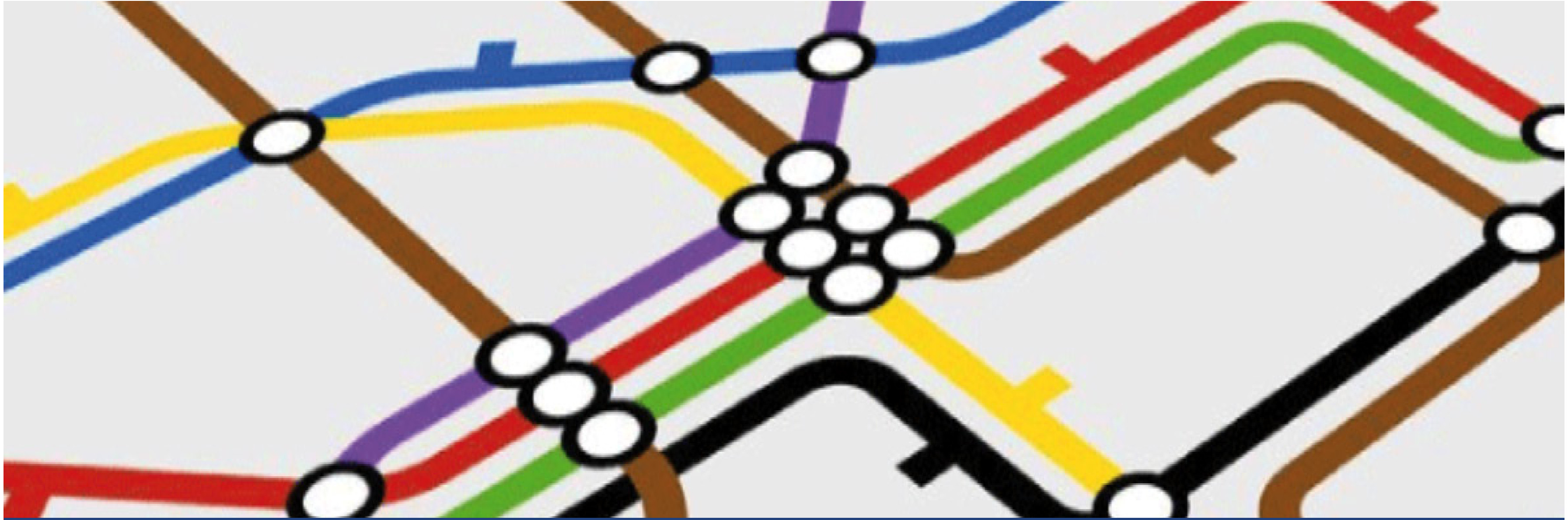
In cooperation with the CTI
Energy funding programme
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

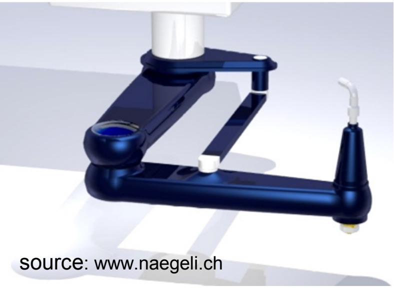


Minimization of Vehicular Energy Demand (CA3)

C. Dransfeld (FHNW), P. Ermanni (ETHZ), G. Georges (ETHZ),
V. Michaud (EPFL), A. Studart (ETHZ)

2nd Annual Conference SCCER Mobility
ETH Zurich, 26-27 August 2015

Motivation for lightweight structures



source: www.naegeli.ch

Newton: F = m·a

better performance

m ↘ & F → ⇒ a ↗

(higher acceleration with equal forces)

→ faster movements possible

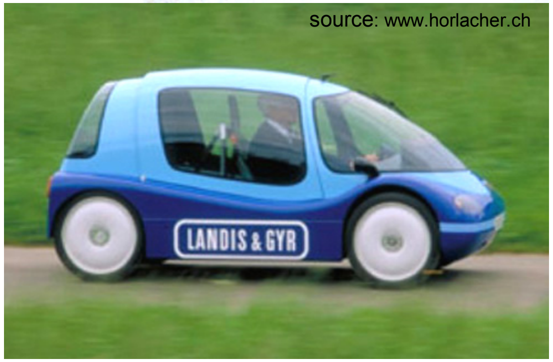
saving energy

m ↘ & a → ⇒ F ↘

(smaller forces at equal acceleration)

→ reduced energy consumption

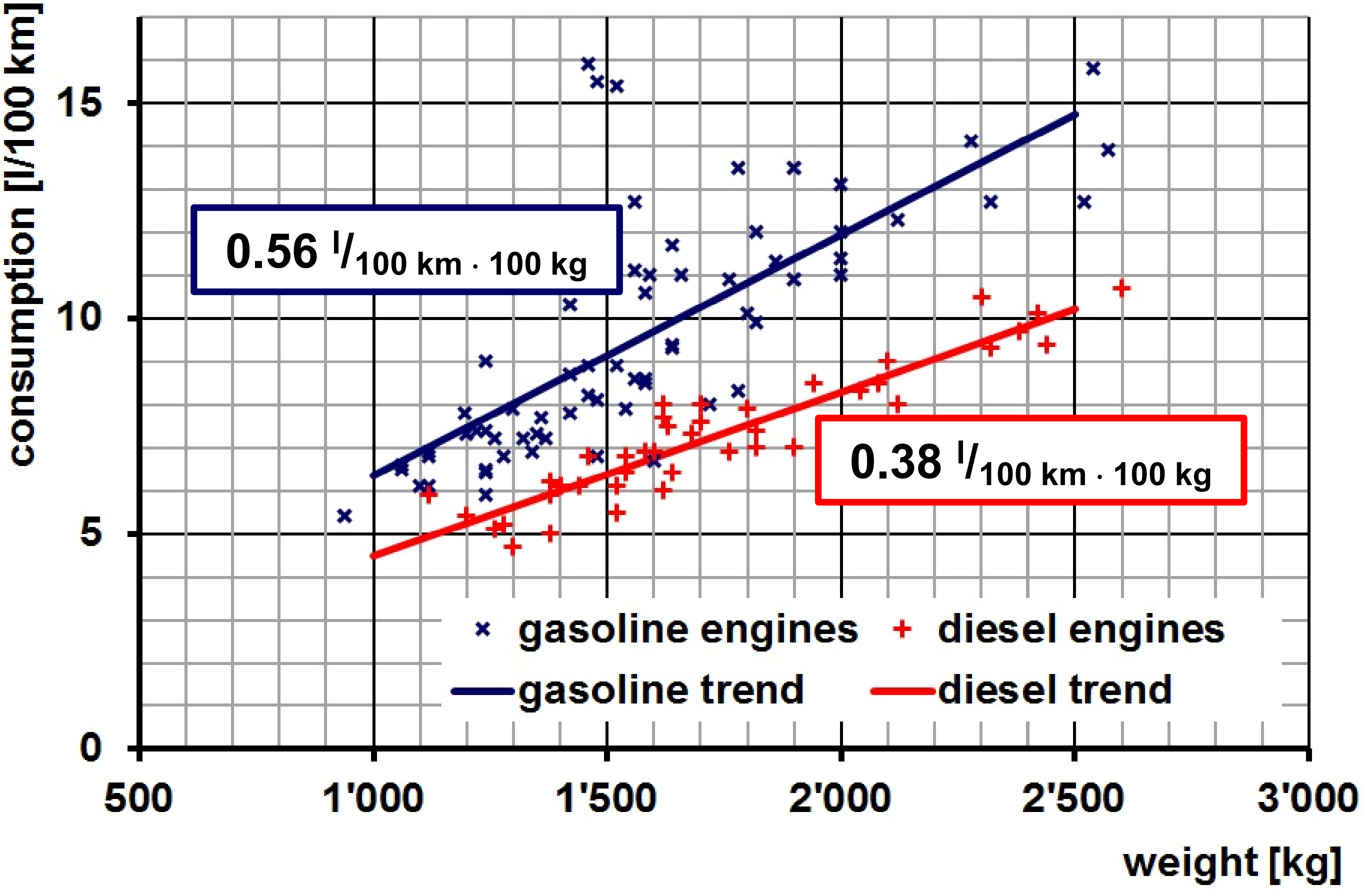
→ less powerful actuators
& simplified secondary
structures possible



source: www.horlacher.ch

Motivation: saving energy

- AR tests 2013: measured consumption & vehicle weight



source: Katalog der Automobil Revue 2014

Capacity Area A3 concentrates its research on technologies for minimization of the energy demand excl. powertrain

