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Programme

12:30 - 13:00 FibData Background and Concept

- **Pasi Kallio** and **Mikko Kanerva**

13:00-15:00 Short presentations

- **Pekka Laurkainen:** Why microbond? – Thoughts on scale "hierarchy" and knowledge gaps
- **Sarianna Palola:** One method, many possibilities; an introduction to material combinations
- **Olli Orell**: Extending the microbond testing possibilities – aging tests
- **Olli Orell**: Towards automated finite element analysis
- **Jarno Jokinen:** finite element modelling
- **Royson DSouza**: Future Microbond test – Towards local strain measurements
- **Markus Kakkonen:** Automation: How to remove the human
- **Dhanesh Kattipparambil:** Microbond testing - machine vision -based movement tracking for enhanced automation

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FibData

Revolution in Data-based Fibre Material Science using Microrobotics and Computational Modelling

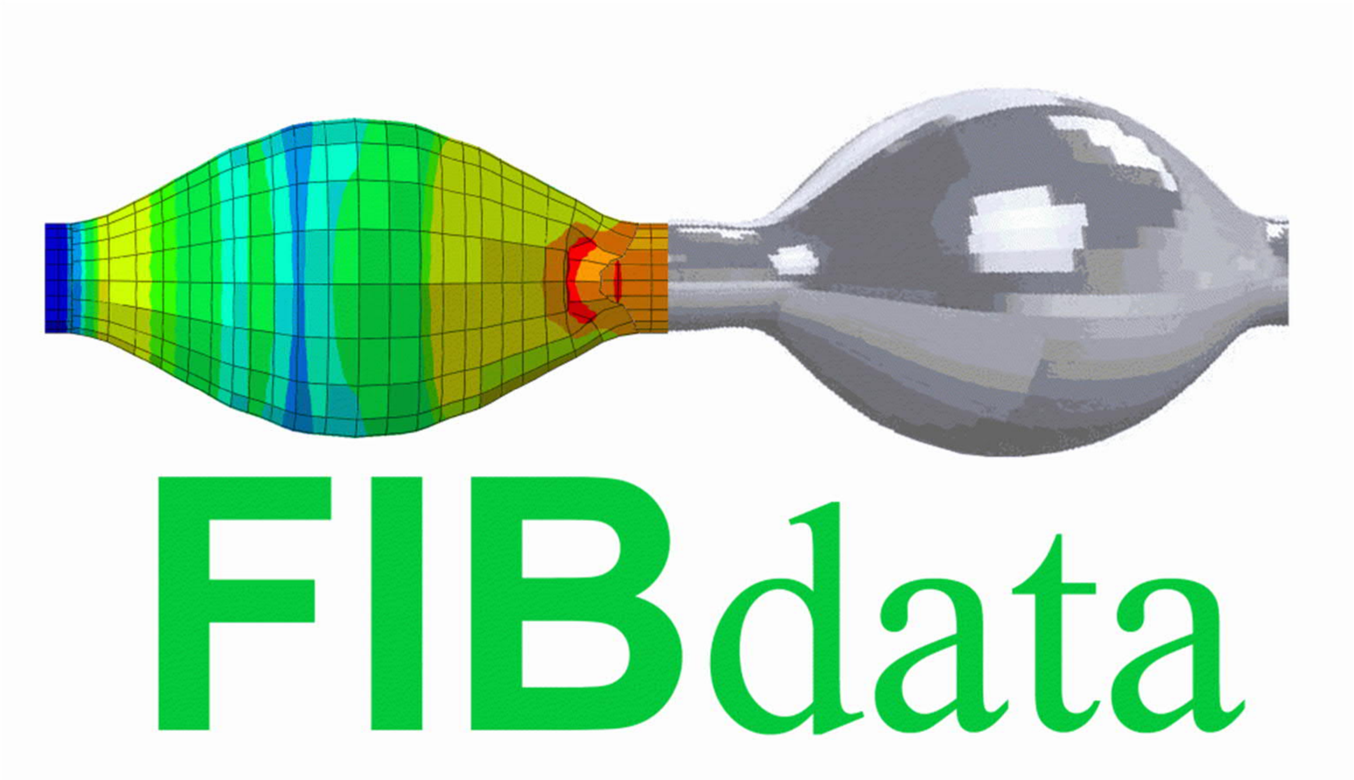
FIBdata

Open Seminar
26.1.2021
Prof. Pasi Kallio

FIBdata

Outline

- Project Information
- FibData Approach
- About Interfacial Properties
- Microbond Test
- Seminar Overview



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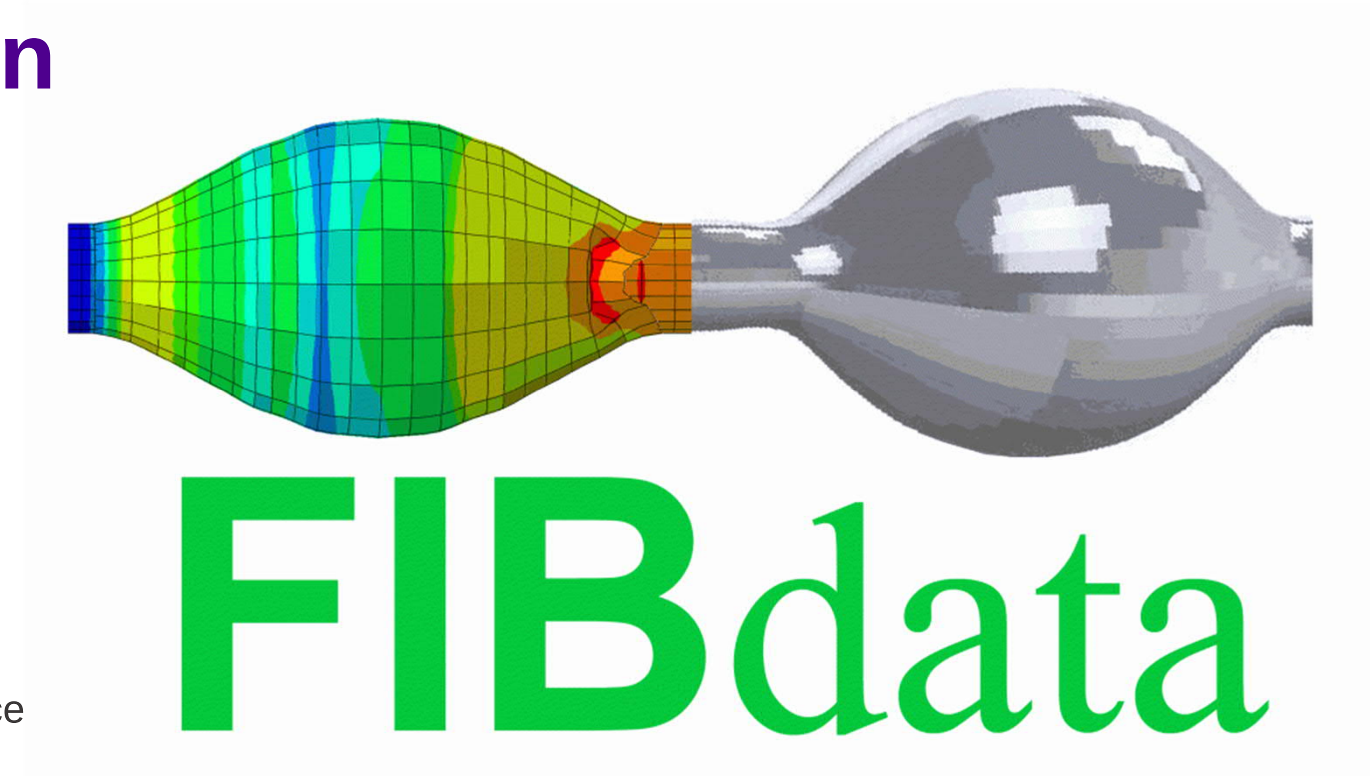
Project Information

- Funded
  - Technology Industries of Finland Centennial Foundation and
  - Jane and Aatos Erkko Foundation
- Duration:
  - 1.1.2019-31.12.2021
- Objectives
  - To demonstrate characterization of mechanical properties of **fibre-matrix interfaces** at high throughput,
  - To automate experimental interface characterization and numerical interface modelling methods
  - To produce large data sets with selected industrially relevant material combinations



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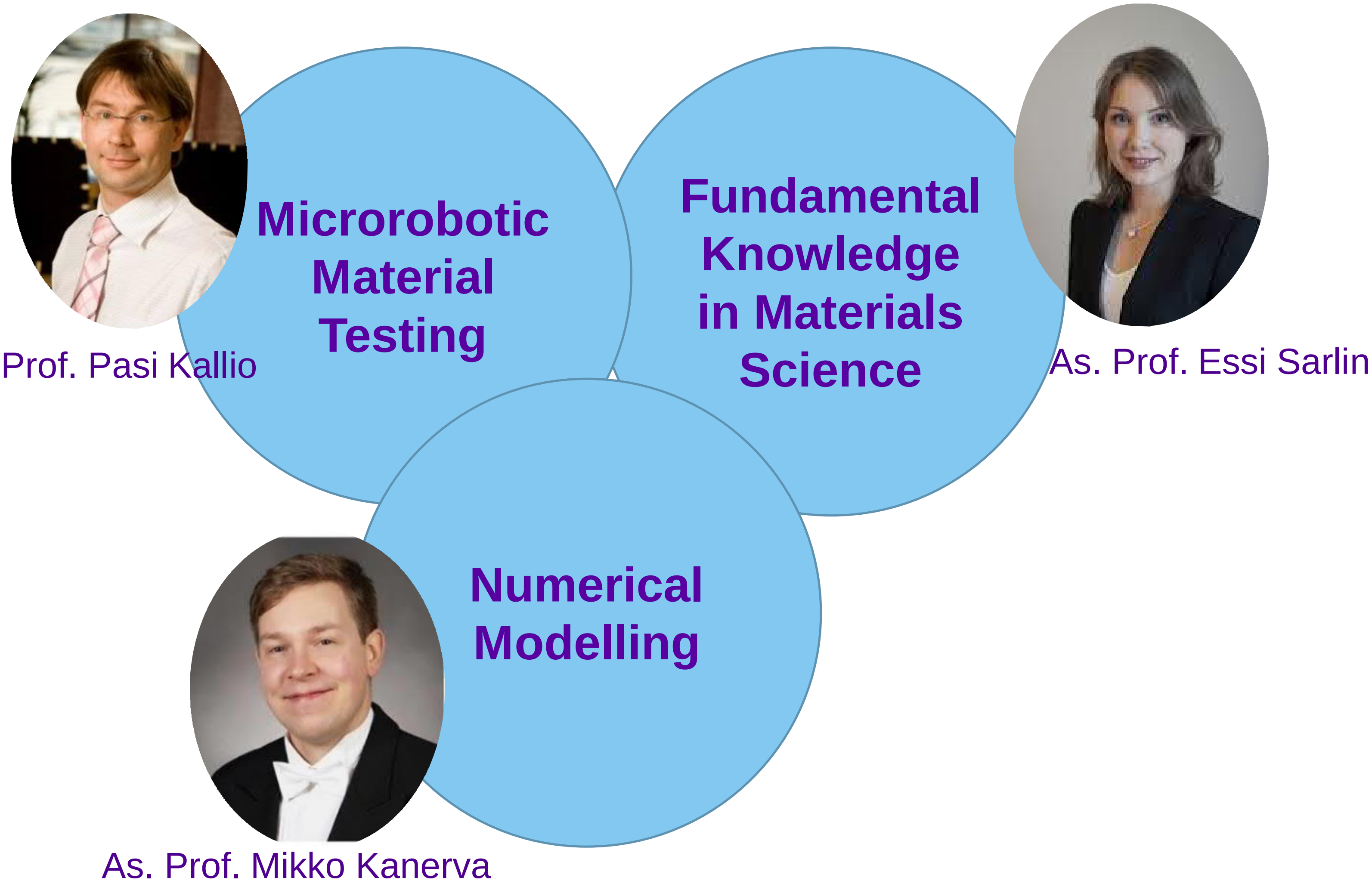
Team Leaders



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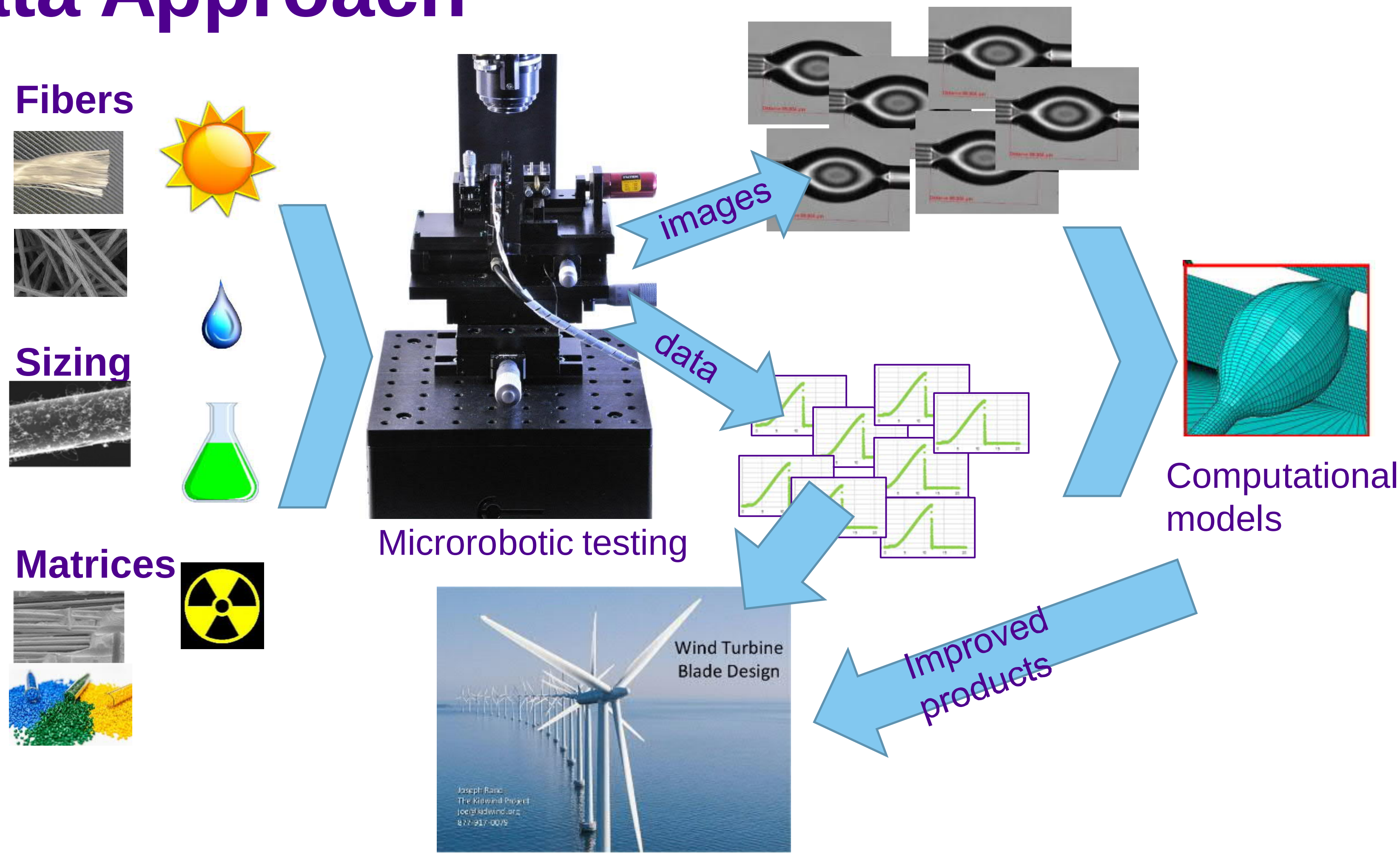
FibData Approach



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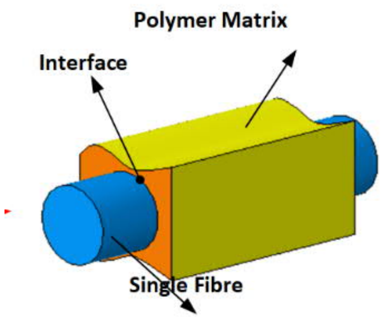
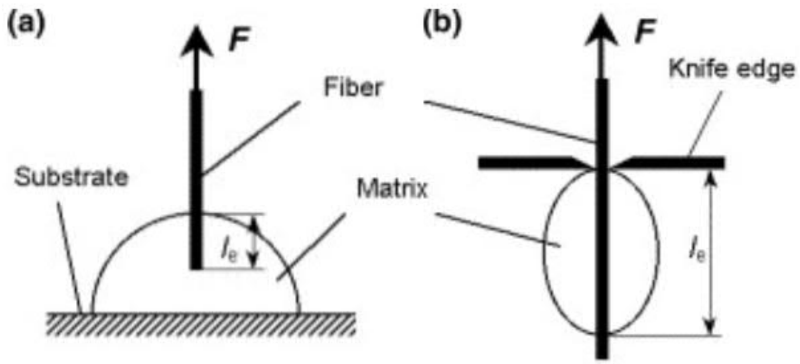
Interfacial Properties

- Interfacial properties of the fibre-matrix system play crucial role in the mechanical properties of composite products
  - Adequate stress transfer between the fibres and the matrix is needed
  - Influenced by the sizing applied on the fibre surface
- Common measure for the stress transfer capabilities of the interface is the interfacial shear strength (IFSS)
- IFSS is measured with single fibre methods, such as
  - single fibre pull-out test, Figure (a)
  - **microbond test, Figure (b)**





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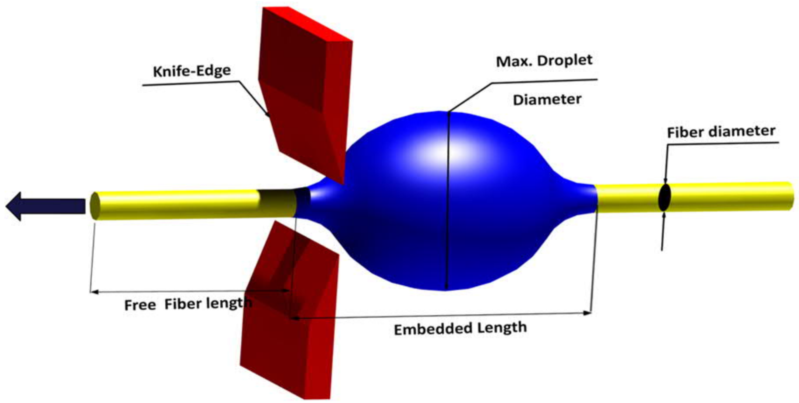
Microbond Test?

- Microbond developed by Miller et al. in 1987.
- The method in brief
  1. First applying a resin drop onto the surface of a single fiber
  2. Curing the fiber-resin system to form the droplet.
  3. Applying a shearing force to pull the fiber out of the droplet or vice-versa.
  4. Measuring the adhesion force.
  5. Calculating the IFSS from the measured force and the embedded area of the droplet

$$Apparent\ IFSS = \frac{F_{max}}{\pi . d_f . l_e}$$

IFSS → Interfacial Shear Stress
F_{max} → Maximum Force
d_f → Diameter of the fibre
l_e → Embedded length



Slide provided by Royson D'Souza, Tampere University

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Motivation for Microrobotics

- The measurements typically require tedious manual work and the produced data often has really high scatter

- Our goal has been to develop automated high-throughput IFSS tester

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Sample Preparation

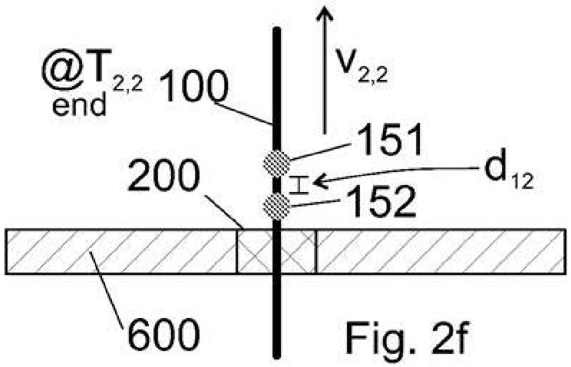
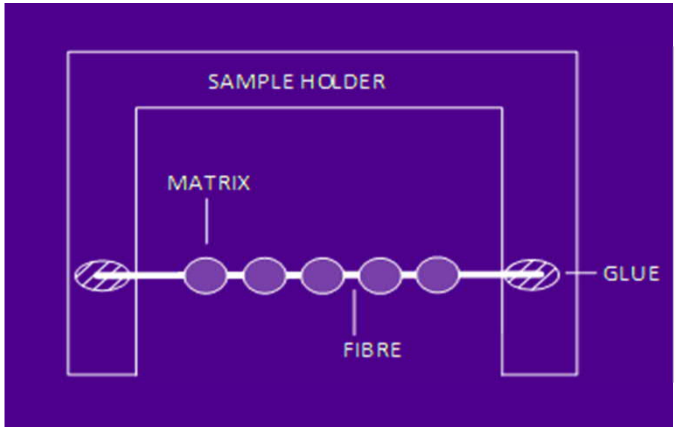


Fig. 2f

Technology patented by Fibrobotics oy

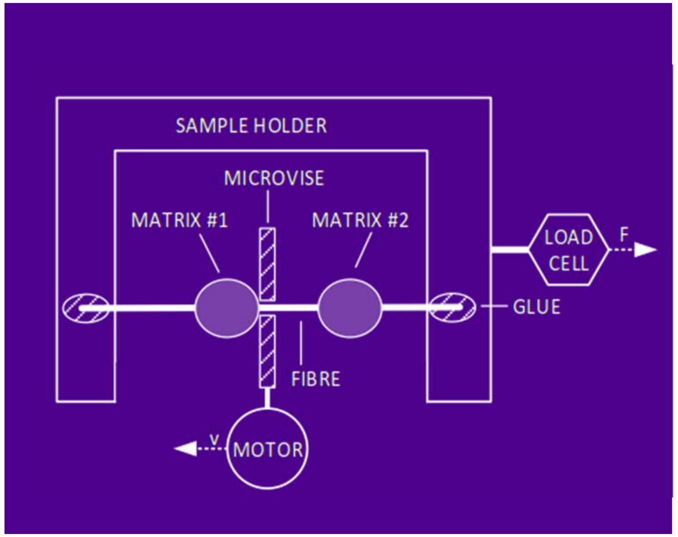


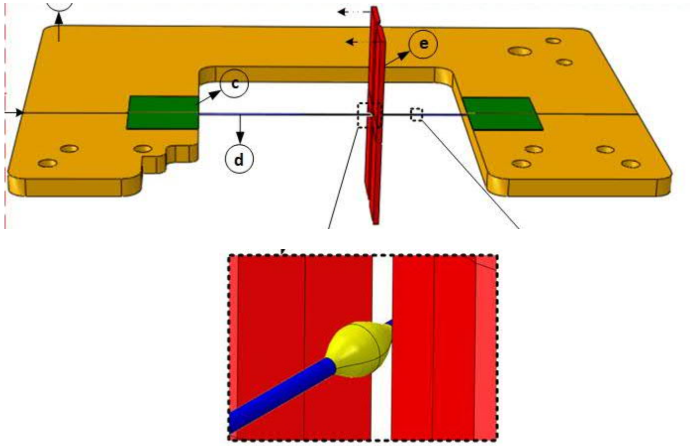
- The method enables deposition of tens of droplets on a single fibre filament
  - Typically 40-60 droplets / fibre
  - **Droplet size can be controlled**

- Samples are placed on U-shape sample holder

Measurement Principle 1/2

- Measurement is performed by pulling the droplets out of the fibre
- Sample holder is connected to force sensor
- Microblades exert force on the droplet
  - Gap between the plates can be controlled with submicron resolution





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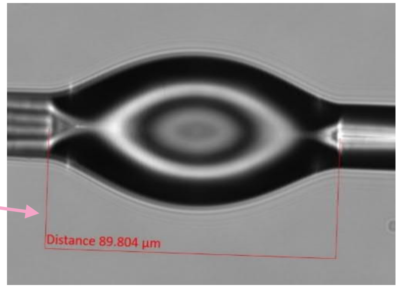
Measurement Principle 2/2

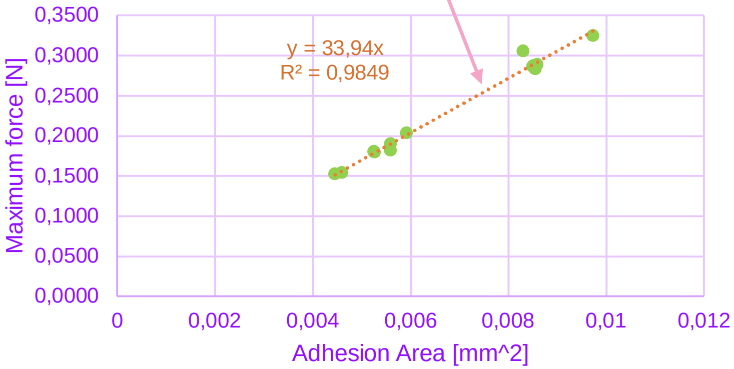
- From each droplet, we estimate
  - Adhesion area (microscope image)
  - Debonding force (max)

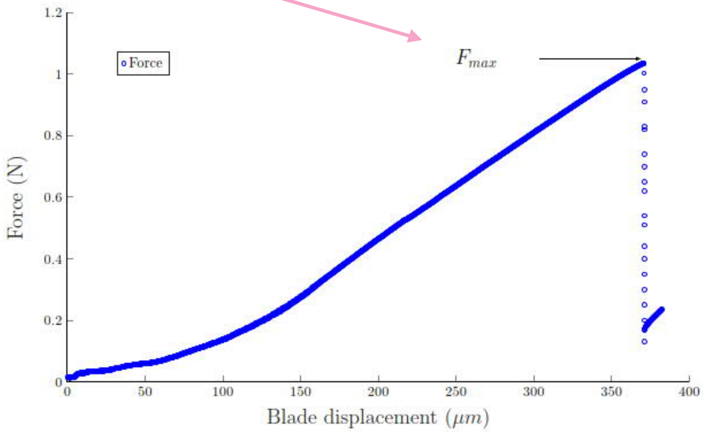
- We determine IFSS through a line fit



Microscope image with embedded length determined

Example result (IFSS = 33.94MPa)





Possible Research Questions

- How to modify the interphase by modifying the sizing?
- How does the storage time influence the sizing and thus the resulting interphase?
- How does the matrix material influence the interfacial properties?
- How to maximize the viability of recycled fibres?
- What is the role of ageing in modifying the interfacial properties? (e.g. UV, hygrothermal, etc.)

