CASMaT
Villum Center for Advanced Structural and Material Testing

DTU

Determination of face/core fracture toughness in aircraft honeycomb sandwich composites using the SCB test method

1st International Symposium on Multi-Scale Experimental Mechanics

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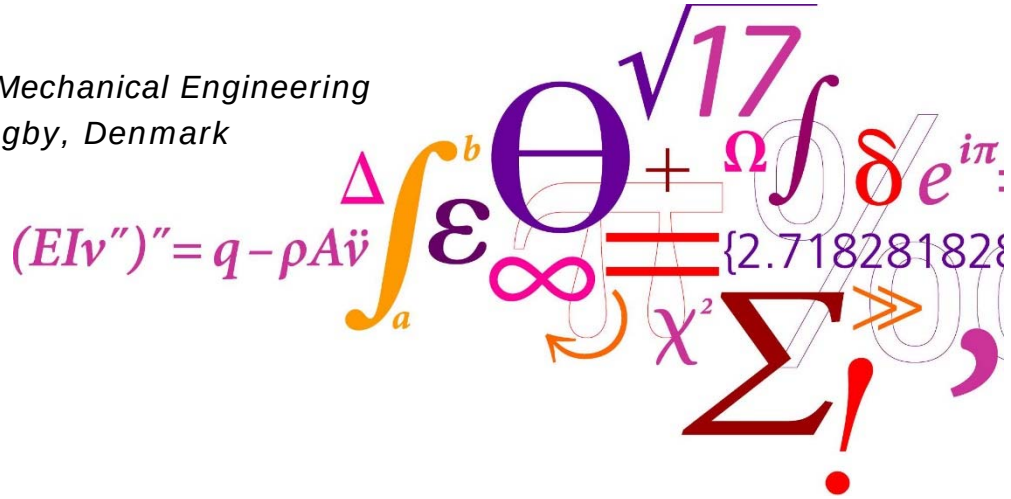


DTU Mechanical Engineering
Department of Mechanical Engineering

Agenda

- Problem statement
- SCB test rig
  - Design
  - Friction reduction
  - Calibration
  - Test setup
- Round Robin
  - Overview
  - Results
- Digital Image Correlation (DIC)
- Conclusions & further developments

Problem statement

- **Main objective:**

  Determination of the fracture toughness in the sandwich composite.

  – Design and construct the SCB test rig.

  – Execute test and comment the results obtained.

- **Seven laboratories**

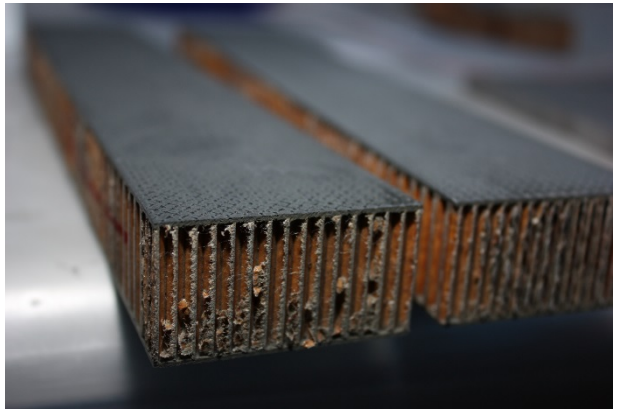
Lab #	Laboratory
Lab 1	University of Utah
Lab 2	NIAR
Lab 3	DuPont
Lab 4	NASA
Lab 5	Fraunhofer
Lab 6	Airbus
Lab 7	DTU

