A new in situ device for applying stress to tomographic samples

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Abstract

At the imaging beamline P05 [1] at the PETRA III storage ring at DESY, Hamburg, Germany a push/pull-out device is developed which allows the acquisition of tomographic data sets under static or cyclic load conditions. The design is modular such that the device can be adopted for different actuators and load cells in order to apply and monitor load over wide range of stresses. Device control and logging will be fully integrated into the beamline control and data format, respectively. For absorption contrast tomography the spacer diameter is such that it will fit into the field of view to avoid local tomography. For phase-contrast tomography a spacer with a considerably large diameter will be available in order to avoid strong phase variations. In the future temperature and humidity will be controlled and monitored.

The Modular Applying Stress System

Features

- Modular system
- Wide range of stresses
- Adapted wall thickness
- Various spacer diameters according to the mechanism of contrast formation
- Variable methods and devices for accommodating samples on the load cell
- Capability to add additional sensors e.g. temperature, humidity
- Capability to rinse the cell with protective gas
# Components

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<th>Actuator</th>
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<th>Sample housing</th>
<th>Load transducer</th>
<th>Force measurement</th>
<th>Signal matching</th>
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<td>VICKERS indentor for spot loading</td>
<td>Light-tight X-ray transparent Actuator position fixed</td>
<td>Coupling device for compressive stress</td>
<td>Load cell for low forces</td>
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<td>Visible light transparent X-ray transparent Actuator position fixed</td>
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### Assemblies

<table>
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<th>Synchrotron environment</th>
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<td>Planar loading</td>
<td>Spot loading</td>
<td>Spot loading</td>
<td>Planar loading</td>
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Technical notes
Load cells manufactured by Burster Präzisionsmesstechnik GmbH & Co KG with the measuring range 20 N, 50 N, 100 N, 200 N, 500 N or 1 kN can be installed.

The load cells are read out using an electronic system manufactured by Hottinger Baldwin Messtechnik GmbH.

The maximum force of the MP-20 micro pusher manufactured by Physik Instrumente (PI) GmbH & Co. KG is 125 N.

The maximum force of the customized MA-35 micro actuator manufactured by Physik Instrumente (PI) GmbH & Co. KG is 1 kN.

Applying the maximum force of 1 kN the elongation of the PEEK spacer is about 50µm.

The push/pull-out device mounted on the tomographic cameras air-bearing rotation stage in the experimental hutch of the IBL beamline
The closure ring of the spacer has been removed.
Applications

- Morphological characterization of biodegradable metal implants in bone [2, 3]
- Characterization of tooth filling
- Studies of biomimetic materials
- Fatigue tests
- Investigation of the metal bone interface [4]
- Elucidation of implant degradation and failure mechanisms

Application examples

Formation of Cracks in Ivory
Imke Greving et al. unpublished

Using a Vickers indentor a compression stress of approximately 0.5 GPa was applied to a cubic piece of ivory with an edge length of 1 mm in order to investigate the formation of cracks. The delamination of the surface layer could be observed. The diamond pyramid of the Vickers indentor at the top margin of the radiograph is nearly transparent for x-rays.

Biodegradable magnesium-based implants in bone
Julian Moosmann et al. unpublished

Tomographic reconstruction of a Mg-10Gd screw in a rat femur 12 weeks after implantation. Before the acquisition of the tomogram the force was set 24 N. The figure depicts a region of the bone-to-implant interface.

Deformation Field around A Bone-Implant
Berit Zeller-Plumhoff et al. unpublished

A screw with a diameter of 2 mm was pushed down into a rat bone using the cylindrical pressing tool. In order to determine the deformation of the sample during loading digital volume correlation was applied using LaVision DaVis 8.4. Using the software, the deformation field was computed. Vector color and size are scaled by displacement magnitude.
The Tomographic Devices at the HZG Outstation PETRAIII

- **Phoenix X-Ray nanotom 180NF**
  - Tube based
  - Cone beam
  - Polychromatic
  - X-ray energy < 180 keV
  - Field of view up to 100 x 100 mm²
  - Coherence no
  - Spatial resolution ≈ 1µm

- **Imagegine BeamLine P05**
  - Synchrotron based
  - Parallel beam
  - Monochromatic
  - X-ray energy 5 – 50 keV
  - Field of view up to 5.5 x 1.0 mm² @ 87.5 m
  - Coherence yes
  - Spatial resolution 0.7 µm / < 100 nm

- **HighEnergyMaterialsScience Beamline P07**
  - Synchrotron based
  - Parallel beam
  - Monochromatic
  - X-ray energy 50 – 300 keV
  - Field of view up to 6.0 x 1.2 mm² @ 100.0 m
  - Coherence yes
  - Spatial resolution 0.7 µm

The Project SynchroLoad

We would like to acknowledge support by the SynchroLoad project (05K16CGA) of the Röntgen-Angström-Cluster (RAC). The project SynchroLoad focuses on the failure of degradable metallic implants. In many orthopedic or traumatological applications non-degradable metals such as titanium (Ti) or steel are used as the gold standard as a material for load-bearing implants. However, in some cases, e.g. in the case of children that are still growing or due to complications occurring (e.g. soft tissue irritations), a follow-up surgical intervention is necessary in order to remove the implant. To avoid such complications biodegradable implants can be used instead of permanent ones. Magnesium (Mg) is a promising candidate for such applications due to its mechanical stability, bio-compatibility, and degradation properties. By using Mg alloys the corrosion rate of the implant can be controlled such that the bone is sufficiently stabilized until the bone defect healed.

Within the scope of the project SynchroLoad of the Röntgen Angstrom Cluster we aim to fully characterize the bone-to-implant interface of biodegradable metal implants using high-resolution computed tomography. At the interface biochemical reactions and corrosion processes form a complex network of interactions. For comparison, non-degradable permanent implants are examined as well. The acquired data will help to elucidate how implant degradation and failure mechanisms work for biodegradable Mg-based implants. [5]

References