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Thank You for Your Attention

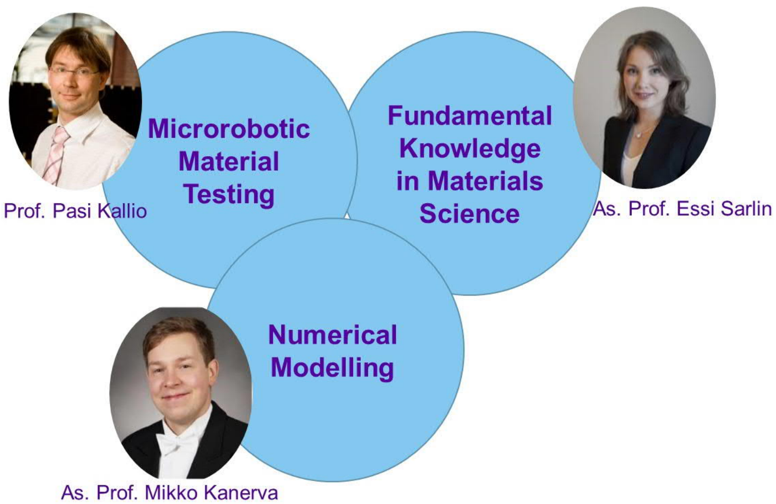
Next Steps?

- Interest in providing samples for testing?
- Interest in any particular aspect presented today?
- Interest in company specific workshops?

Interested in discussing today?

- raise your ”hand”

Or contact us later using email



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Human
Potential
Unlimited.

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Associate Professor
Mikko Kanerva

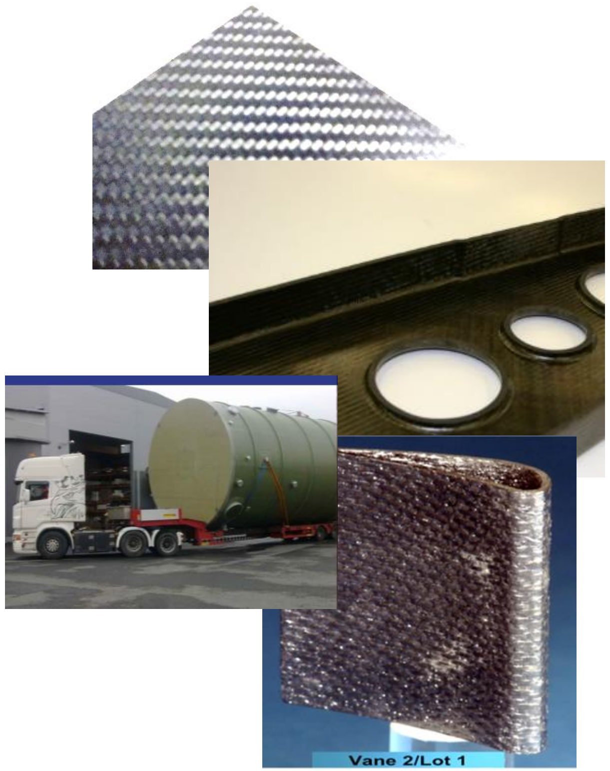
Plastics and Elastomer Technology

22.1.2021

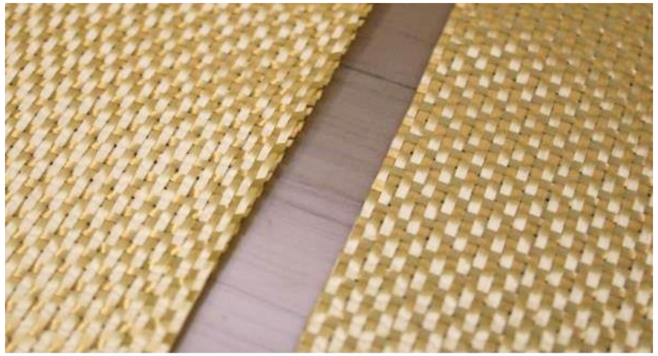
Fibrous materials

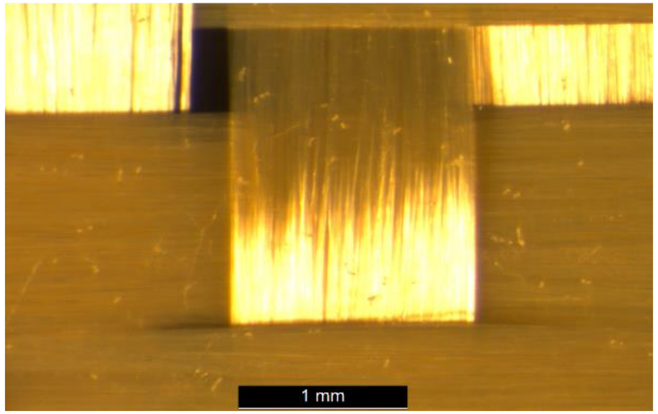
- Allow to apply enormous improvements in material performance
- Lead to anisotropy (on **macro** scale)
- Lead to interfaces on **micro** scale

- Require multiscale framework



https://technology.nasa.gov/

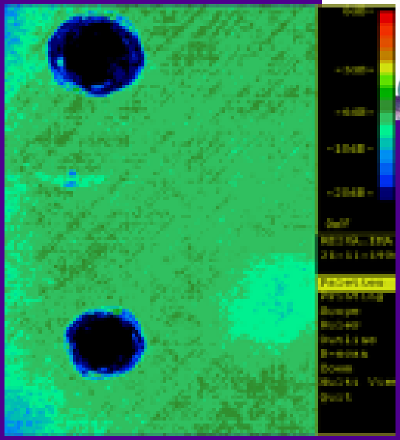


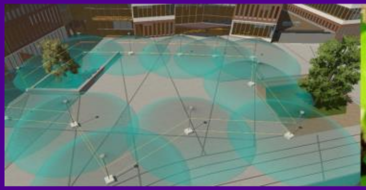


Anisotropy

- Complex theme when material has strong multiscale relationships
- Allows to <u>tailor and optimize</u> material locally in precise application and operation

- Handling requires **exact and reliable material data**





https://www.luxturrim5g.com/

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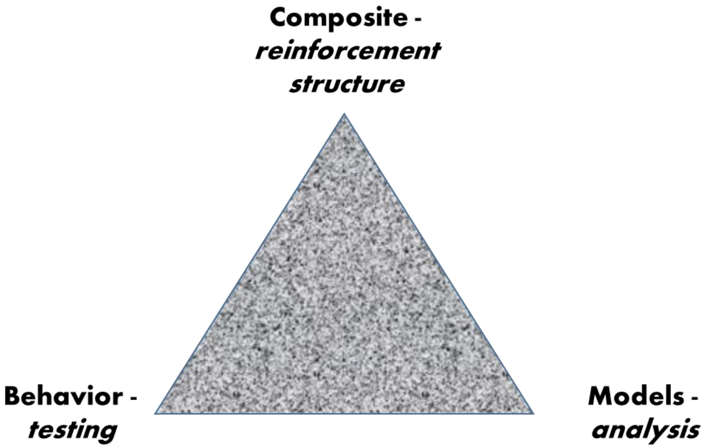
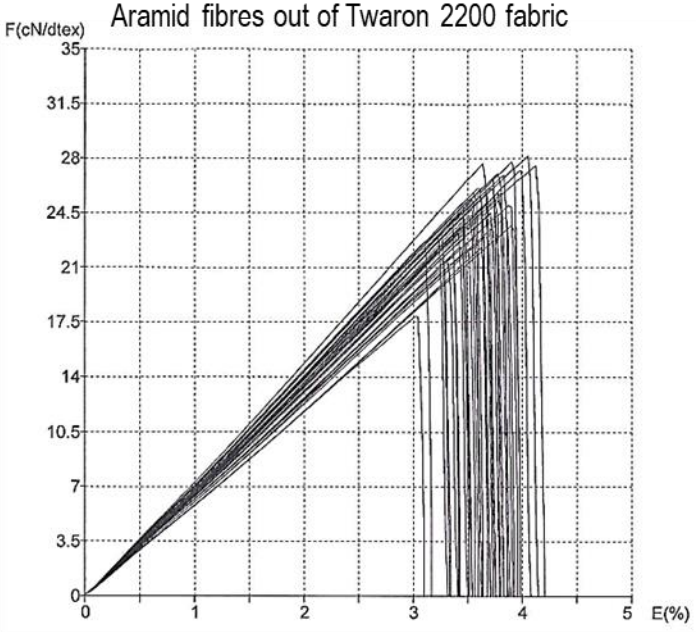
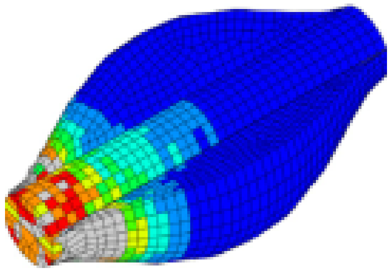
Material data

- Fibre properties are dominating *– e.g. tensile behaviour, thermal expansion, anisotropy*
- Matrix properties are the second important along with **adhesion to fibres**
- Interface affects many of the **composite properties** in a complex fashion



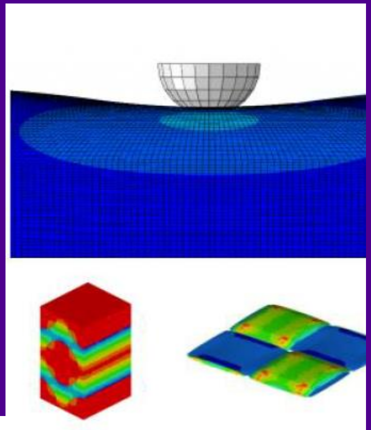


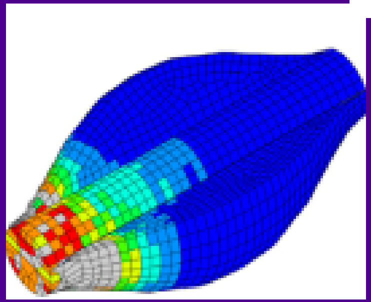


Interface

- Due to small size, small test devices
- ‘Strength’ or adhesion along the interface is <u>not a standard property</u>
- Ideally a 2-D concept – no-volume material

- For almost all modelling and design, implicitly affecting performance
- Properties like interfacial shear strength (IFSS) and interface fracture toughness have been introduced currently





Interfaces tested

- Test devices need to record accurately:
  + ***force***
  + ***displacement or strain***

- Test specimens, to form reasonable sample of a material batch, need to be ***many*** and ***fast prepared***

- ***Statistical analysis*** of data is important

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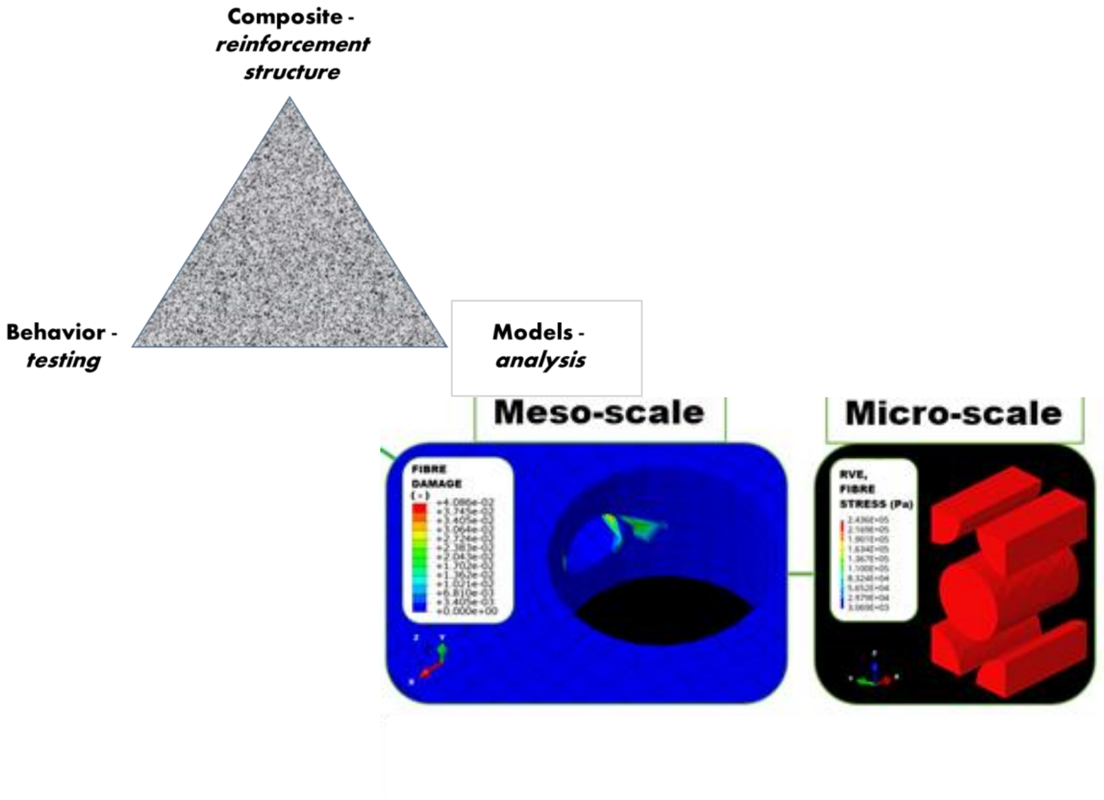
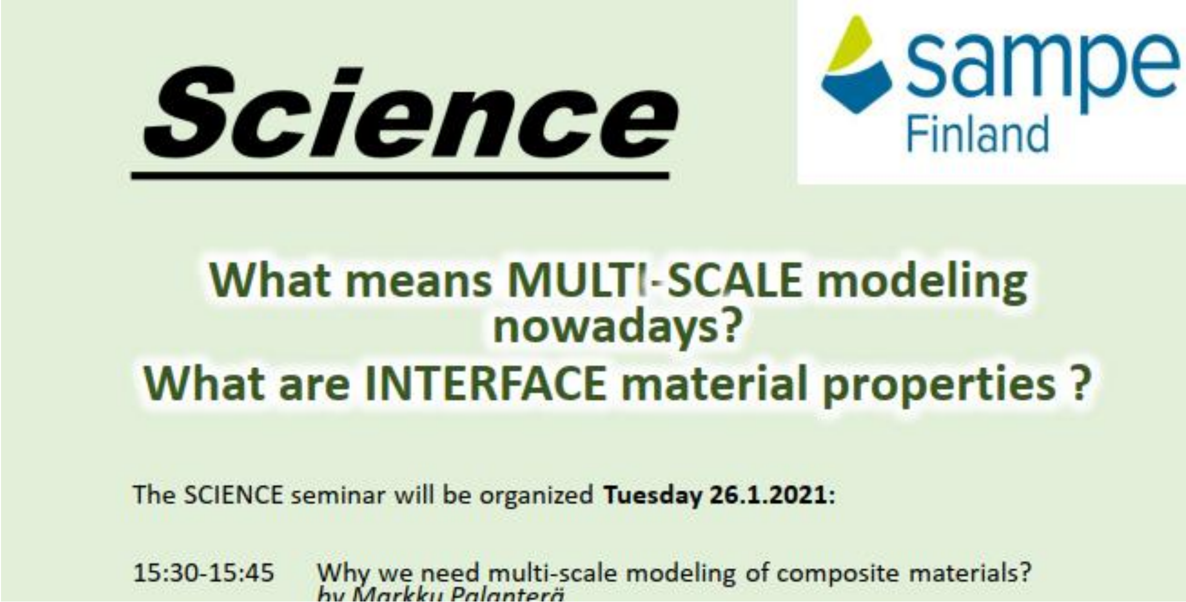
Models and design

- Typically laminate theory is in use for composites – even when embedded (for FEM)
- For single fibre-matrix analysis, multiscale approaches can be used, e.g. with representative volume elements (RVEs)
- Industry requires ***fast design and simulation codes***





Why microbond? – Thoughts on scale “hierarchy” and knowledge gaps

Pekka Laurikainen

Doctoral researcher (M.Sc)

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Contents

What does microbond measure?

What are the problems?

What is the point?

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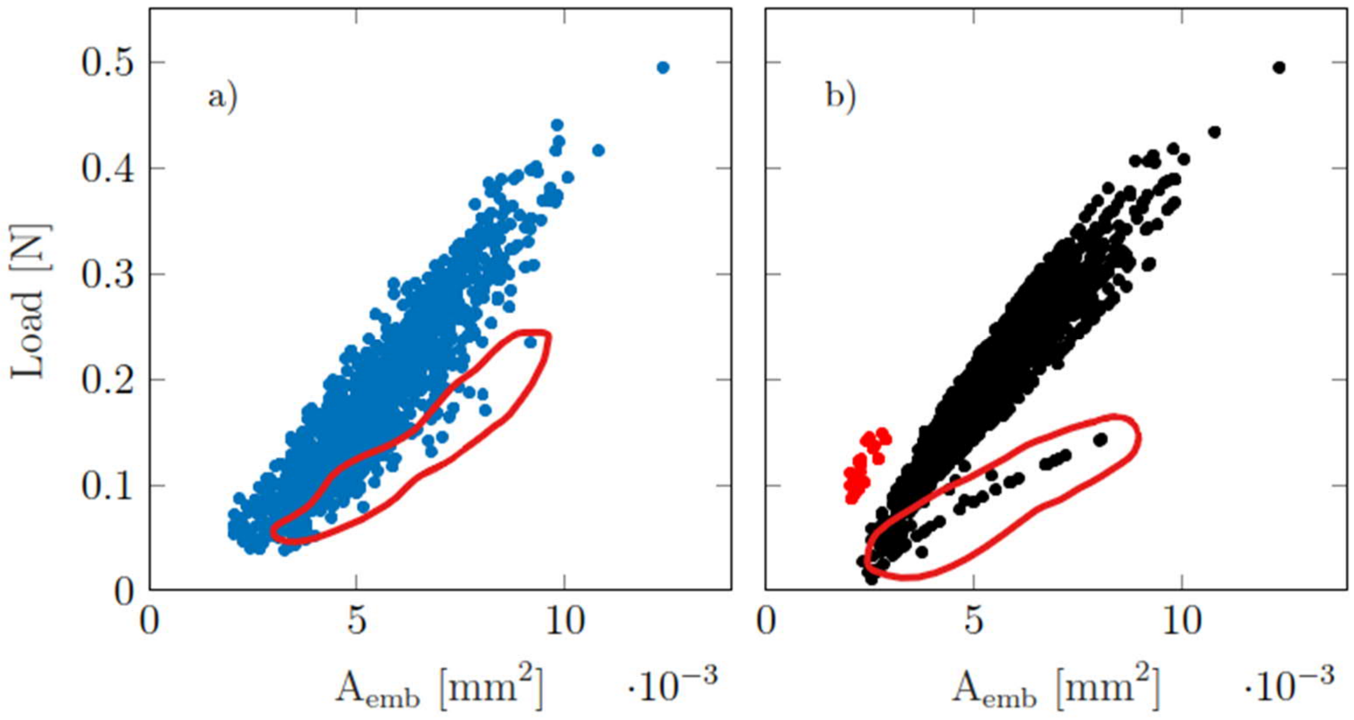
What does microbond measure?

- Repeatability is key!
  - Representative dataset needs adequate sampling to ensure the range of properties
  - Conceptually more similar to fibre testing
  - “Traditionally” very labour intensive

- Measurement output – force vs. embedded area – only useful when comparing similar systems
  - Analytical and/or numerical (finite element) models needed to expand applicability.



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What does microbond measure?

Error source	Possible negative outcomes
Load measurement	Over-/Underestimation of the measured load
Device optics	Inaccurate embedded length and/or fibre diameter
Microvise control	Variation of droplet loading state, high scatter in final results
Embedded area range	Basic assumptions of microbond invalid, fibre breakage
Fibre surface	Variation of the results, always present
Resin curing	Inconsistent results, increased scatter, Resin failure

- The amount of possible variables is massive
  - Due to the scale, seemingly insignificant uncertanties can lead to significant errors in measurement.
- Major issues
  - Scale appropriate equipment
    - Loads commonly in range < 0.5 N
    - Accurate motion in micrometer scale and below
  - Selection of representative sample
    - Characterising a short single filament from a fabric or roving requires 20-40 microbond measurements.
    - Resin cure is well known in the scale of millilitres and above (from DSC samples to macroscale parts)
    - Droplets measured in microbond are in the scale of picolitres (10^{-12}).

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So what's the point?

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What is the point?

- Modern state-of-the-art applications can already have major structural parts from composites
- However, current understanding is already pushed to the limit, within reasonable margins of safety.
- So what is needed for the next generation?

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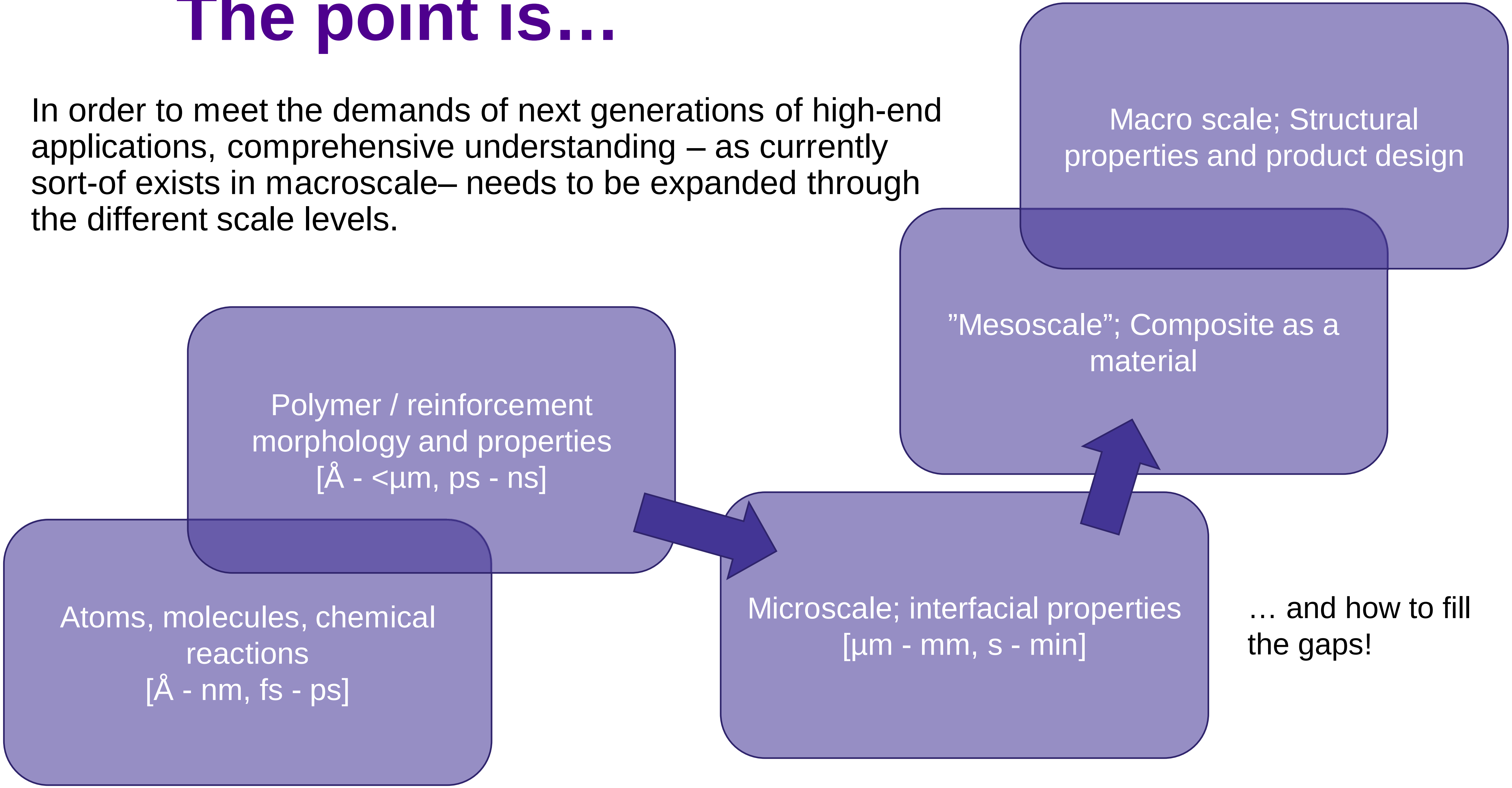
The point is…

- In order to meet the demands of next generations of high-end applications, comprehensive understanding – as currently sort-of exists in macroscale– needs to be expanded through the different scale levels.