- **Fifteen specimens**

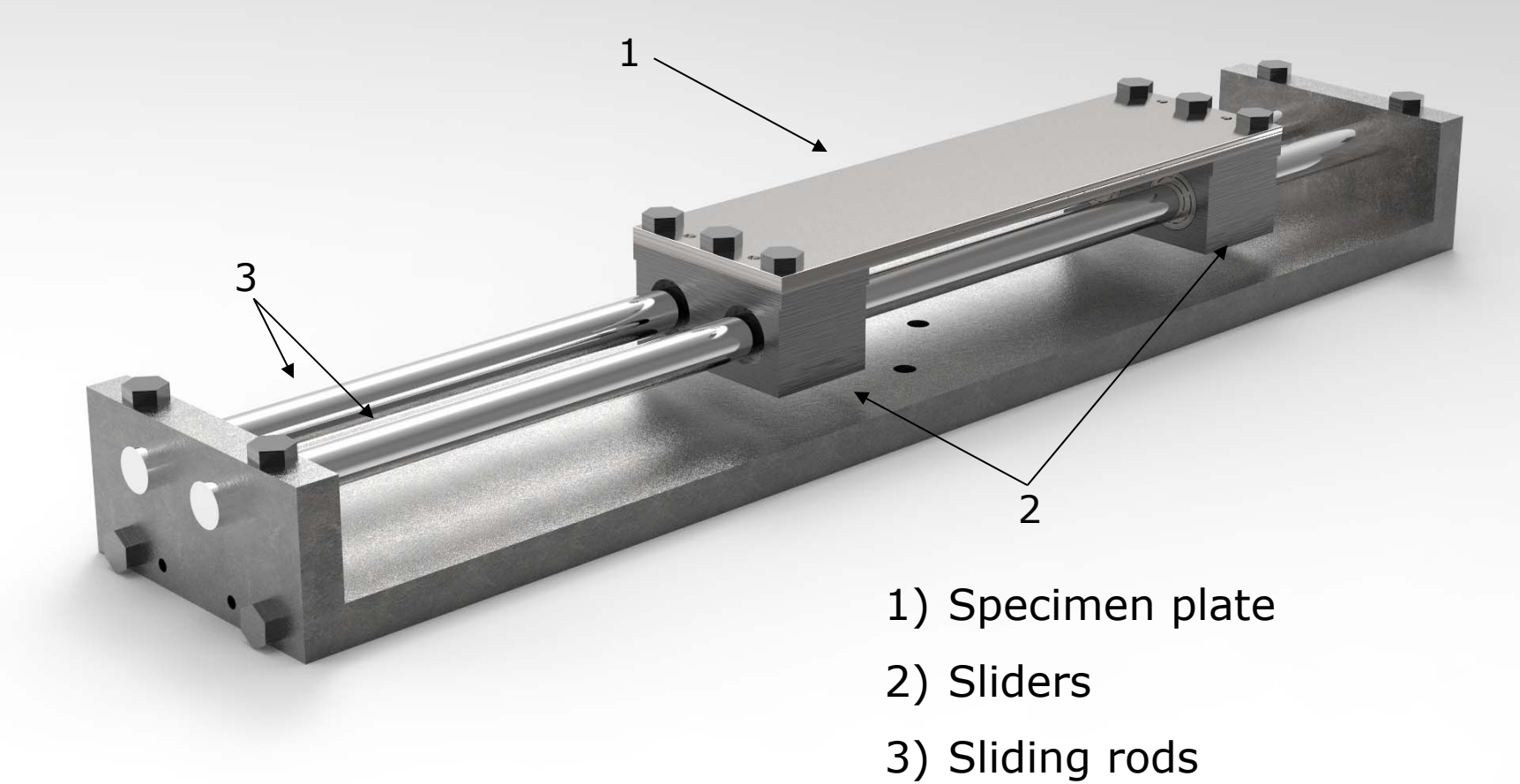
  x5: Baseline (no slider, no doubler)

  x5: Slider (no doubler)

