COMPOSITE MATERIALS RESEARCH @UGENT-MMS

Prof. dr. ir. Wim Van Paepegem

http://www.composites.ugent.be/

RESEARCH AREAS

Key areas for composites:

- **Experimental mechanics** (static, impact, fatigue, creep, fracture mechanics, micromechanical testing,…)

- **NonDestructive Testing – NDT** (ultrasound, thermography, vibrometry, guided waves,...)

- **Computational mechanics** (multi-scale modelling, machine learning, ply-based material models, analytical methods for UD and SFRP,…)

- **Composite processing** (dry fabric simulation, injection moulding simulation, UD tapes, vitrimers,…)

Mission statement:

"To study the mechanical behaviour of composite materials and structures by a combined approach of instrumented experimental testing and adequate numerical modelling, in close collaboration with the composites industry and its suppliers"

PERSONNEL

3	Professors (ZAP)
1	Doctor-assistant (AAP)
25	Researchers (internal)
8	Researchers (external)
2	Technicians
15-20	Master thesis students

Department of Materials, Textiles and Chemical Engineering
Ghent University – Faculty of Engineering

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INDUSTRIAL COLLABORATIONS

Automotive

- Siemens
- Honda R&D
- Bosch R&D
- Toyota
- Plastic Omnium
- Fiat
- Bentley
- Recticel

Aerospace

- Sabca
- Ten Cate/Toray
- Safran Aero Boosters
- Rolls Royce
- Airborne
- Qinetiq Space
- Airbus CFK Valley

Wind / wave / tidal

- LM Windpower
- Siemens/Gamesa
- Engie
- Suzlon SE Blades
- DEME
- Damen
- Xant

Materials

- Eastman Chemicals
- Mitsubishi Rayon
- Arkema
- BASF
- AGC
- Covestro (Bayer Material Science)
- Domo
- Solvay
- 3D Weaving
- Dutch Polymer Institute (DPI) / SABIC, DSM, Shell, Teijin, SKF, Nouryon
- M2i (Materials Innovation Institute)
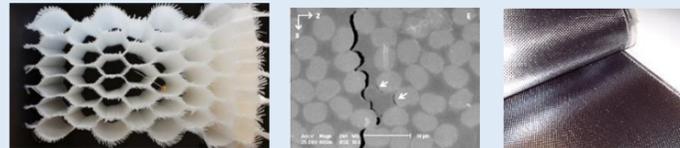
Simulation software

- Simulia / Dassault
- Siemens
- e-XStream / MSC.Software
- 4RealSim
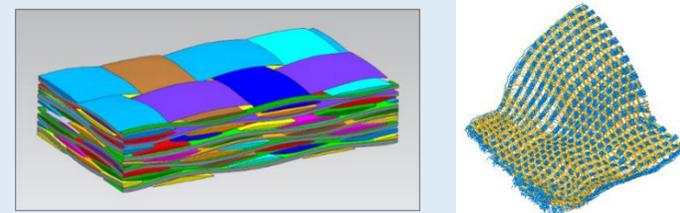
Industry/construction

- Bekaert
- Atlas Copco
- Parker
- Sioen
- Spiromatic
- OCAS
- Picanol
- Vandewiele
- Samsonite
- Deceuninck

Hydrogen

- Toyota
- Honda
- Plastic Omnium
- Syensqo (Solvay)
- Sharp Composites
- AMS Robotics
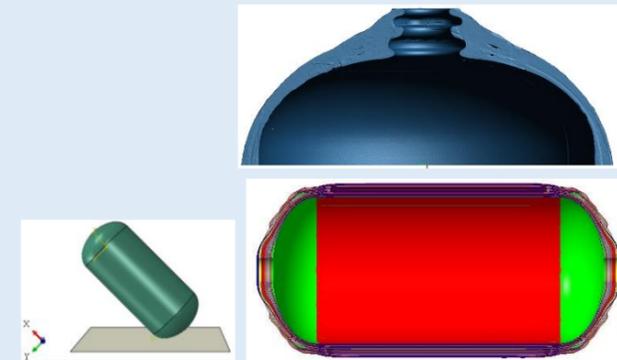
3D printing

- Materialise
- Siemens
- 3D Systems (Layerwise)
- Vigo
- Asco, BMT Aerospace
- Vibrant
- Engie
- Oceanz, EXO-L, 3D LifePrints (3DMED)
- GKN, Ramlab, M2i

Materials,
y – Facult

o://www.co

MECHANICAL TESTING

- **Static testing**
  - Sample preparation (specimen design, cutting, end tabs, fixture design,…)
  - Measurement of (orthotropic) stiffness, strength and failure strain
  - Temperature chambers (-150 °C to +250 °C)
  - Loading in tension, compression, shear, bending
  - Calibration of all load cells, actuators and machine alignment
- **Dynamic Mechanical Analysis (DMA)**
  - Visco-elastic properties
  - Time- and temperature-dependent stiffness
- **Fracture Mechanics testing**
  - fracture properties of bulk polymer (SENB)
  - mode I testing (DCB)
  - mode II testing (ENF, ELS)
  - Central Cut Ply (CCP) specimens
  - mixed mode testing (MMB, SLS)
  - fracture properties of adhesives/coatings
- **Micromechanical testing**
  - Scanning Electron Microscope (SEM) with in-situ tensile stage
  - In-situ strength properties of polymer micro-fibres
  - Fibre-matrix interface test
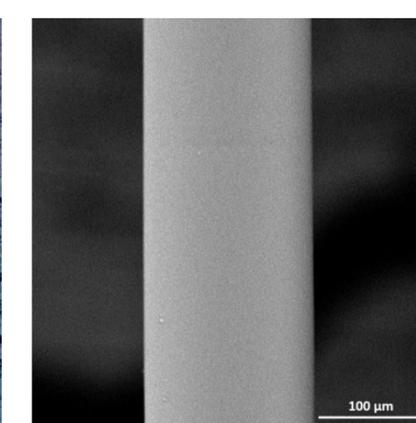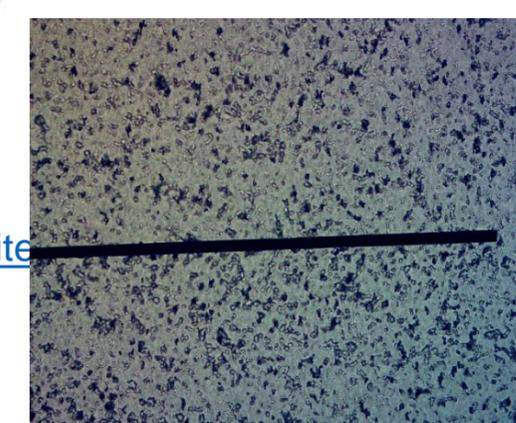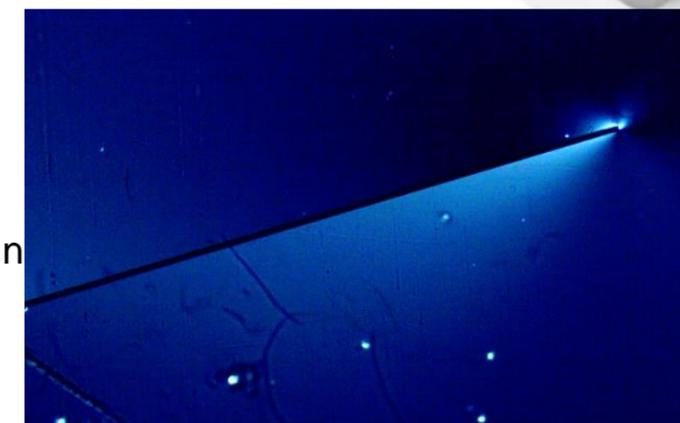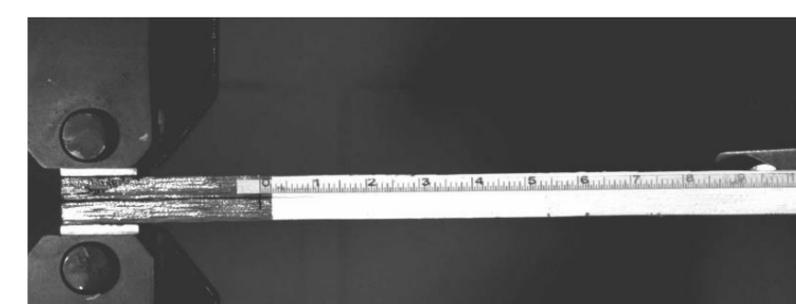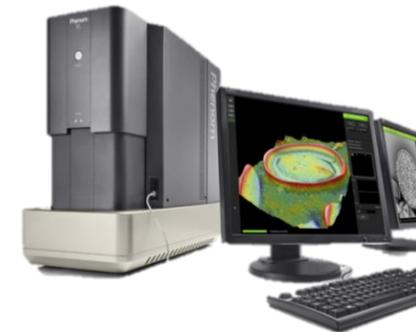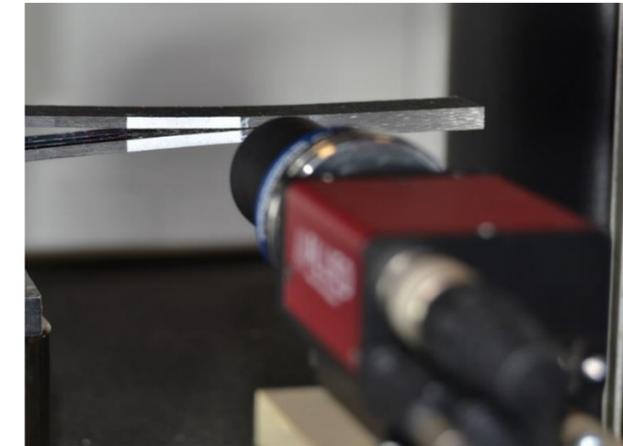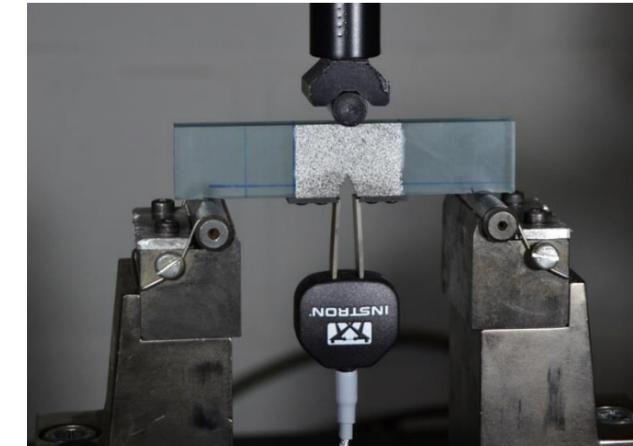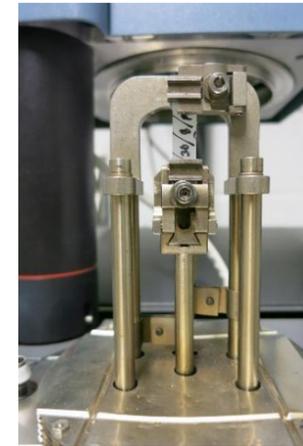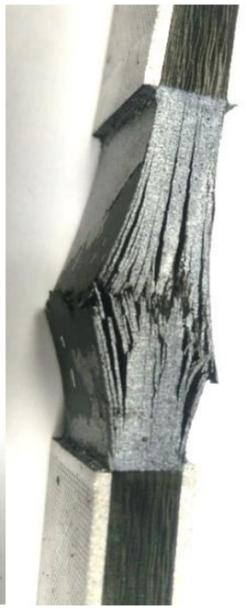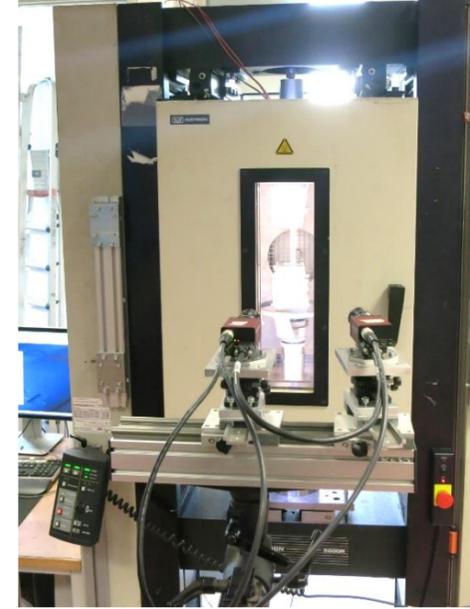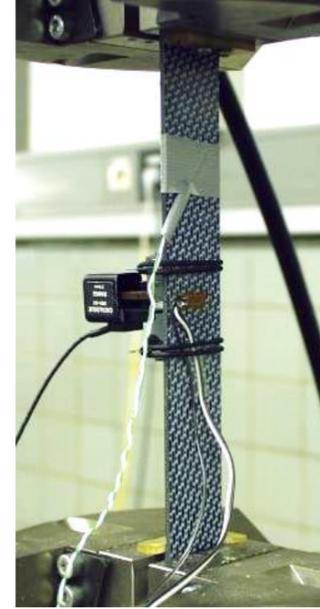
DYNAMIC MECHANICAL TESTING