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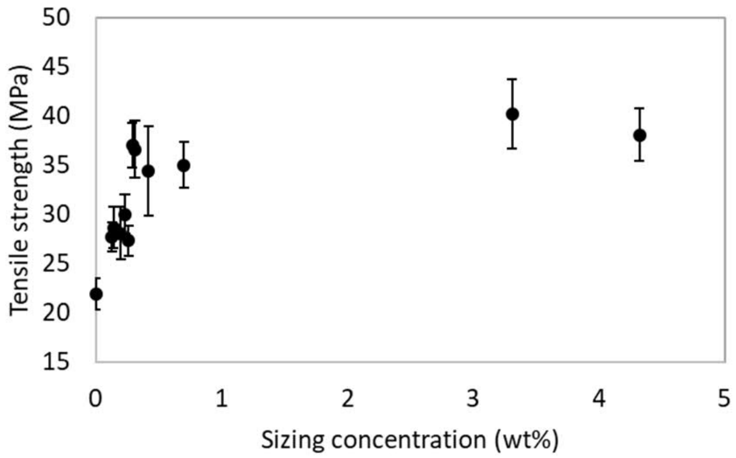
In practice

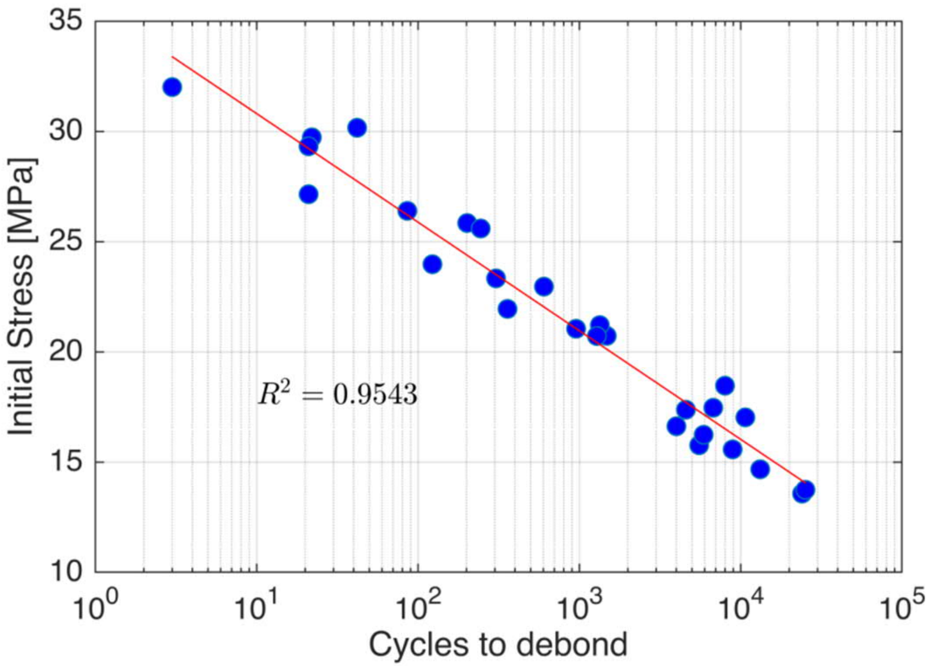
The scales are mostly explored individually. Problems:

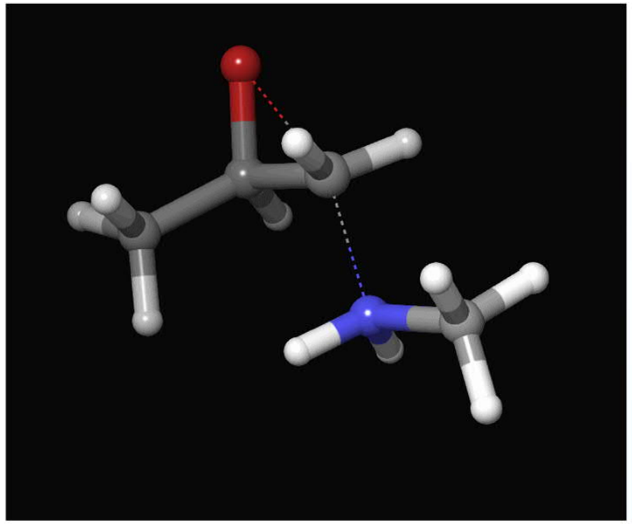
- Inherent problems in upscaling specific phenomena
  - E.g., computational cost
  - ”Ensemble averages”
- Relevance
- And, of course, the information gaps

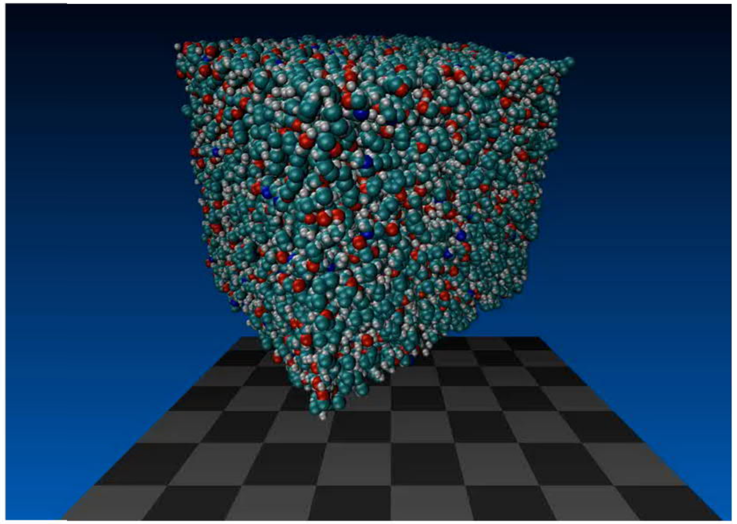
Tying the scales together is one of the biggest future challenges for composites.

And the gaps might just be the largest around interfacial testing methods!









Thank you!

Any questions?

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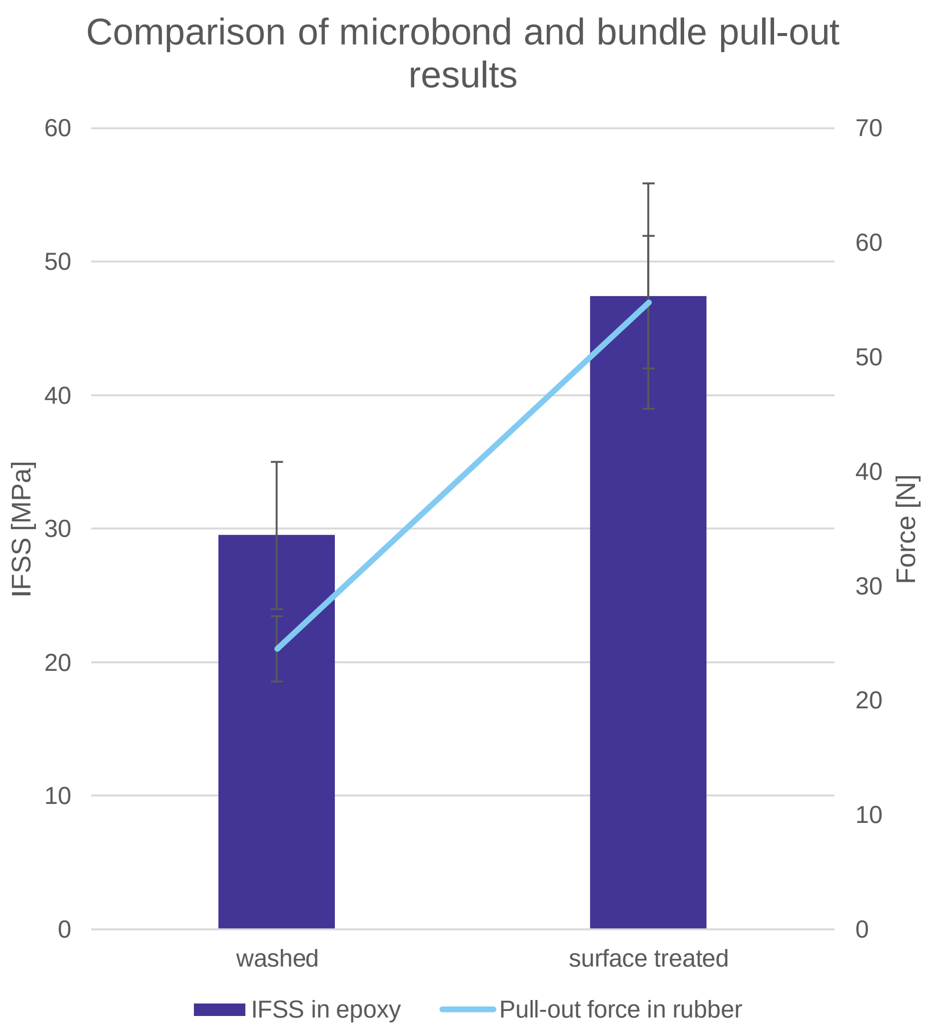
One method, many possibilities;

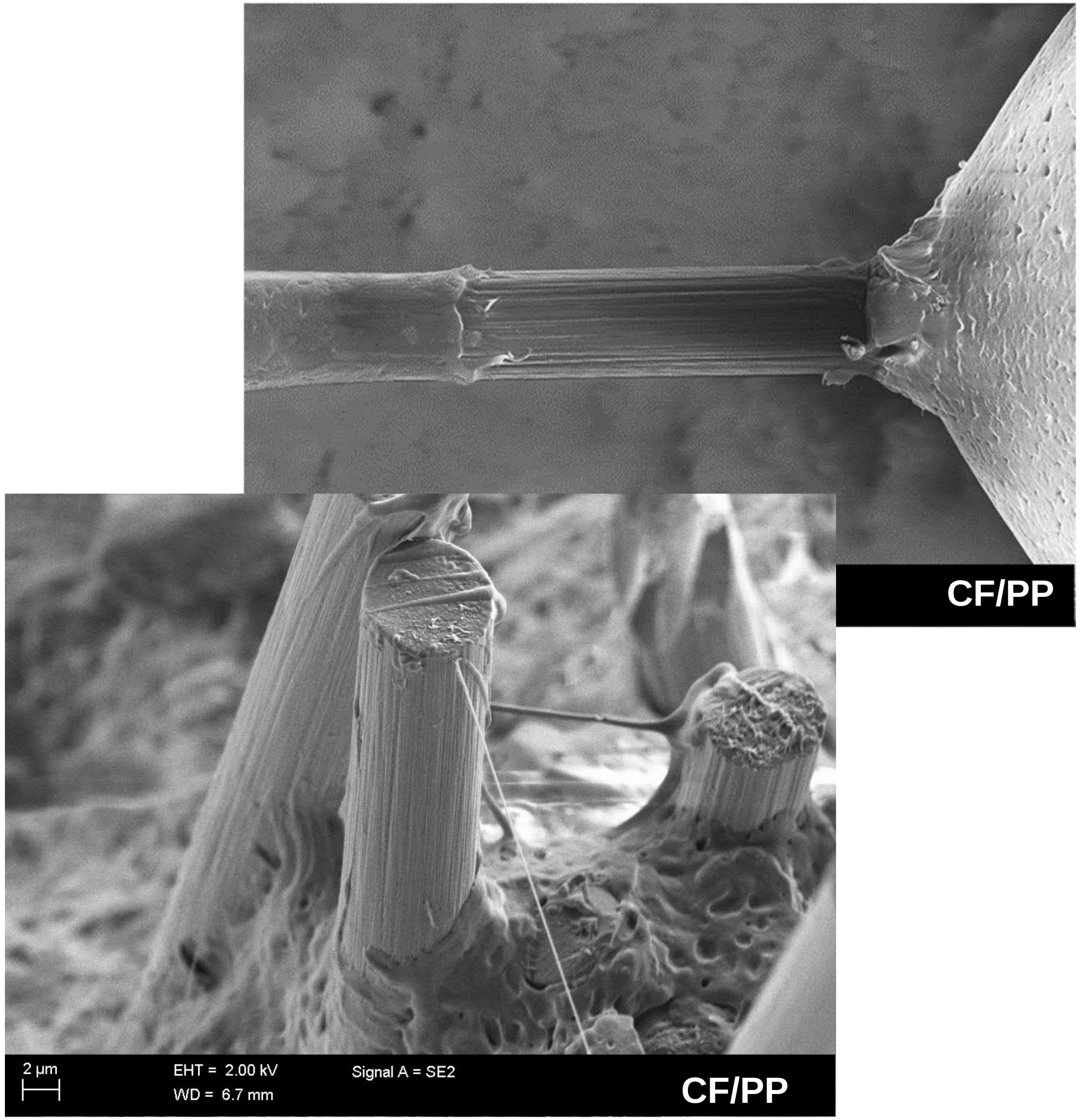
An introduction to material combinations

FibData seminar 26.1.2021
Sarianna Palola

- What?
  - A versatile method to study fiber – matrix interphase
- Why?
  - Interfacial properties impact greatly composite performance
- How?
  - “The sky is the limit” with possible material combinations
  - Fiber: synthetic vs natural
  - Matrix: thermoset vs thermoplastic

From microscale to macroscale





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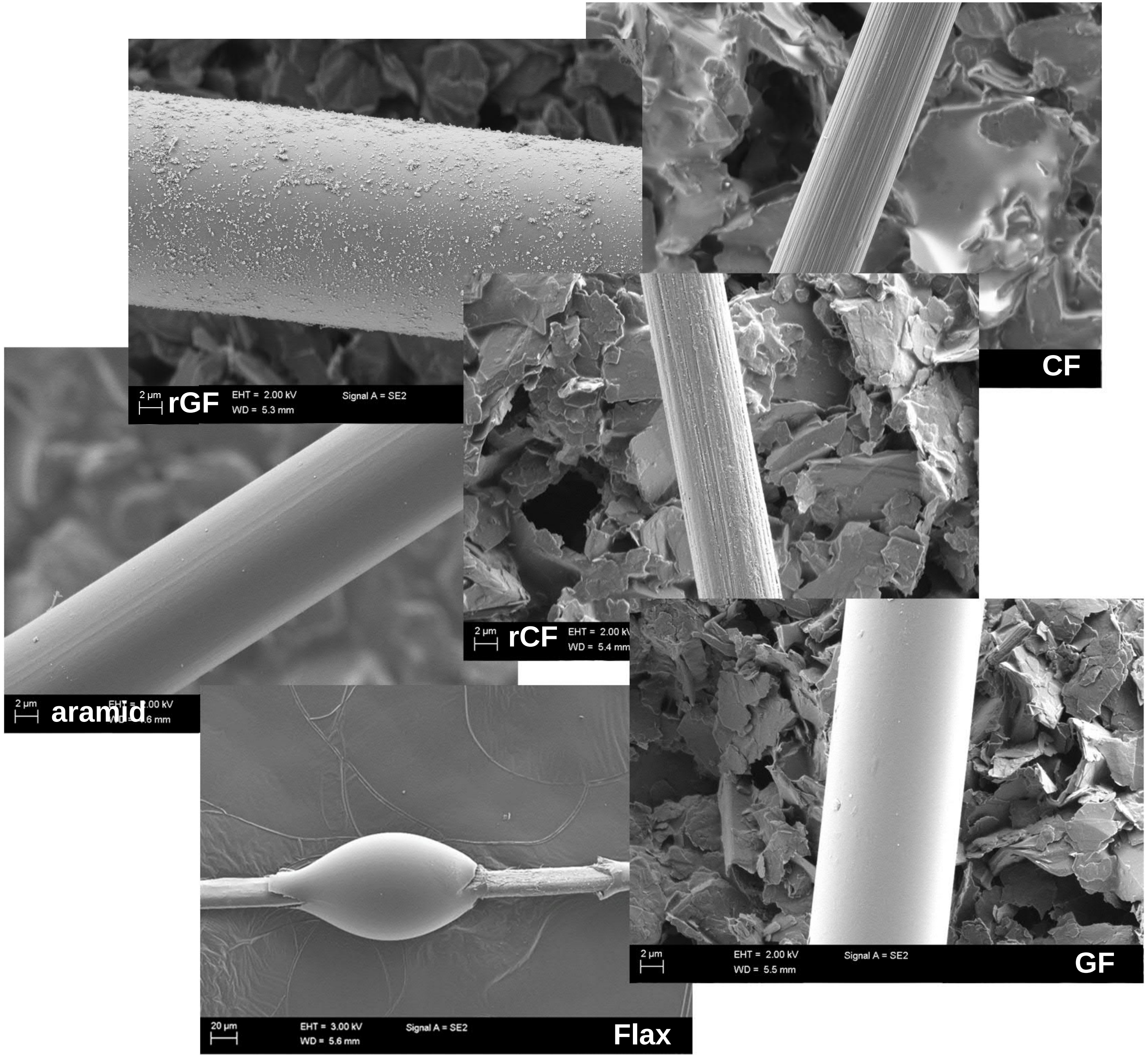
Fibers

- Synthetic fibers tested so far:
  - Carbon fiber (CF)
  - Recycled carbon fiber (rCF)
  - Glass fiber (GF)
  - Recycled glass fiber (rGF)
  - Aramid fiber
  - Polyethene fiber
- Natural fibers tested so far:
  - Flax
- With or without surface treatements



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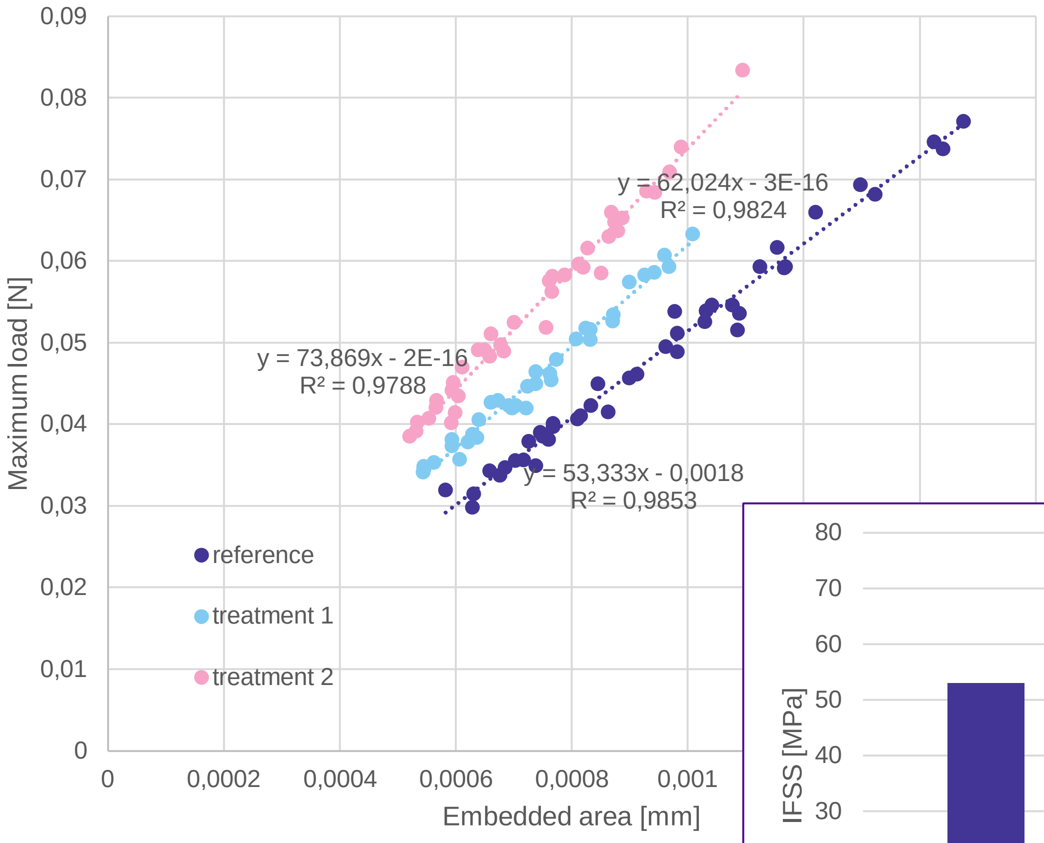
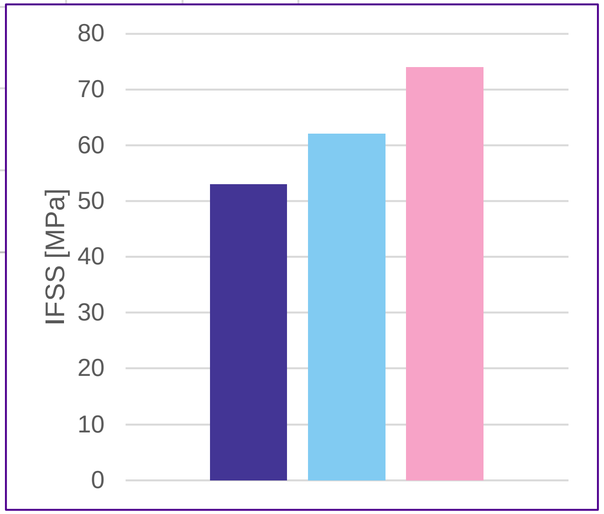
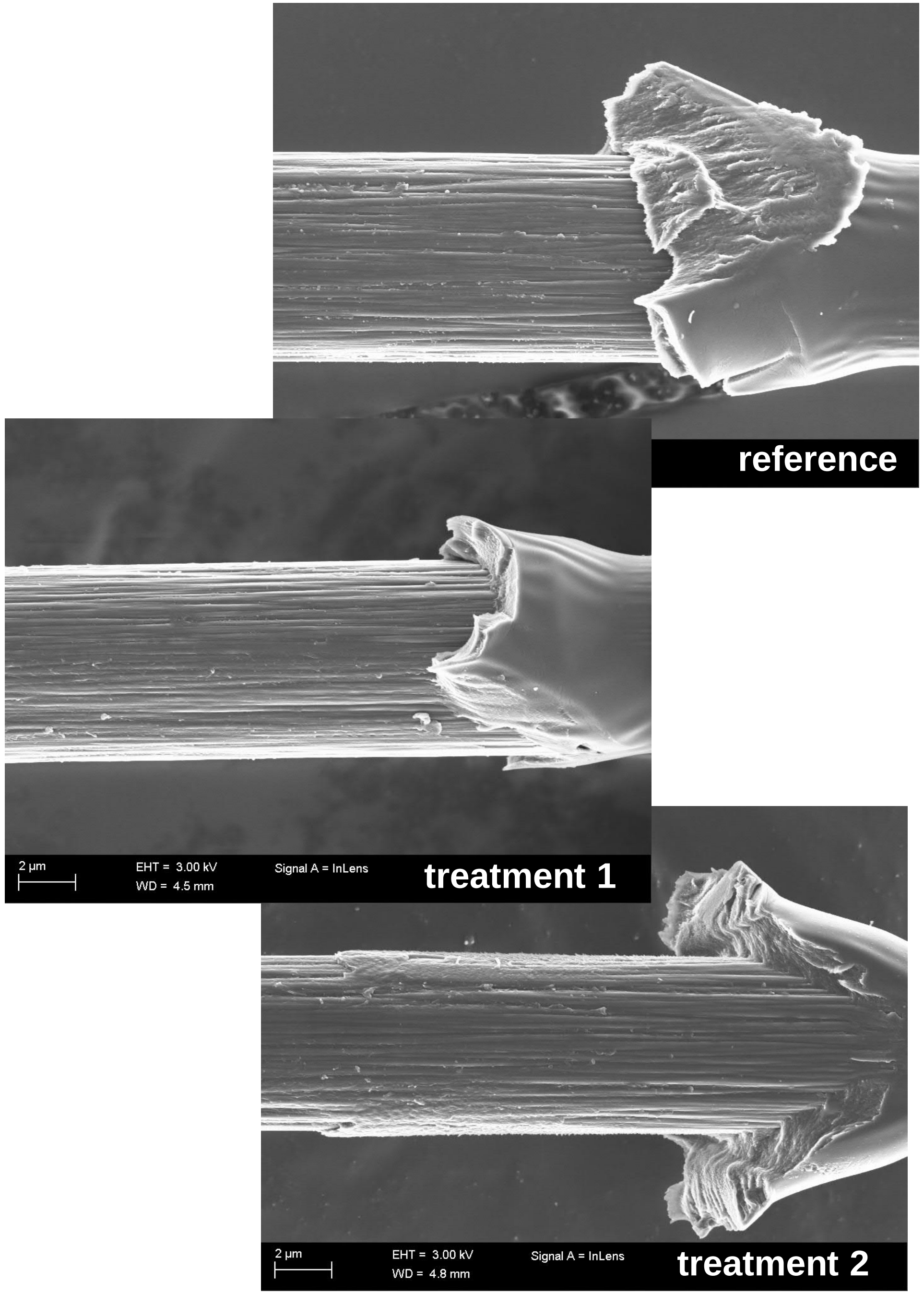
Fibers; case example