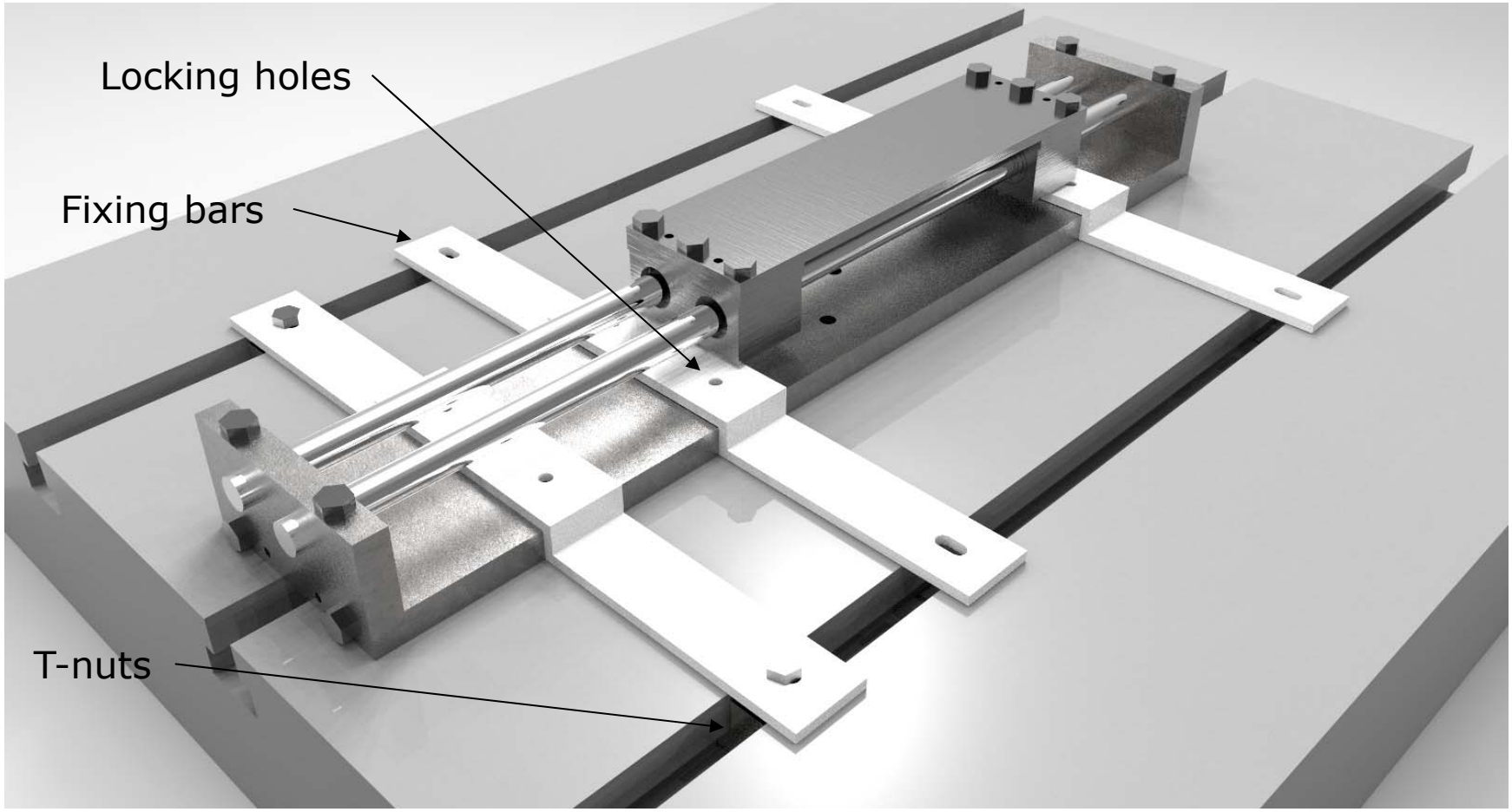
  x5: Doubler (fixed).