- **Impact testing**
  - drop weight impact
  - Compression After Impact (CAI)
  - high strain-rate testing
  - crushing and energy absorption
  - dynamic delamination testing
  - High speed camera's (up till 500,000 frames per second)
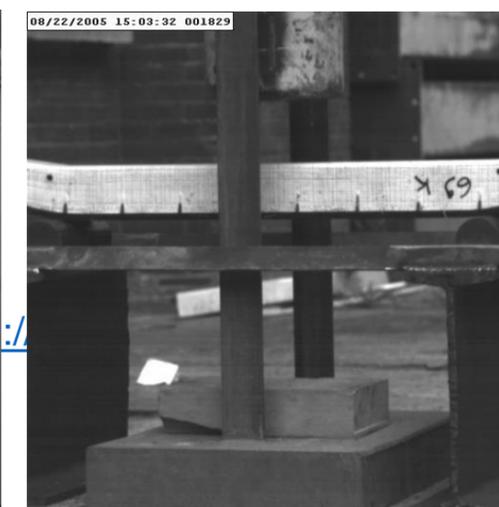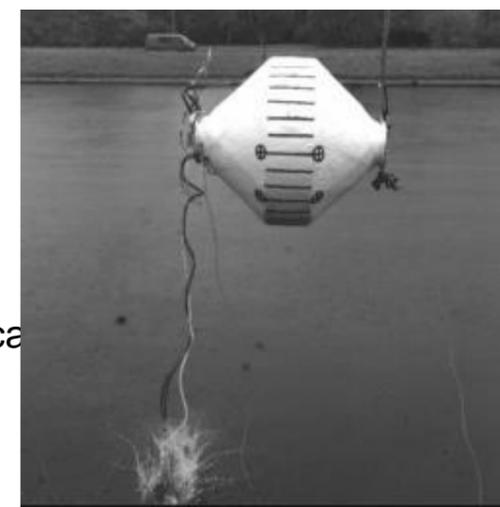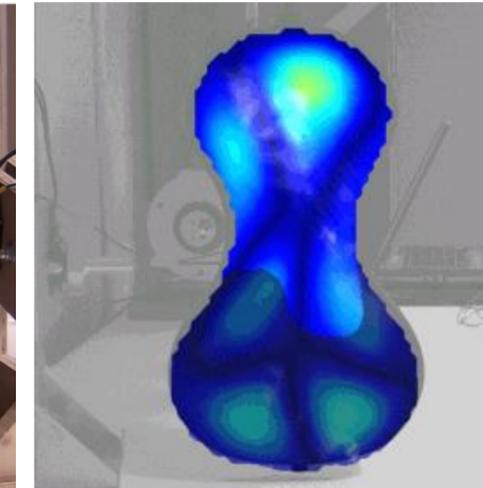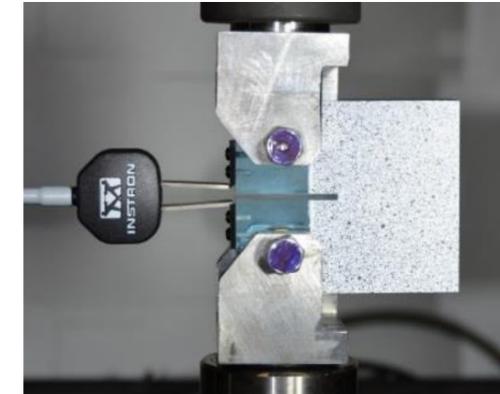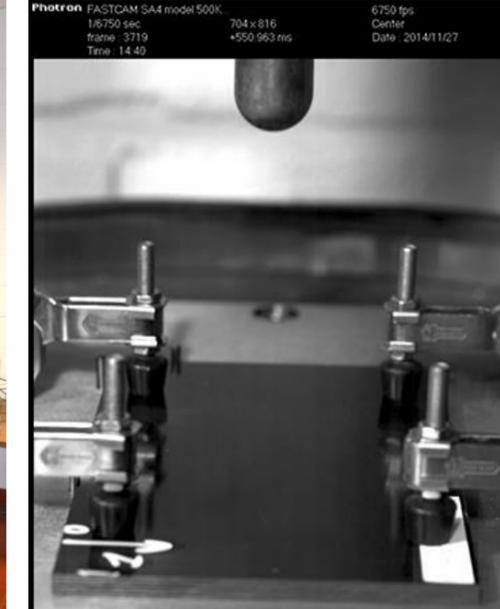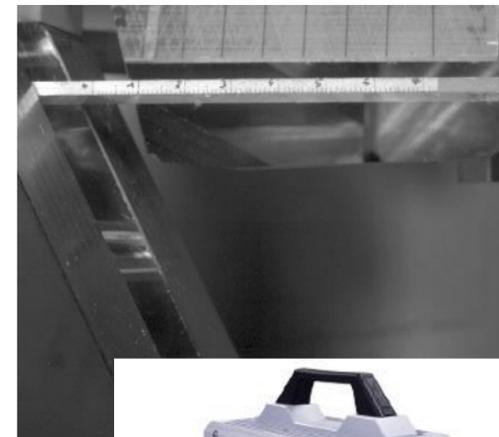- **Fatigue testing**
  - tension/compression, bending, shear
  - multiaxial fatigue (tension/torsion)
  - fatigue of delaminations and joints
- **Vibration/NVH testing**
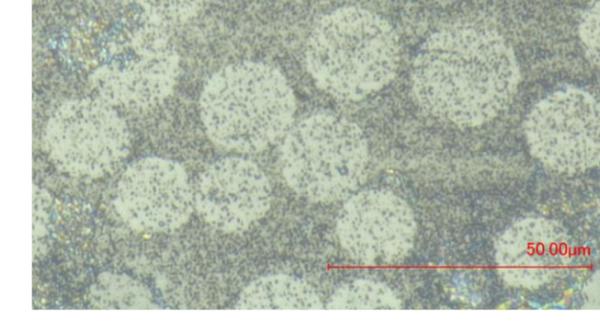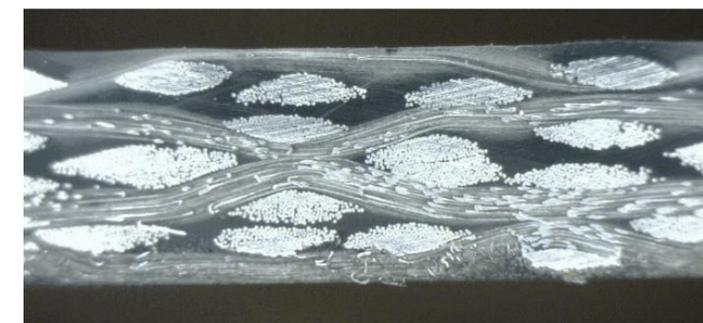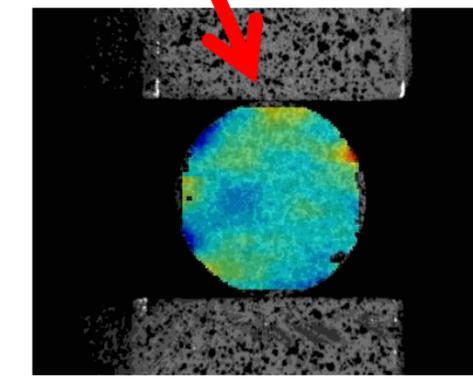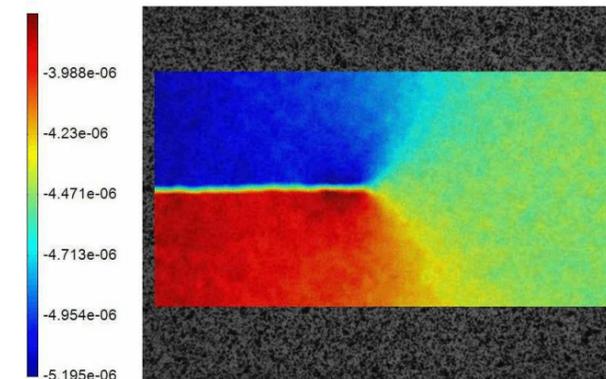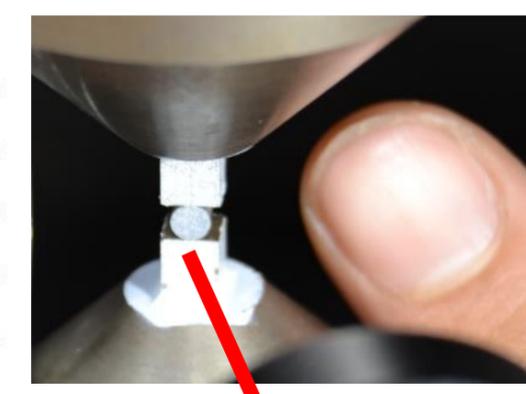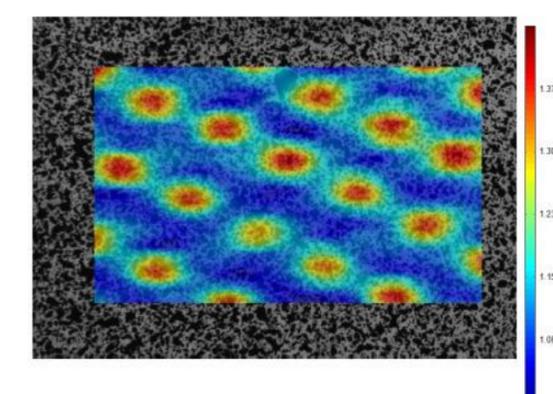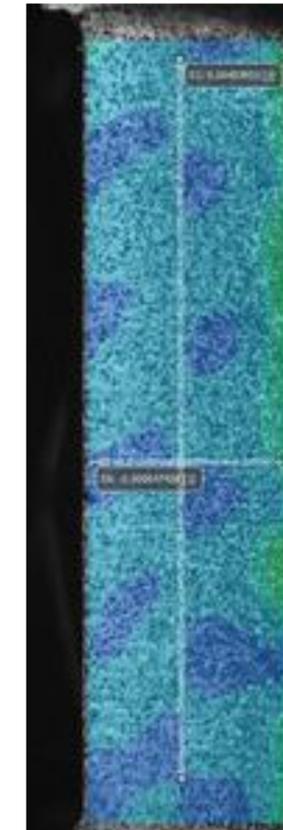 - damping measurements
  - modal analysis
- **Structural testing**
  - bird strike testing
  - impact testing of large composite components
  - testing of racing bicycle frames
  - outdoor testing (wave impact, blast testing, sailing yachts,…)