Effect of surface treatment on IFSS in CF/PMMA







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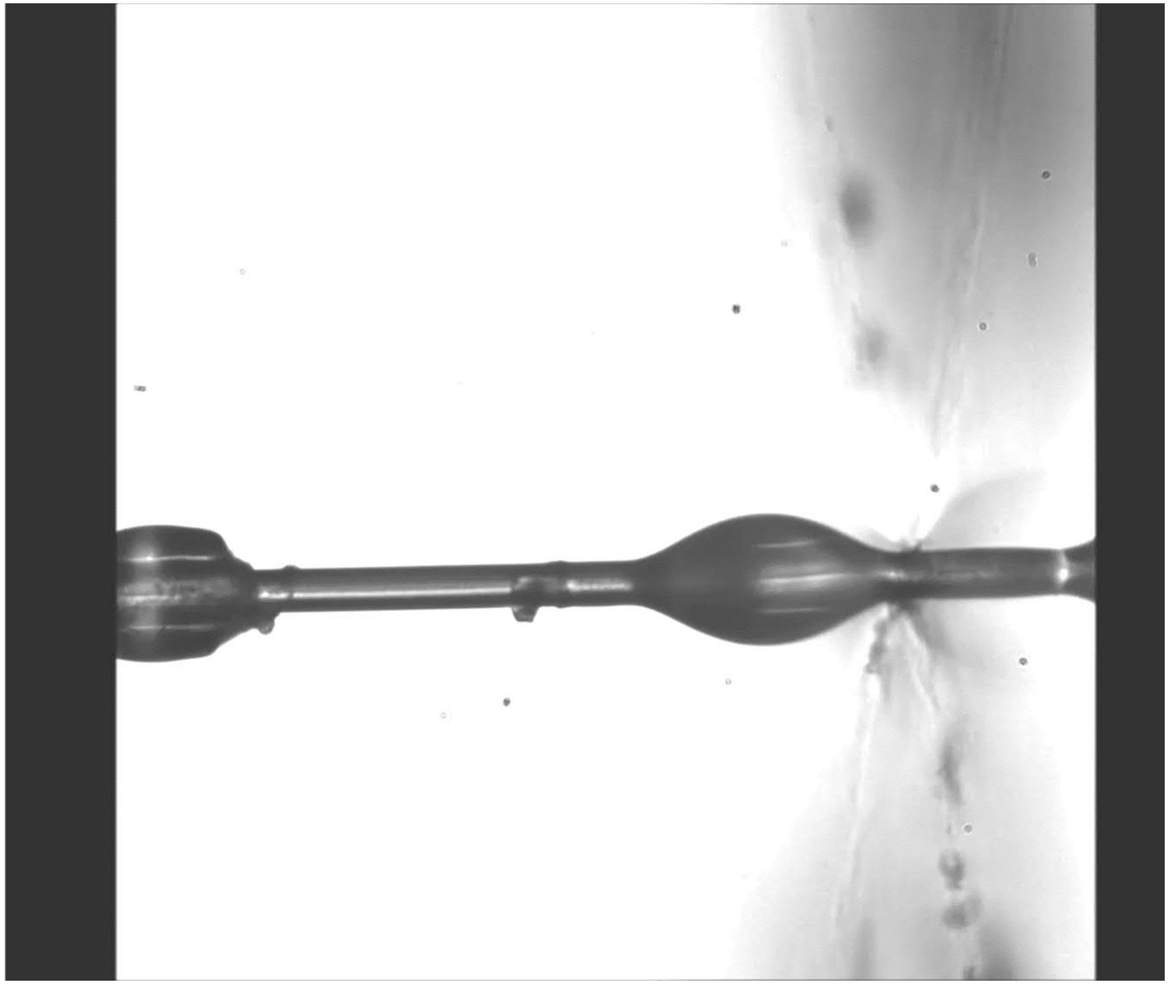
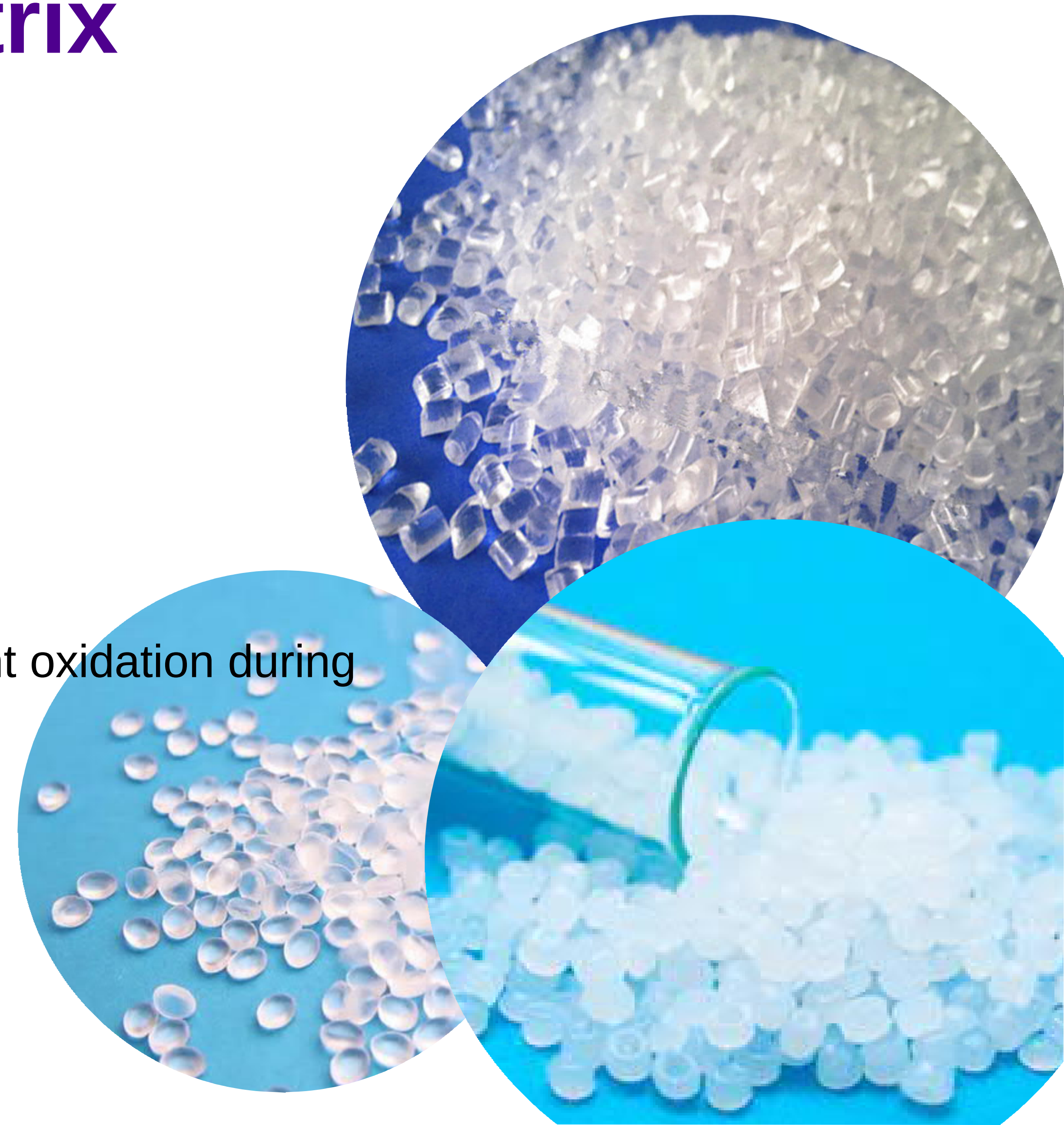
Thermoset matrix

- Tested so far:
  - Epoxies
  - Polyvinylesters
  - Polyester
  - Polyurethane
  - Silicone
- Pot life of 10 minutes adequate but longer is better
- Protective N2 atmosphere can be used during
  - Sample manufacturing
  - Curing



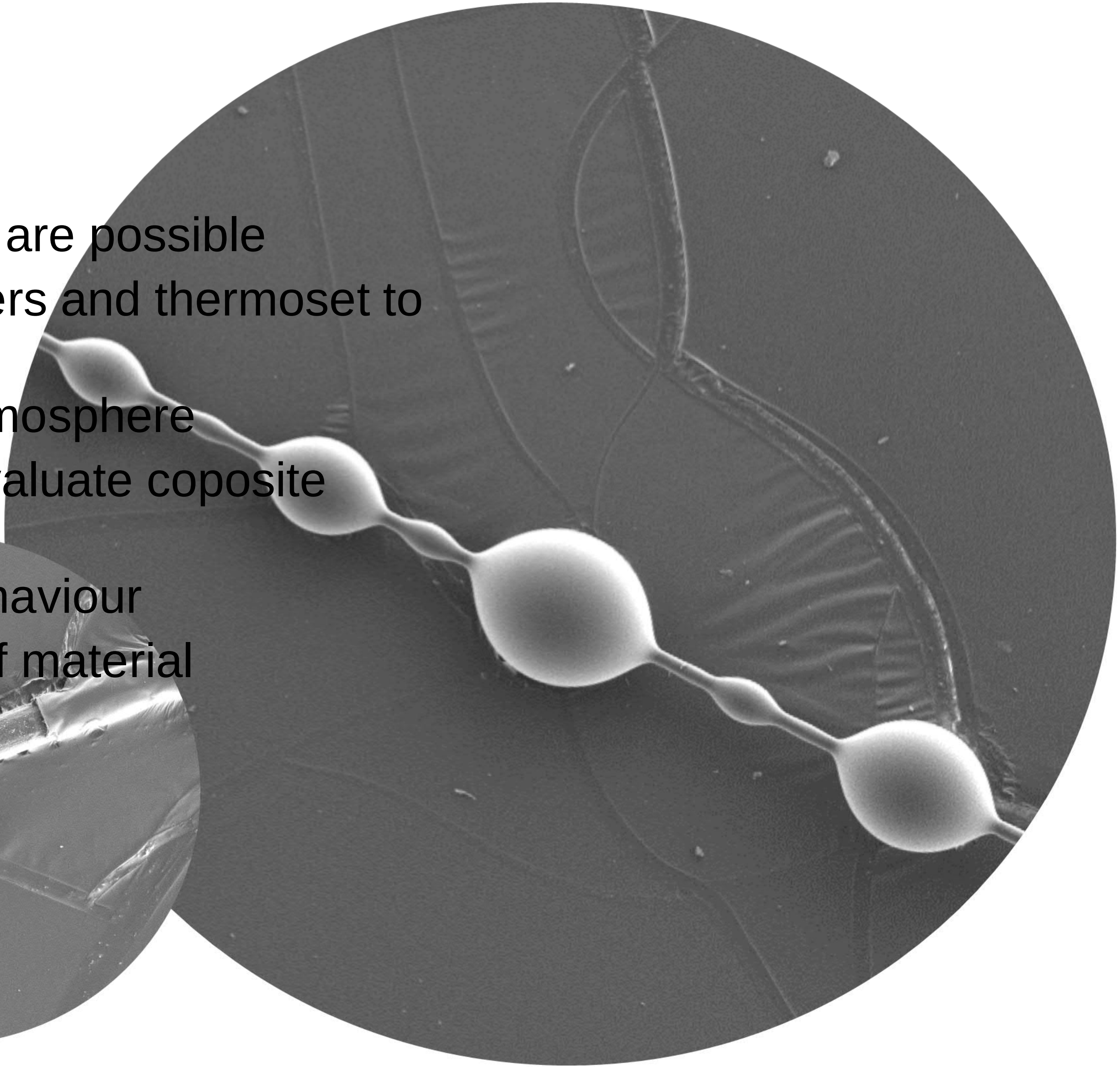
Thermoplastic matrix

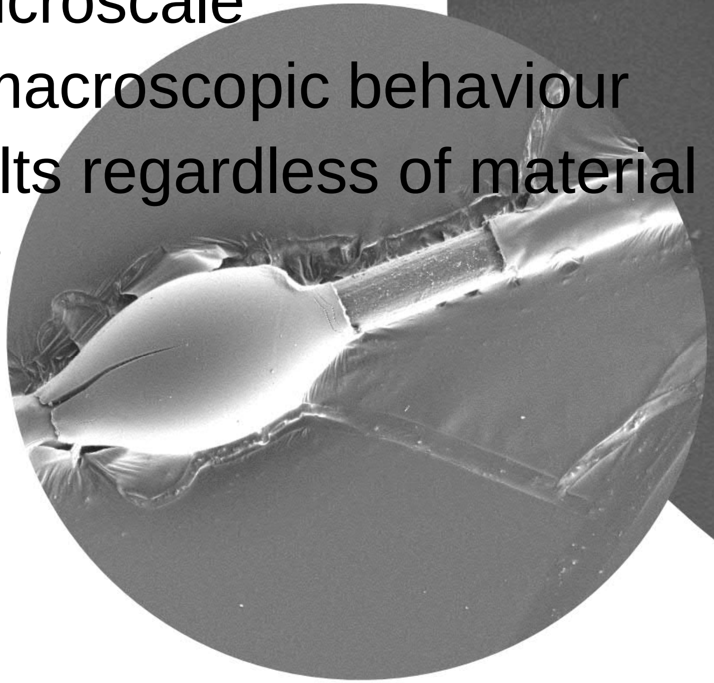
- Tested so far:
  - Polypropene (homo- and copolymer grades)
  - Polyamide
  - Polycarbonate
  - Polyester
  - PMMA (poly(methyl methacrylate))
  - PEEK (polyether ether ketone)
  - PEI (polyetherimide)
- Protective N2 atmosphere can be used to prevent oxidation during sample preparation
- Low melt viscosity materials work the best



Conclusions

- Multiple material combinations are possible
  - From synthetic to natural fibers and thermoset to thermoplastic matrix
  - With or without protective atmosphere
- Fast and efficient method to evaluate coposite properties in microscale
  - Represents macroscopic behaviour
  - Reliable results regardless of material combinations





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Thank you!

Any questions?

Extending the microbond testing possibilities – aging tests

Olli Orell, Jesse Savolainen

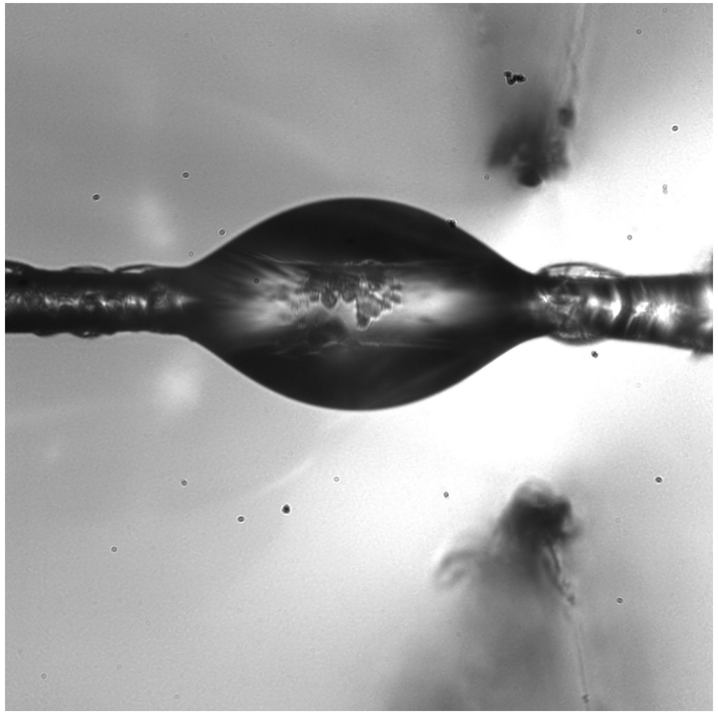
Aging tests for composites

- Mechanical properties of FRPs degrade due to adverse environmental conditions

- Laminate scale aging tests are carried out routineously
  - realistic in-service environments or accelerated by temperature

- Microbond testing using the current technology offers high throughput method with minimal amount of materials and simple manufacturing

→ Several benefits to study the aging phenomena of the 'purely' interfacial properties of composites



Microbonds and aging

- Sample preparation can be carried out normally

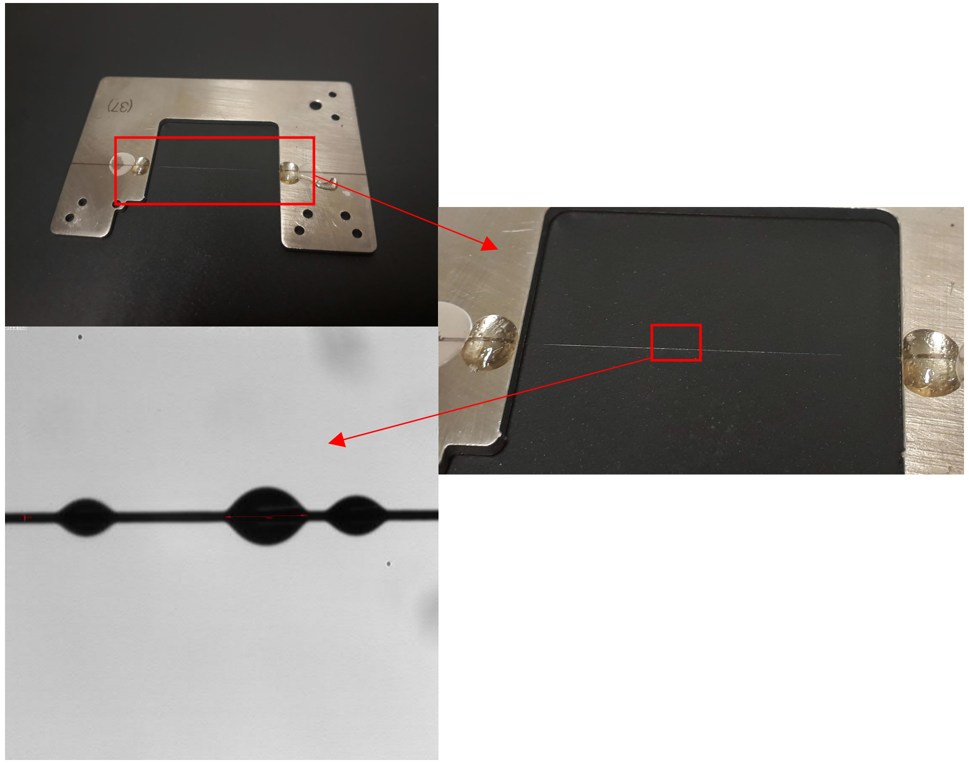
- Aging possibilites:

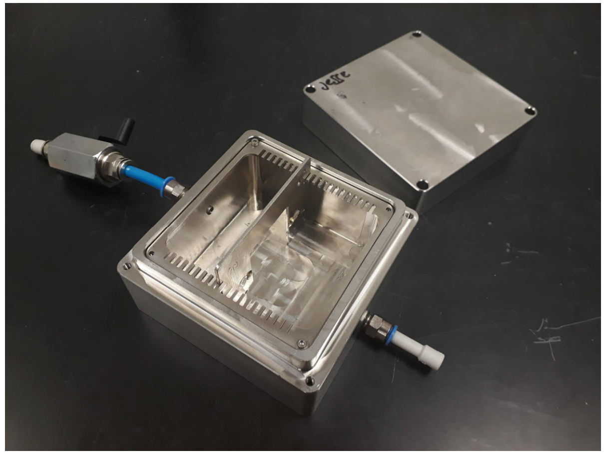
a) Full immersion in liquid
   - The acid resistant sample holders allow use of even corrosive media

b) In controlled atmosphere
   - The impermeable sample holder can be controlled to desired atmosphere by flushing with gases
   - Saturated salt solutions in the closed box can be used to achieve desired relative humidity

c) Thermal/moisture cycling

d) UV exposing





Example case

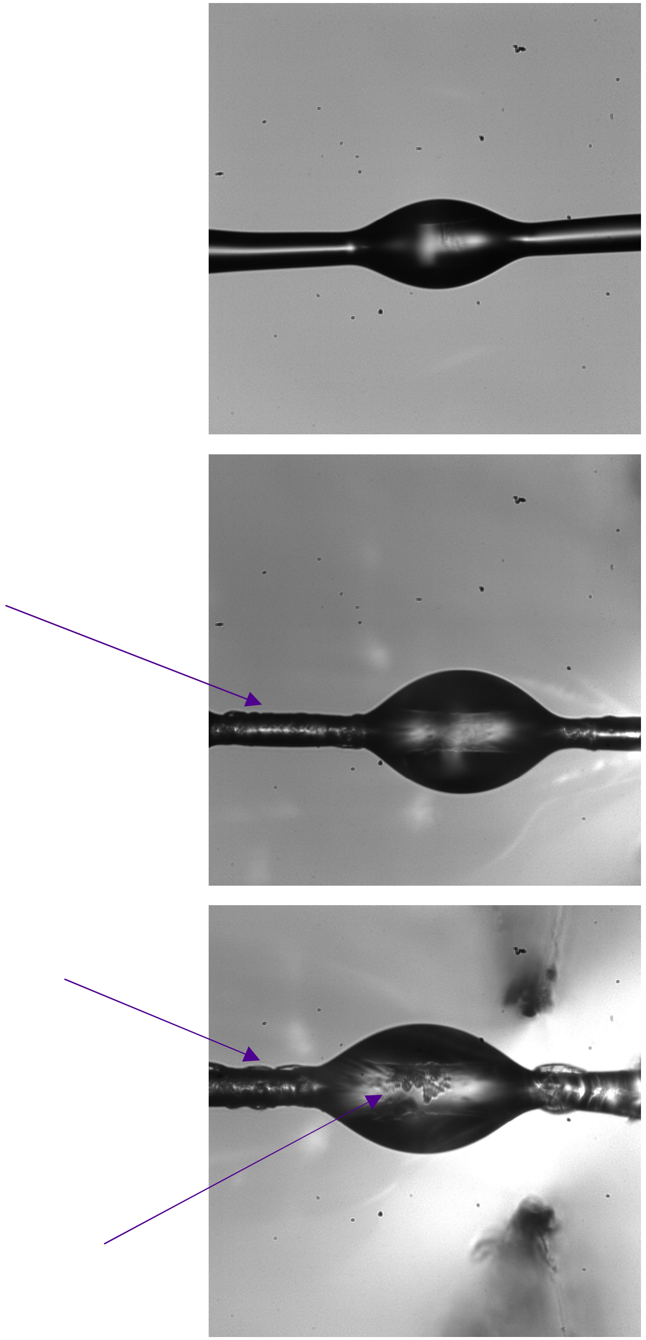
Matrix: Vinylester

Fiber: ECR glass

Aging media: DI water (*and 75% RH)*

Temperatures: RT and 60 C (and *40 C*)

Aging time: 0h, 24h, 50h, (68h)



Ref

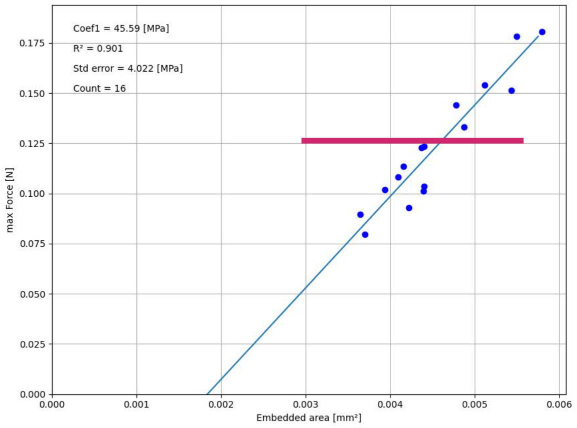
50h @23C

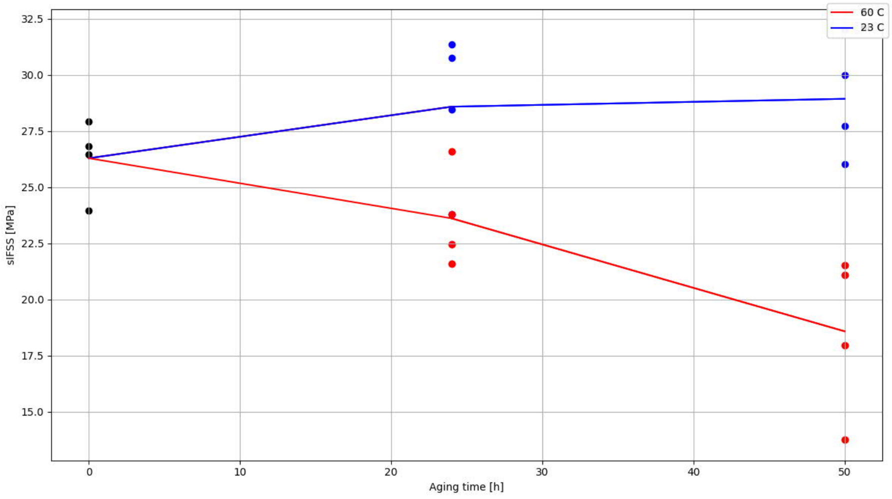
50h @60C

Test observations

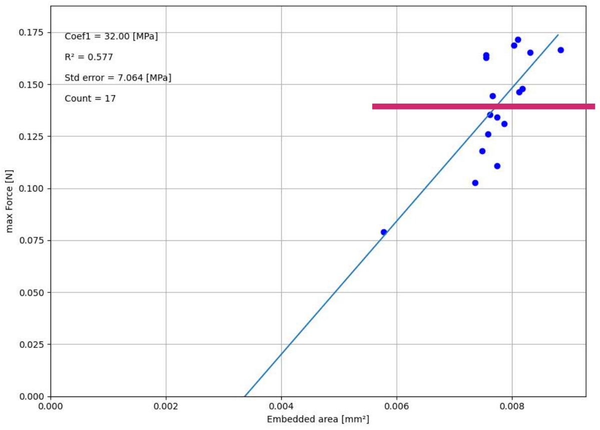
- Change in the behaviour - scatter increases
- Some droplets remain visully almost original, but some show radical changes
- Apparent average interfacial shear strength shows decreasing trend for aging in 60 C