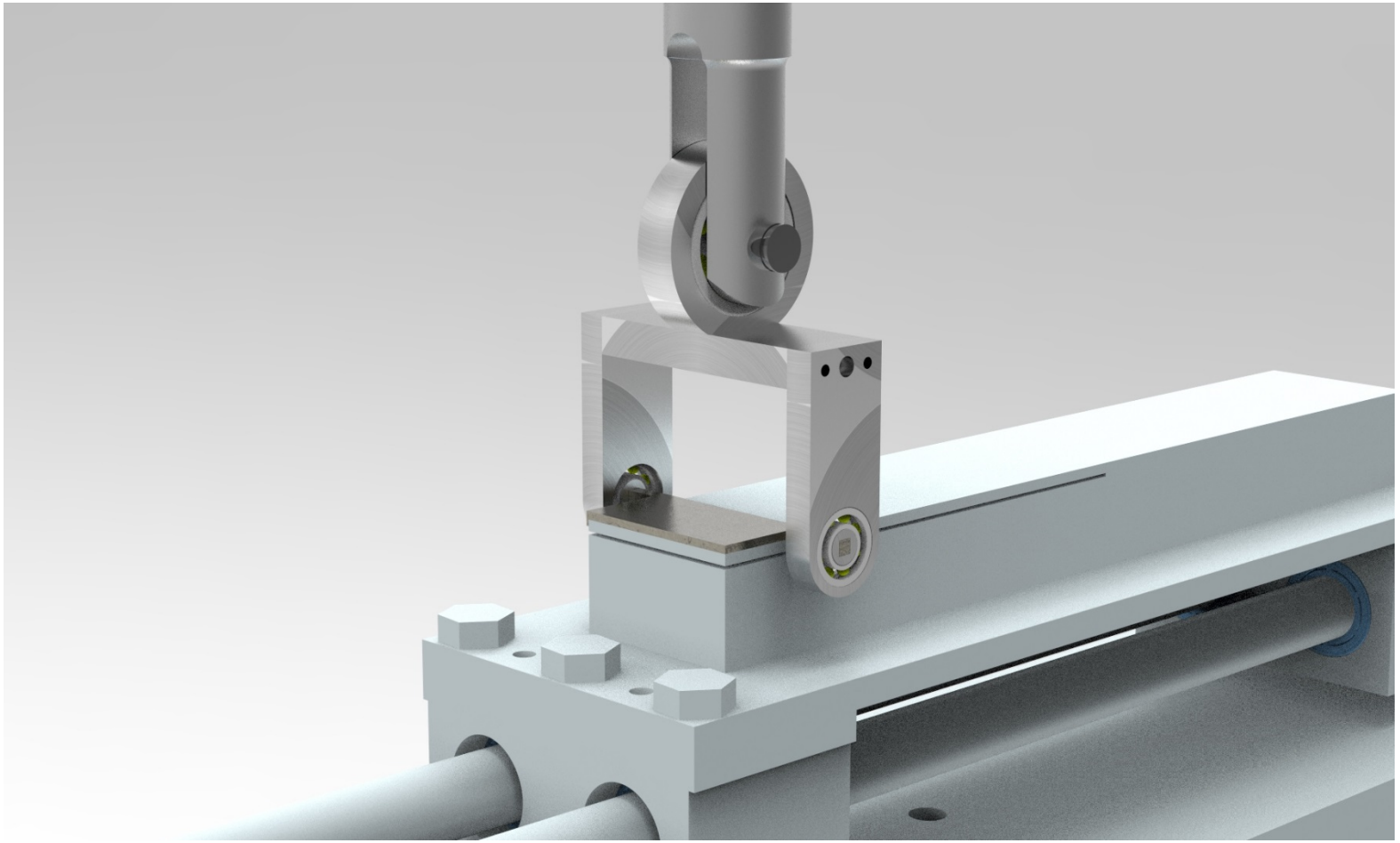
SCB Test rig



SCB Test rig

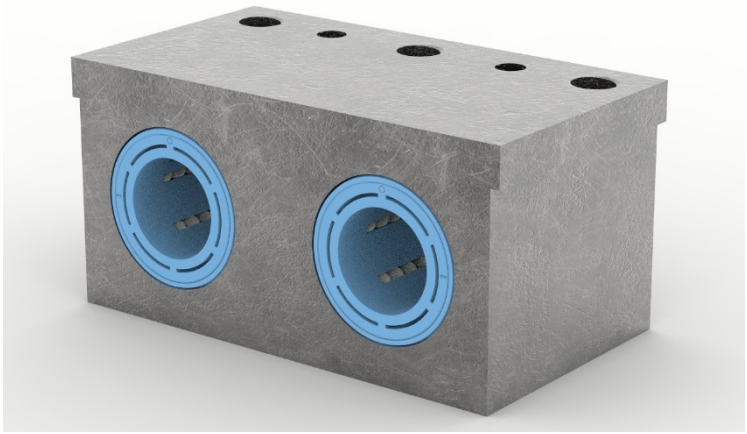


SCB Test rig

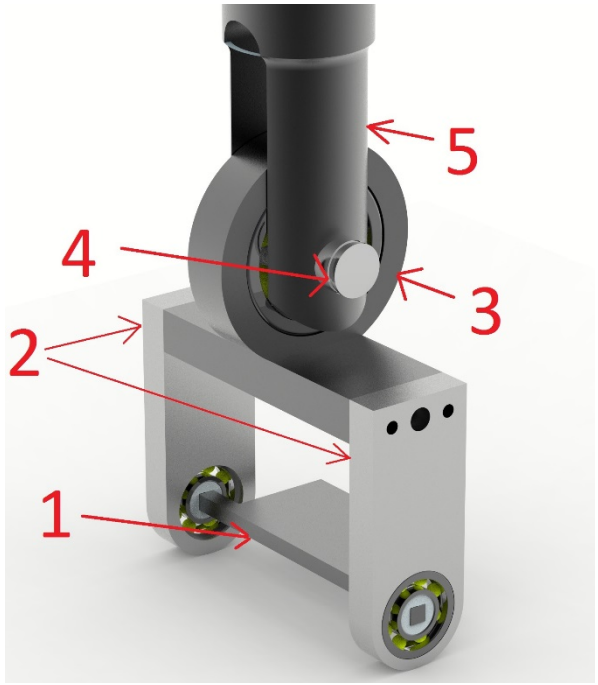


SCB Test rig – Friction reduction

x4 (linear) bearings in the sliders.



x3 bearings in the hinge.



1. Hinge
2. Hinge's housings
3. Pulling rod – hinge link
4. Pin
5. Pulling rod

SCB test rig - Calibration

- **Objective:**

Determine the amount of energy used to move the parts of the rig.

- **Method:**

To quantify the friction effect over the fracture toughness results, **specifically tuned aluminium** specimens are to be used.