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Ghent University – Faculty of Engineering

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COMPOSITES
at Ghent University

CHARACTERIZATION AND MONITORING

- **Digital Image Correlation (DIC)**
    - full-field strain measurement
    - high-speed DIC (500 000 fps)
    - high-resolution DIC (~mm field of view)
    - real-time DIC in fatigue
    - sub-micron DIC
- **Optical fibre sensors**
    - surface mounted and embedded in composites
    - down to 60 μm diameter
- **Optical grating methods**
- **Online video-microscopy**
    - monitoring of crack growth
    - evolution of fatigue damage
- **Micro-tomography (micro-CT)**
    - in-situ loading of dry fabrics and composites
    - Digital Volume Correlation
    - Contrast agents for micro-CT
    - CT imaging > geometry reconstruction > FEM mesh
- **Optical microscopy**
    - stitched high-resolution microscopy
    - magnification up till 2000x
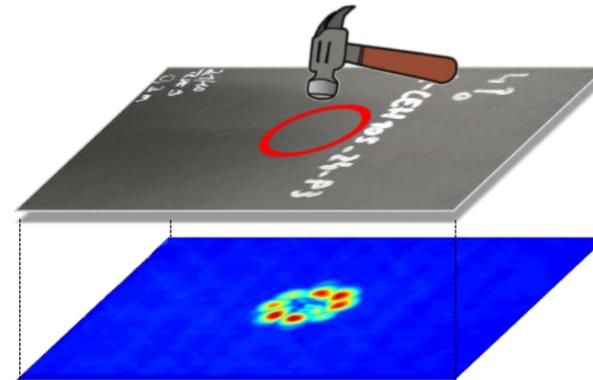- **Scanning Electron Microscopy (SEM)**

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COMPOSITES at Ghent University

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Ghent Univers
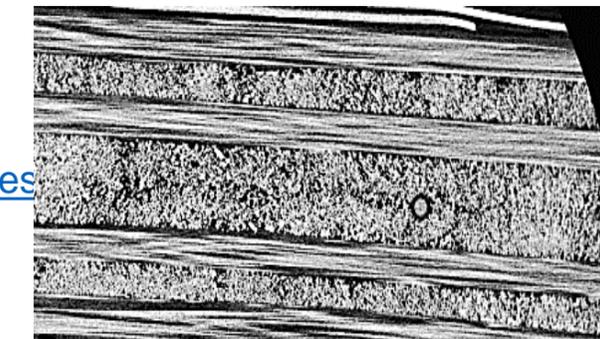
NONDESTRUCTIVE TESTING (NDT)

Winner of European "NDT in Aerospace" challenge (Paris, 2019)
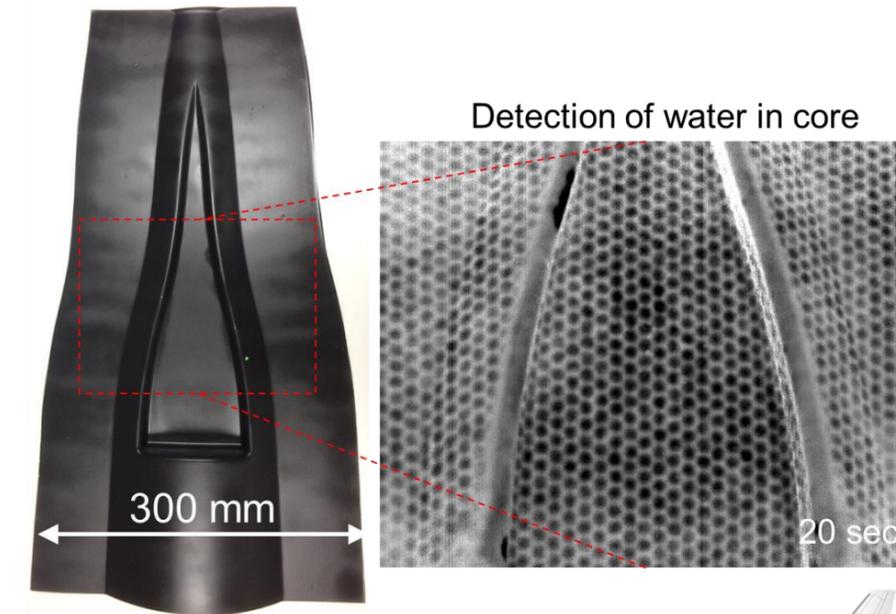
- **Ultrasound scanning**
  - measurement of delaminations
  - measurement of full orthotropic stiffness tensor
  - thickness measurement of coatings
  - high-frequency ultrasound (75 MHz)
  - air-coupled ultrasound
- **Active thermography for defect detection**
  - lockin thermography
  - vibrothermography
  - Thermoelastic Stress Analysis (TSA)
  - numerical simulation of thermographic inspection
- **Laser scanning vibrometery for defects**
  - 3D scanning Laser Doppler Vibrometer
  - Local Defect Resonance (LDR)
  - modal analysis of composite components
- **Guided waves**
  - Linear and nonlinear elastic waves
  - Wave spectroscopy
  - Sparse array tomography
- **Mechanoluminescent powder**
  - light emittance under mechanical stress
  - long-term solution for NDT ?
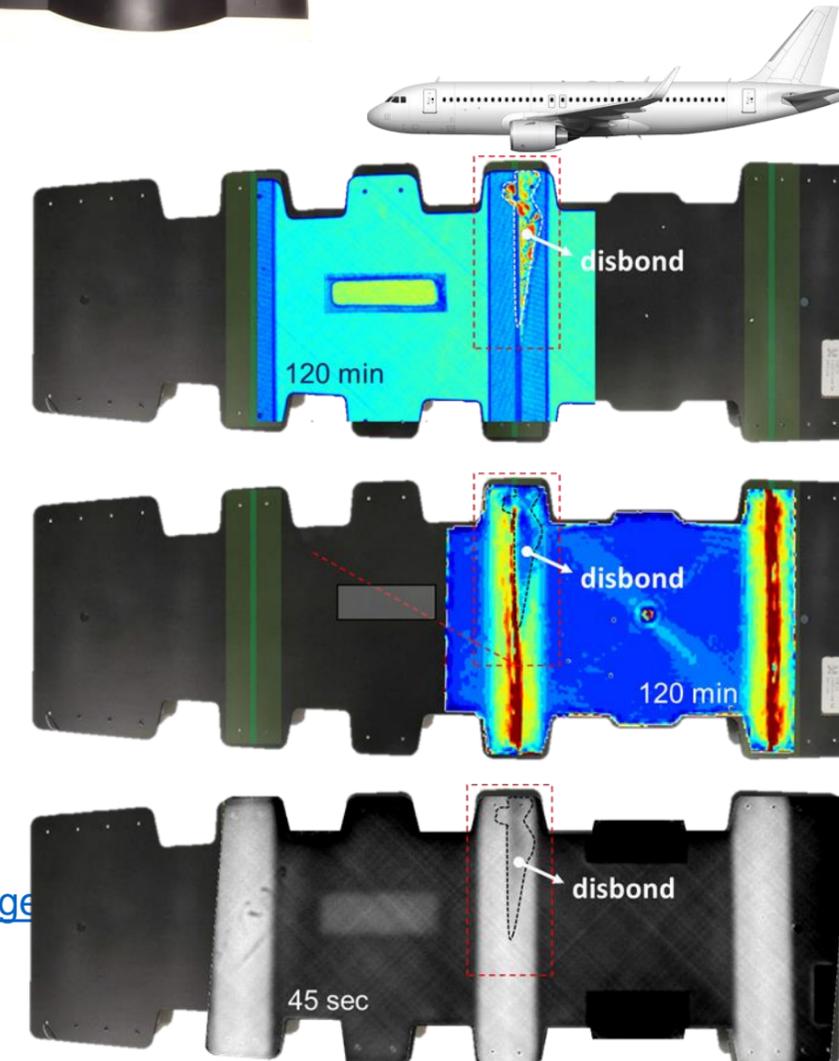
Detection of water in core