REF



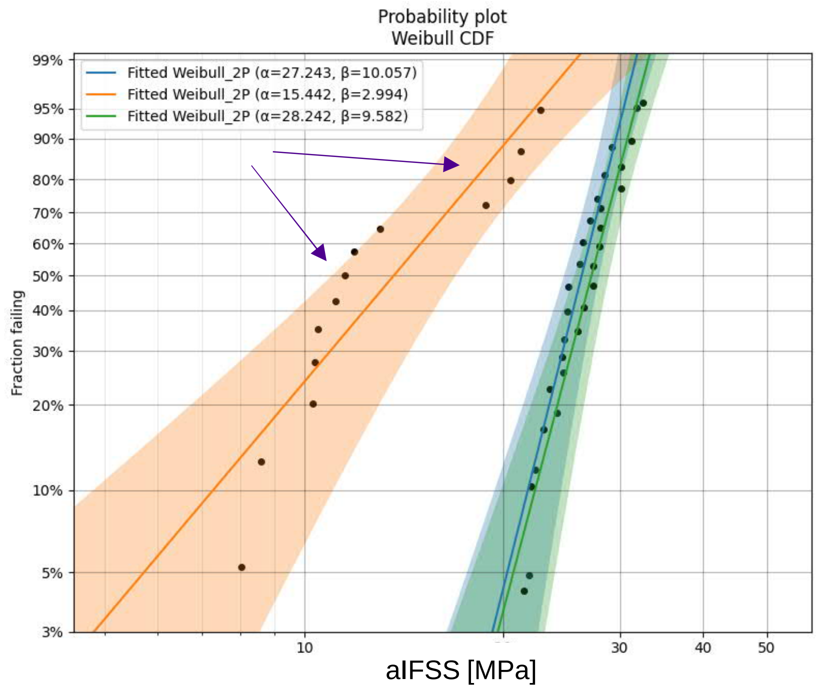


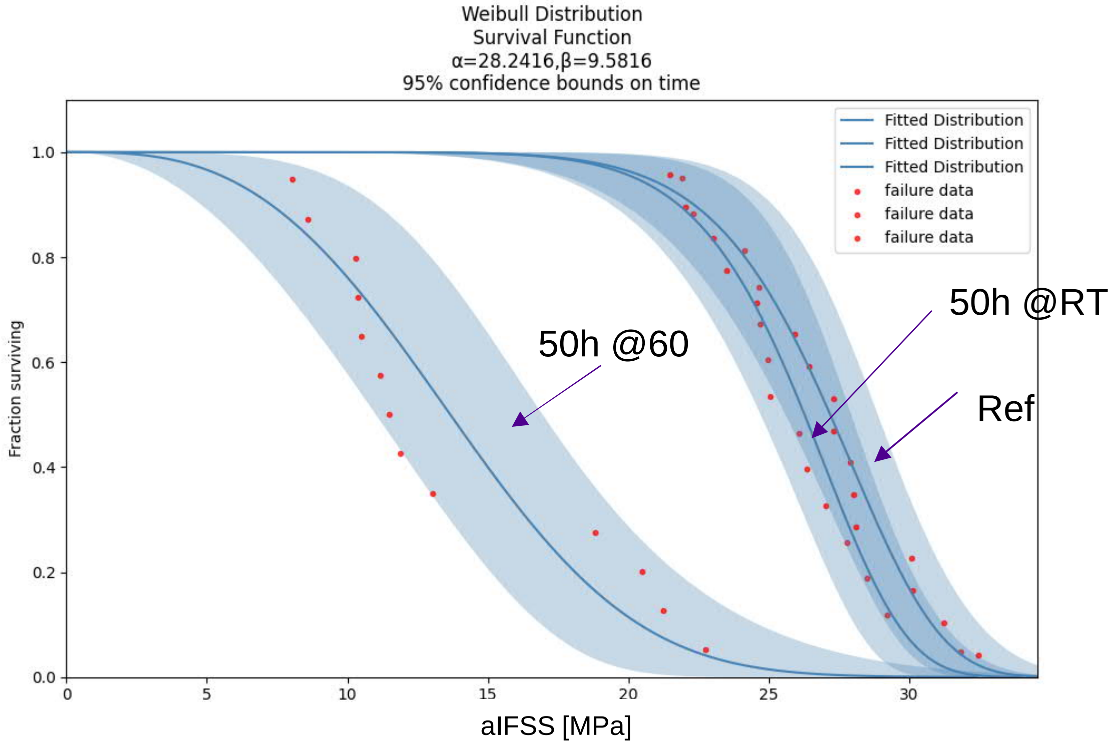
50h @ 60C



Reliability analysis with large datasets

- Large datasets will enable various analysis methods –statistics or propabilities
- Eg. 2-P Weibull analysis can reveal differences in the fracture behaviour





Lessons learned

- Suitable for **comparison** studies between different materials or aging parameters
- Quick tests compared to normal aging tests with coupons
- High scatter - result analysis needs rethinking
- Consistent specimen fabrication is essential - laborious screening for specimen fabrication often needed
- How to ’age the interface’, not the fiber (or matrix)

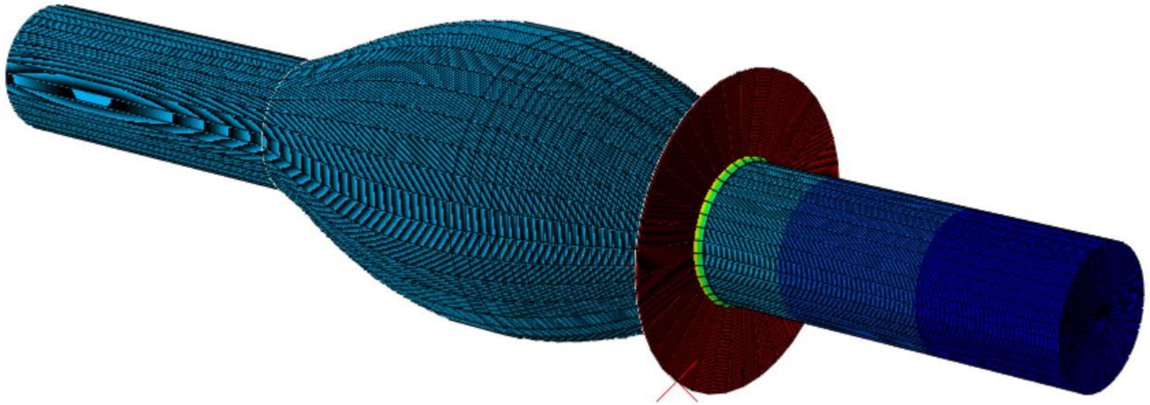
Thank you for attention!

Towards automated finite element analysis

Olli Orell, Jarno Jokinen

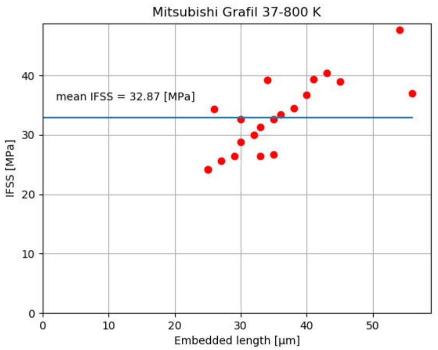
Contents

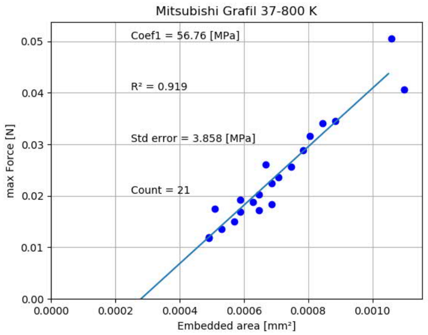
- Motivation - Current state of microbond analysis
- Input for analysis
- Approach for an automatic finite element analysis
- FE model features and results



Motivation –
Current state of microbond analysis

- The comparison of microbond tests are typically based on 'Apparent Interfacial shear stress (IFSS)
  - Using the force maxima, fiber thickness and droplet length
  - Provides average stress value
- IFSS is easy and quick method for post-processing, but do not take account:
  - geometric shapes,
  - residual stresses
  - nonlinear materials,
  - contacts
- **Need for more accurate analysis method, applicable for automated post-processing**





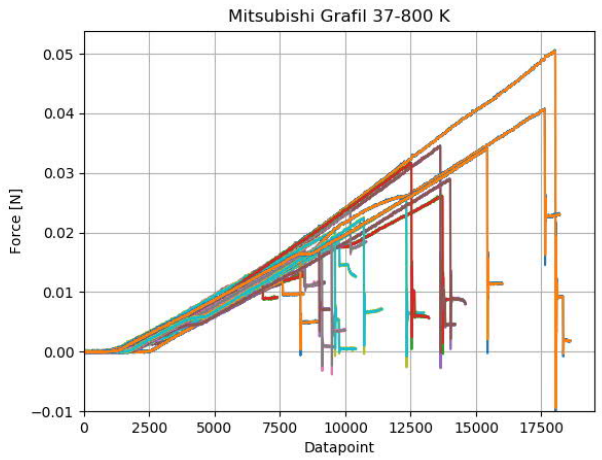
$$\tau = F/A$$

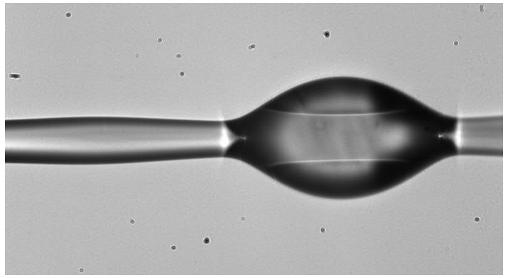
Finite element analysis

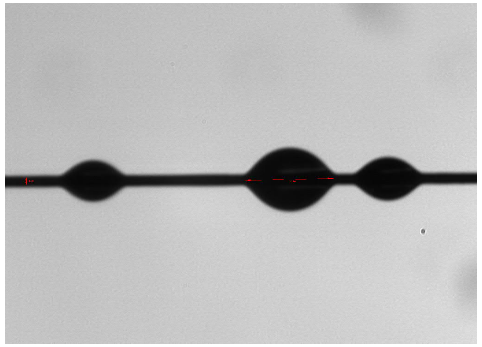
Tampere University

Input for model –
Available raw data

- More experimental data available for modelling (than maximum force and diameter):
    - Force-time curves of the tests
    - Images of the droplets
    - Fabrication parameters (curing) of the matrix
    - Droplet position in the test fixture
    - *Displacement*







Input for model -
Database based data storage

- Amount of test data is extensive
  - 15-30 droplets for each fiber specimen (CSV result files and images)
  - Several paraller specimens

- All the results are collected into database (MongoDB) instead of separate files allowing simple querying of the data
  - Force data, droplet images, material properties, sample manufacturing parameters, material bathes, etc.

Approach for an automatic FEM analysis

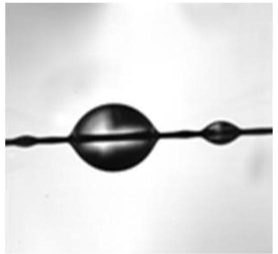


Image of the tested droplet

CSV result file from the test device

Python program

Find the tested droplet from the image

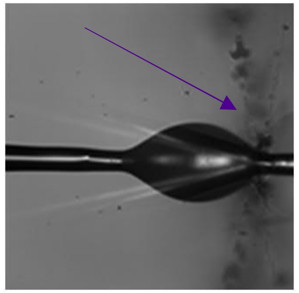
Separate the droplet into matrix and fiber instances

Create rigid loading blades into correct position

Create the mesh (2D / axisymmetric)

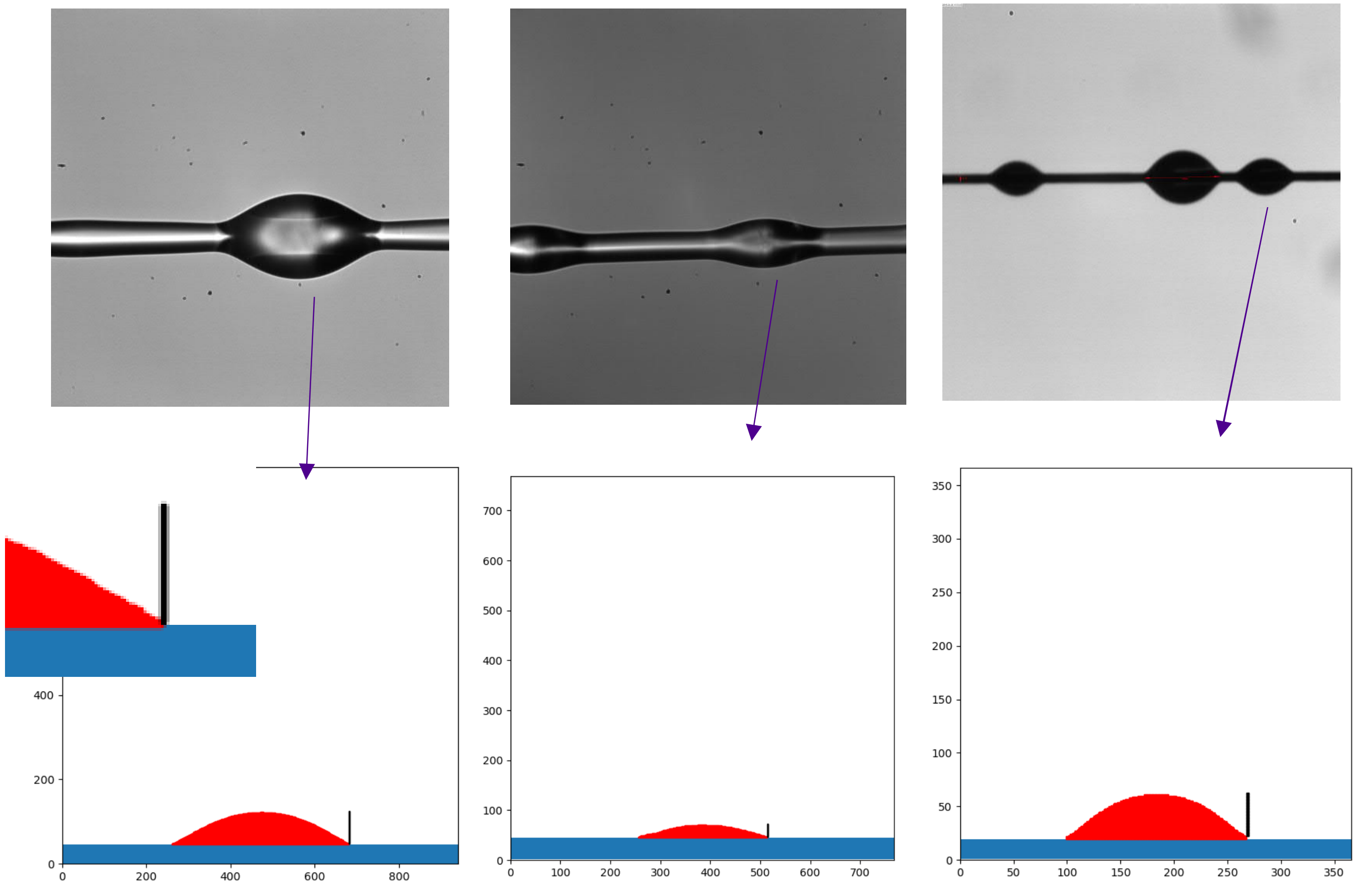
Read the experimental load data and material properties from the database

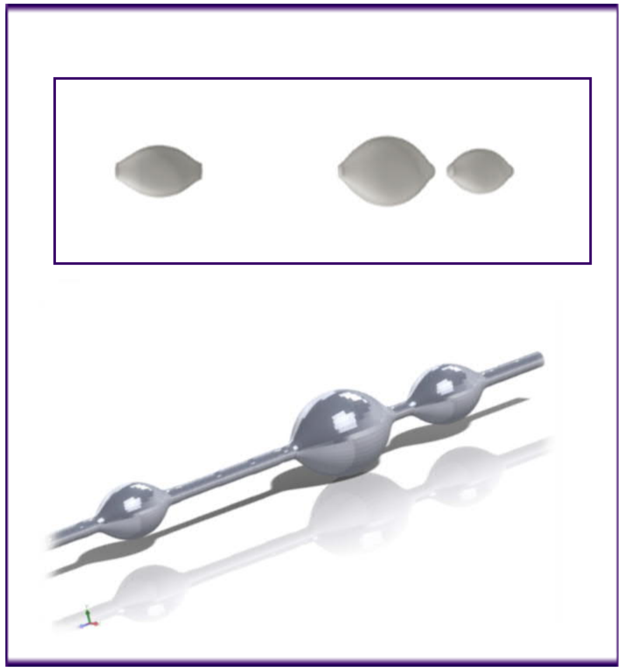
Export the problem for the FE solver (Abaqus .inp file)



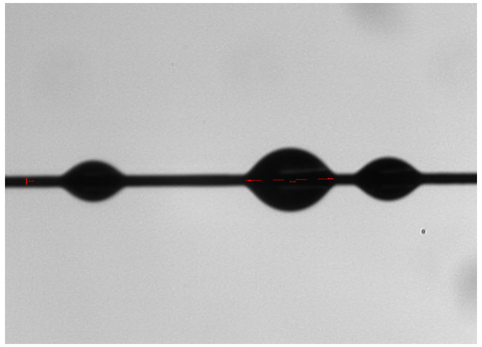
Run FEA and export desired outputs

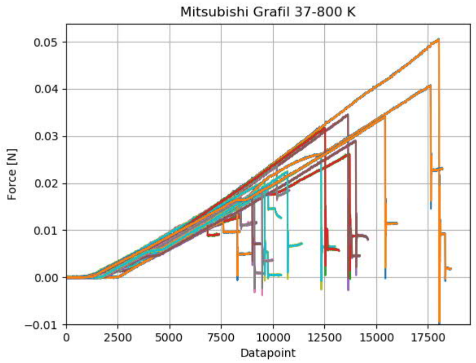
From images to mesh - examples

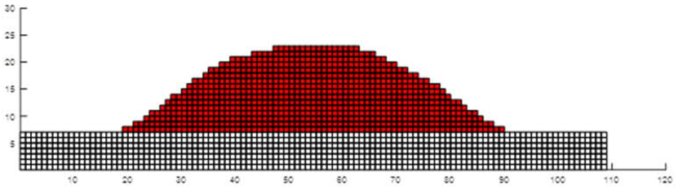




Ready FE problem in text format to be send to FE solver with no efforts required by the user!







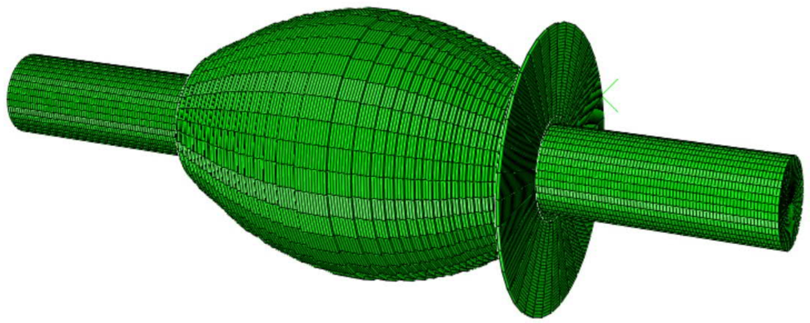
```
10161,
10162,
10163,
10164
*Node
1,43.0,220.0,0
*Nset, nset=rp
1,
** Constraint: Constraint-1
*Tie, name=Constraint-1, adjust=yes
dropletInterfaceSurface, fiberInterfaceSurface
** Constraint: Constraint-2
*Rigid Body, ref node=rp,pin nset=bladeNodes
*End Assembly
**
** MATERIALS
**
*Material, name=Fiber
*Elastic
70000, 0.2
*Material, name=Droplet
*Elastic
2500, 0.35
*Material, name=Blade
*Elastic
210000, 0.33
**
** INTERACTION PROPERTIES
**
*Surface Interaction, name=Kitkaton
1.,
*Friction
0.,
*Surface Behavior, pressure-overclosure=HARD
**
**BOUNDARY CONDITIONS
**
** Name: RightFiberEnd Type: Displacement/Rotation
*Boundary
rightFiberEnd, 1, 1
rightFiberEnd, 2, 2
** Name: refPoint Type: Displacement/Rotation
*Boundary
rp,2,2
rp,6,6
**
```

FE features

Advantages

- Based on real geometry
- Complicated material models both droplet, fiber and interface can be included
- Contact included between blade and droplet
- Realistic load value

FEA enables taking account the various factors in order to analyse of the interface



Current model advantages

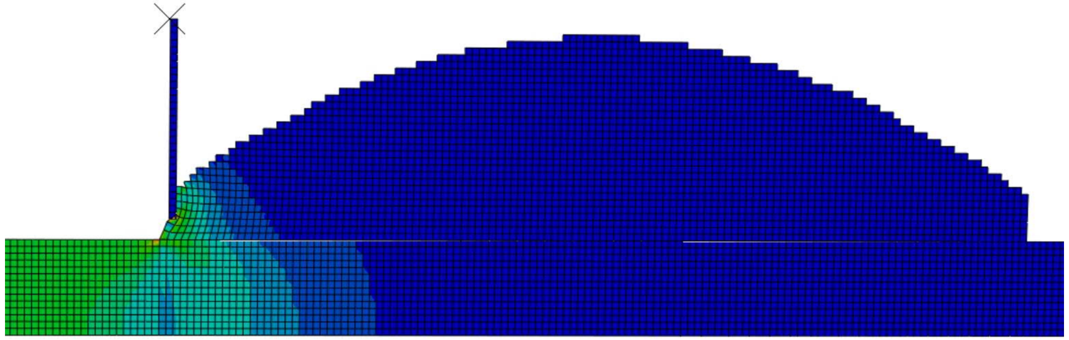
- Efficient analysis
- No need for manual modifications of the input

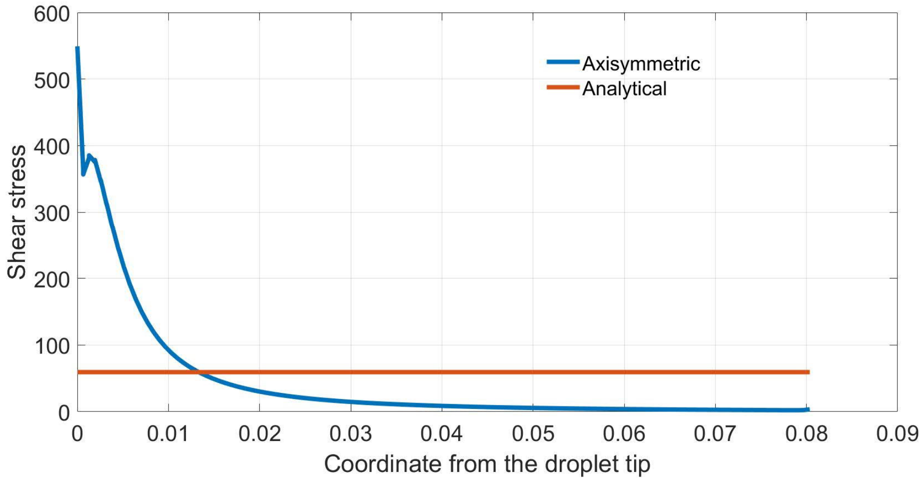
Limitation

- Axisymmetric model (visualization shown in figure)

Results

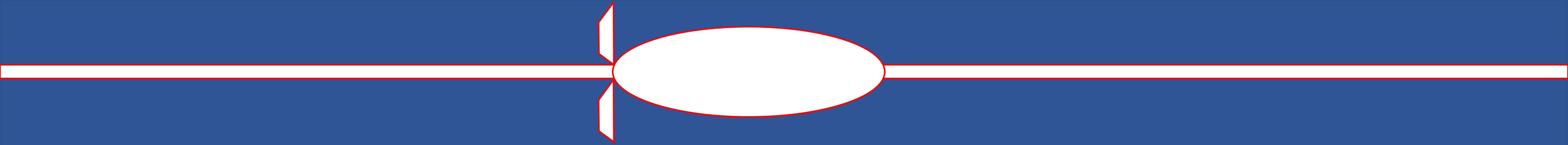
- Stress analysis
  - Interface (average vs distribution)
  - Plasticity
- Deformation
  - Strain
  - *Displacement*





- FEA will be likely carried as batch runs after tests
  - Fluent data handing will be necessary
  - Future development: automatization of post-processing

Thank you for your attention!



Future Microbond tests – Towards local strain measurements

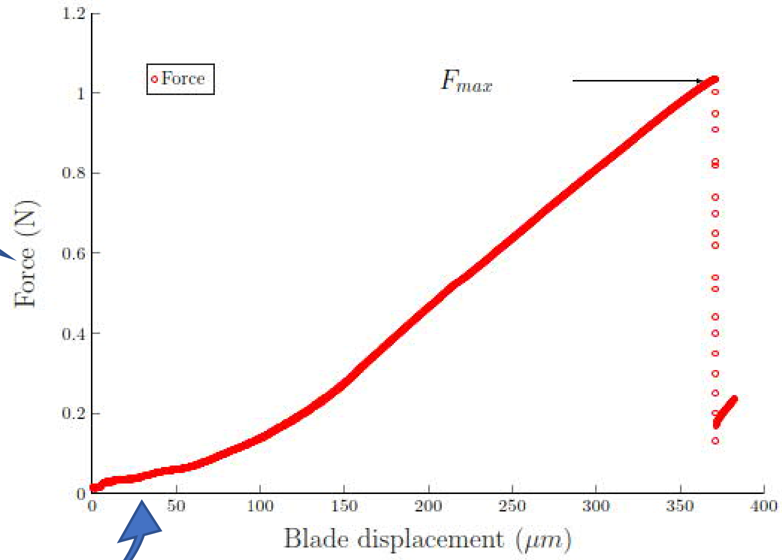
Royson Donate D'Souza
Doctoral Researcher
Tampere University,
Finland.