- Experiments: calculate the load-unload cycle energy (hysteresis).
- Beam theory: calculate the strain energy.

$$\text{Energy loss due to friction} = \frac{Hysteresis\ area}{Strain\ energy}$$

SCB test rig - Calibration

Aluminium characterization for calibration specimens' design

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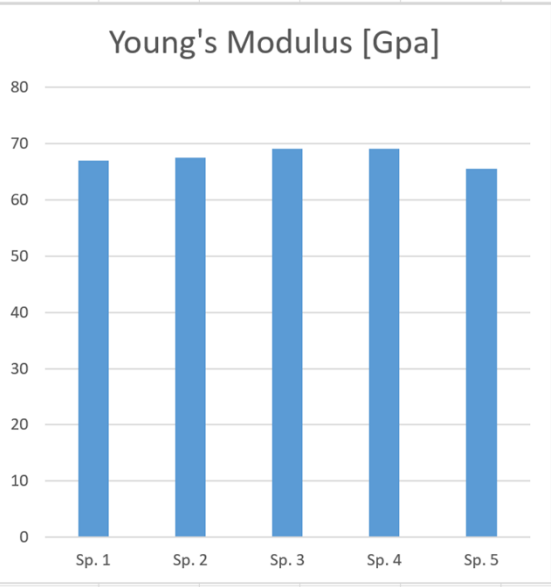
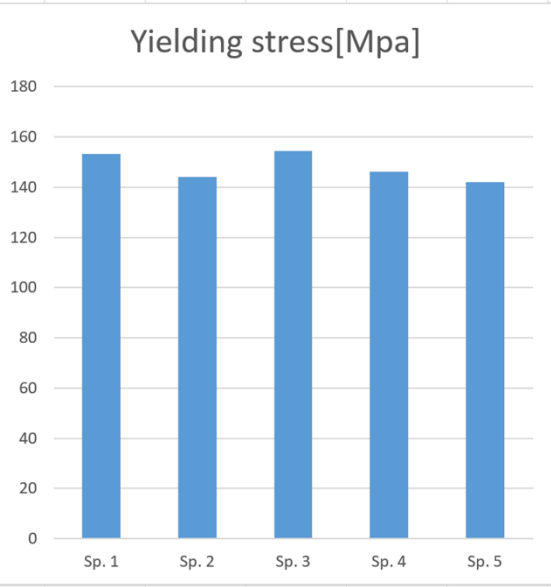
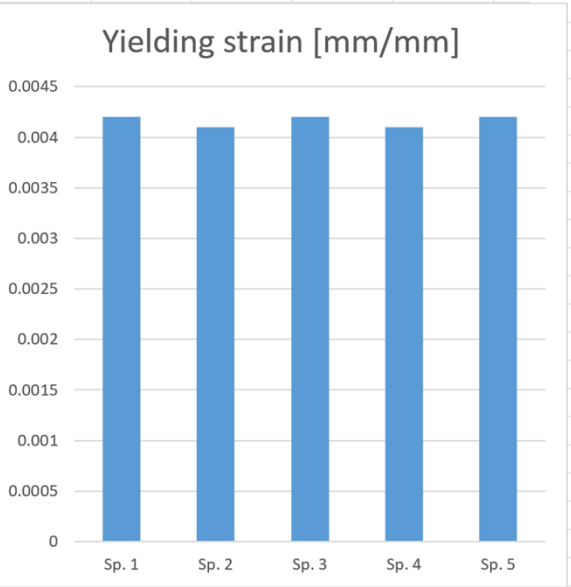
Young's modulus:		Yielding stress (0.2% offset):	Yielding strain (0.2% offset):
Sp. 1	67.043	153.38	0.0042
Sp. 2	67.564	144.07	0.0041
Sp. 3	69.066	154.43	0.0042
Sp. 4	69.111	146.22	0.0041
Sp. 5	65.522	141.94	0.0042
Average	**67.6612 GPa**	**148.008 MPa**	**0.00416 mm/mm**