300 mm

20 sec

RIDLEY

EDDY MERCKX

BVID

600 mm

Ø 60 mm

30 min

disbond

120 min

disbond

120 min

disbond

45 sec

defects

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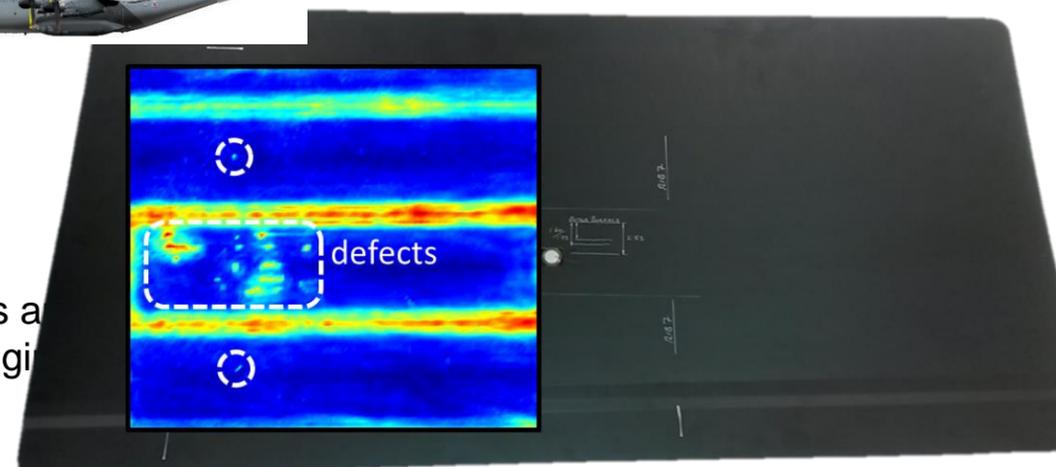
NUMERICAL MODELLING

- **Micro-scale modelling**
  - unit cell with periodic boundary conditions
  - coupled visco-elasto-plasticity-damage-failure
  - fibre/matrix interface debonding
- **Meso-scale modelling**
  - unit cell of textile composites
  - static damage development
  - fatigue initiation and propagation
  - Reduced Order Modelling for RVE simulations
- **Fracture mechanics**
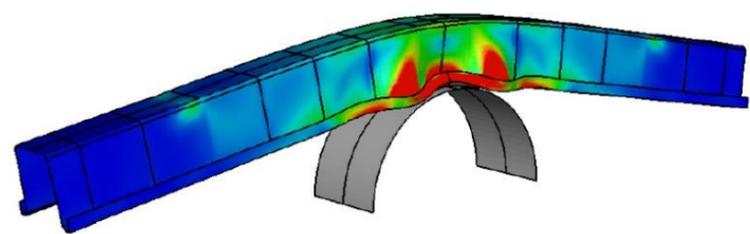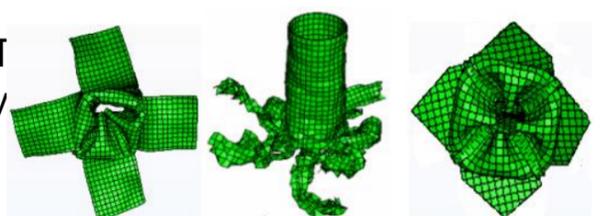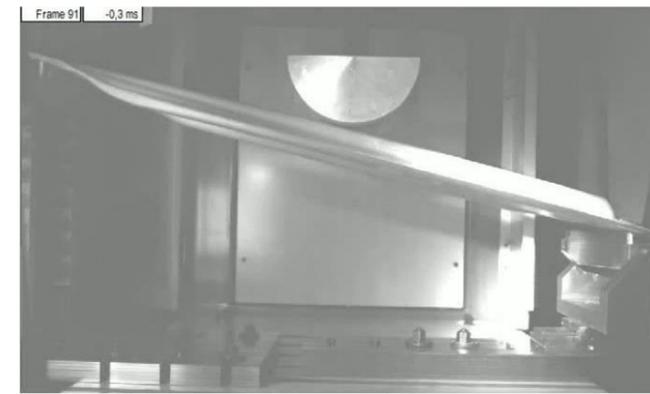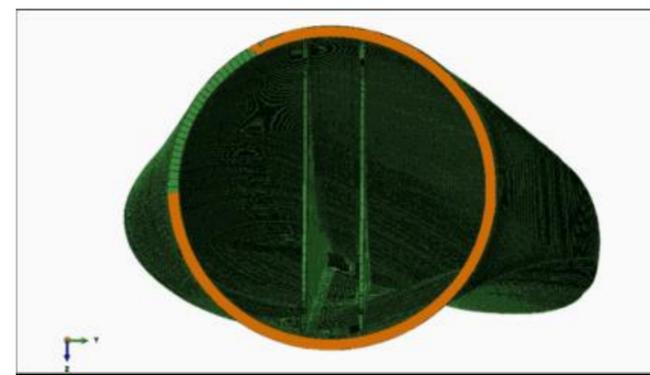 - stress intensity factors
  - (dynamic) delamination modelling
- **Macro-scale (ply-based modelling)**
  - orthotropic visco-elasto-plasticity-damage-failure
  - fatigue initiation and propagation
  - low-velocity impact and Compression After Impact (CAI)
  - strain-rate dependent stiffness, strength and toughness
 - dynamic crushing
- **Structural scale modelling**
  - hydrogen storage tanks
  - bird strike modelling
  - wind turbine blade modelling
  - topology and shape optimization
 - miscellaneous (tent structures, bicycle frames,…)

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COMPOSITES
at Ghent University

Department of Materials, T
Ghent University – Faculty
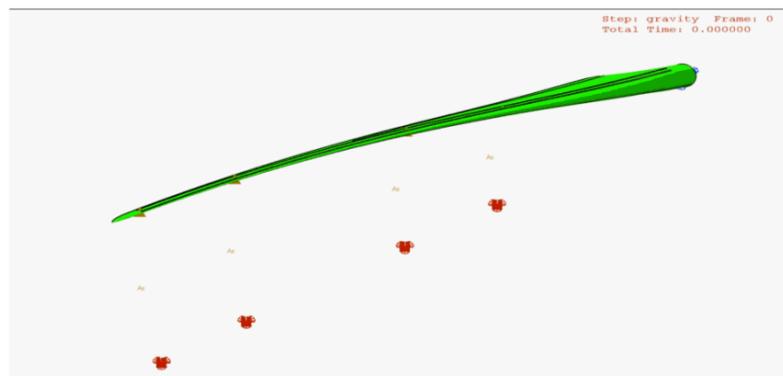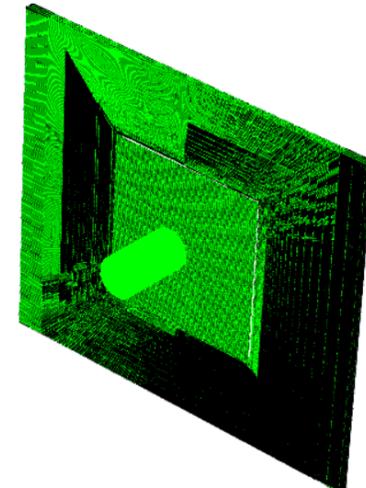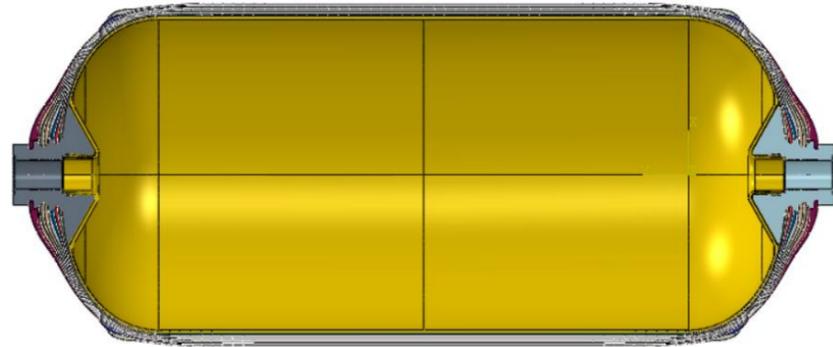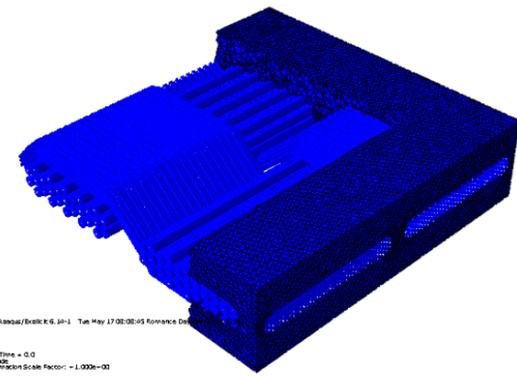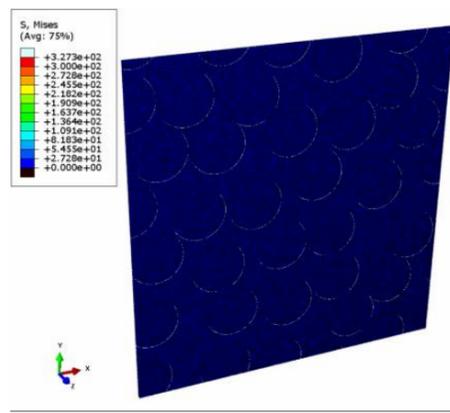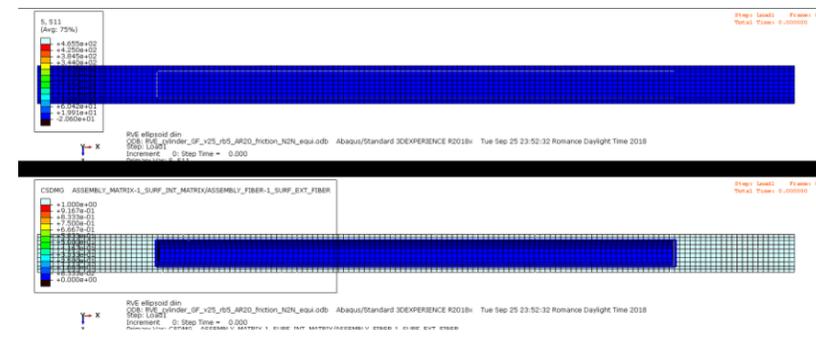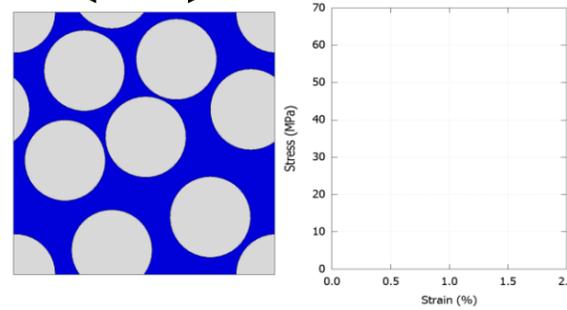
Loading direction