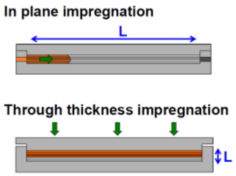
- High volume lightweight thermoplastics
- Bio-inspired composites
- Functional integration of thermal insulation into composites and thermal management of vehicles

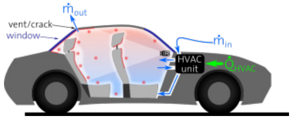
Raw Materials:
Reinforcement: Fibres or particles
Matrix: Thermoplastic polymer

Processing:
Novel impregnation methods for fibres
Alignment of particles

Vehicle in use:
Weight saving effect
Thermal management in electrical vehicles

End of life:
Recycling of thermoplastic composite parts





CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- New routes to high volume production of lightweight thermoplastic composites:
  - Liquid Composite Molding (LCM) with high-fluidity thermoplastic melts,
  - Combination of injection molding and compression resin transfer molding
  - Hybridization and commingling techniques
- Bio-inspired materials:
  - Micro-structured composites with enhanced fracture toughness,
  - Materials with self-healing properties and extended durability.
- Smart thermal management technologies:
  - Use of unsteady heat sources for HVAC through thermal energy storage,
  - Actively conditioning the vehicle while non-operational

CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- New routes to high volume production of lightweight thermoplastic composites:
  - **Liquid Composite Molding (LCM) with high-fluidity thermoplastic melts**

Liquide Composite Molding (LCM) with high-fluidity thermoplastic melts for high-volume automotive applications

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
LABORATOIRE DE TECHNOLOGIE DES COMPOSITES ET POLYMERES

Why LCM?

- ✓ Complex shapes in a single-stage process
- ✓ Low pressure, possibility to insert functional elements
- ✓ Cost-effective

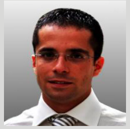
Why low viscosity thermoplastics?

- ✓ Low viscosity PA and PPA show similar mechanical properties to reference PA systems
- ✓ Compatible with RTM processes
- ✓ Possibility to recycle, higher toughness compared to TS matrices

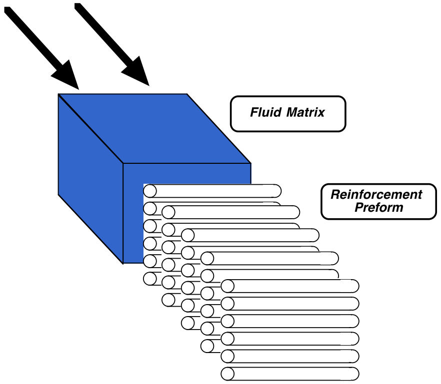
Prof. Véronique Michaud

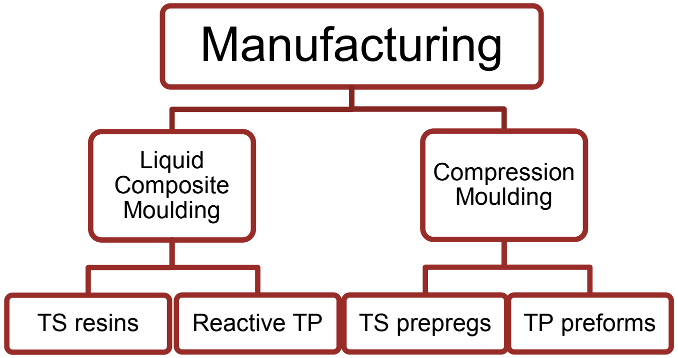
Dr. Sara Dalle Vacche

Mr. Maxime Cattin

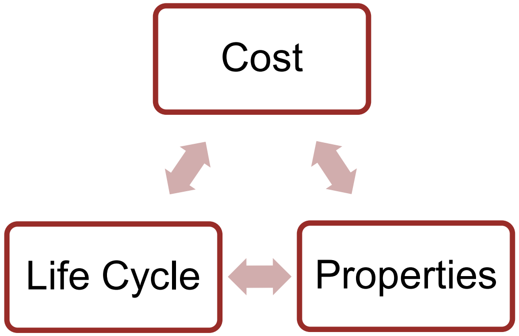


Mr. Damiano Salvatori





Manufacturing
- Liquid Composite Moulding
  - TS resins
  - Reactive TP
- Compression Moulding
  - TS prepregs
  - TP preforms



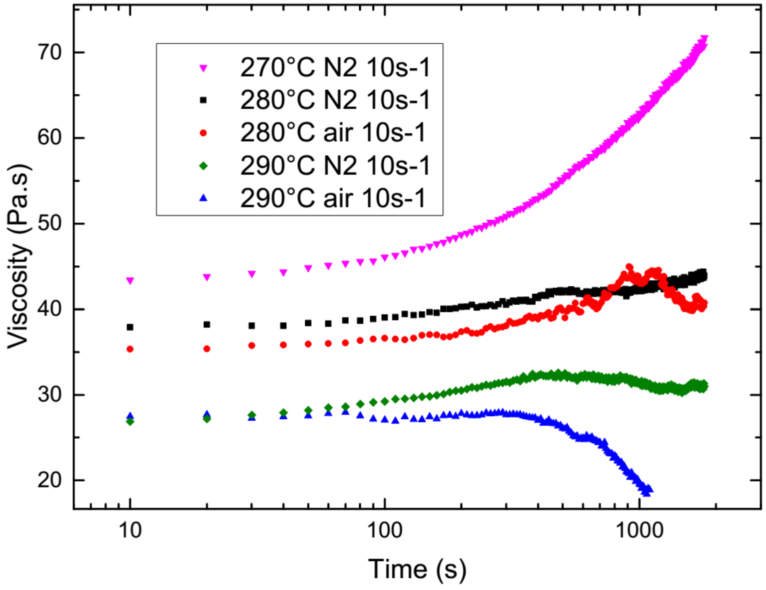
Cost

Life Cycle

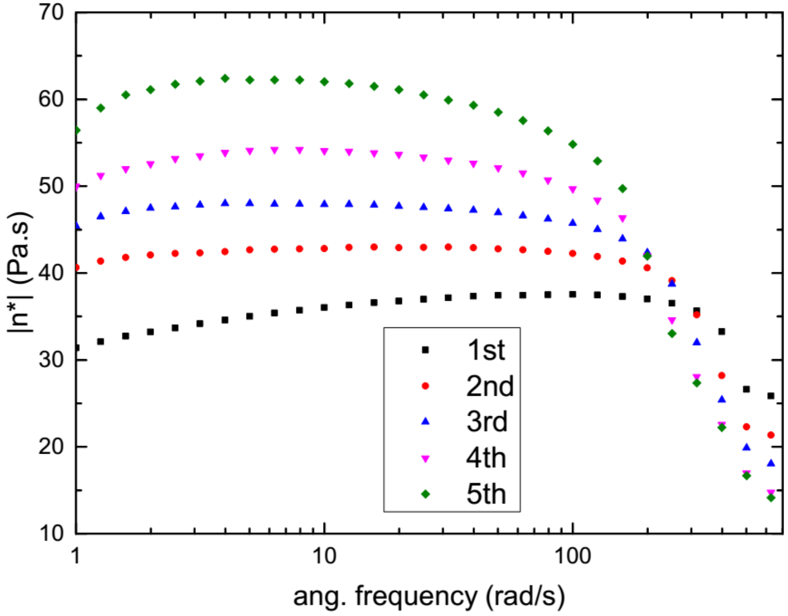
Properties

Rheology of High-Fluidity PA66 by Solvay

Flow peak-hold (plate-plate)



Oscillation frequency sweep (100%) 280°C under N_2 (plate-plate)



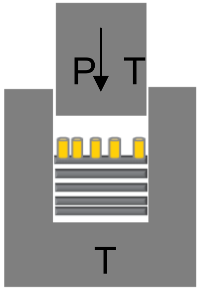
Competition between degradation and condensation

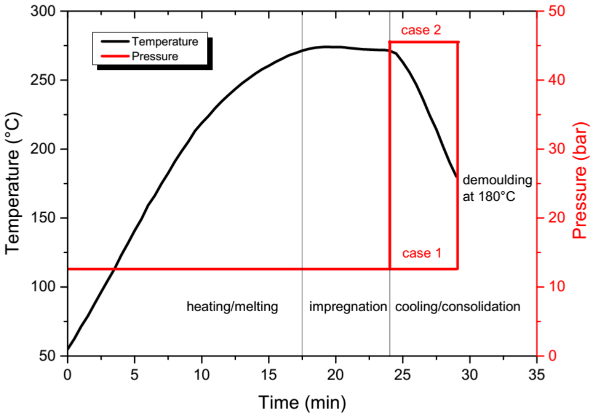
$$H_2N{-}R{-}NH_2 + HOOC{-}R'{-}COOH \rightleftharpoons H_2N{-}R{-}CONH{-}R'{-}COOH + H_2O$$