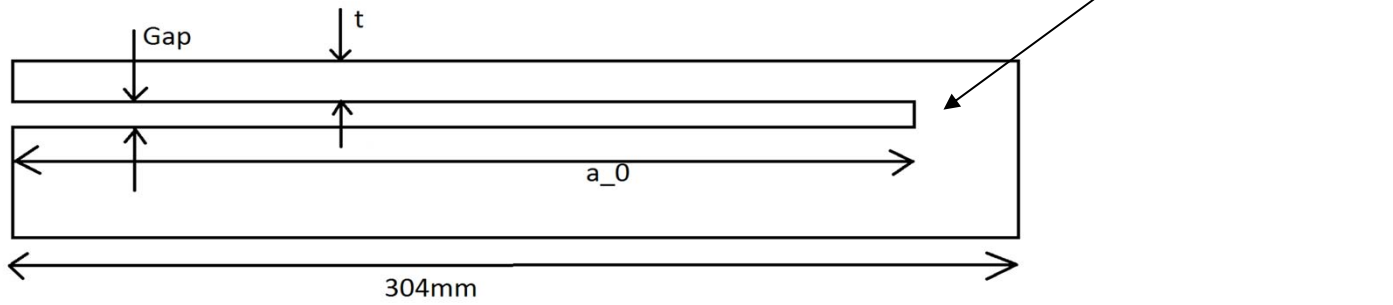
SCB test rig - Calibration

Calibration specimens sizing:

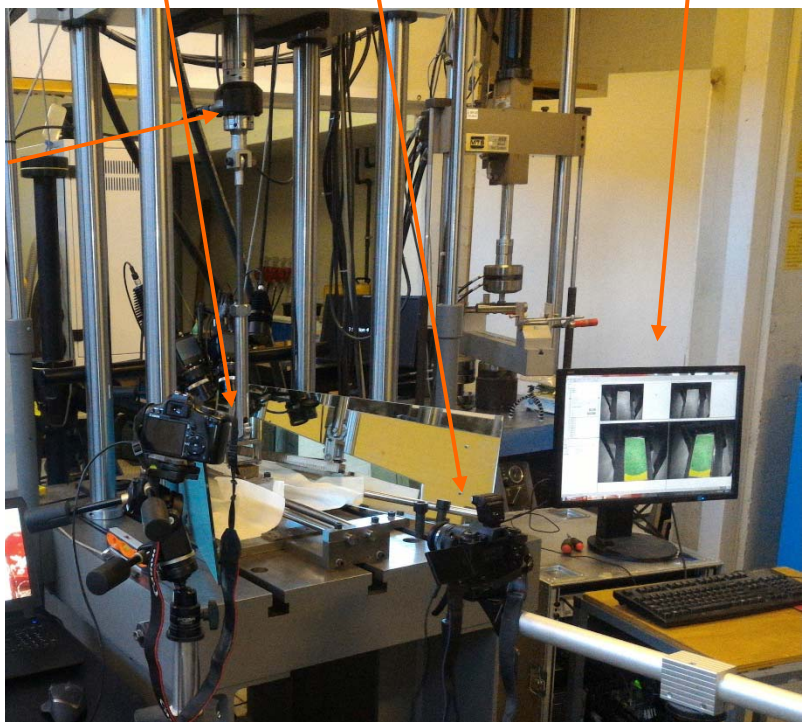
Calibration load windows:

- Doubler test expected loads → 0~300N
- No-doubler test expected loads → 0~120N

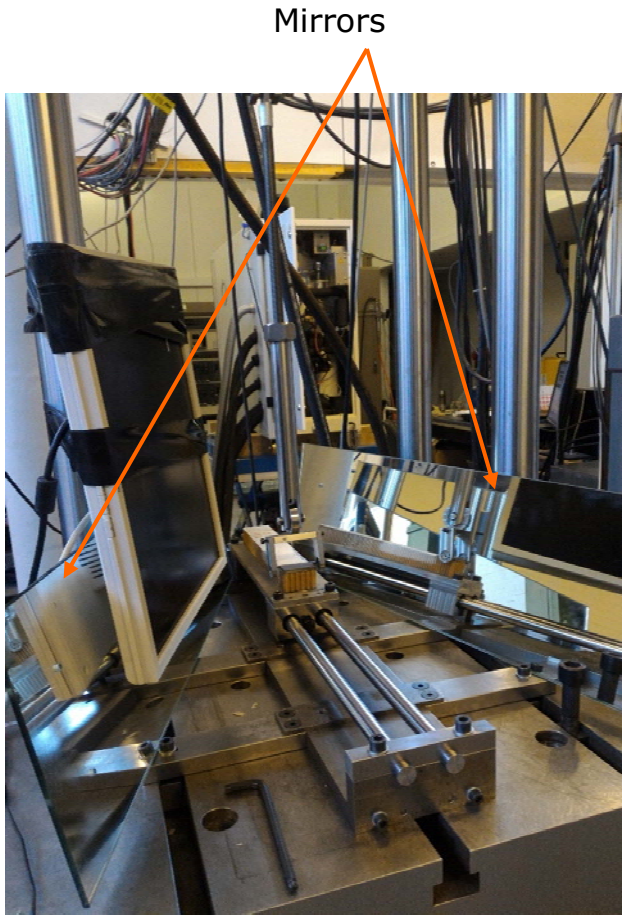
P_{MAX} [N]	t [mm]	Gap [mm]	a_0 [mm]	Lift off [mm]	σ_{MAX} [MPa]
120	4.7	6	200	13.5	150
300	8	6	200	6.19	150