SPECIALIZED NUMERICAL METHODS

- **Variational methods for Uni-Directional composites**
  - prediction of matrix cracking and delamination in UD composites
  - arbitrary lay-up, multi-axial in-plane and bending loading
  - exact calculation of free-edge interlaminar stresses
  - very fast semi-analytical method (~ seconds)
- **Mean-field homogenization (MFH) methods for short fibre composites**
  - temperature-coupled visco-elasto-plasticity of short fibre thermoplastics
  - thermomechanical creep of short fibre composites
  - progressive fibre/matrix debonding in short fibre composites
- **eXtended Finite Element Method (XFEM)**
  - crack growth in concrete, polymers and (3D printed) metal
  - crack growth in self-healing materials
- **Fluid-structure-interaction (FSI)**
  - aero-elasticity of wind turbine blades (BEM + FEM)
  - drop tests of beverage cans (CEL)
  - air cavities in tyres and footballs (acoustic meshes)
 - slamming wave impact on offshore structures (SPH)
  - survivability of wave energy converters (SPH)
  - ditching of aircraft (SPH)
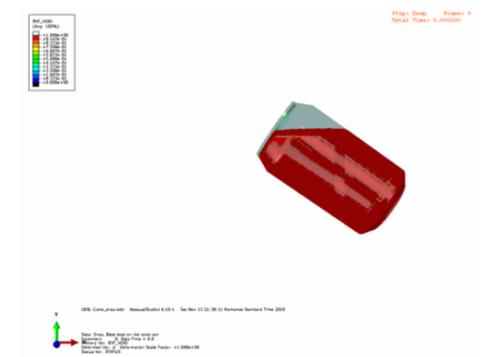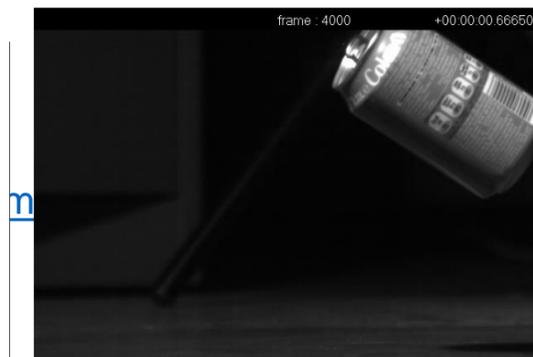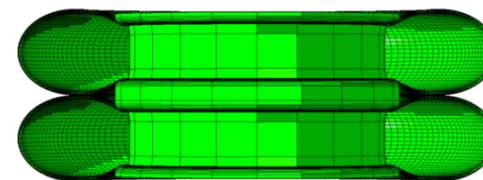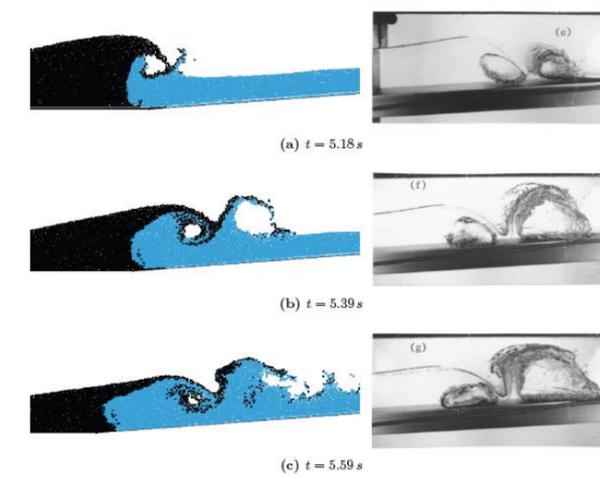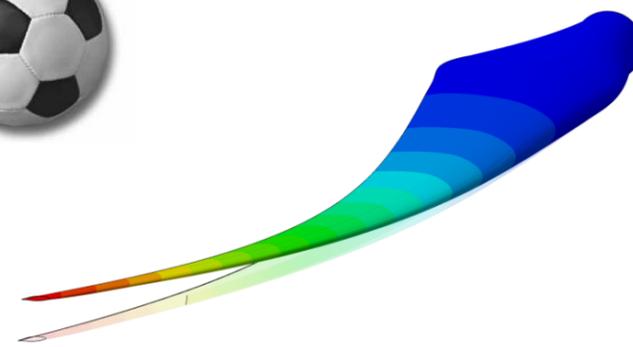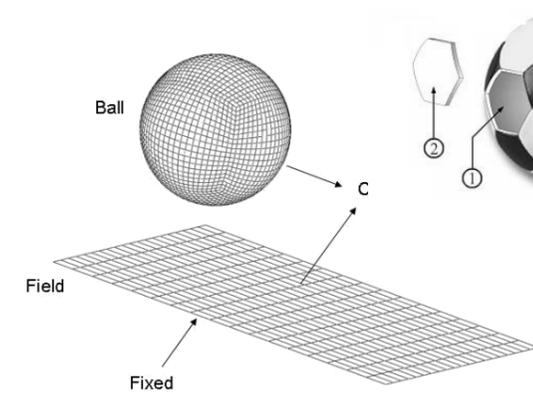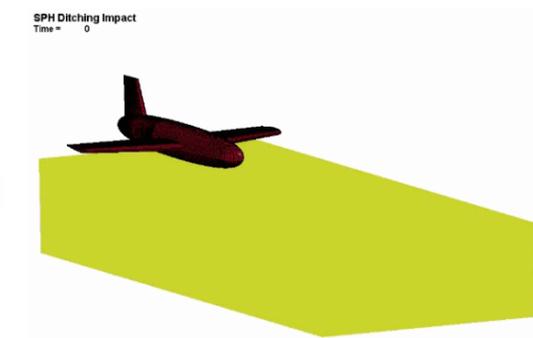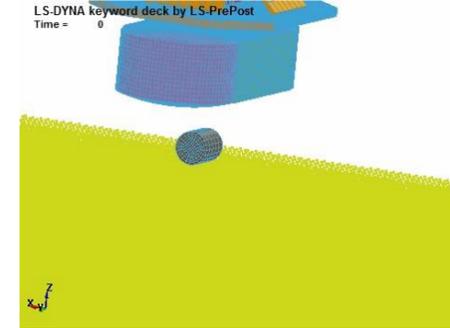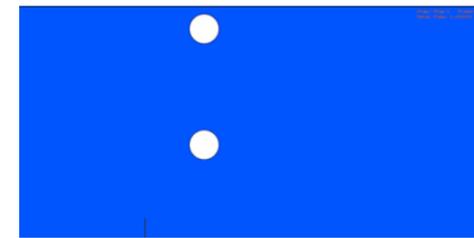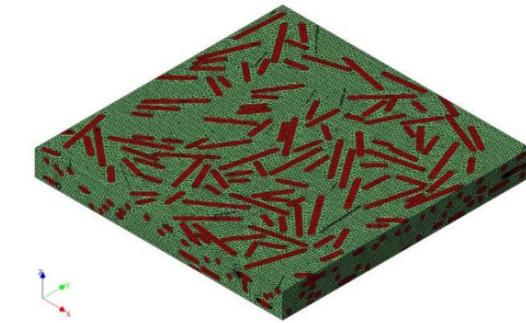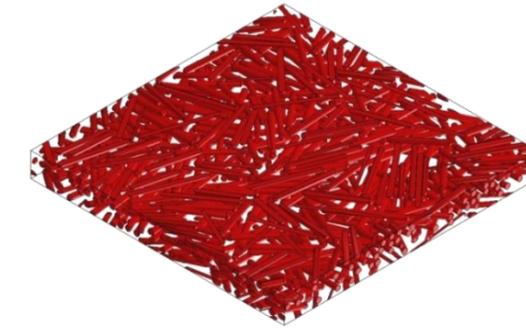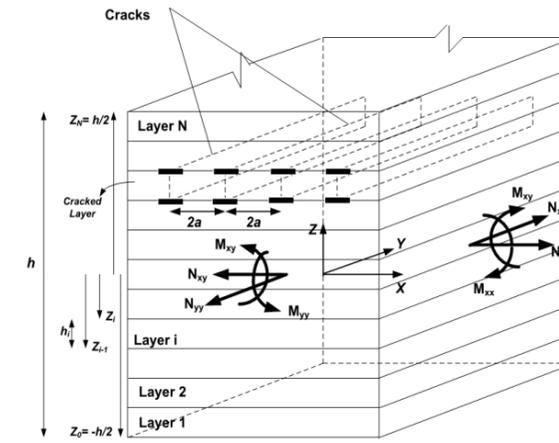
COMPOSITE PROCESSING