Compression molding

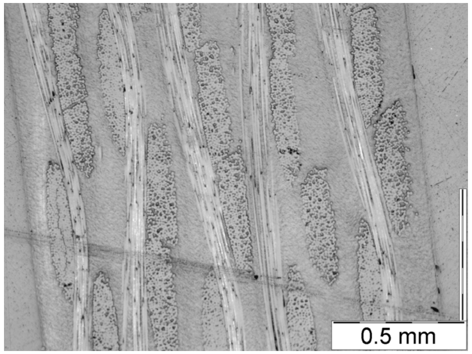
HF-PA66/GF satin 8H 35%

T-P cycle in hydraulic press

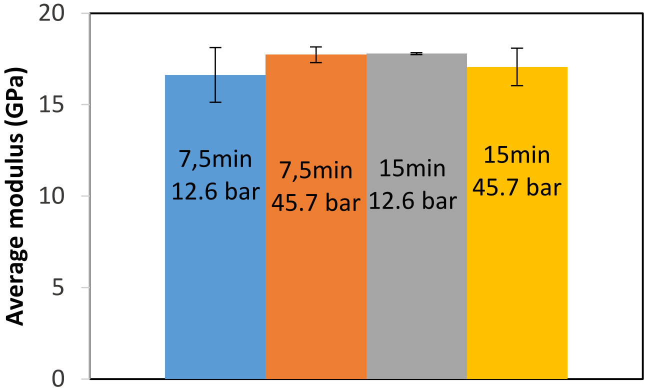


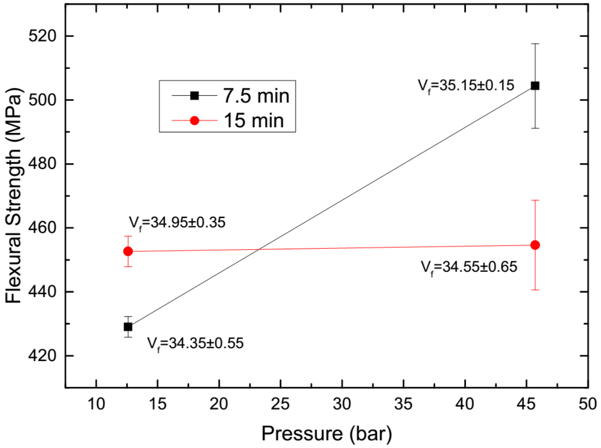


Successful impregnation through-thickness



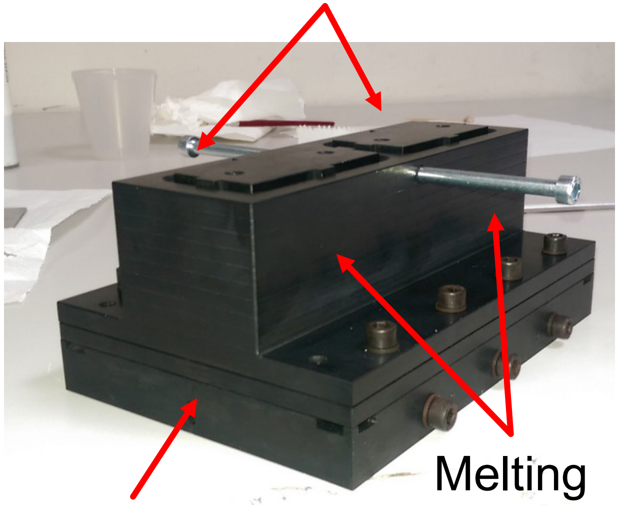
Effect of time and P on flexural strength and modulus:





Liquid Composite Molding

M-RTM tool



pistons

Mould cavity
(fabric)

Melting
pots
(polymer)

Selected Glass fabrics from *Chomarat:*

- GFLow: Leno Weave for TS infusion

Measured unsaturated in-plane permeability:

Measure ID	$K_{unsat}(10^{-10}\ m^2)$
# 1	6.0 ± 0.9
# 2	7.6 ± 1.1
Average	6.8 ± 0.8

Impregnation time with HFPA66

$$t = -\frac{L^2\eta(1-V_f)}{2K_{unsat}\Delta P}$$

η=35 Pa s
V_f = 0.5
P_{inj} = 40 bar
L = 20 cm

➡ t = 132 s

Summary

- A high fluidity PA66 suitable for LCM has been identified and characterized in terms of rheology, crystallization and mechanical properties,
- Several fabrics have been identified and characterization is on-going for improved permeability,
- Preliminary compression molding tests led to good through-thickness impregnation and will be used for comparative purposes,
- A tool for LCM has been fabricated and LCM tests are now ongoing.

CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- New routes to high volume production of lightweight thermoplastic composites:
  - **Combination of injection molding and compression resin transfer molding**

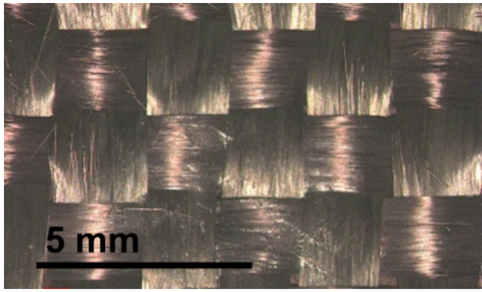
Novel approach: Thermoplastic injection impregnation

n|w University of Applied Sciences and Arts Northwestern Switzerland
Institute of Polymer Engineering
Julia Studer, Clemens Dransfeld
Institut für Kunststofftechnik, Fachhochschule Nordwestschweiz, Hochschule für Technik

Thermoplastic composites

- Lightweight parts for automotive application
- Advantage of recyclability
- State of the art:
  - Overinjected organosheets
- Challenges of direct impregnation:
  high viscosity increases impregnation time
  - Viscosity of thermoplastic matrix: 10 - 10000 Pas (syrup – honey)
  - Viscosity of thermoset matrix usually used: 0.001 - 0.1 Pas (water – olive oil)

www.gkconcept.de

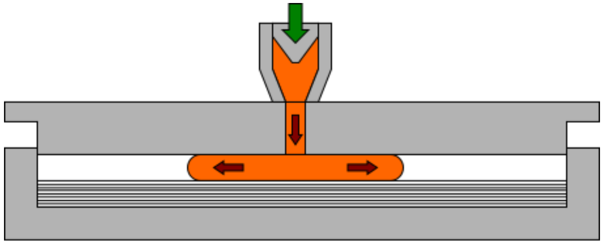


carbon fabric

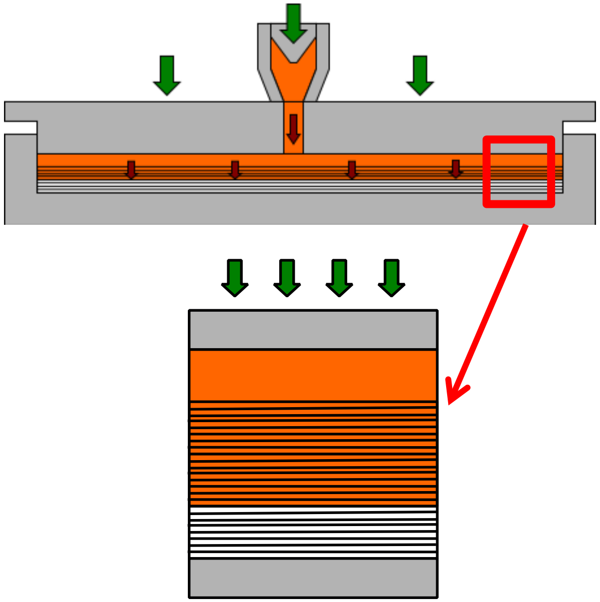
Novel approach: Thermoplastic injection impregnation