SCB test rig – Test setup



DTU SCB experiment setup



SCB test rig – Test setup

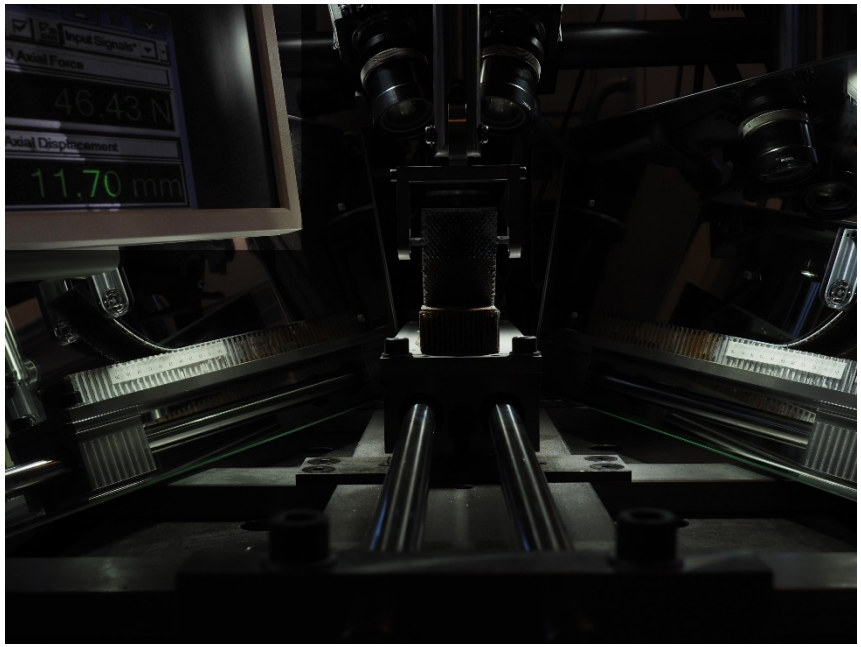
The test program executes the following steps:

- Start from **0.0 N**
- Move the crosshead (at **5 mm/min** rate) up to the pre-defined **displacement level**.
    - Displ. (1st load-cycle) = 8mm
    - Displ. (2nd load-cycle) = 13mm
    - Displ. (3rd load-cycle) = 20mm
    - Displ. (4th load-cycle) = 27mm
    - Displ. (5th load-cycle) = 36mm
    - Displ. (6th load-cycle) = 44mm
- Hold the position and then go back (at **30 mm/min** rate) to **0.0 N**.
    - Pictures are shot at 6 second intervals.
    - Data (displacement and load) are recorded at a 5Hz rate.

SCB test rig – Test setup

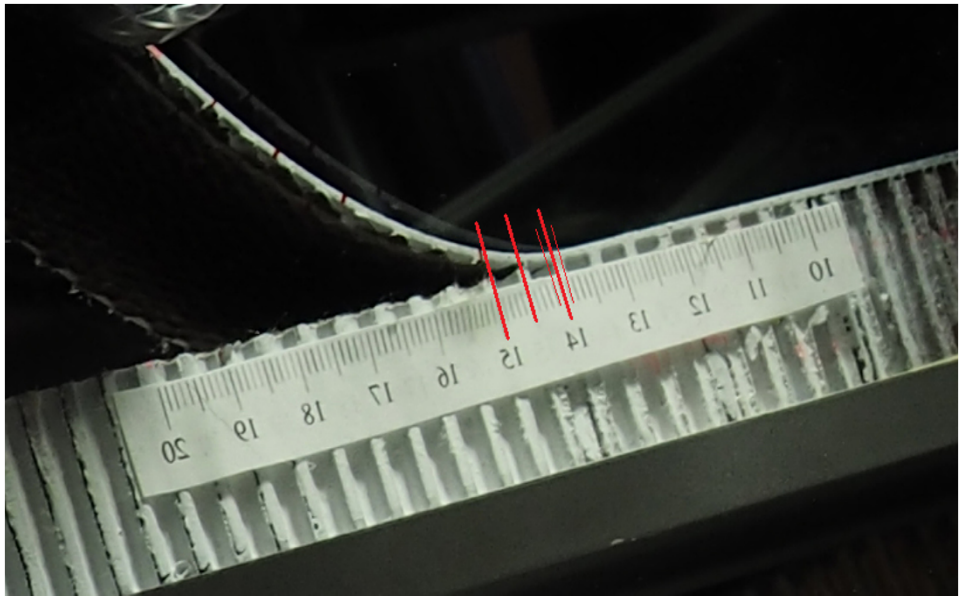
Example of pictures shot from the camera during the test:

- Focal length is calibrated to get the sharpest area around the crack;
- Brightness and contrast are to be adjusted during the post processing.