Tampereen yliopisto
Tampere University

Motivation towards strain measurements

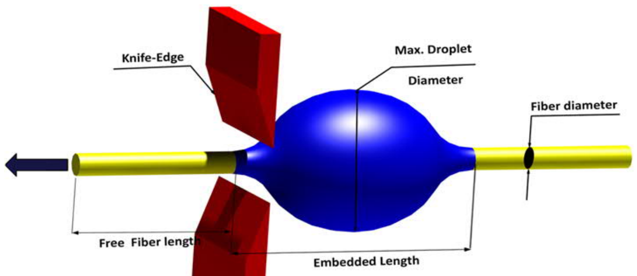
Numerical model with complex damage at interface with just one output parameter ????

The current measures of fibre matrix interfacial adhesion rely only on single parameter i.e., Force.



Current interface test methods for microbond can result in force and blade displacement data.

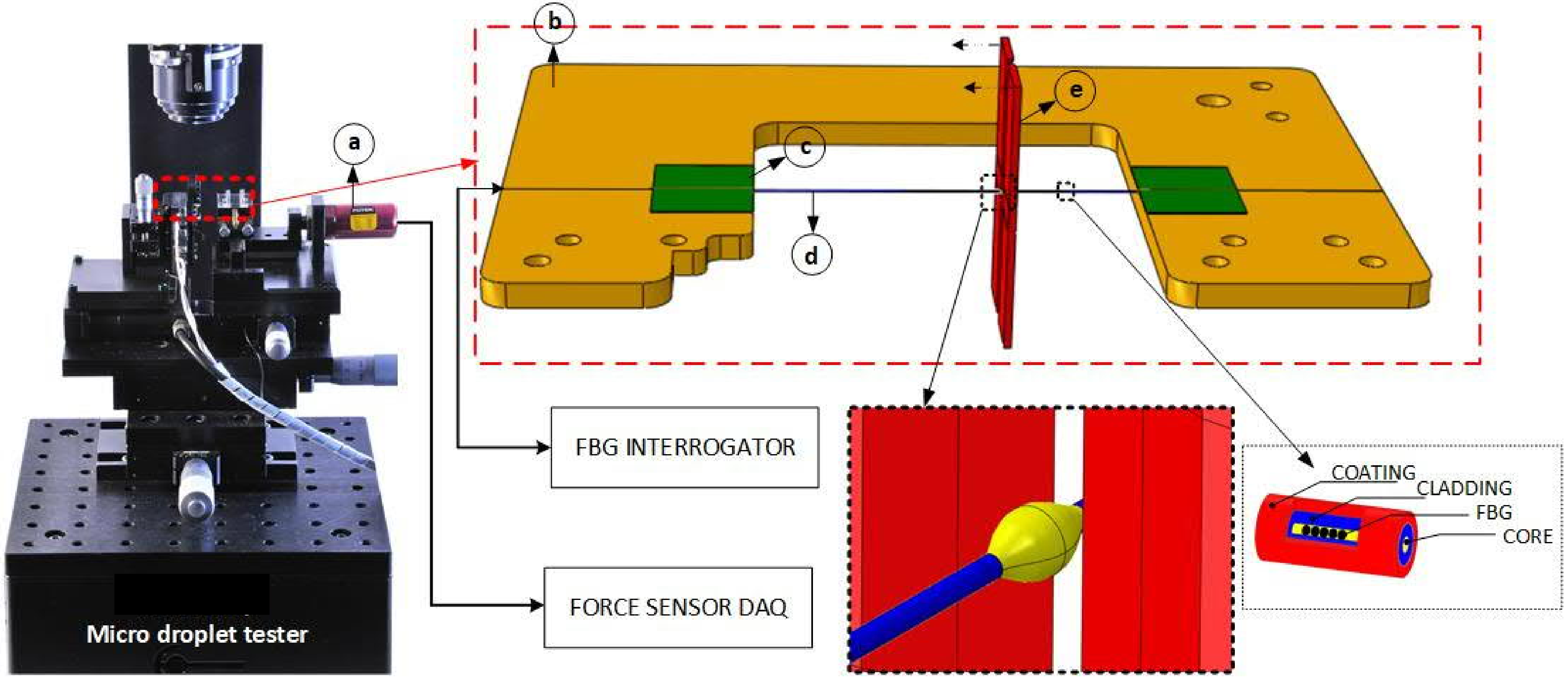
Cross-head displacement is basically never used for standard fracture testing of interfaces.



Fracture process in a laminate or ply cannot be described well without parameters giving allowables to interfacial dissipation.

Investigation on strain measurements

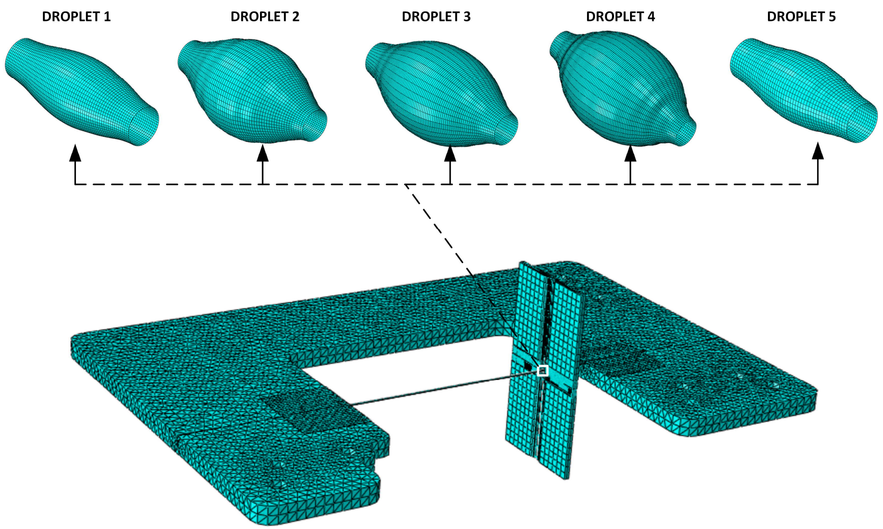
FibreNet



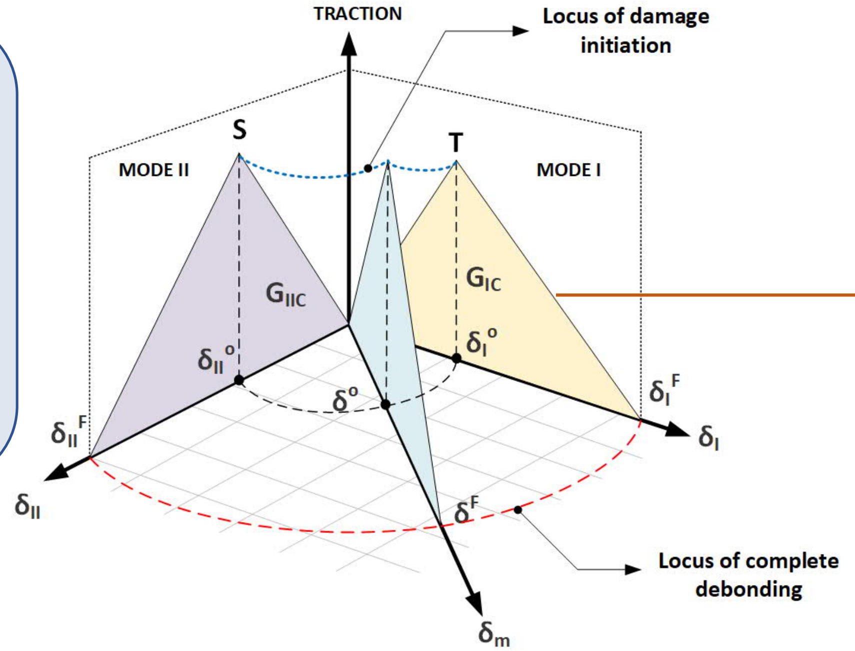
a. Force Cell b. Sample Holder c. Adhesive d. Optical fibre with FBG e. Blades

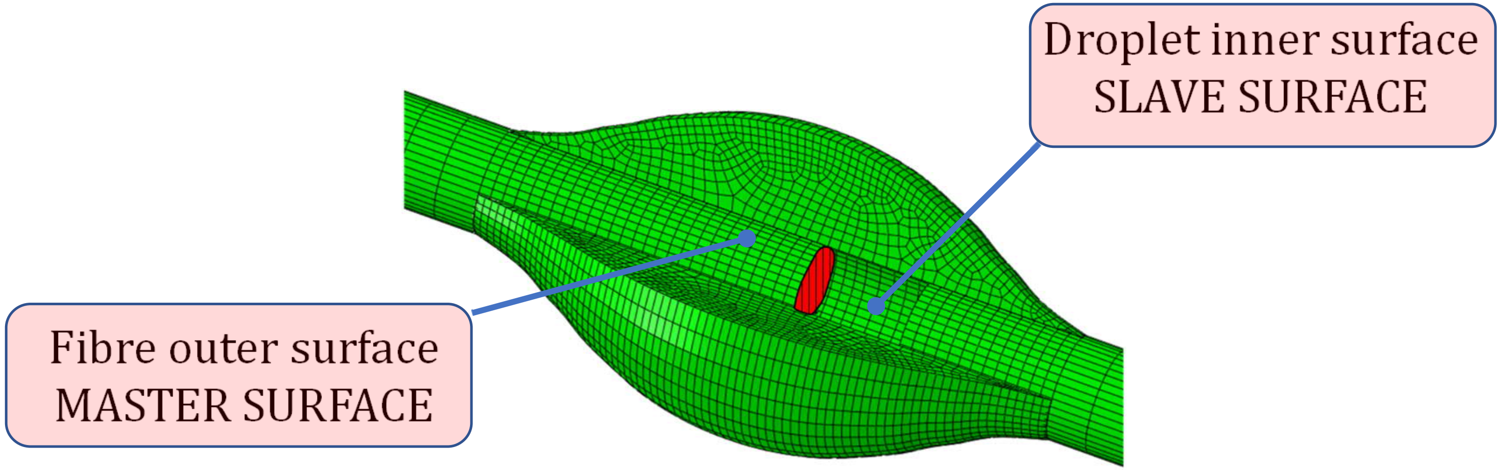
Constituent	Optical FBG fibre	Droplets	Sample holder	Knives
Material	Glass fibre (GF1, Nufern)	Araldite® 5052-resin Aradur® 5052-hardener (Huntsman)	Acrylic	Stainless steel

Finite Element Model



- Surface based **Cohesive Zone model** is used.
- The response of the CZM element is defined by a traction-separation law.
- Bilinear traction separation law is employed in the model.





$$\sigma = \begin{cases} K_0\delta & if \quad \delta \le a_0 \\ \dfrac{a_1-\delta}{a_1-a_0}\sigma_0 & if \quad a_0 \le \delta \le a_1 \\ 0 & if \quad \delta \ge a_1 \end{cases}$$

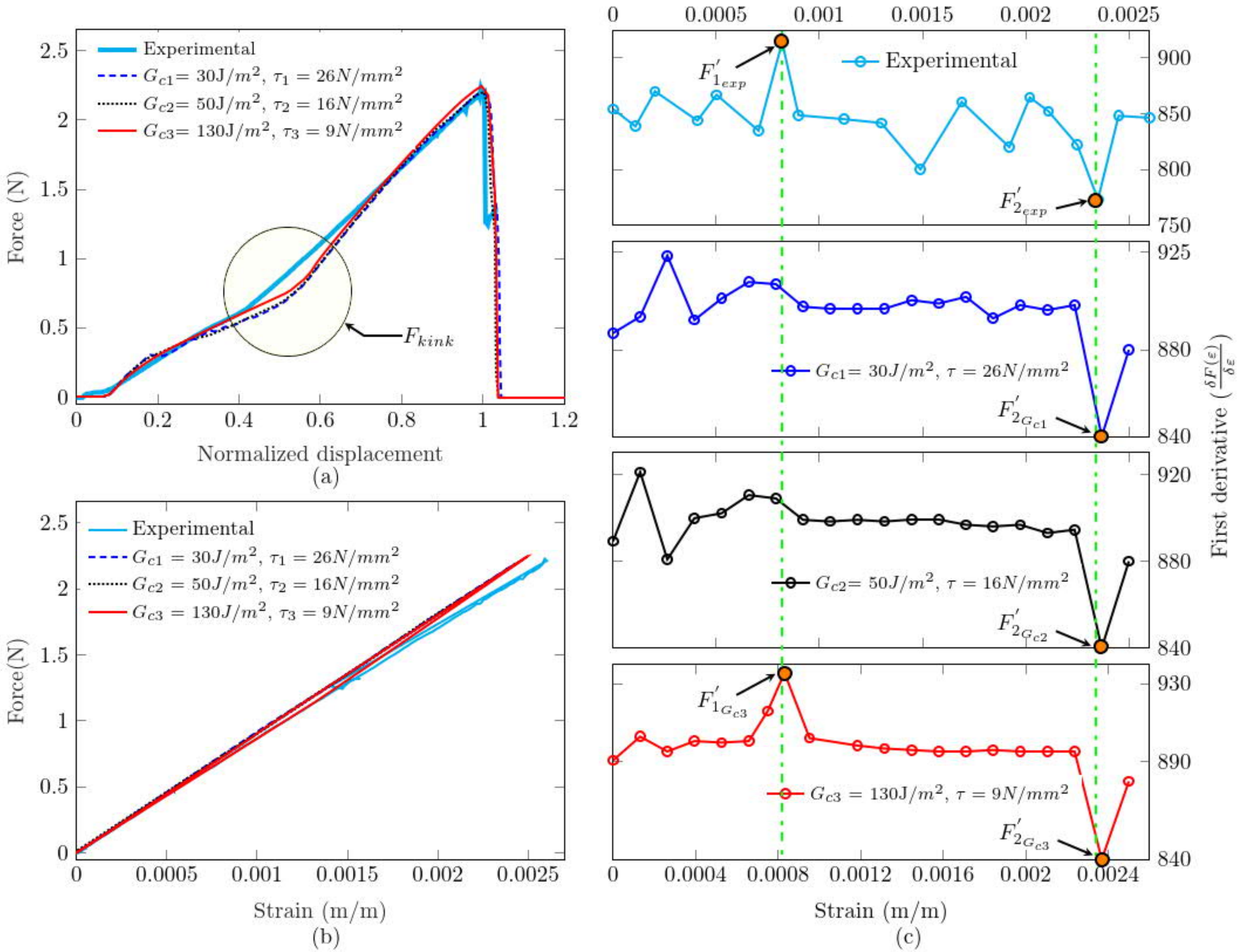
$$a_0 = \frac{\sigma_0}{K}$$

$$a_1 = \frac{2G_c}{\sigma_0}$$

Features revealed by force-strain data

- ❑Local strain measurement using optical fibres not only enhance the microbond test but also provides additional parameter for solving interfacial fracture phenomenon.

- ❑Peak strain, peak force and first derivative of force strain profile are crucial to understand fracture process.



Derivatives of force strain curves provide accurate estimation of Gc and τ.

Fracture process at the interface

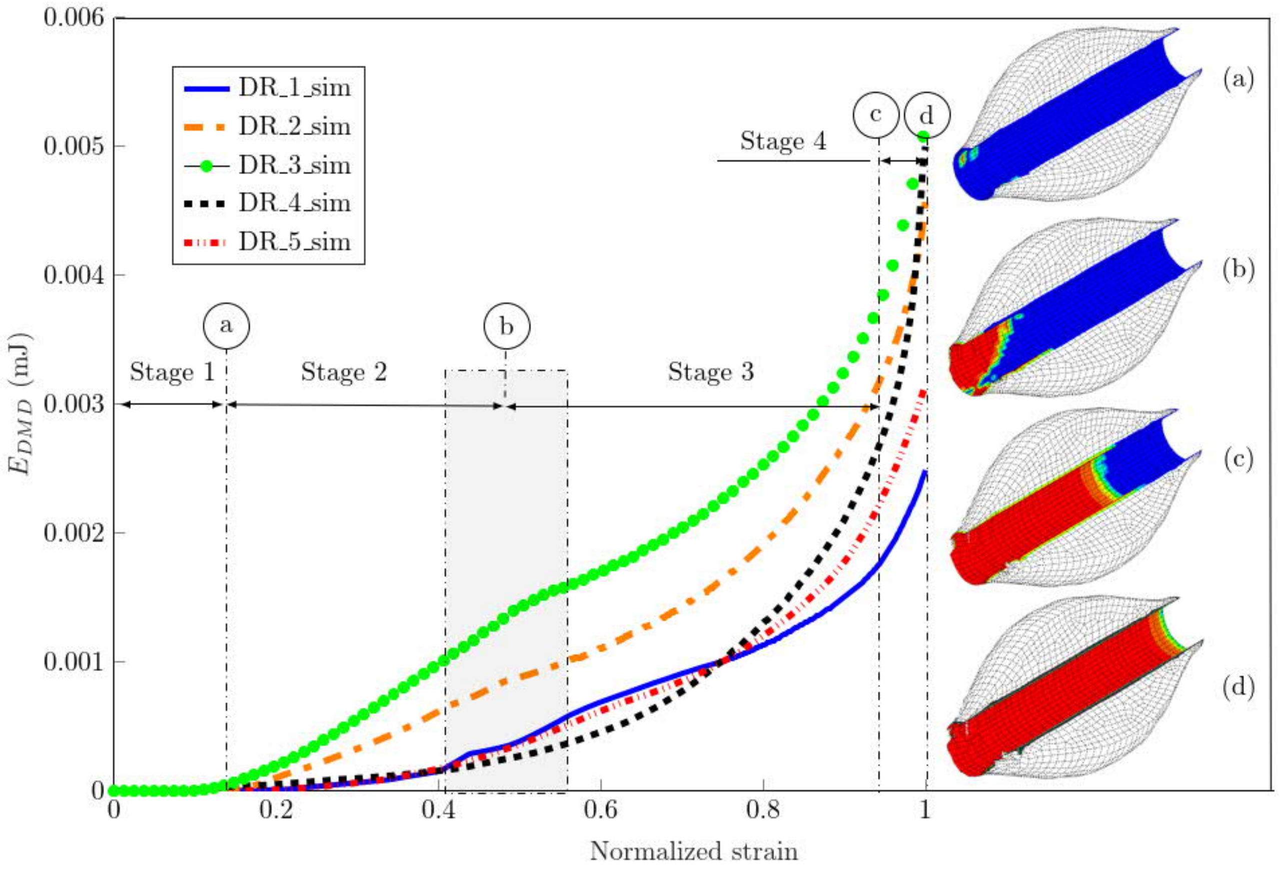
Four stages of fracture:

Stage 1: Fibre elongation and deformation of the droplet.

Stage 2: Damage progresses circumferentially.

Stage 3: The interfacial damage progresses and extends spatially in the fibre's longitudinal direction.

Stage 4: There is an abrupt rise in the consumption of interfacial damage energy



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- Pekka Laurikainen
- Farzin Javanshour
- Olli Tanhuanpää
- Dr. David Seveno

Tampere University

FibreNet

universidade de aveiro

FIBROBOTICS

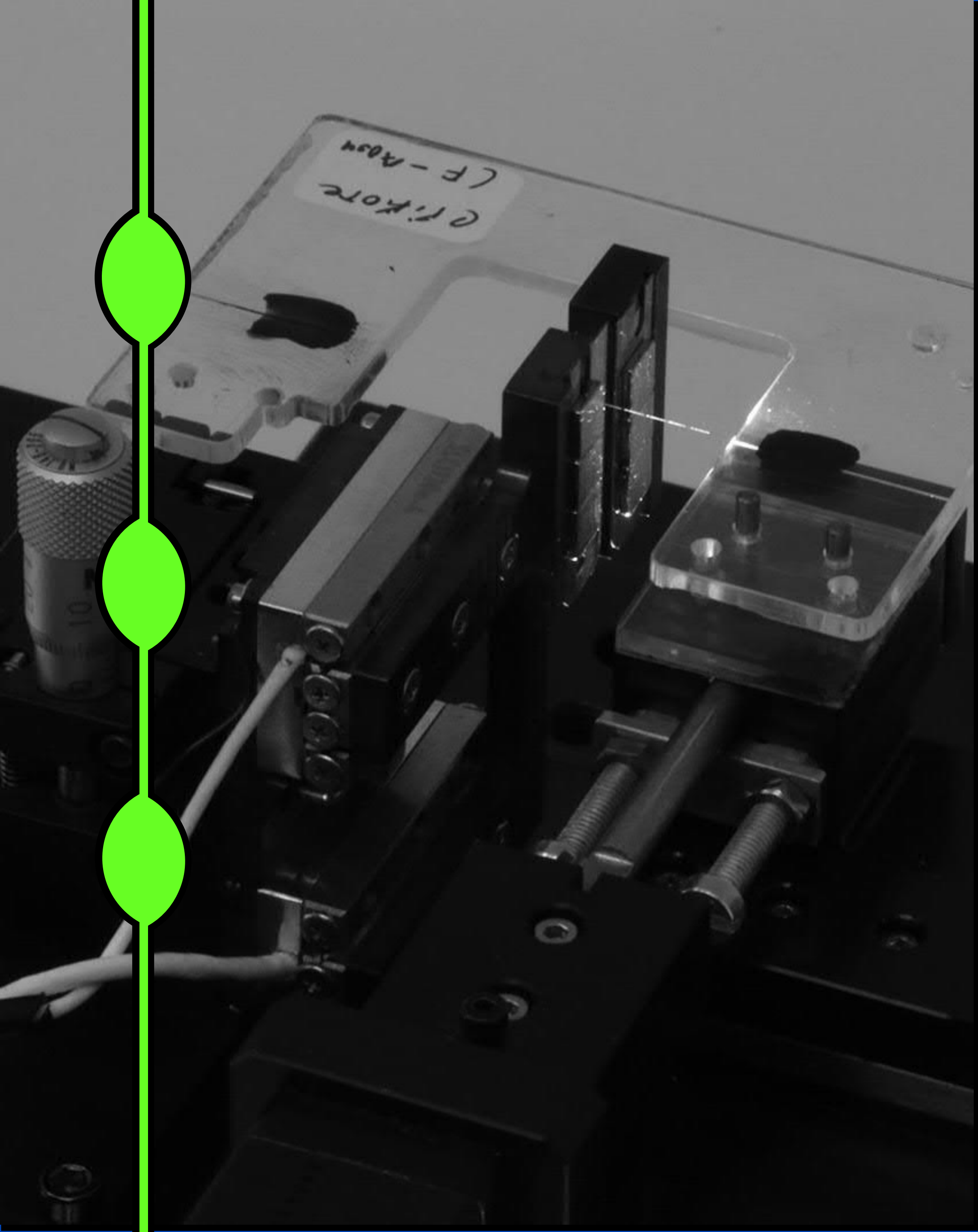
KU LEUVEN

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 764713.


THANK YOU
kiitos!