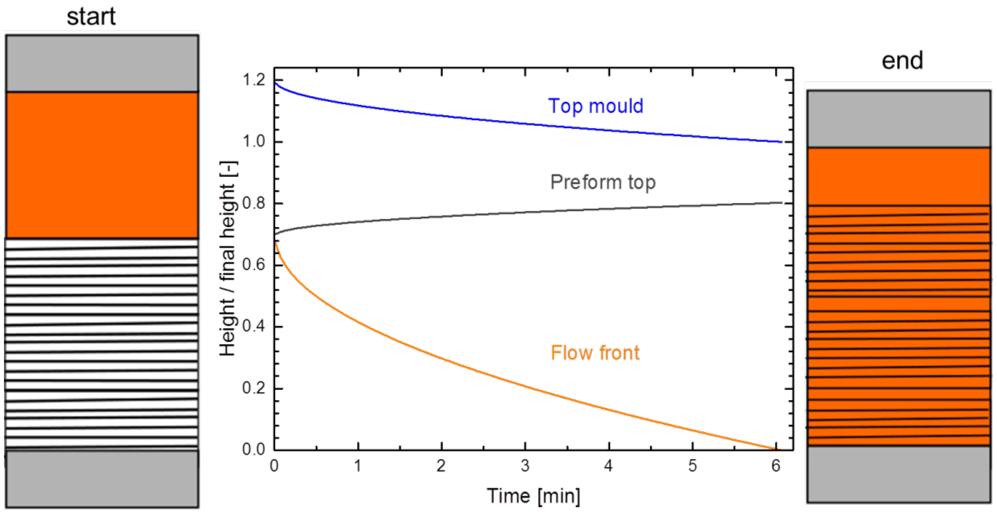
- Combination of injection moulding and compression resin transfer moulding

1. Injection of matrix into a gap above the fabric

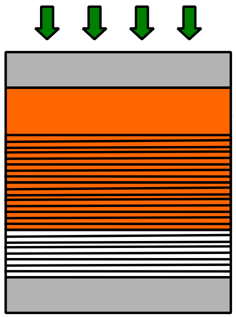


2. Through thickness impregnation of fabric



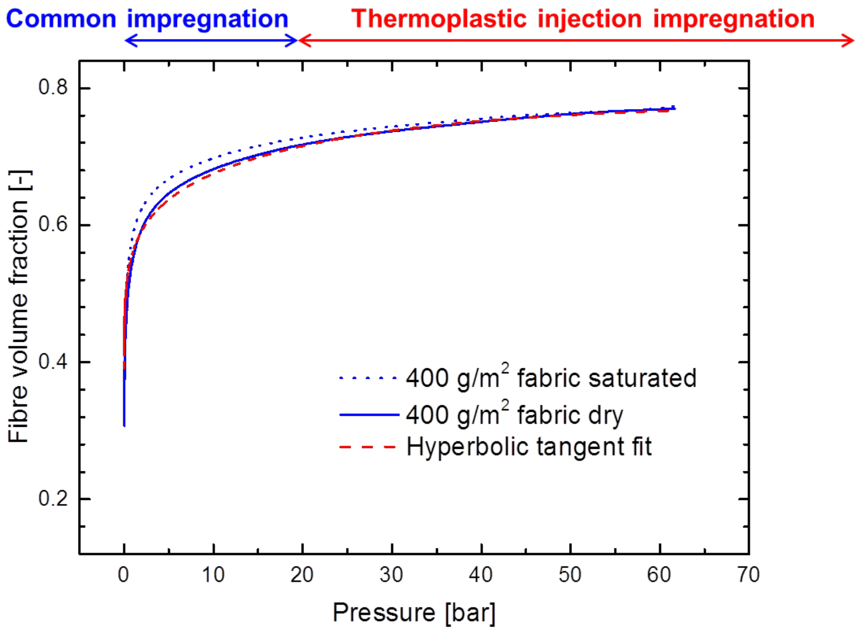


Challenge in describing through thickness impregnation

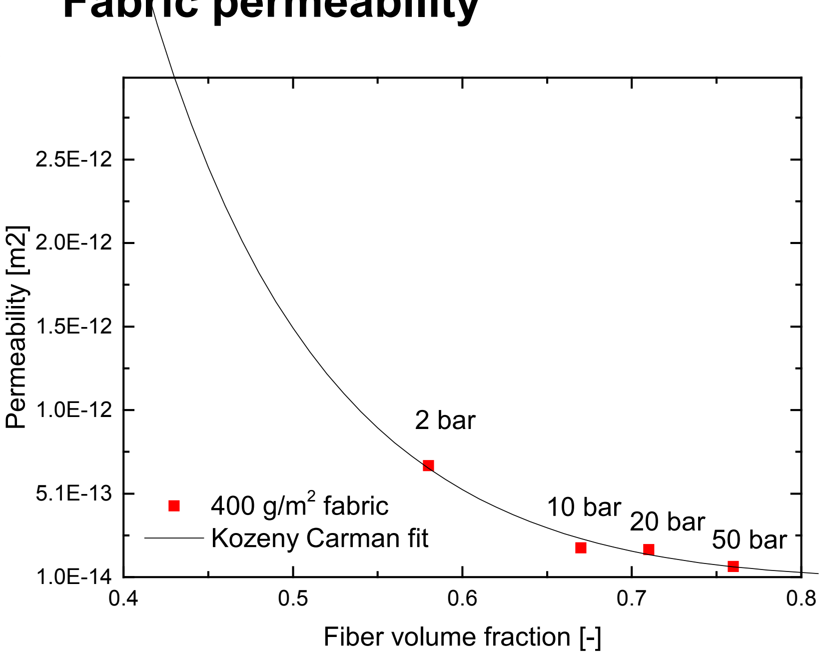


- **Coupling of matrix pressure and fabric compaction**
- **Material behavior needed for impregnation model:**

