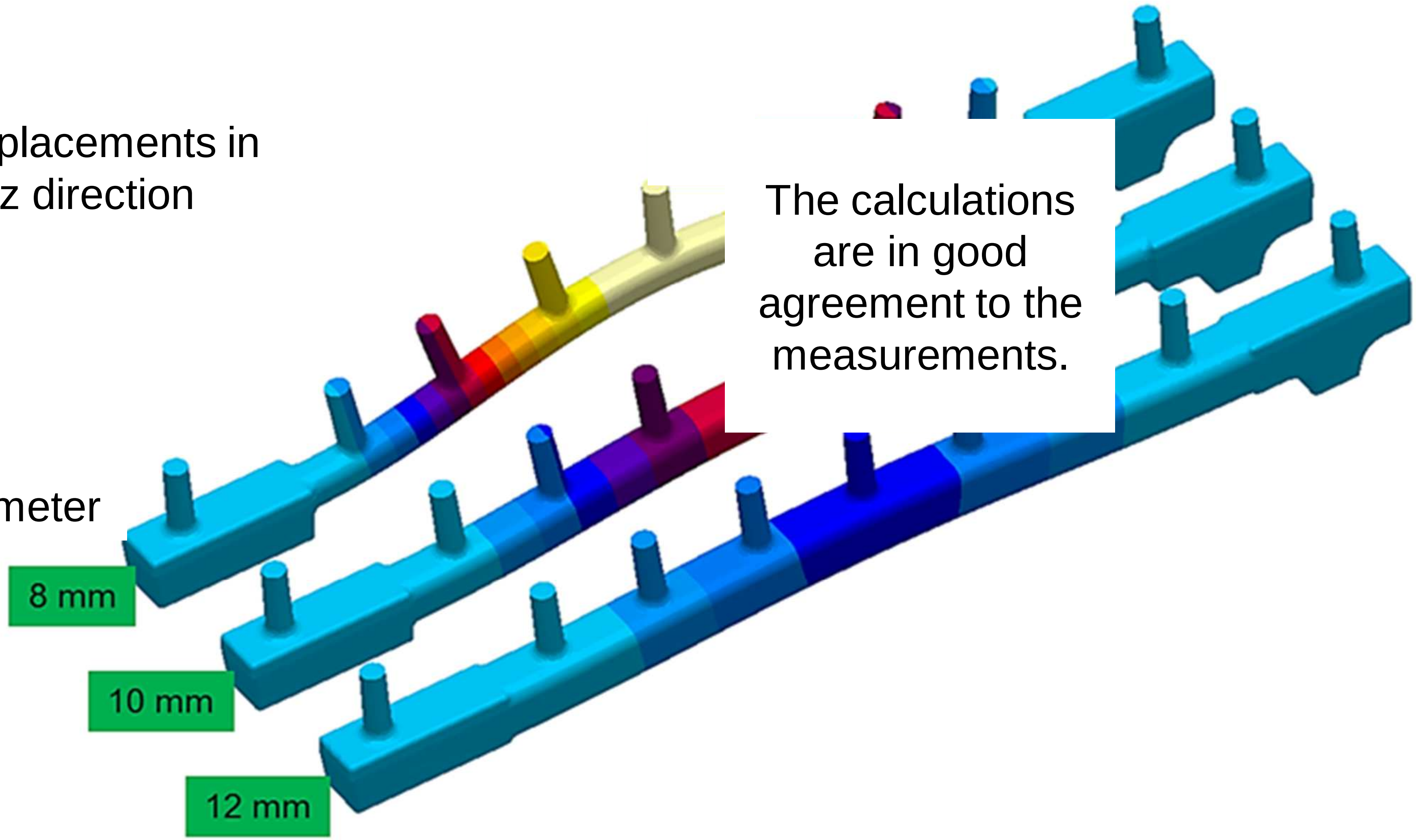


Creep 3 point bending



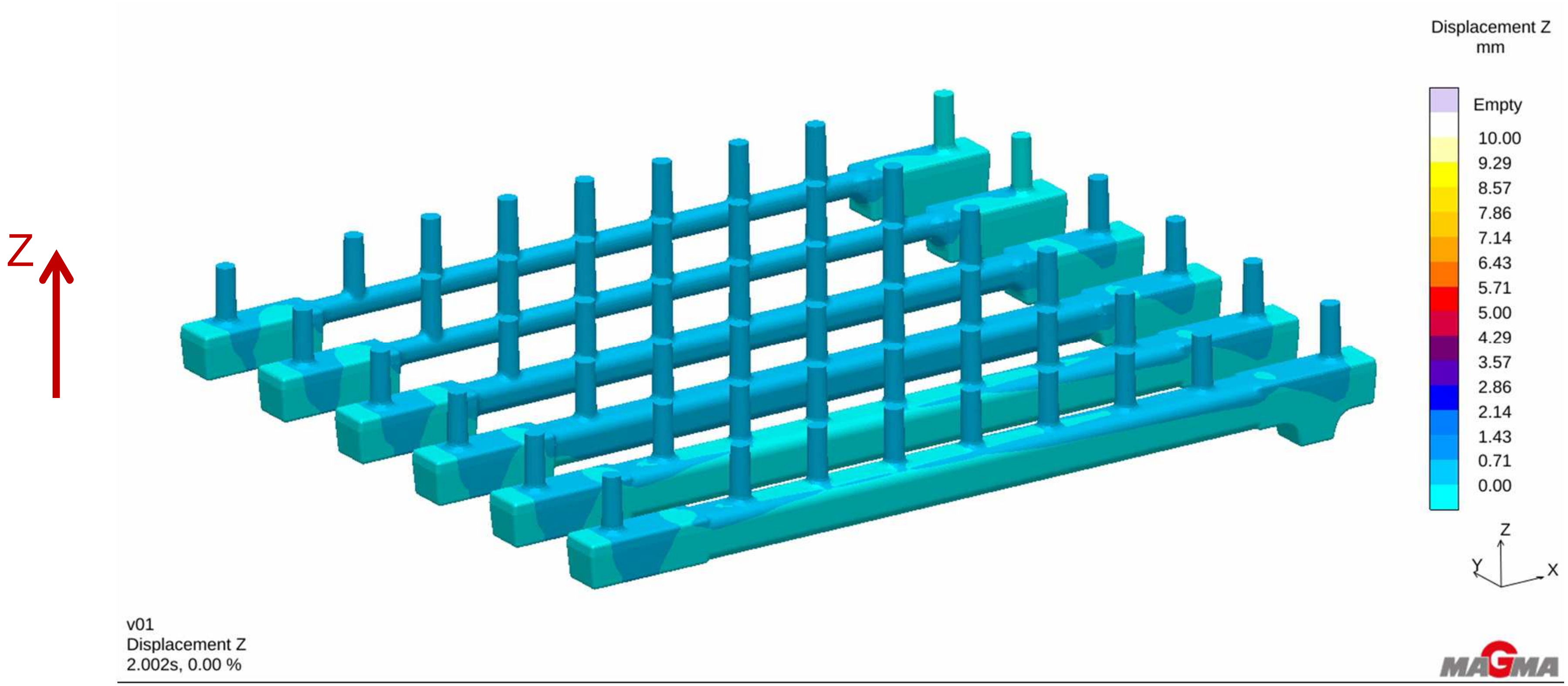
Displacements in z direction

Bar diameter



The calculations are in good agreement to the measurements.

Visualisation of core distortion



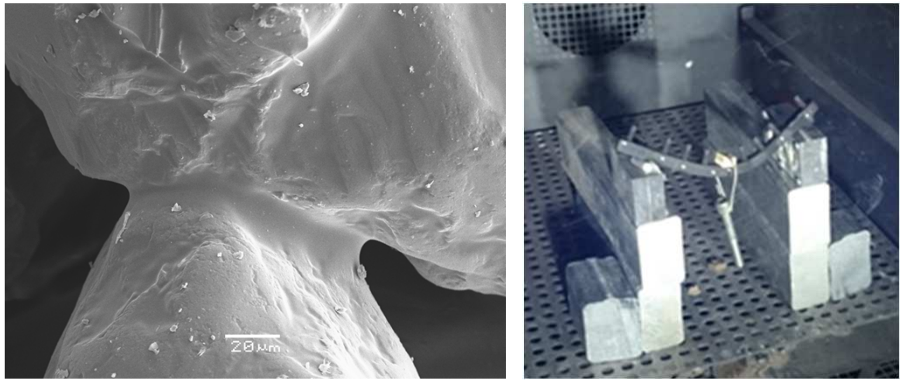
Different cores (thickness 6-12 mm)

- Different mechanical, thermophysical and demonstrator tests have been performed on bonded sand cores for different sand/binder systems
- Material data have been extracted for the Drucker Prager and Cam Clay soil plasticity models
- The new material models have been implemented in MAGMAstress and applied to demonstrator examples and real cores in the casting process
- The influence of thermal expansion, location of the core prints and the forces from buoyancy due to density differences have been evaluated

- Further investigation of the deformation mechanisms
- Additional measurements for other sand types
- Evaluation of the interaction between the solidifying shell of aluminum and the deformation due to buoyancy
- Further evaluation with the other partners in the project

Understanding the deformation mechanisms of bonded sand

Brittle material at lower temperature



Creep behavior at higher temperature

Theses and publications