Automation: How to Remove the human

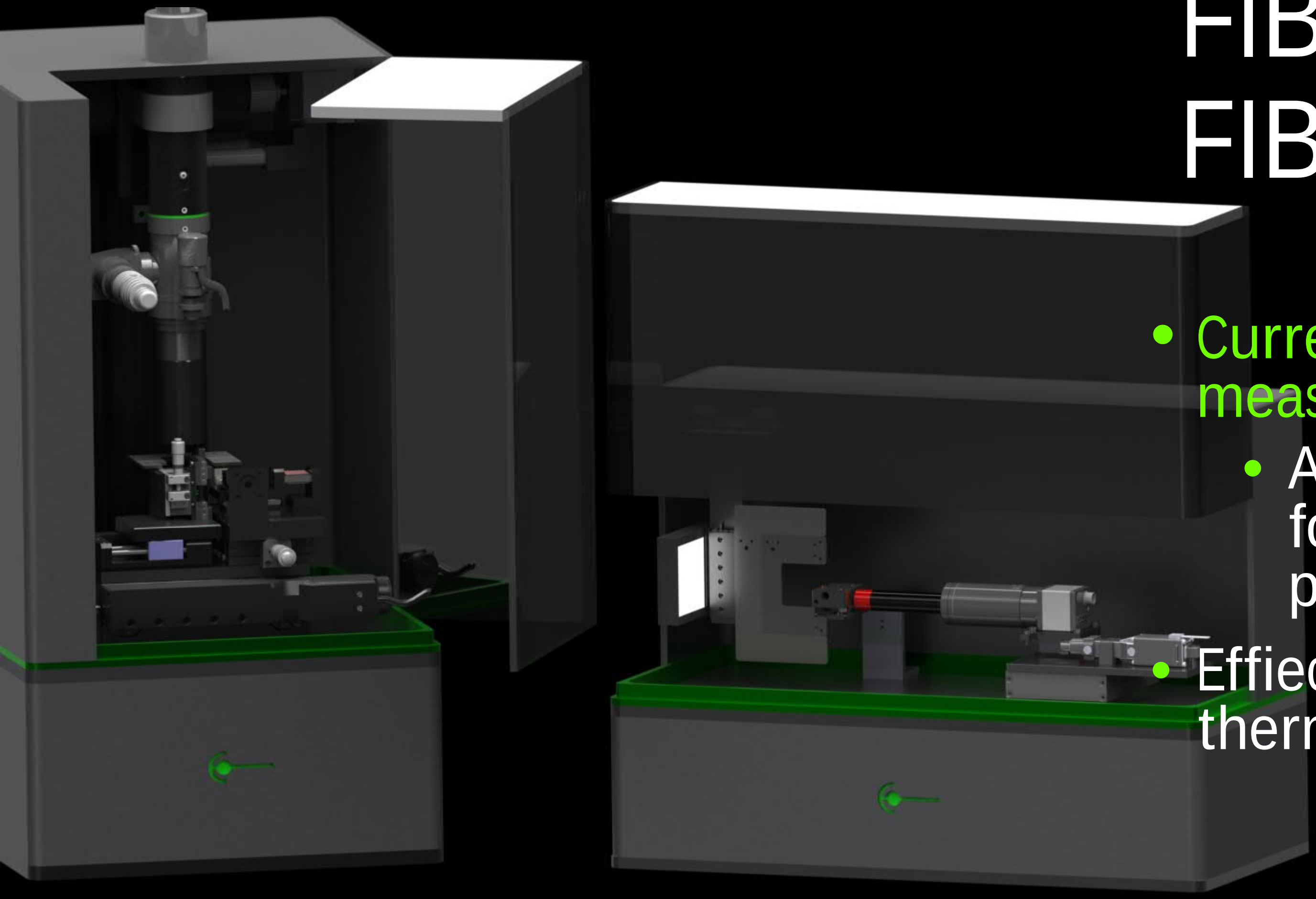
Markus Kakkonen
Markus@fibrobotics.com



Start-up from Tampere University of Technology

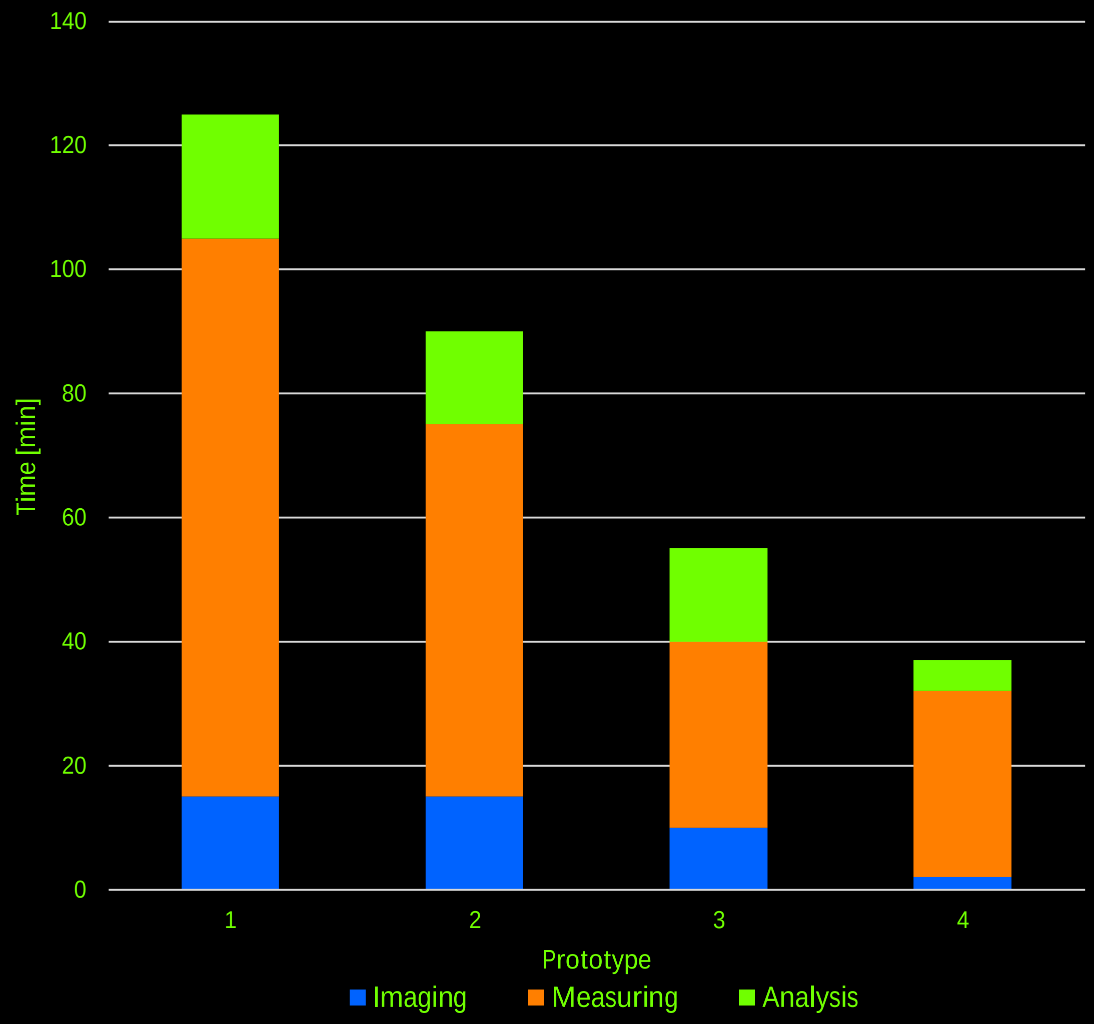
- Project FIBRobotics (2015-2017) developed micromechanical characterization of fibrous and fiber reinforced materials
  - Funded by Finnish Agency for Innovations
- Technological goal: develop a high-throughput interfacial shear strength (IFSS) tester
- Start-up company established Q2/2019
- Market launch 2021

FIBRObond and FIBROdrop

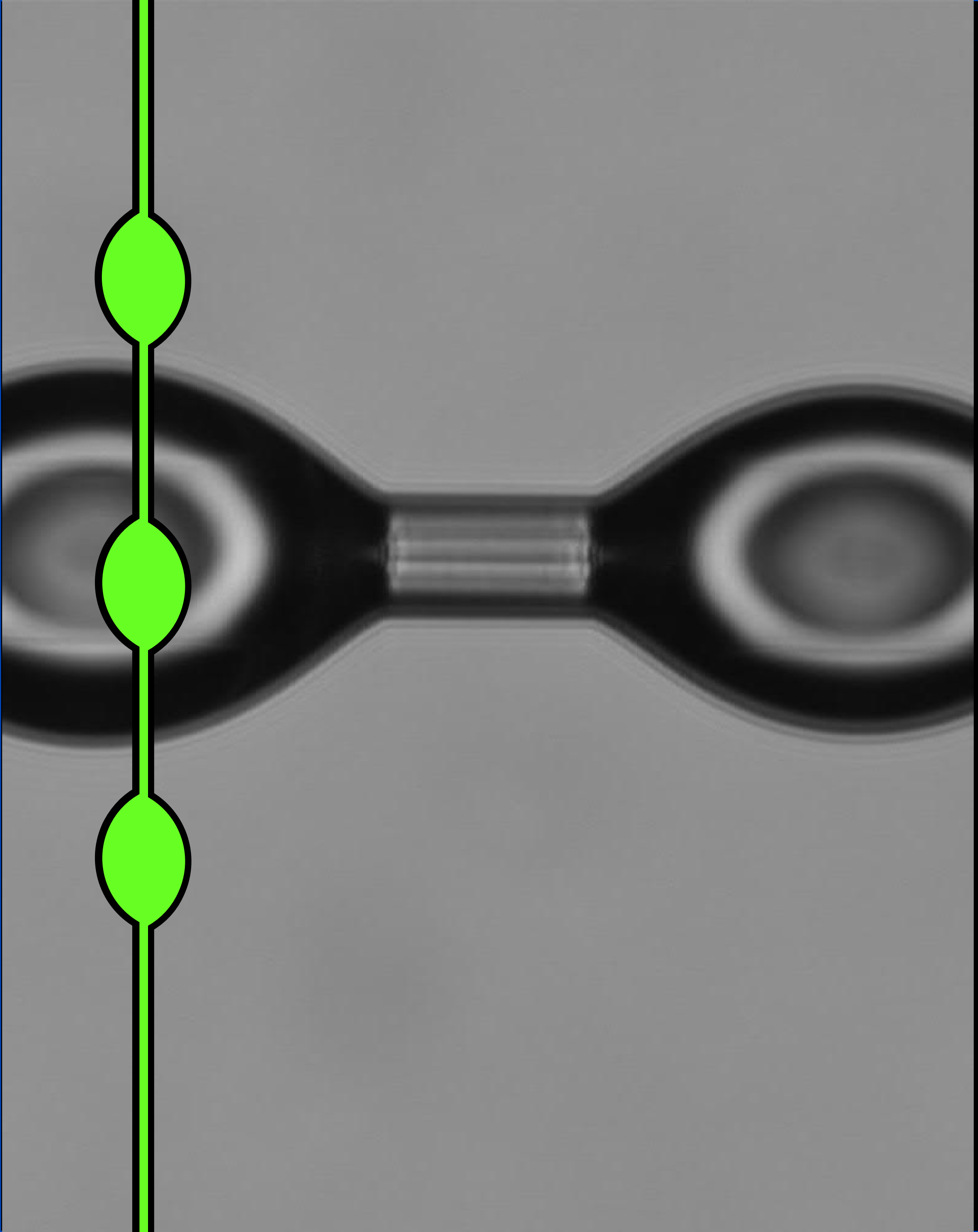


- Currently we can perform 40 measurement events / hour
  - A measurement event measures the force that is required to debond a polymer droplet from a fiber
- Effiecient sample manufacturing for thermoset and thermoplastic samples

FIBRObond

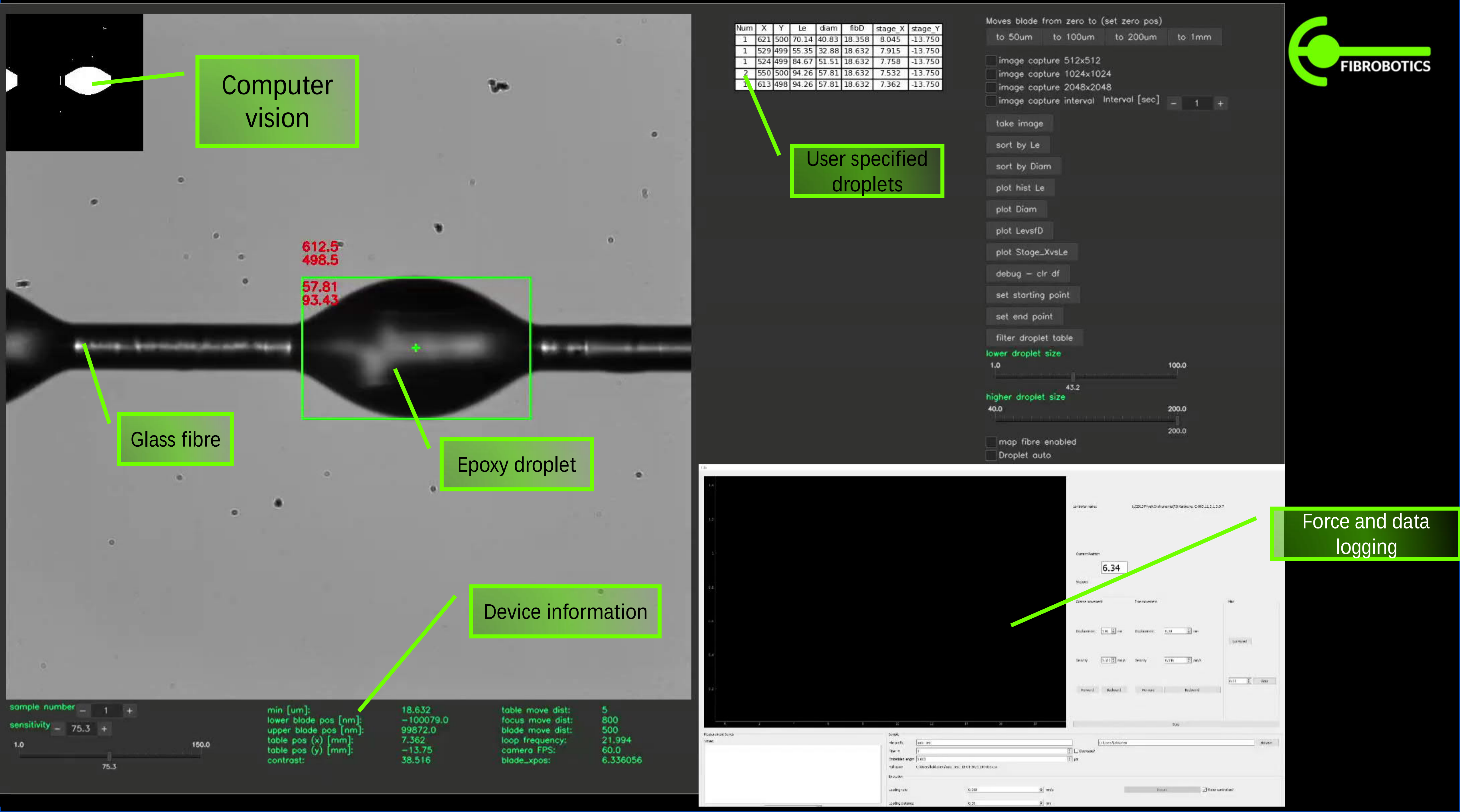


- Time spend on measuring is dependant of material properties
- Even if total time of measurement is lower.
  - General user can not do more than 150 measurement events per day. Equal to 5 samples
  - Limiting factor is human
  - Next step is to automatize the measurement



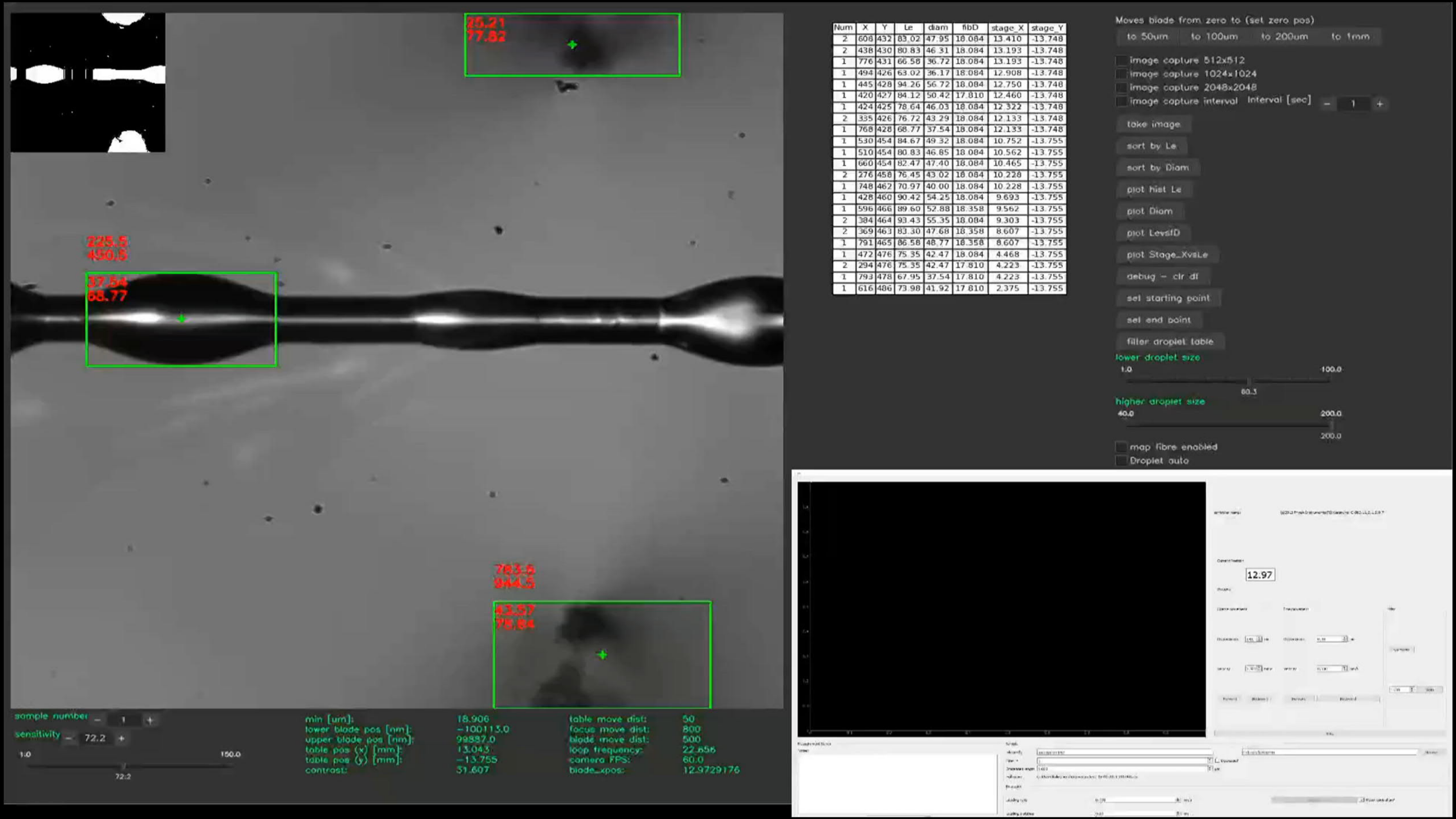
Automation

- All actuators in Fibrobond has encoder
  - Positions are known
- Requires user to input a filter for measurable droplets
- Based on information for computer vision



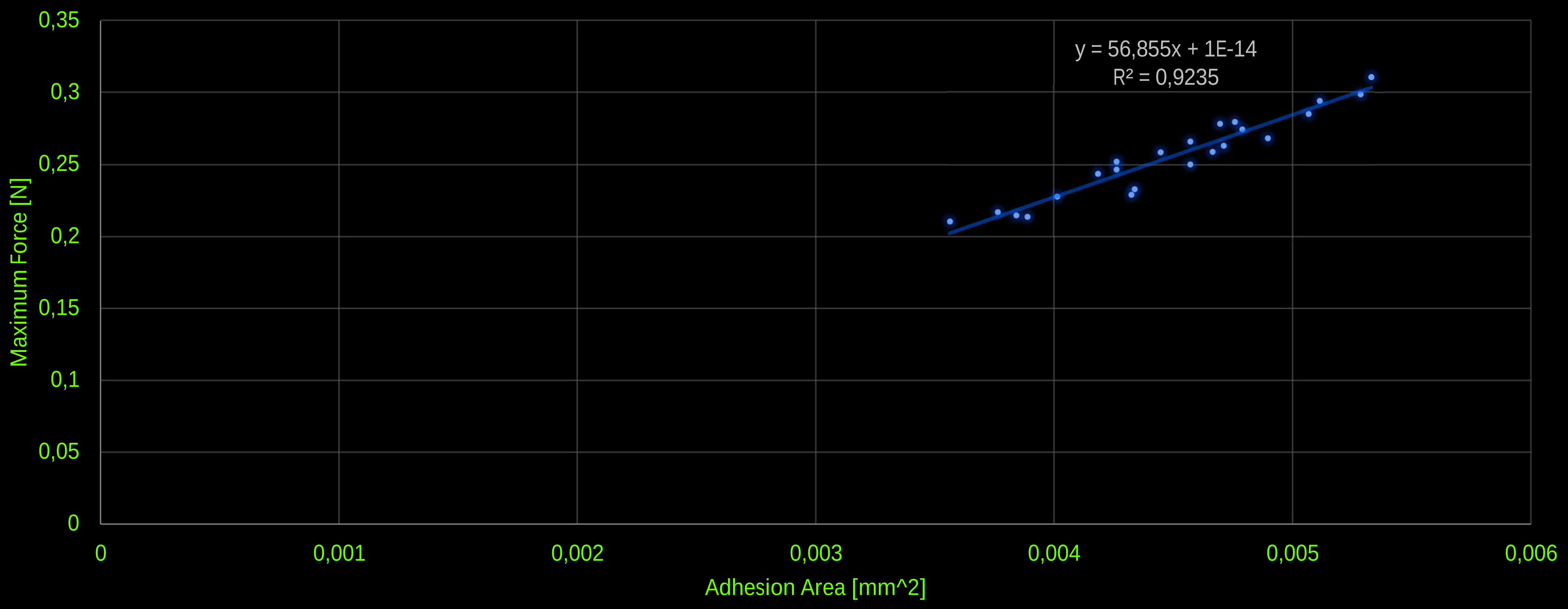
Computer vision
Glass fibre
Epoxy droplet
Device information
User specified droplets
Force and data logging
FIBROBOTICS
612.5
498.5
57.81
93.43
Num X Y Le diam fibD stage_X stage_Y
1 621 500 70.14 40.83 18.358 8.045 -13.750
1 529 499 55.35 32.88 18.632 7.915 -13.750
1 524 499 84.67 51.51 18.632 7.758 -13.750
2 550 500 94.26 57.81 18.632 7.532 -13.750
1 613 498 94.26 57.81 18.632 7.362 -13.750
Moves blade from zero to (set zero pos)
to 50um
to 100um
to 200um
to 1mm
image capture 512x512
image capture 1024x1024
image capture 2048x2048
image capture interval
Interval [sec]
take image
sort by Le
sort by Diam
plot hist Le
plot Diam
plot LevsfD
plot Stage_XvsLe
debug – clr df
set starting point
set end point
filter droplet table
lower droplet size
1.0
100.0
43.2
higher droplet size
40.0
200.0
200.0
map fibre enabled
Droplet auto
6.34
sample number
sensitivity
75.3
1.0
150.0
min [um]: 18.632
lower blade pos [nm]: −100079.0
upper blade pos [nm]: 99872.0
table pos (x) [mm]: 7.362
table pos (y) [mm]: −13.75
contrast: 38.516
table move dist: 5
focus move dist: 800
blade move dist: 500
loop frequency: 21.994
camera FPS: 60.0
blade_xpos: 6.336056

Automated measurement of 23 droplets (video is sped up 4x)



Num	X	Y	Le	diam	fibD	stage_X	stage_Y
2	608	432	83.02	47.95	18.084	13.410	-13.748
2	438	430	80.83	46.31	18.084	13.193	-13.748
1	776	431	66.58	36.72	18.084	13.193	-13.748
1	494	426	63.02	36.17	18.084	12.908	-13.748
1	445	428	94.26	56.72	18.084	12.750	-13.748
1	420	427	84.12	50.42	17.810	12.460	-13.748
1	424	425	78.64	46.03	18.084	12.322	-13.748
2	335	426	76.72	43.29	18.084	12.133	-13.748
1	768	428	68.77	37.54	18.084	12.133	-13.748
1	530	454	84.67	49.32	18.084	10.752	-13.755
1	510	454	80.83	46.85	18.084	10.562	-13.755
1	660	454	82.47	47.40	18.084	10.465	-13.755
2	276	458	76.45	43.02	18.084	10.228	-13.755
1	748	462	70.97	40.00	18.084	10.228	-13.755
1	428	460	90.42	54.25	18.084	9.693	-13.755
1	596	466	89.60	52.88	18.358	9.562	-13.755
2	384	464	93.43	55.35	18.084	9.303	-13.755
2	369	463	83.30	47.68	18.358	8.607	-13.755
1	791	465	86.58	48.77	18.358	8.607	-13.755
1	472	476	75.35	42.47	18.084	4.468	-13.755
2	294	476	75.35	42.47	17.810	4.223	-13.755
1	793	478	67.95	37.54	17.810	4.223	-13.755
1	616	486	73.98	41.92	17.810	2.375	-13.755

Results from automated measurement



Conclusion

- FIBRObond automation is proof of concept what the device is capable
- To unleash the full potential of the device automation is the key
  - Sample manufacturing is fast enough to support this
  - Releases user to do other tasks

Any Questions ?

More information at
www.fibrobotics.com

Tampere University

Microbond testing – Machine vision-based movement tracking for enhanced automation

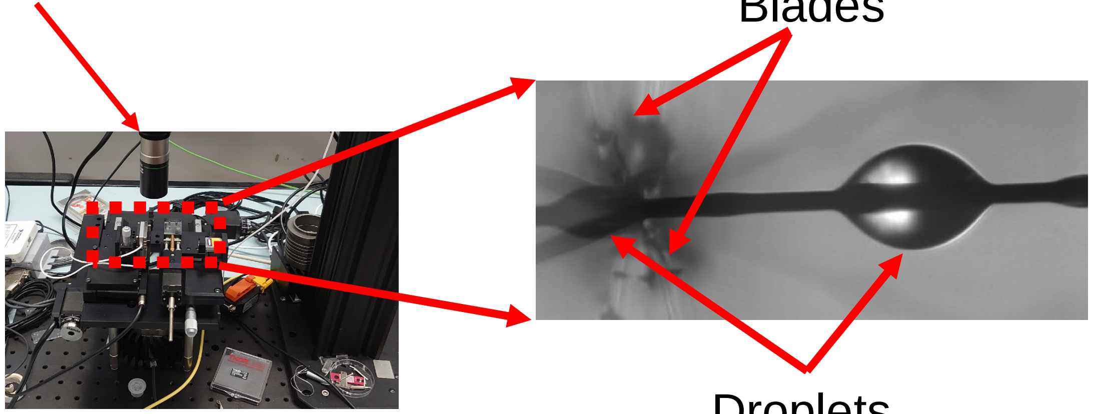
FIBdata

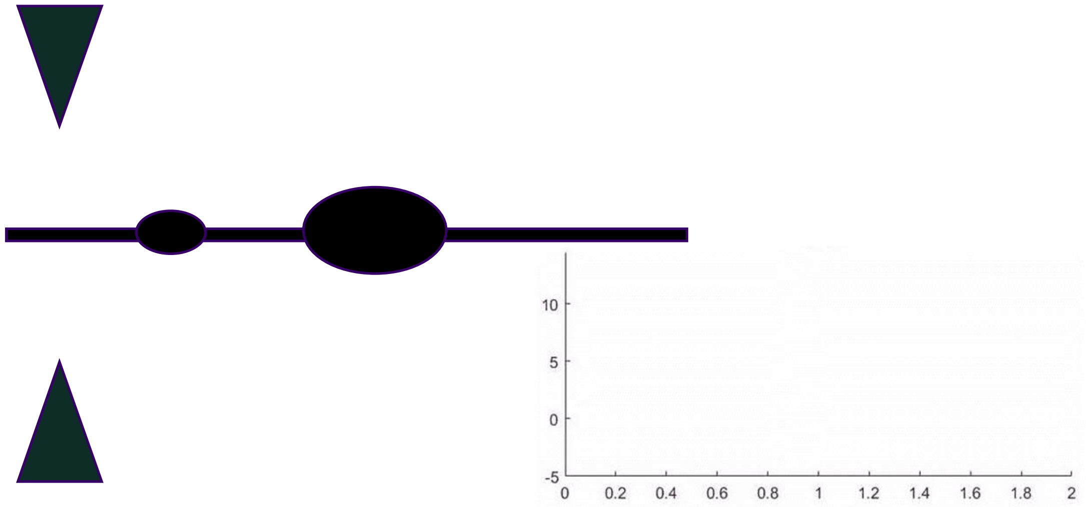
Dhanesh Rajan
PD Research Fellow

26.1.2021

Microbond testing device

- Single droplets are pulled apart from the filament using microtome blades and the force required for this is recorded
  - **Enhanced automation of microtome blade 'vertical' movements**
    - ✓ Detect the blade-to-fibre contact reliably.