Fabric compaction

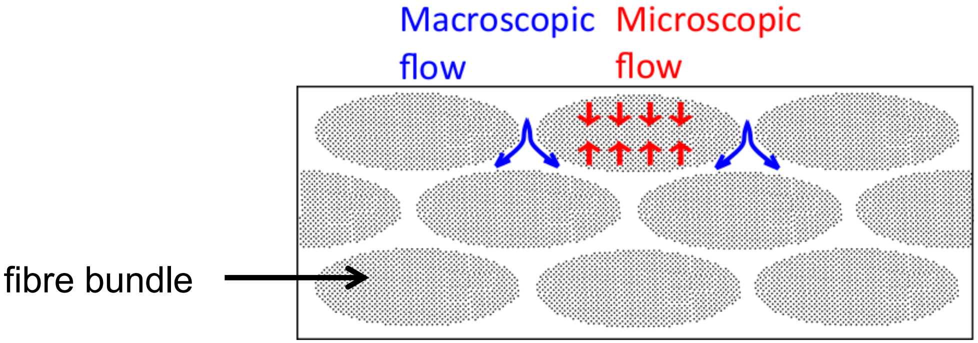


Fabric permeability

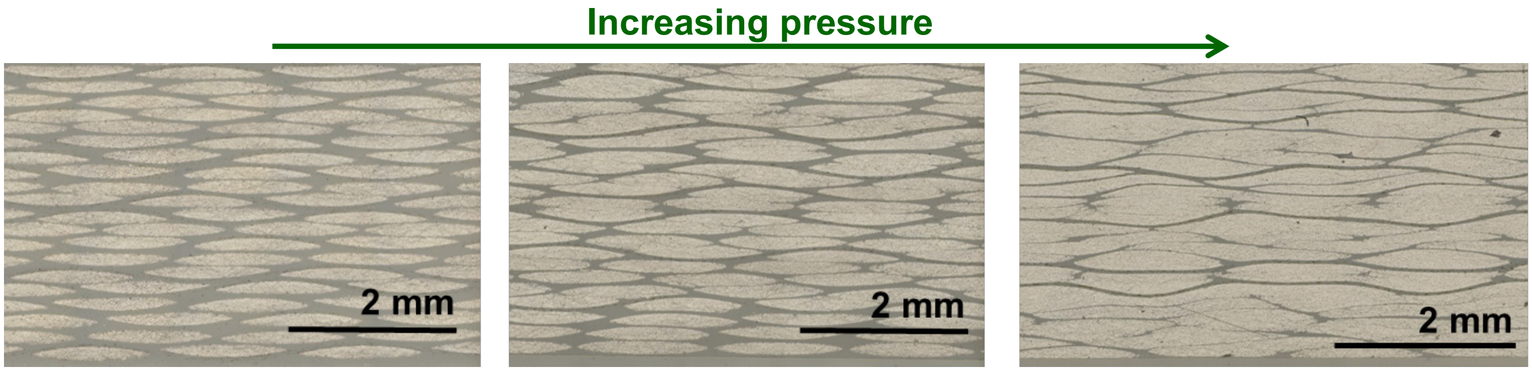


Outlook: Implementation of dual scale flow

- Global flow → microscopic and macroscopic flow



- Increasing pressure decreases the distance of the fibre bundles



Courtesy of A. Keller, FHNW

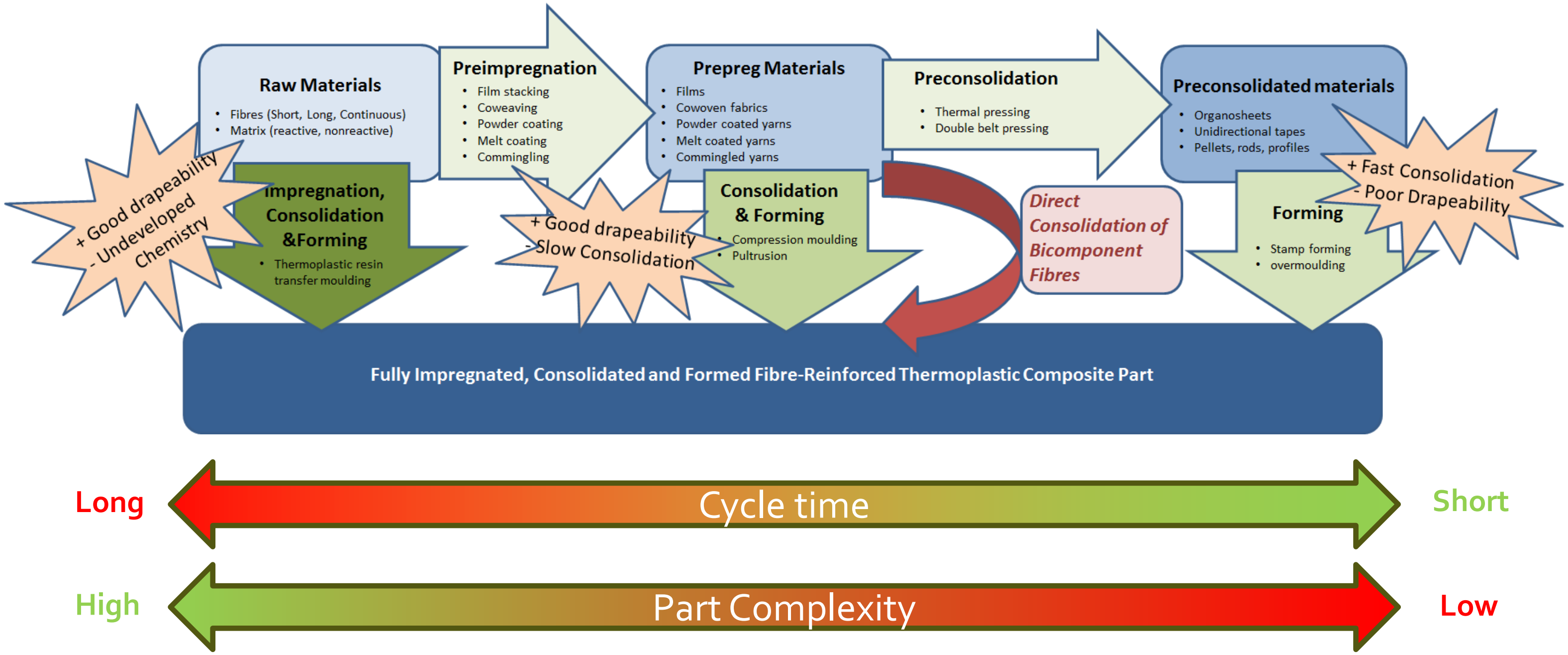
CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- New routes to high volume production of lightweight thermoplastic composites
  - **Hybridization and commingling techniques**

Bicomponent Fibers for Thermoplastic Composites: Towards a new intermediate material for rapid stamp forming

Christoph Schneeberger, Joanna C. H. Wong, Paolo Ermanni
Laboratory of Composite Materials and Adaptive Structures, ETH Zurich

Existing Processing routes for thermoplastic composites



Raw Materials
- Fibres (Short, Long, Continuous)
- Matrix (reactive, nonreactive)

Preimpregnation
- Film stacking
- Coweaving
- Powder coating
- Melt coating
- Commingling

Prepreg Materials
- Films
- Cowoven fabrics
- Powder coated yarns
- Melt coated yarns
- Commingled yarns

Preconsolidation
- Thermal pressing
- Double belt pressing

Preconsolidated materials
- Organosheets
- Unidirectional tapes
- Pellets, rods, profiles

Impregnation, Consolidation &Forming
- Thermoplastic resin transfer moulding

Consolidation & Forming
- Compression moulding
- Pultrusion

Direct Consolidation of Bicomponent Fibres

Forming
- Stamp forming
- overmoulding

+ Good drapeability
- Undeveloped Chemistry

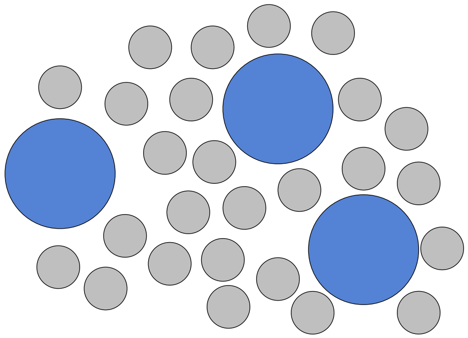
+ Good drapeability
- Slow Consolidation

+ Fast Consolidation
- Poor Drapeability

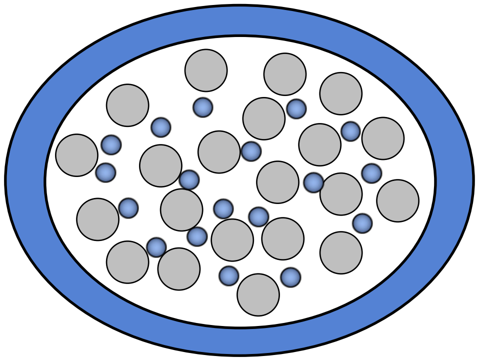
Fully Impregnated, Consolidated and Formed Fibre-Reinforced Thermoplastic Composite Part

Need for **flexible, perfectly mingled** materials for thermoplastic composites

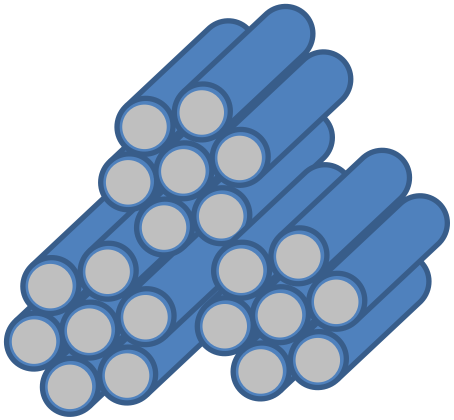
Bicomponent fibers reduce flow length of thermoplastic resin compared to commingled or powder coated yarns



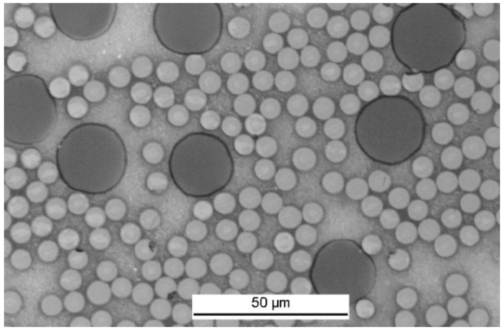
Commingled Yarns



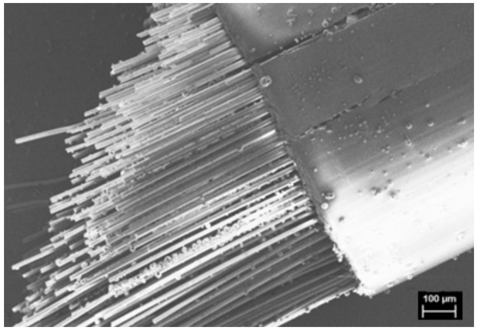
Powder Coated &
Sheathed Yarns

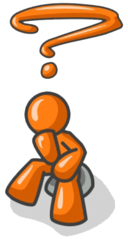


Bicomponent Fibers



U. Thomann, 2003





Research Strategy

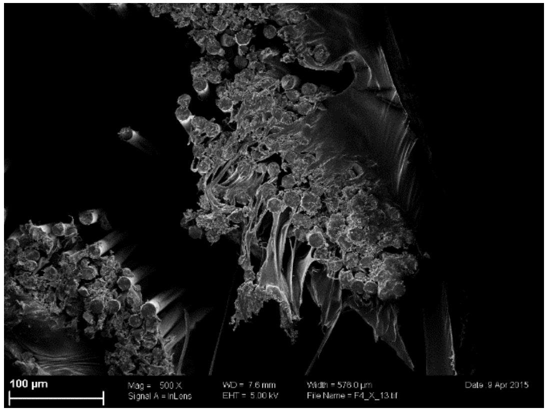
- Using low viscosity thermoplastics (η=3 Pa·s)
- Using low fibre count rovings (n~200)
- Processing by dip coating in melt or solution
- Processing by overjacketing/extrusion

DOW

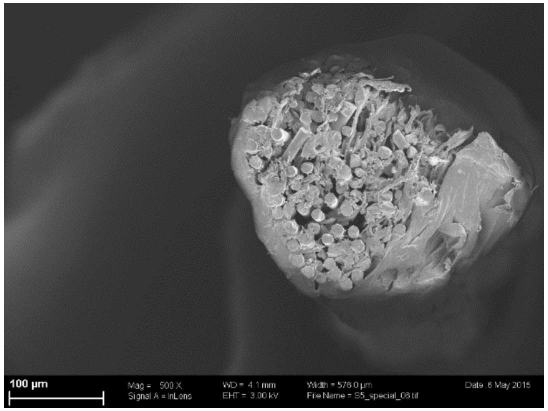
EMPA
Materials Science & Technology

Leibniz-Institut
für Polymerforschung
Dresden e.V.