- *Bachelor thesis (finished 2013): Sebastian Jan Hamdan (Technical University of Denmark (DTU), Mechanical Engineering) “Evaluation of the mechanical properties of coldbox sand cores”*
- *Mini thesis (finished 2014): Nishanth Rajendran (RWTH Aachen, Metallurgical Engineering) “Thermomechanical analysis of PUR-Coldbox binders”*
- *Mini thesis (ongoing): Mokirala Swarup Chnadu Rao (RWTH Aachen, Metallurgical Engineering) “Analysis of the material behavior of Coldbox bending bars”*
- *Master Thesis (ongoing) Torsten Rothhöft (RWTH Aachen, Wirt-Ing.) “Untersuchung der Haupteinflussgrößen auf den Verzug von PUR-Coldbox Kernen”*
- *Publication: F. Öhl, U. Vroomen, C. Thomser, J. Thorborg, S. Fischer, A. Bührig-Polaczek „Maßhaltigkeit bei komplexen Innenkernen – Experiment und Simulation des Heißverzugs“, 1. Internationales Deutsches Formstoff Forum 2016; „Wissenschaftliche Erkenntnisse für Praktiker“*

Final Remarks
AMAP Research Cluster

- The companies Nemak and MAGMA together with the Foundry Institute of the RWTH Aachen University formed the project consortium

- Many thanks to the AMAP Research Cluster for the support!

- Many thanks for the contribution of all members of the AMAP P6 project team!

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Thank you very much for your attention!