- **Dry fabric mechanics**
  - Prediction of textile geometry after weaving (as-woven properties)
  - Through-thickness compaction of dry fabric stacks
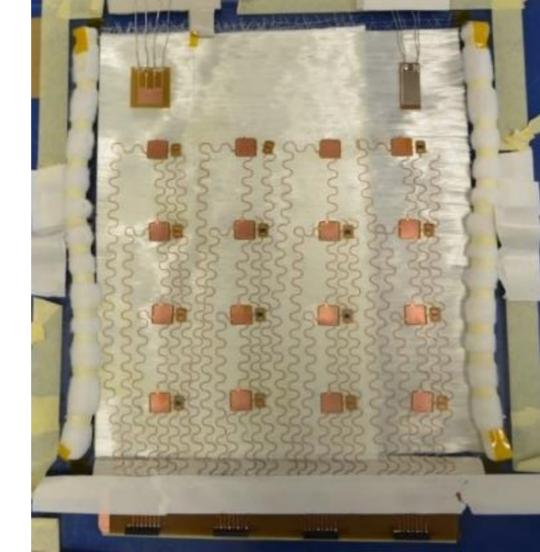 - Shear properties of dry fabrics
  - Draping of dry fabrics
- **As-manufactured geometry reconstruction**
  - Bad X-ray contrast for carbon fibre-reinforced composites -> difficult segmentation
  - Segmentation methods based on variational approaches and deep learning methods (Convolutional Neural Networks)
  - Denoising by fusion of CT images
  - FEM meshing for numerical homogenization
- **Injection moulding of short fibre composites**
  - Coupled simulation of injection moulding (Moldex3D), local material properties (Digimat) and thermomechanical simulation (Abaqus)
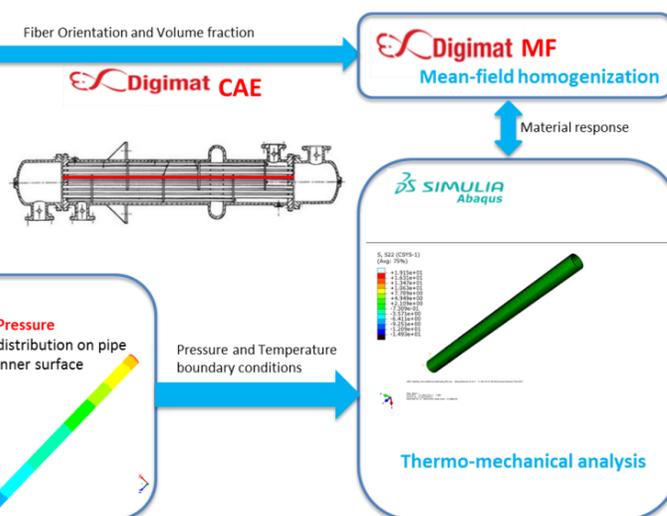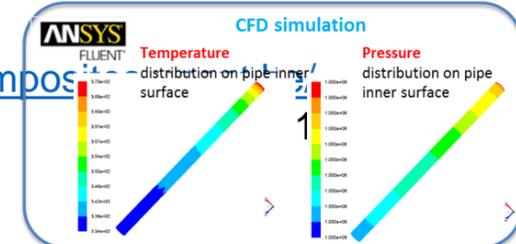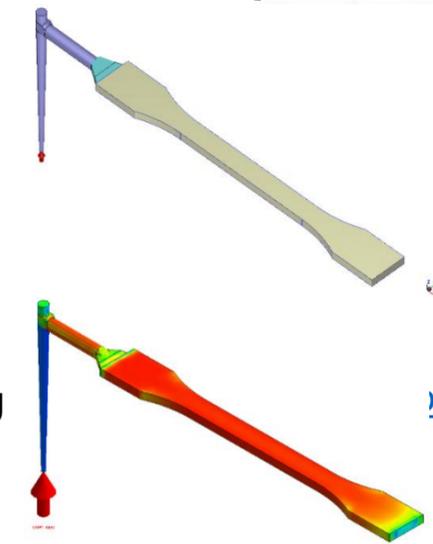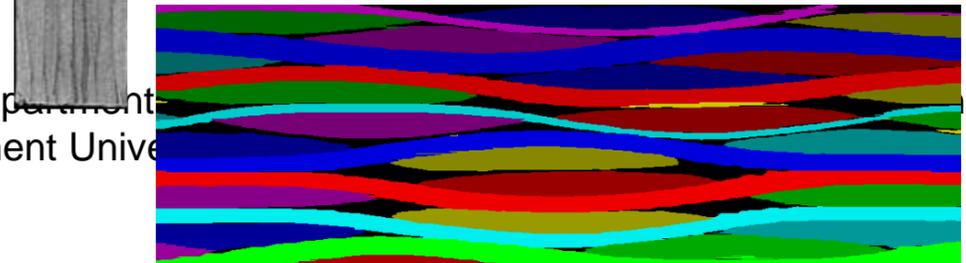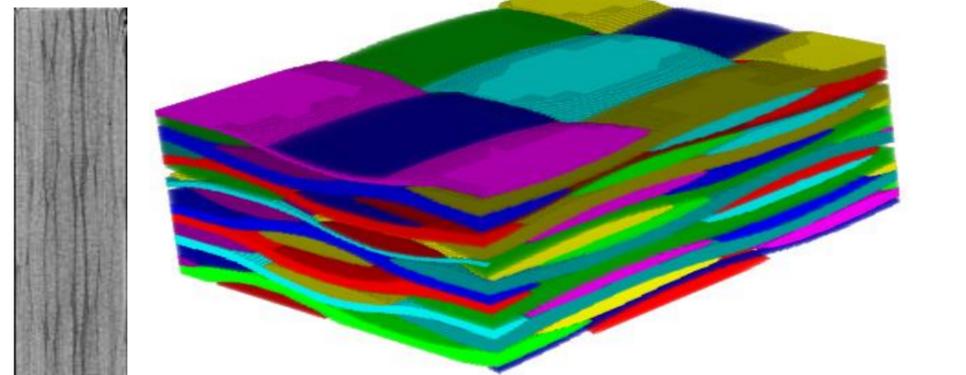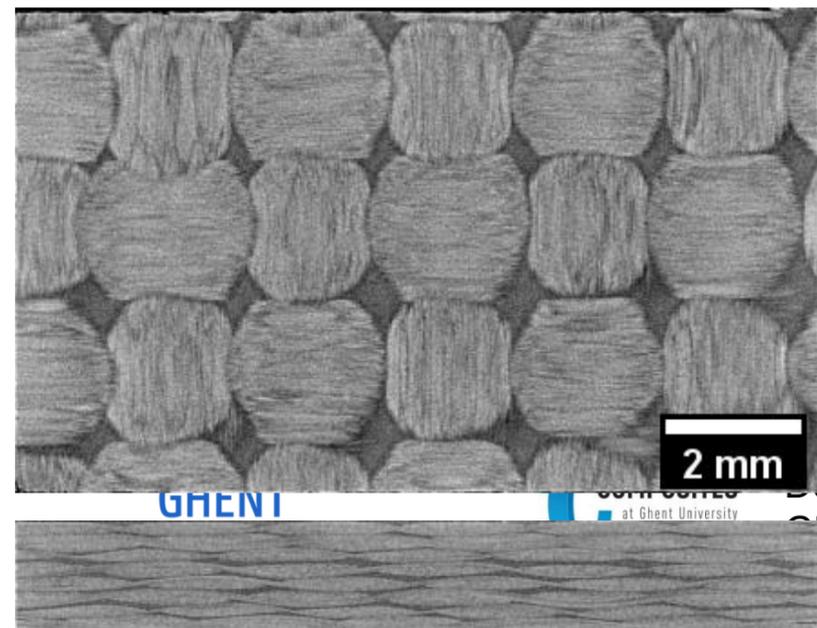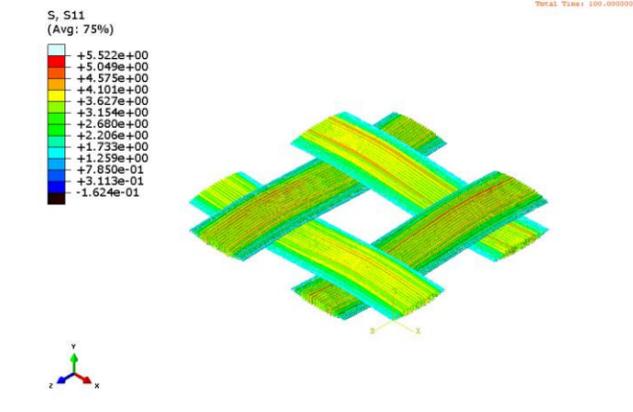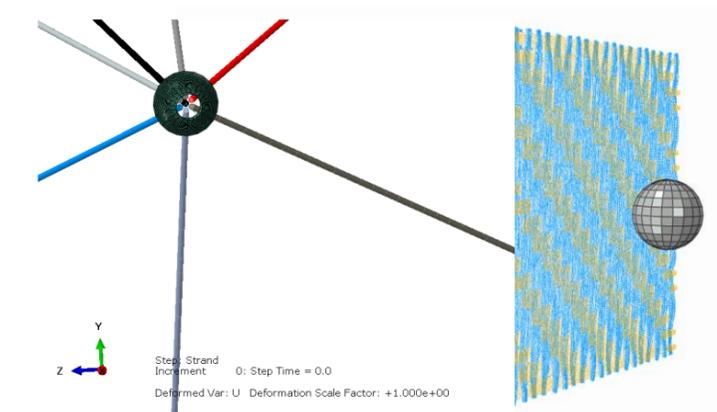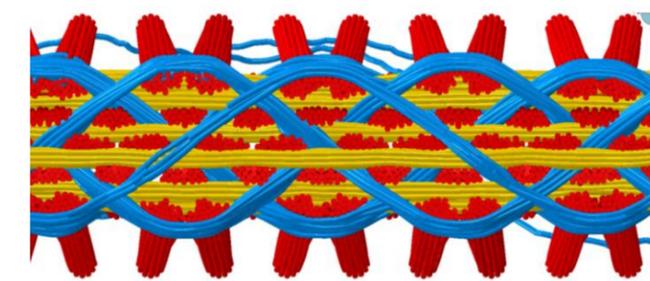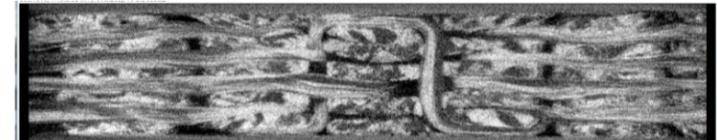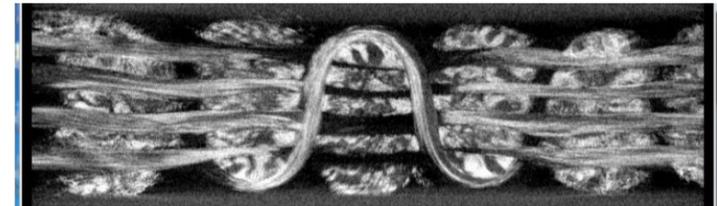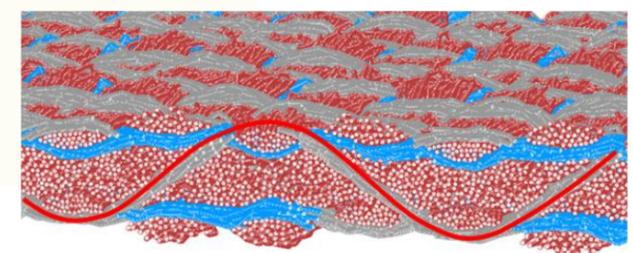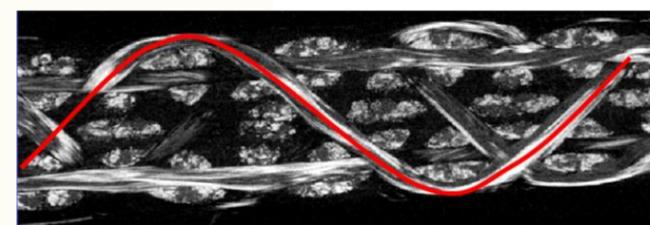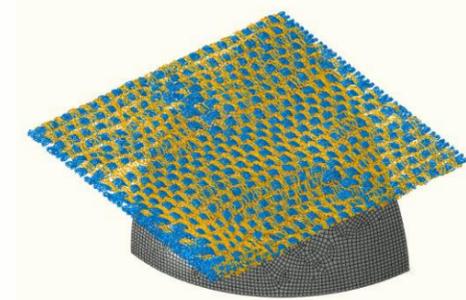
COMPOSITE PROCESSING