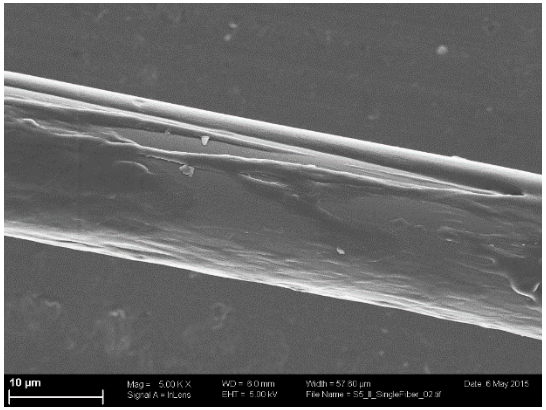
Preliminary Results



Extrusion



Dip coating small roving



Dip coating single filament

Current Challenges & Next Steps

Goal: Fast continuous coating process

Landau, Levich and Derjaguin

$$h = 1.34 r Ca^{\frac{2}{3}}$$

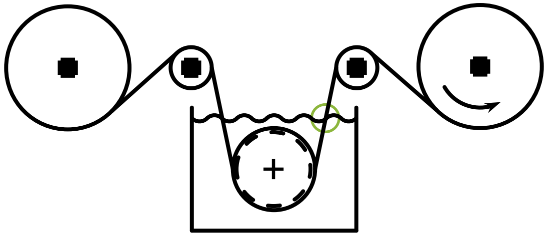
White and Tallmadge

$$h = \frac{1.34 r Ca^{\frac{2}{3}}}{1 - 1.34 Ca^{\frac{2}{3}}}$$

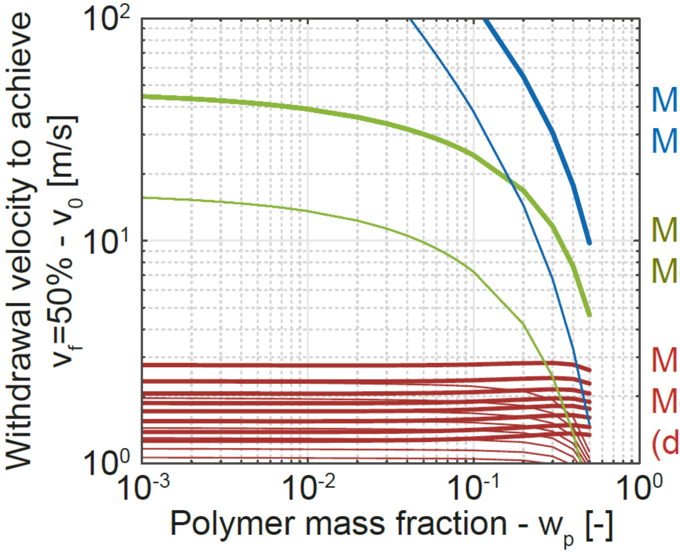
De Ryck and Quéré

$$h = \frac{1.34 r Ca^{\frac{2}{3}}}{1 - We}$$

D. Quéré, 1999



- Models for continuous fiber dip coating, considering:
  - No inertia, small Ca
  - Corrected for bigger Ca
  - Corrected for viscoinertial regime



Max and min velocities
Model: Landau, Levich and Derjaguin

Max and min velocities
Model: White and Tallmadge

Max and min velocities
Model: De Ryck and Quéré
(dependent on core fiber diameter)

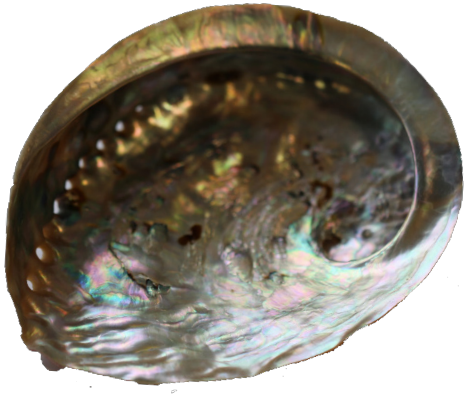
CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- **Bio-inspired materials:**
  - Micro-structured composites with enhanced fracture toughness,
  - Materials with self-healing properties and extended durability.

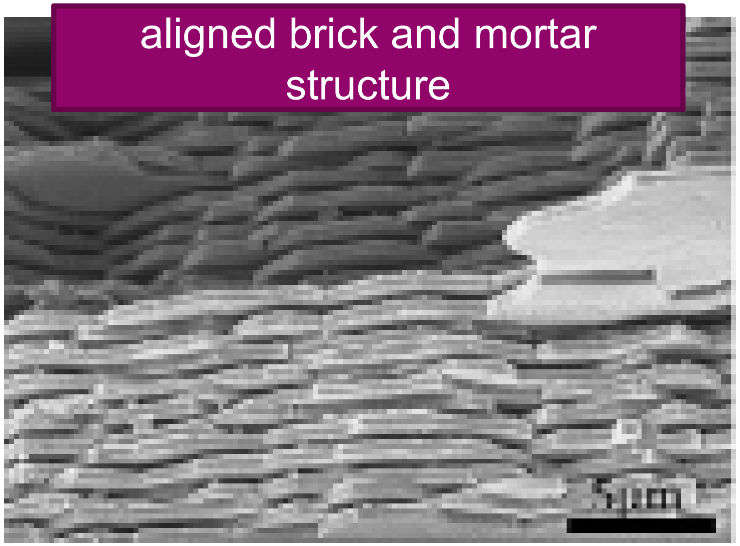
Nacre's structure is a promising new composite architecture

Madeleine Grosman, Rafael Libanori, André R. Studart
Complex Materials, Department of Materials, ETH Zurich

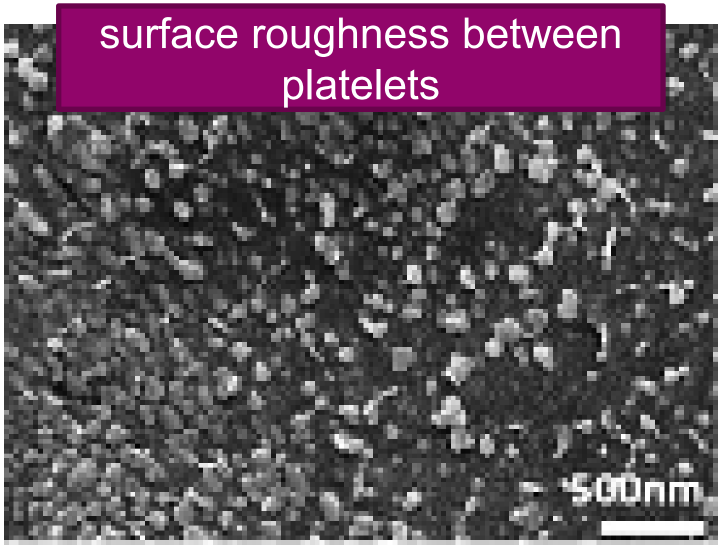
Evolution has used microstructure, not chemistry to create strength and fracture toughness



Two key features



aligned brick and mortar structure



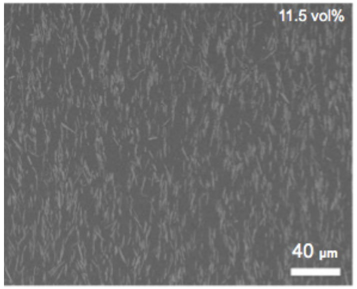
surface roughness between platelets

Lopez, M. I., et al., Acta Biomaterialia (2014) 10 (5), 2056

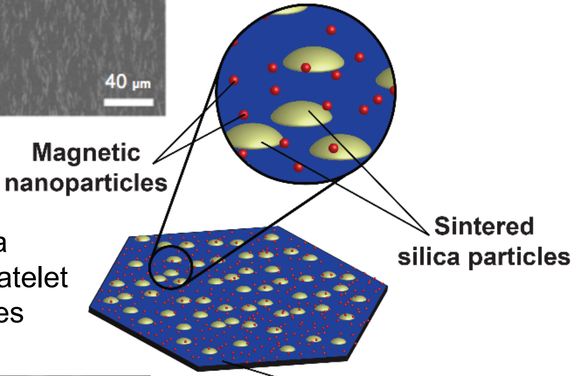
We develop of micro-structured bulk composites to mimic nacre's combination of strength and toughness