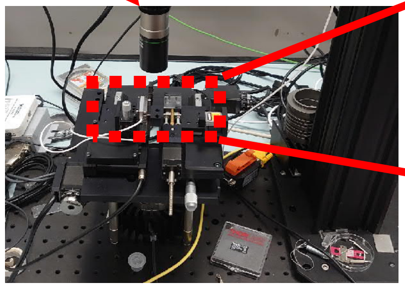


Microbond testing device - enhanced automation

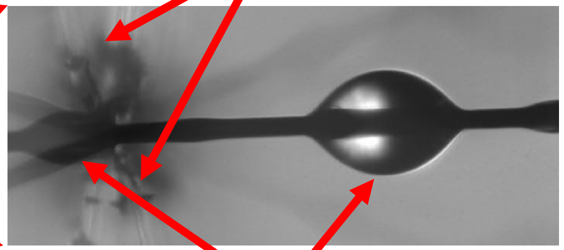
- Single droplets are pulled apart from the filament using microtome blades and the force required for this is recorded
  - **Enhanced automation of microtome blade 'vertical' movements**
    - ✓ Detect the blade-to-fibre contact reliably.

Electrical means?

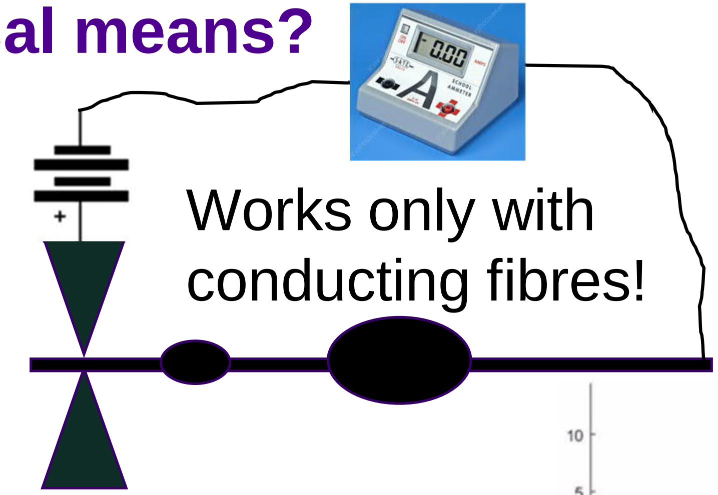
Microscope



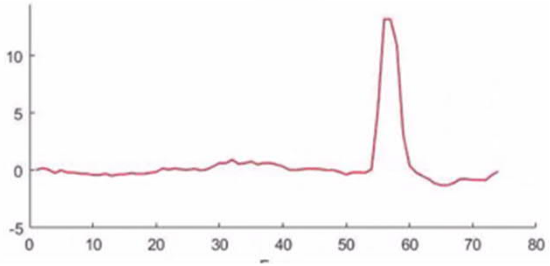
Blades



Droplets



Works only with conducting fibres!



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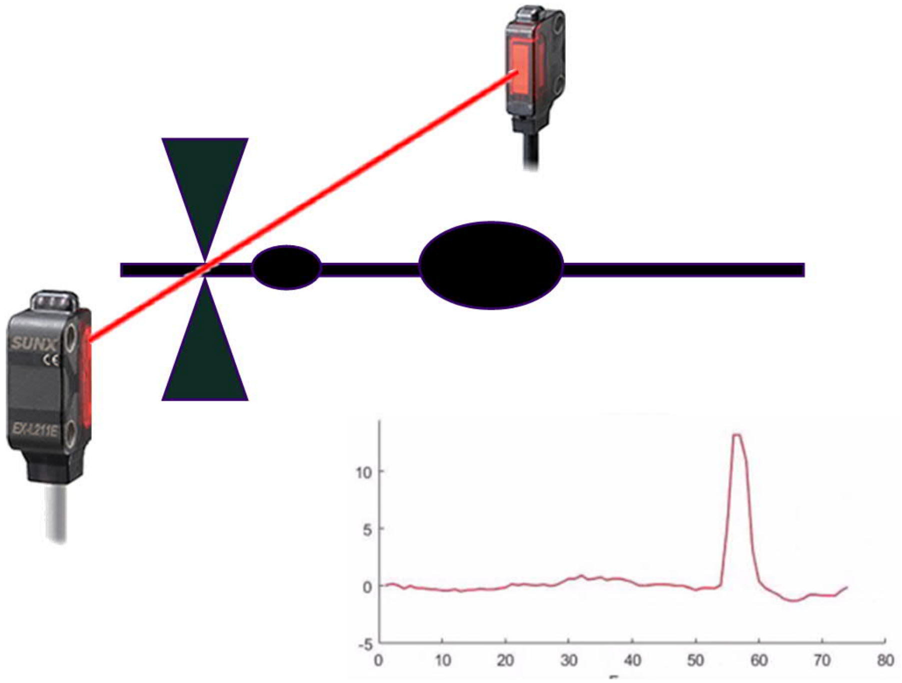
Microbond testing device- enhanced automation

- **Optical methods?**

Laser sensors?



Requires

- additional instrumentation &
- implementation can be complex!

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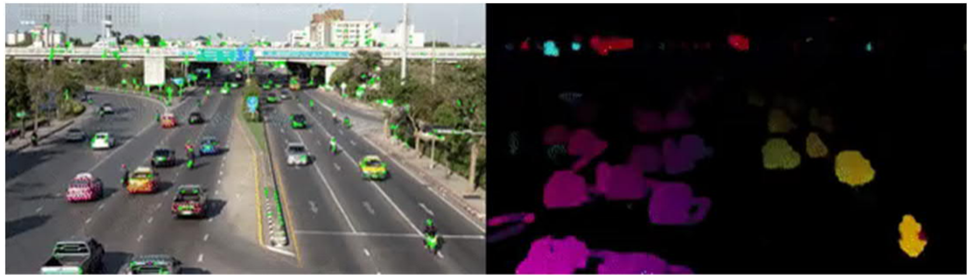
Microbond testing device- enhanced automation

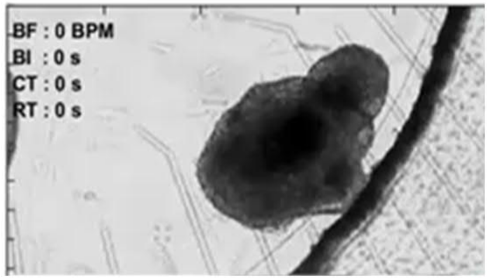
- **Image based methods?** - especially when we have integrated cameras in the system?

  - ✓ Machine vision optical-flow methods

In macroworld (E.g. Traffic surveillance)



In microworld (E.g. Our expertise)



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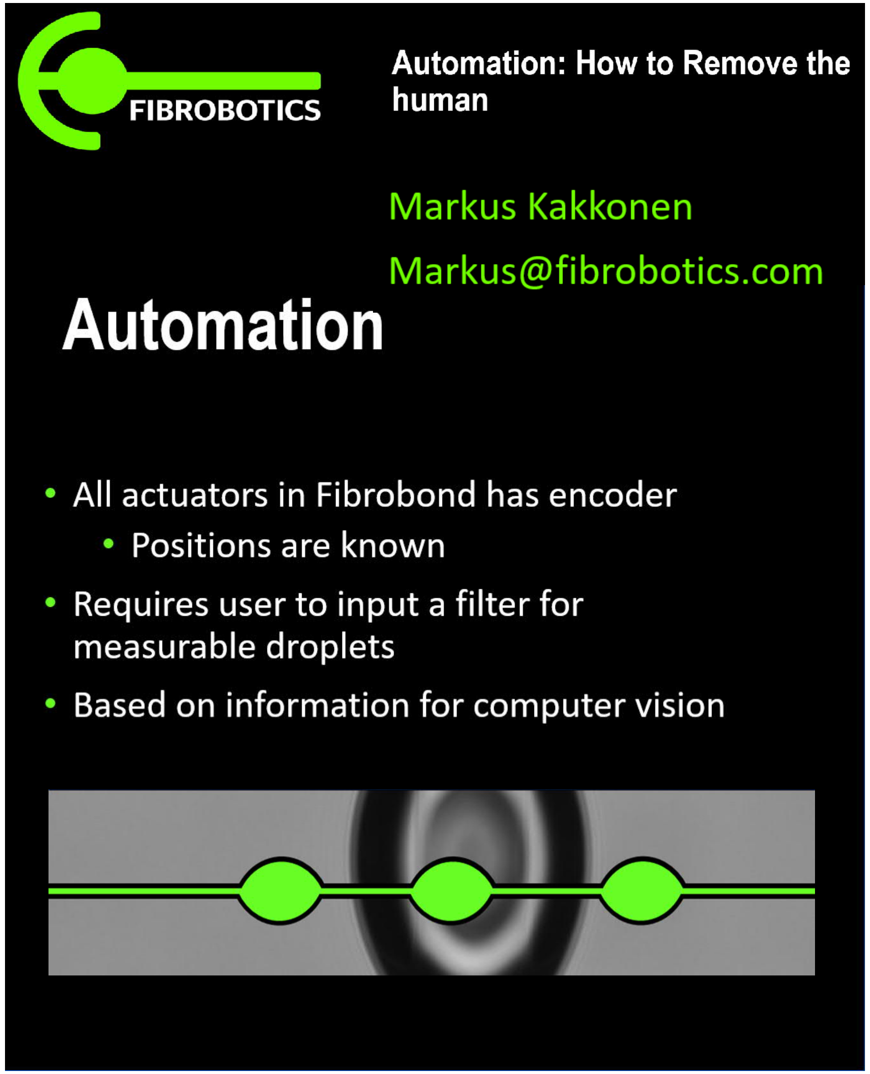
Why do we study about image-based methods?

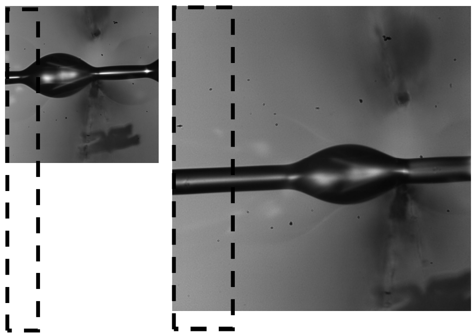


- Automatic droplet removal based on actuator encoder information- K. Markus
- To improve the robustness and reliability
  - Image-based measurements as an additional means for investigating the measurement
  - Fibre types:
    - glass fibres, carbon fibres,…
  - Vibrations, Intensity non-uniformities..
    - An active and suitable measurement method

Optical-flow; How does it work?

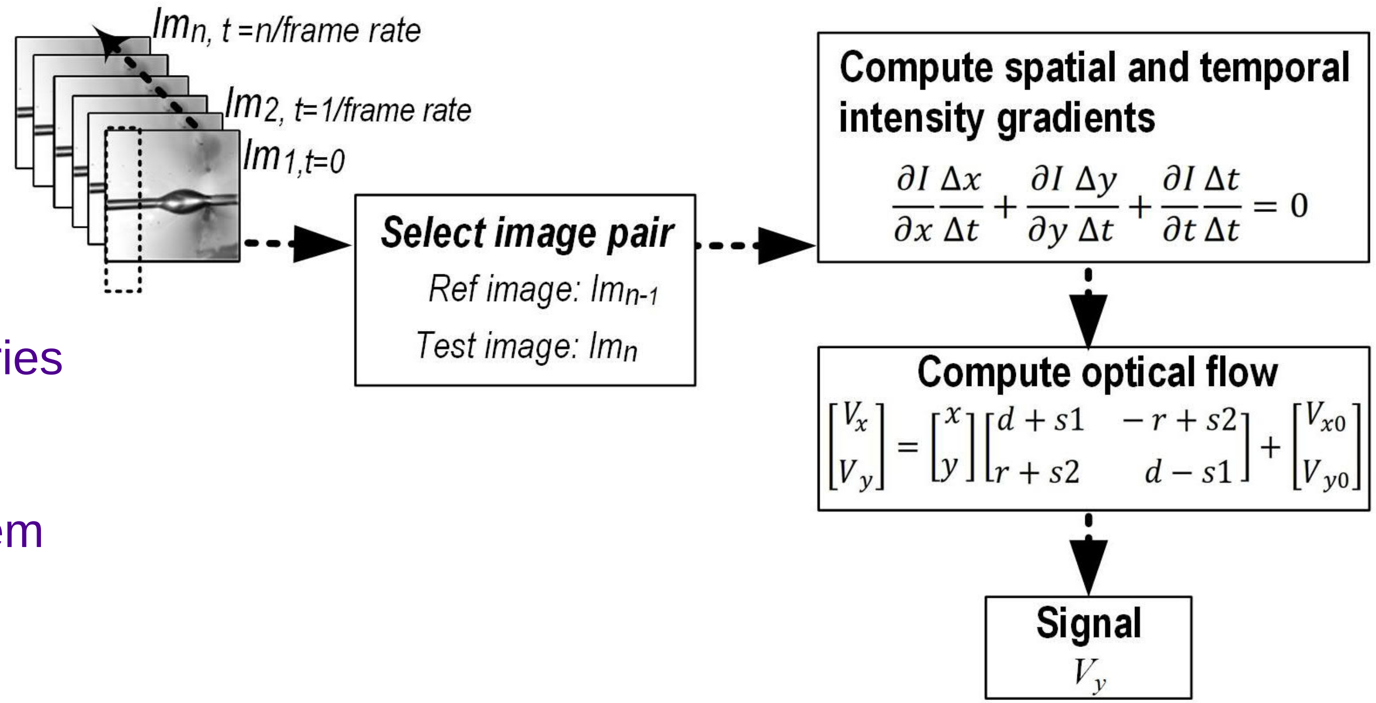
- Track the velocity vectors (motion) from frame to frame.

1024x1024 2048 x 2048



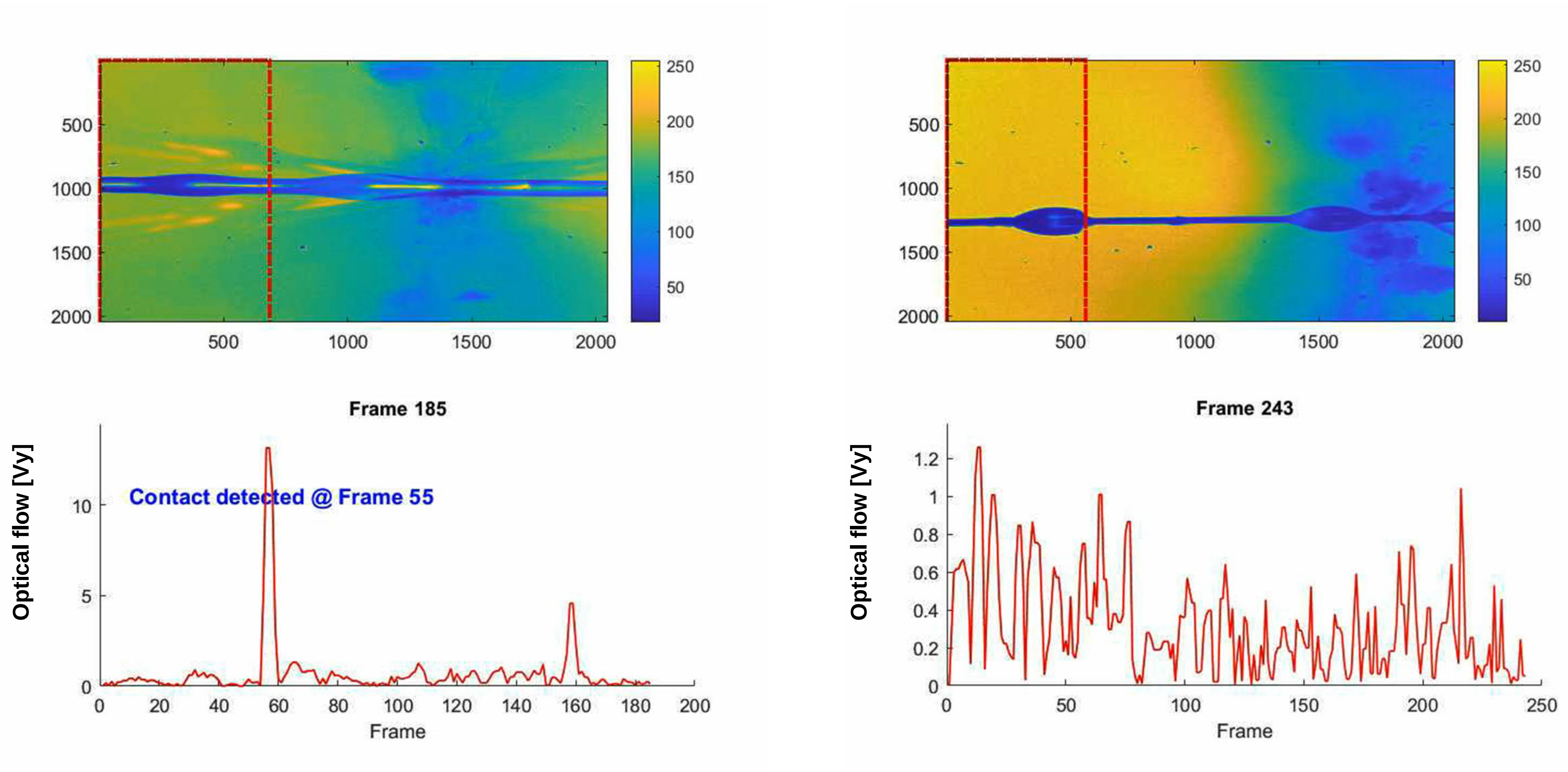
Choose an ROI
(width: 10-20 %
of full frame)

Capture series
of images
+
Process them
in real time



Optical-flow; How does it work?

- Track the velocity vectors (motion) from frame to frame.



Testing a few optical-flow methods

- To tackle challenges with vibration &
- improve the reliability and robustness

frame

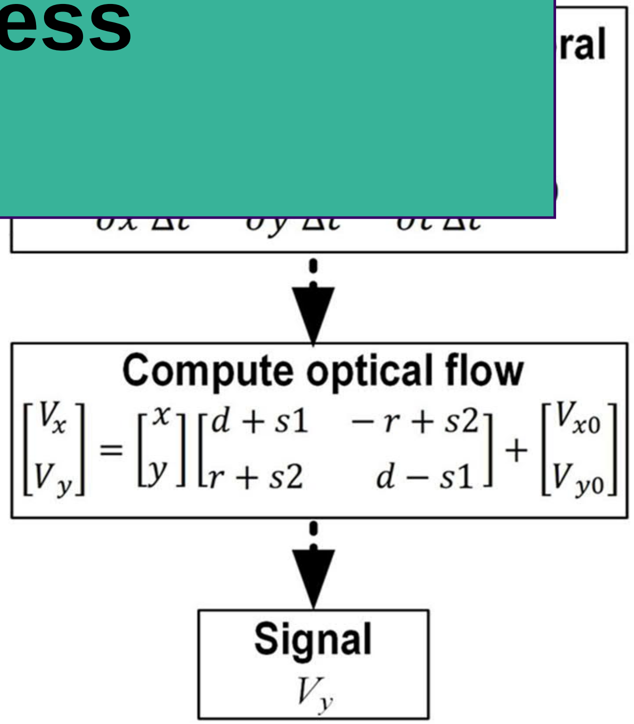
```
if i < fps*1
    AvgImg1
    AvgInt1
elseif i > fps*1 & i < fps*2
    AvgImg2
    AvgInt2
elseif i > fps*2 & i < fps*3
    AvgImg3
    AvgInt3
end
```

```
i > fps*3 +1
```

Pair1: AvgImg1, (Im_n + *BackCorr1)*

Pair2: AvgImg2, (Im_n + *BackCorr2)*

Pair3: AvgImg3, (Im_n + *BackCorr3)*



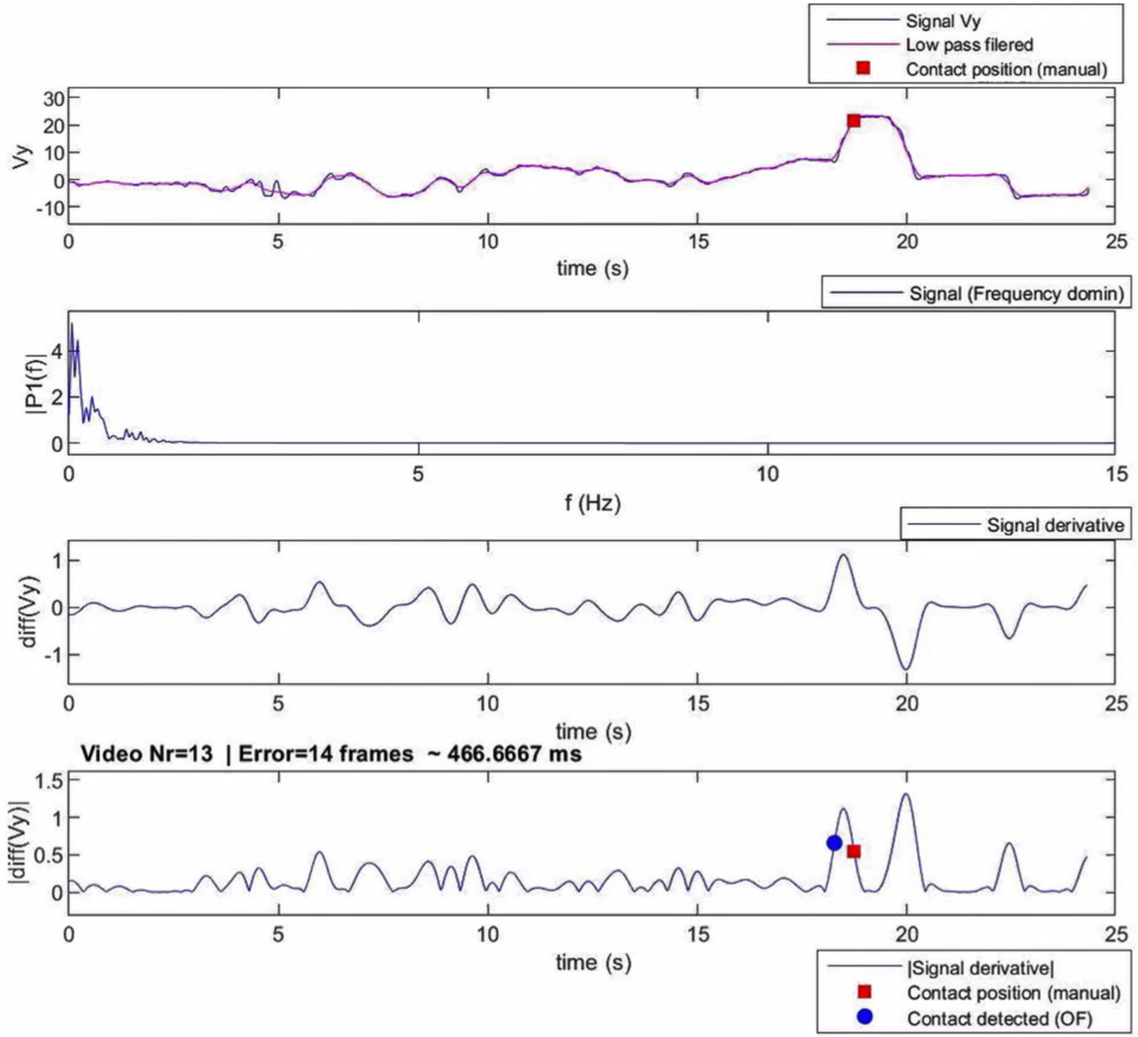
V_y = mean (V_{y1} , V_{y2} , V_{y3})

Method development; current status!

Condition for movement detection

- Thresh=1.29*(mean+std)

Method	Success % [X/45]		
	1s	2s	3s
im1=im2	63.6363636	72.72727	81.81818
im1=avg (4s)	66.6666667	72.72727	75.75758
im1=avg_BackGroundRemoved	80	84.4444	88.8889
im1=avg_BackGroundRemoved old	75.7575758	81.81818	90.90909
im1=avg_1234	69.6969697	72.72727	75.75758
im1=avg_1234_BackGroundRemoved	69.6969697	72.72727	75.75758



What is next?

- Real time image processing
  - Decision making optimization and trigger signal for microbond testing

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Human
Potential
Unlimited.

Thank you!
Questions?