- **Consolidation of thermoplastic tapes and prepregs**
  - Hydraulic press (till 420 °C) with vacuum and thermocouples
  - Mould design and optimization
  - Consolidation of unidirectional glass/PP and carbon/PEEK tapes
- **Fusion bonding of thermoplastic composites**
  - Ultrasonic welding
- **Fused Filament Fabrication (FFF) additive manufacturing**
  - Modelling of extrusion-based filament fabrication processes
  - Coupling with rheology and inter-layer adhesion
- **Vitrimers for composite recycling**
  - New polymer chemistry for recycling of composites
  - Processing of glass/vitrimer composites
- **Capacitive sensors for cure monitoring**
  - cure sensors on chip can be embedded in composite
  - sensor network with stretchable wires
- **3D printed moulds for composites**
  - WAAM process (Wire Arc Additive Manufacturing)
  - Topology optimization for heat transfer and distortion control
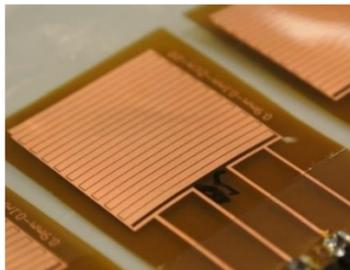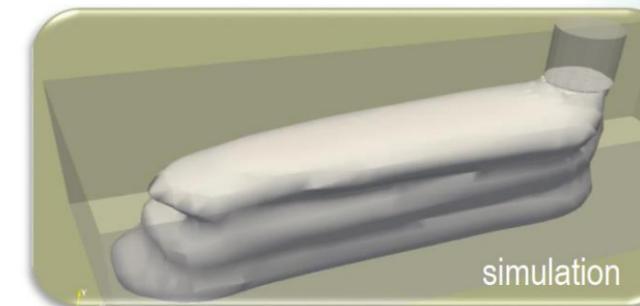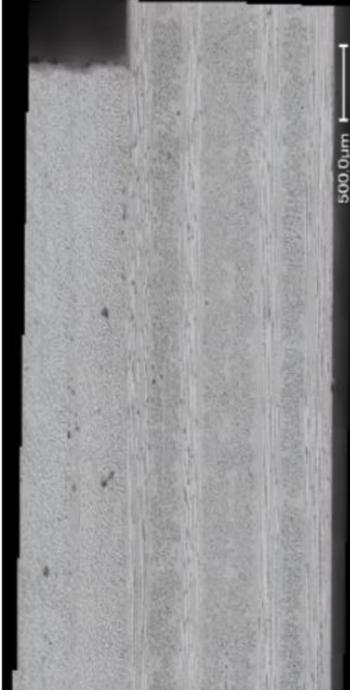
BESIDES COMPOSITE MATERIALS...

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http://www.composites.ugent.be/
13