Two methods for creating surface roughness

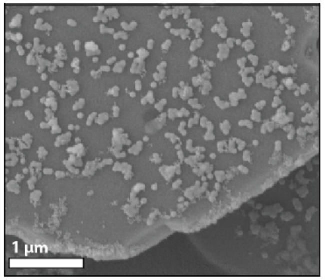
surface roughening of individual platelets



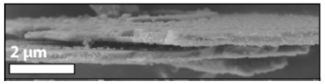
nacre-like composites can be made by magnetically aligning alumina platelets suspended in polymer before curing



sintering silica particles to platelet surface creates roughness

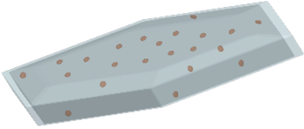


this process offers control of asperity size and density.



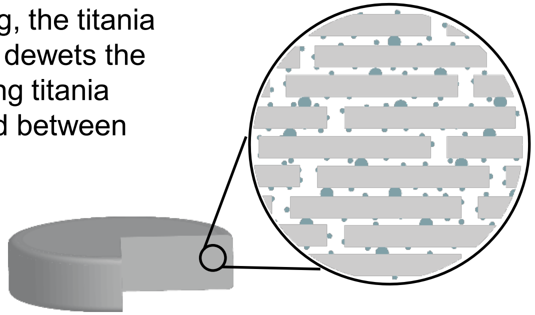
Roughened platelets can then be suspended in polymer and magnetically aligned to produce nacre-like composites

in-situ roughening in aligned ceramic scaffolds

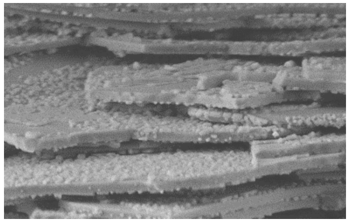


Magnetised titania@alumina platelets are processed into aligned ceramic scaffolds.

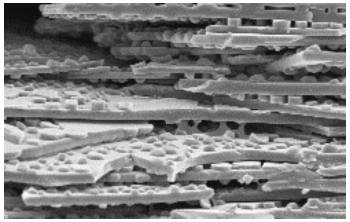
During sintering, the titania spontaneously dewets the alumina, forming titania droplets on and between platelets. this



By variation of sintering temperature, size of the titania droplets can be tuned, influencing the strength of the mineral bridged connections within the scaffold.



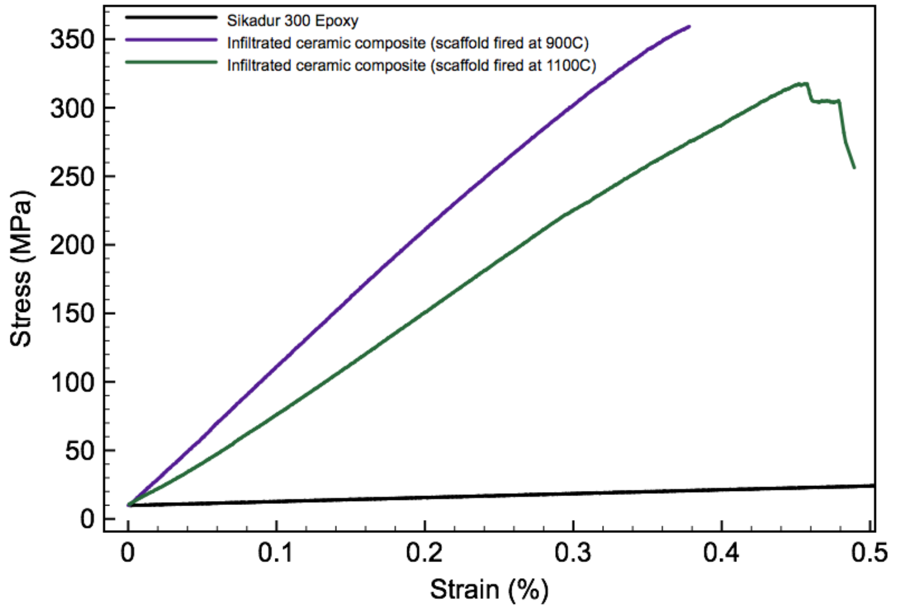
sintered at 900 C



sintered at 1100 C

Results

constant 60% mineral density



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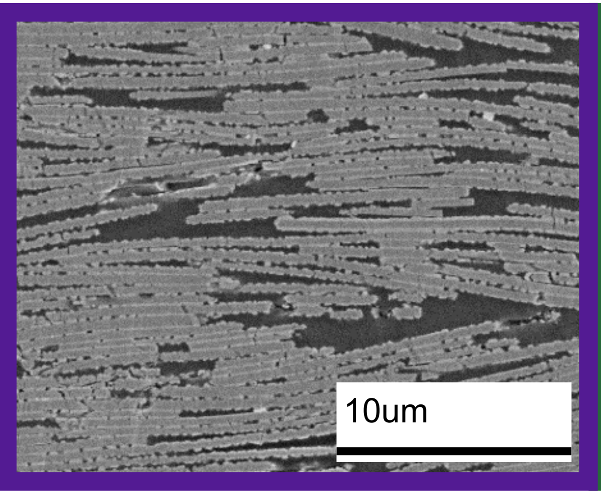
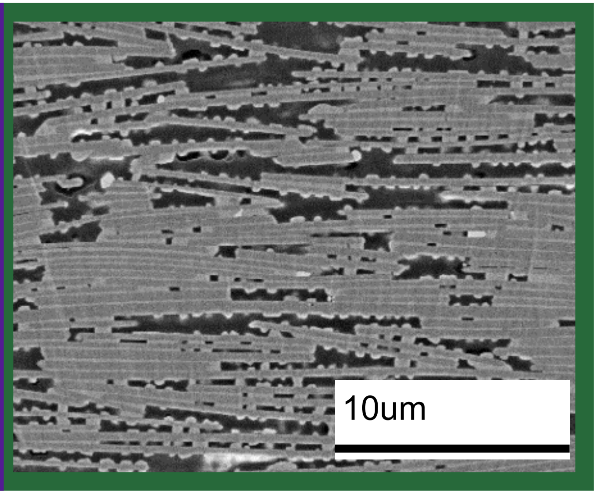
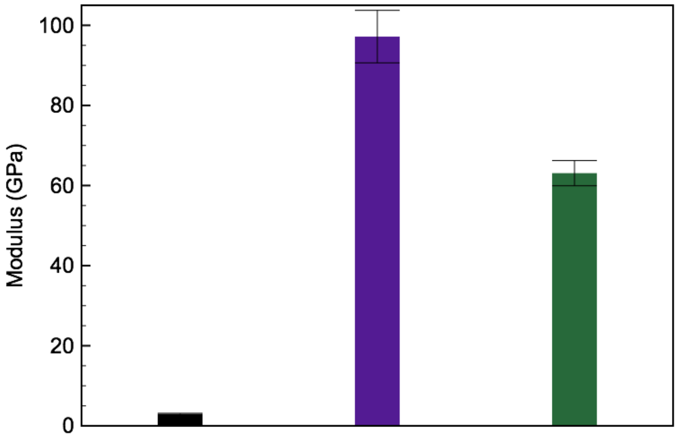


sintered at 1100 C





CA3 is addressing novel approaches of mass reduction leading to smaller power demands for acceleration

- **Smart thermal management technologies:**
  - Use of unsteady heat sources for HVAC through thermal energy storage,
  - Actively conditioning the vehicle while non-operational

Overview of activities: completed and on-going

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Aerothermochemistry and Combustion Systems Laboratory, ETH Zurich

- Completed
  - Model → energy demand of heating/cooling the cabin
    - Implemented, using traffic and weather data for Zurich
  - Influence of the weather → comparison under different climates
- On-going
  - Validation / extension to other vehicle types
    - Collaboration with EMPA → air-conditioned roll-test bench
    - Cool-down tests → different cars
  - Co-simulation with internal combustion engine (ICE) based powertrains
    - Model → Heat-rejection of an ICE in a conventional powertrain
    - Heat rejection in hybrids (engine shut off periodically)
    - Inclusion of heat-storage devices for continuous heating

