COMPOSITE MATERIALS RESEARCH
@UGENT-MMS

Prof. dr. ir. Wim Van Paepegem
http://www.composites.ugent.be/
PERSONNEL

3 Professors (ZAP)
1 Doctor-assistant (AAP)
29 (+ 5) Researchers (internal)
4 Researchers (external)
2 Technicians
15-20 Master thesis students
PERSONNEL

Evolution of the number of postdoctoral researchers, internal and external PhD students and master thesis students in the research group UGent-MMS (2002-2019)

Number [-]

Year [-]

- Postdocs
- Internal PhD students
- External PhD students
- Master thesis students

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

Automotive
- Siemens
- Honda R&D
- Bosch R&D
- Toyota
- 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

Industry/construction
- Bekaert
- Atlas Copco
- Parker
- Sioen
- FiberCore
- Spiromatic
- OCAS
- Samsonite

Sports
- Eddy Merckx Cycles/ Ridley
- Lazer Sport
- Koga

Simulation software
- Simulia / Dassault
- Siemens
- e-XStream / MSC.Software
- 4RealSim

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

Valorization consortium “Composites” at Ghent University

- Coordination by our group UGent-MMS
- Full-time business developer
- Liaison officer for all valorization activities/technology transfer to industry

Four spin-off companies
- Com&Sens - Composites & Sensing (http://www.com-sens.eu/)
- MadSis - MAterials, Design, Simulations, Software (http://www.madsis.eu/)
- BikeLabs International – Bicycle testing & consultancy (http://www.bikelabsinternational.com/)
- TechSpert – Mechanical testing

Recognized service department by Vlaio for “KMO-cheques”
125 *Science Citation Index (SCI)* publications over last 7 years (average output of 18 publications/year)

1/3 is top 10% publications in SCI peer-reviewed journals

**PUBLICATION OUTPUT**

**Distribution of all 125 Science Citation Index publications**

- **1st quartile**: 92 publications
- **2nd quartile**: 25 publications
- **3rd quartile**: 6 publications
- **4th quartile**: 2 publications

**Dedication to quality !!!**
ADVANCED CALCULATION ENVIRONMENT

- CAE/CAD: SolidWorks, Catia, FreeCAD
- Finite elements: Abaqus, LS-Dyna, Siemens SimCenter/NX, Samcef, Code_Aster, Morfeo/Crack
- Composite draping modules: Catia/CPD, Simulayt/Composite Modeler
- Digimat (e-XStream/MSC) software for short-fibre composites
- Mimics Innovation Suite (Materialise): CT image segmentation and 3D printing design
- Optimization software: iSight, Tosca, Samcef/TOPOL, evolutionary strategies
- UM software for kinematics and multibody dynamics
- Access to HPC cluster for finite element calculations (12000+ cores, 3.2 Terabyte RAM)
- Advanced professional user of the finite element code Abaqus (Simulia)
- Strategic collaboration agreement with Siemens Industry Software
- In-house developed software
  - large collection of user material models (visco-elasto-plasticity, (fatigue) damage, strain-rate, hyperelasticity, Ladeveze,…)
  - software suite (Matlab) for prediction of matrix cracking and free-edge interlaminar stresses in UD composites
  - SERVE: Statistically Equivalent Representative Volume Element (RVE)
  - ORAS: Object-Oriented RVE Assembly Software
  - Blade Mesher: meshing tools for large wind turbine blades
  - DEM (Discrete Element Method) solver for million+ particles

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RESEARCH AREAS

Key areas for composites:

- **Impact** (bird strike, drop weight tower, crushing, low velocity impact,...)
- **Fatigue** (tension/compression, bending, shear, delamination,...)
- **NDT/NDE** (ultrasound, thermography, vibrometry, guided waves,...)
- **General mechanics** of composite materials

Mission statement:

“To study the mechanical behaviour of composite materials by a combined approach of instrumented experimental testing and adequate numerical modelling, in close collaboration with the composites industry and its suppliers”
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, …)
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)**
NONDESTRUCTIVE TESTING (NDT)

• Ultrasound scanning
  • measurement of full orthotropic stiffness tensor
  • measurement of delaminations
  • thickness measurement of coatings
  • high-frequency ultrasound (75 MHz) and air-coupled ultrasound

• Active thermography for defect detection
  • lockin thermography
  • vibrothermography
  • Thermoelastic Stress Analysis (TSA)
  • numerical simulation of thermographic inspection

• Laser scanning vibrometry for defects
  • 3D scanning Laser Doppler Vibrometer
  • Local Defect Resonance (LDR)
  • modal analysis of composite components

• Capacitive sensors for cure monitoring
  • cure sensors on chip can be embedded in composite
  • sensor network with stretchable wires

• Mechanoluminescent powder
  • light emittance under mechanical stress
  • long-term solution for NDT

Winner of European “NDT in Aerospace” challenge (Paris, 2019)
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**
  - bird strike modelling
  - wind turbine blade modelling
  - topology and shape optimization
  - miscellaneous (tent structures, bicycle frames, …)
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

- **Injection moulding of short fibre composites**
  - Coupled simulation of injection moulding (Moldex3D), local material properties (Digimat) and thermomechanical simulation (Abaqus)

- **Consolidation of thermoplastic tapes and prepregs**
  - Hydraulic press (till 420 °C) with vacuum and embedded thermocouples
  - Mould design and optimization
  - Consolidation of unidirectional glass/PP tapes
  - Consolidation of unidirectional carbon/PEEK prepreg’s

- **Vitrimers for composite recycling**
  - New polymer chemistry for recycling of composites
  - Processing of glass/vitrimer composites
BESIDES COMPOSITE MATERIALS…
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
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 Deposition Modelling (FDM) processes of thermoplastic polymers

- **Quality control**
  - Micro-tomography (micro-CT) imaging of voids
  - Scanning Electron Microscopy (SEM) inspection of surface roughness, voids and failure initiation

- **High-frequency resonant testing for NDT of 3D printed parts**
  - Complex AM geometry -> conventional NDT methods do not work
  - Shift in high-frequency resonance peaks due to defects

- **Mechanical characterization**
  - Stiffness and strength of PA12, PP, Titanium, Stainless steel...
  - Topology optimization

- **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 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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