POLYMERS, FOAMS, ADHESIVES, GLASS,…

- **Thermoset and thermoplastic polymers**
  - Dynamic fracture models for brittle and ductile polymers, including rate-dependence and crack branching
  - Combined visco-plastic/damage/fracture material models for polymeric materials
- **Foams**
  - Simulation of impact and energy absorption behaviour of EPS foams for bicycle helmets
  - Use of foams and other novel materials in string music instruments
- **Joints / coatings**
  - Testing and simulation of adhesive joints
  - Pull-off dolly tests for strength of adhesive interfaces and coatings
  - New on-site joining technologies for PTFE sealant rings
- **Laminated glass**
  - Directional brittle smeared cracking models for glass
  - Strain-rate dependent hyperelastic models for soft polymer interlayers in laminated glass
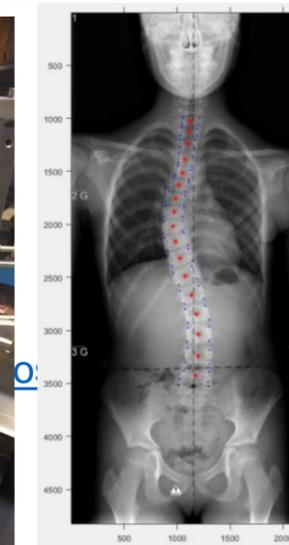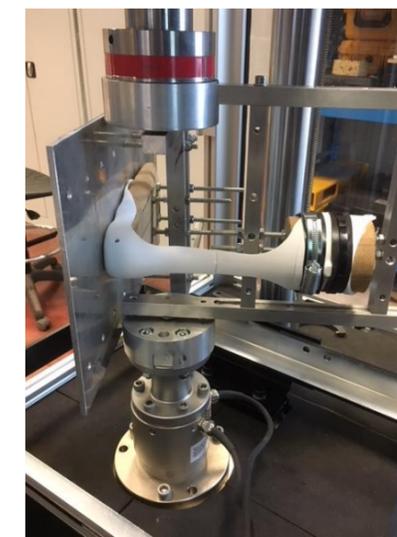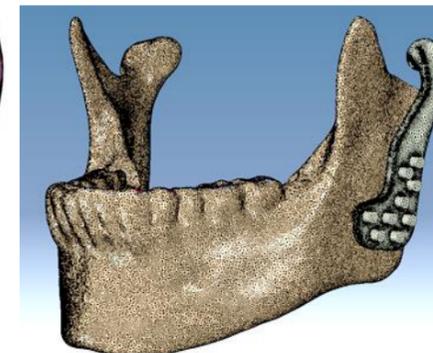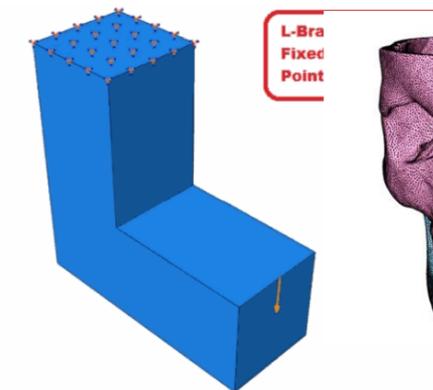
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COMPOSITES at Ghent University
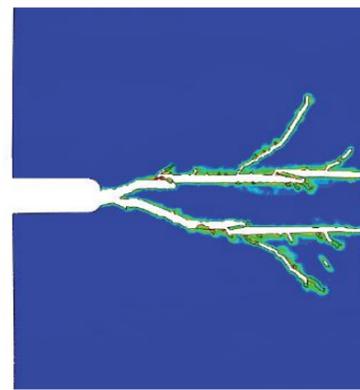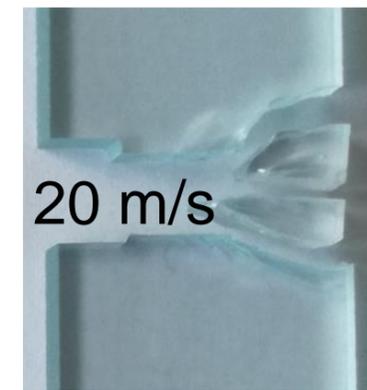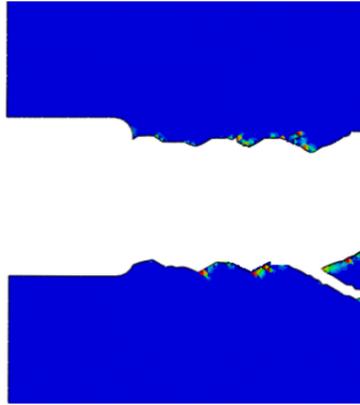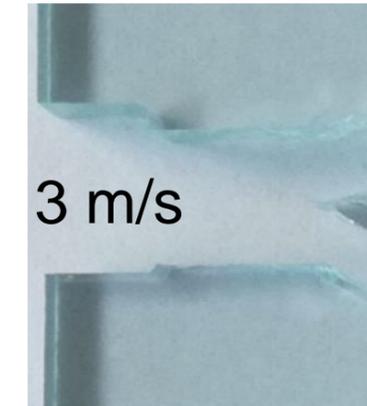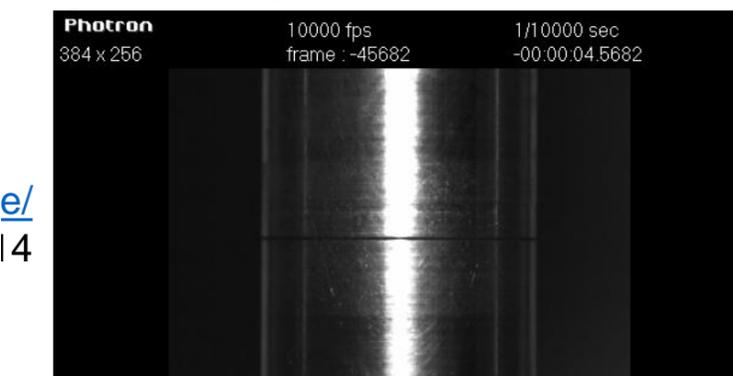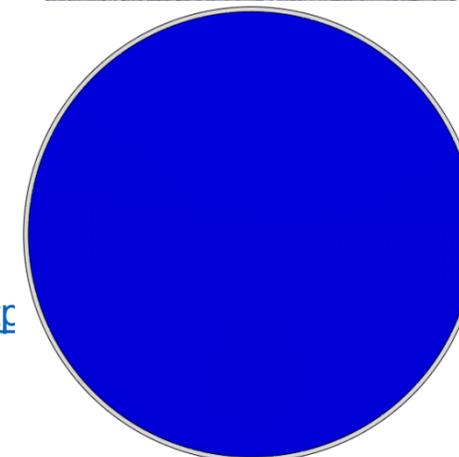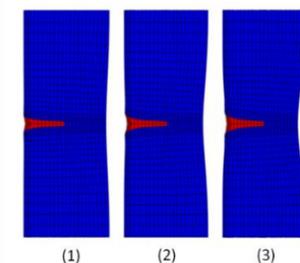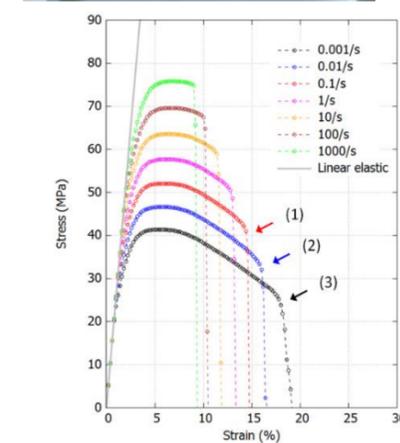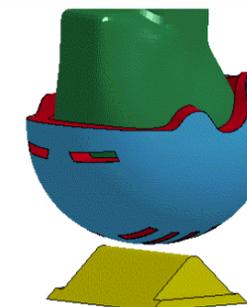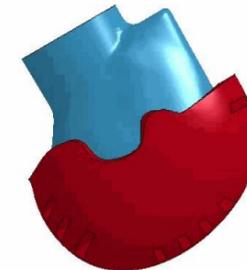
ADDITIVE MANUFACTURING

- **Additive Manufacturing Process simulation**
  - Discrete Element Method (DEM) simulations for powder deposition in powder-based printing processes (SLM, SLS)
  - Computational Fluid Dynamics (CFD) simulations for Fused Filament Fabrication (FFF) processes of polymers/mortar/concrete
- **Fast inspection of 3D printed parts**
  - Complex AM geometry -> conventional NDT methods do not work
  - shift in high-frequency resonance peaks due to defects
- **Topology optimization**
  - For large 3D components under combined thermomechanical loads
  - Multi-material topology optimization
  - Multi-physics topology optimization for electrical machines
- **Fatigue testing and simulation**
  - Fatigue properties of PA12, Titanium, Stainless steel,…
  - Fatigue crack growth tests (Compact Tension tests)
  - Simulation of effect of voids and surface roughness on fatigue life of AM metals (Titanium, Stainless steel, Inconel alloys)
- **Medical applications**
  - Fatigue of Ankle Foot Orthosis (AFO)
  - Titanium implants for Temporo-Mandibular joint, trauma plates,…
  - Scoliosis braces

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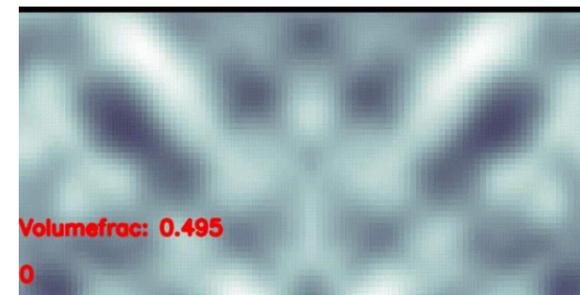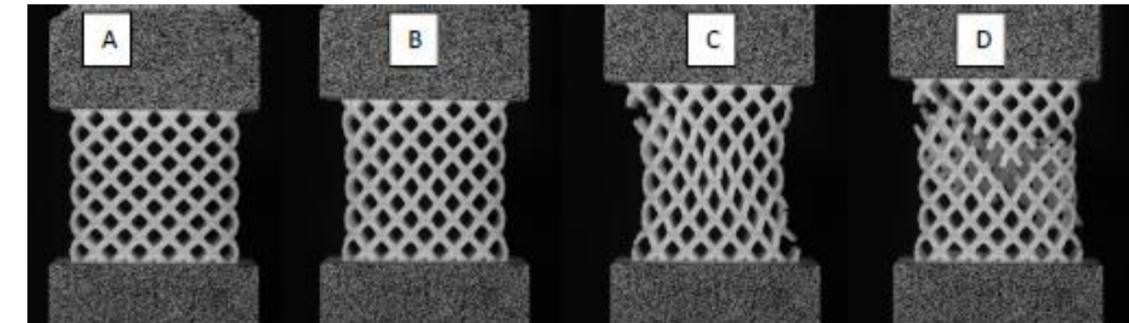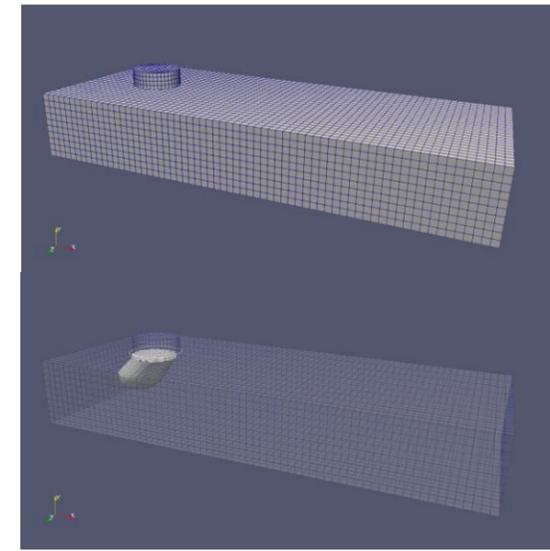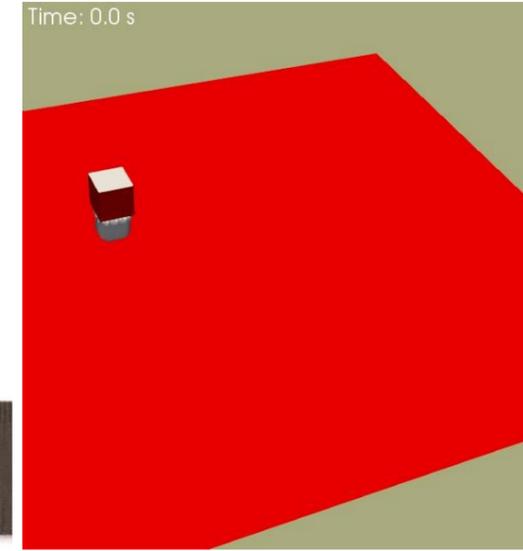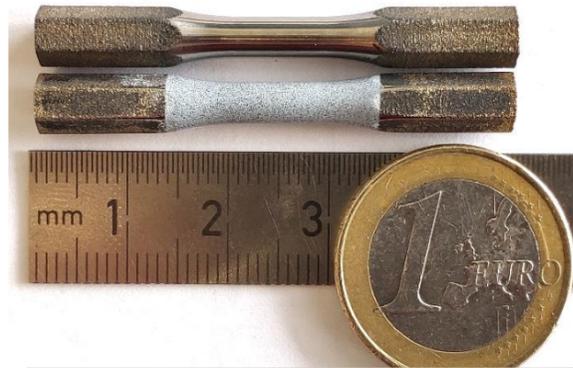
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