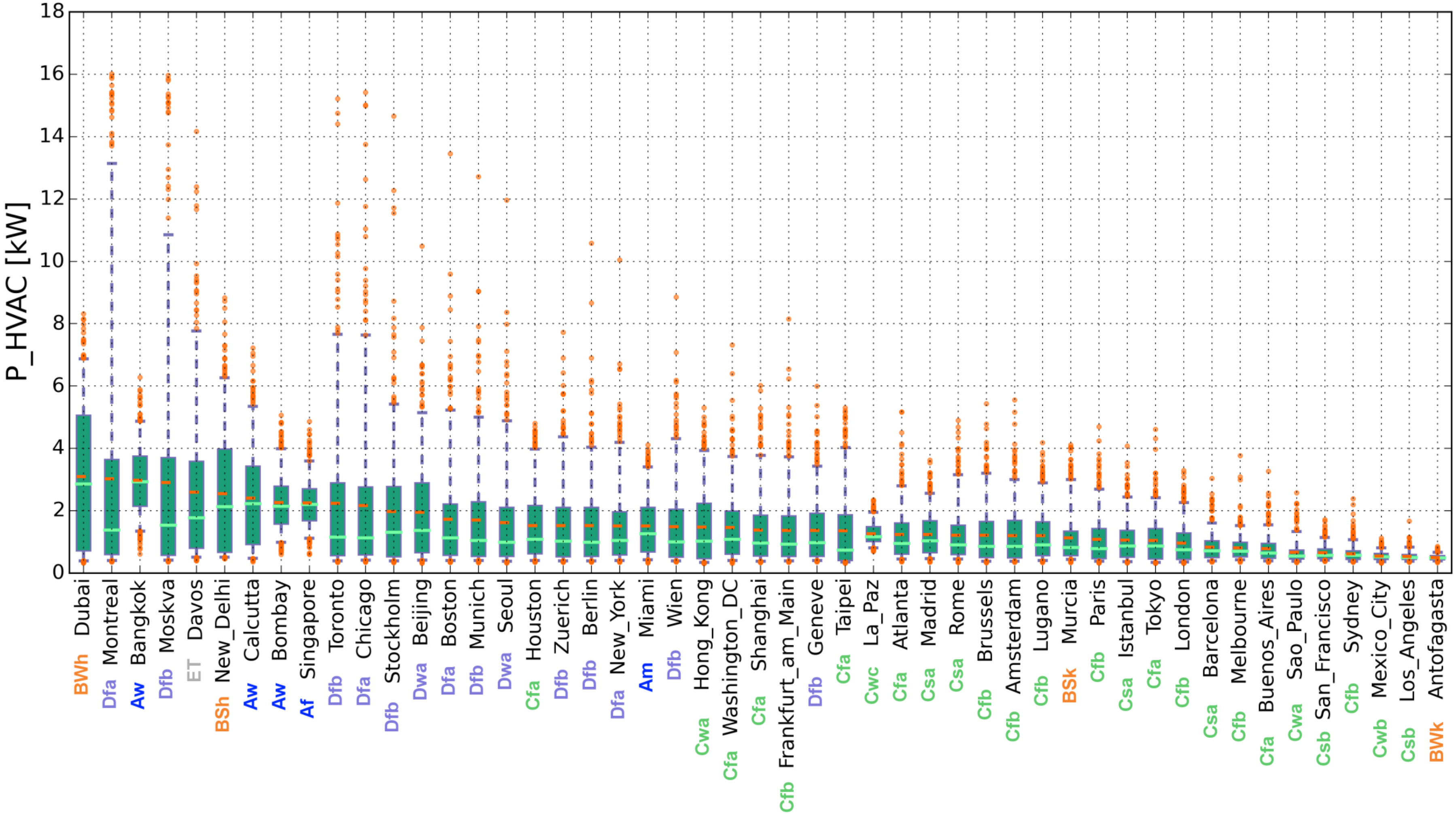
CA A2 – ETHZ-LAV

Overview of activities: next steps

- Extension towards other vehicle types
  - Public transport: busses / trains
- Integration into «strategic guidance model» (→ CA-B2)
  - realistic energy-demand values (incl. weather dependence)
- Mitigation measures (intra CA-A3 cooperation)
  - Lightweighting with/versus integrated insulation
  - Reducing the thermal heat capacity of components within the cabin
  - Glazing with restrictive transmission spectra
  - Passive heating and cooling (e.g. capilary driven evaporative cooling)
  - Alternative heating and cooling devices (e.g. IR heating)
  - Operation strategies (energy harvesting / thermal management)

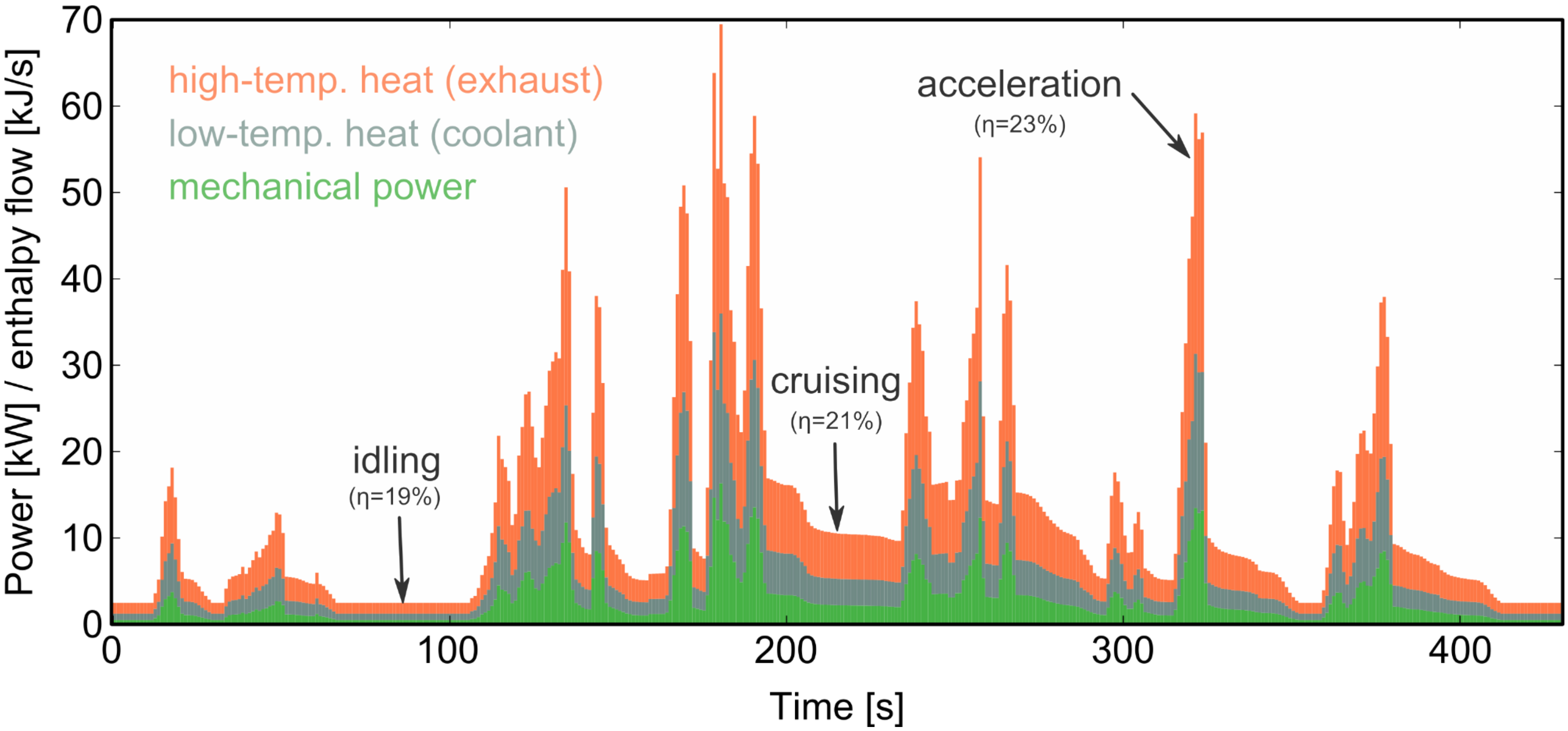
Highlights: influence of the weather

climate dependence of the heating/cooling load



Highlights: ICE-based powertrains

heat energy/power availability in a conventional powertrain



driving cycle: WLTC class 2

Highlights: ICE-based powertrains (cont'd)

histogram of power availability in a conventional powertrain