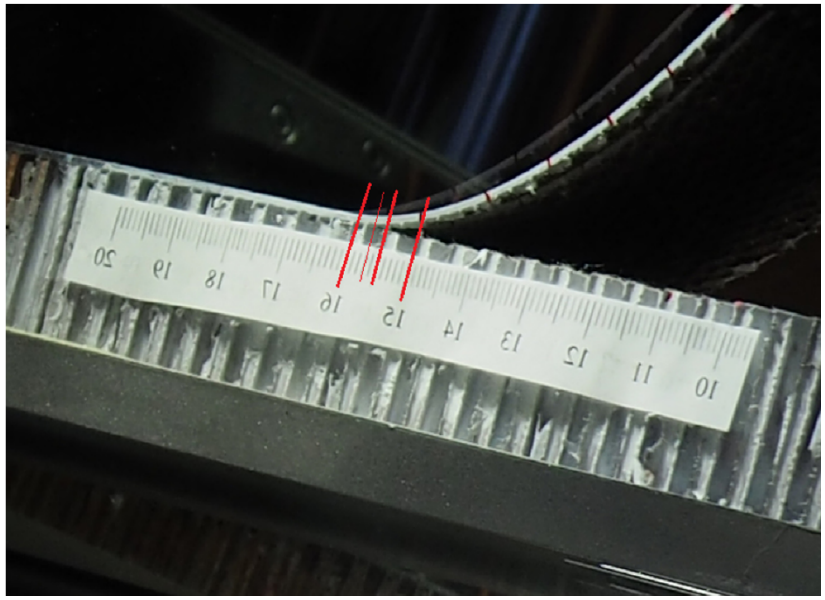


SCB test rig – Test setup

Example of pictures shot from the camera during the test – close up:



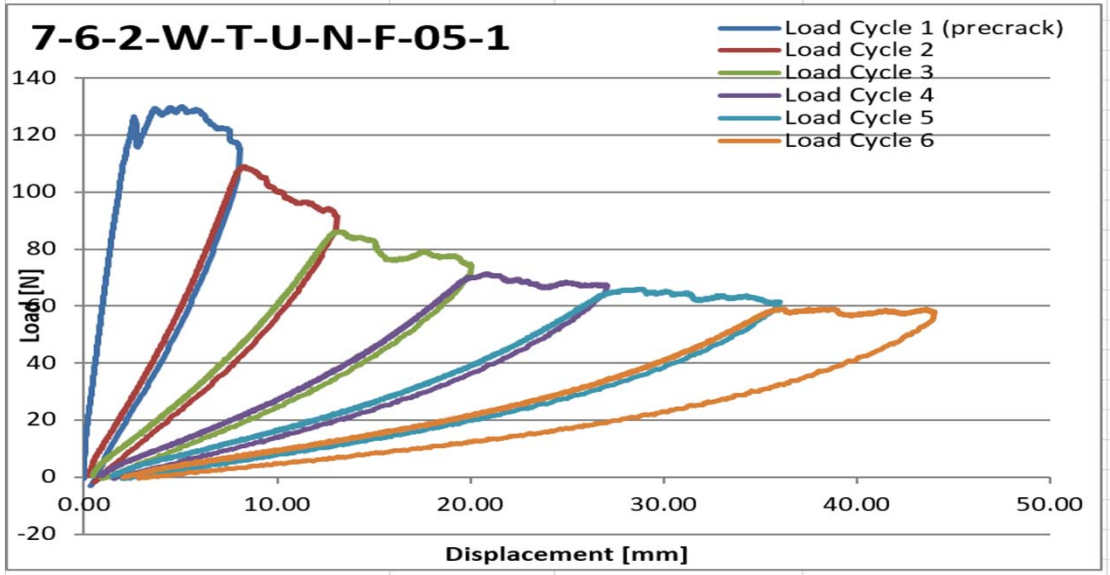
Left side's crack length: 60mm



Right side's crack length: 57mm

Round Robin - SCB Test Procedure

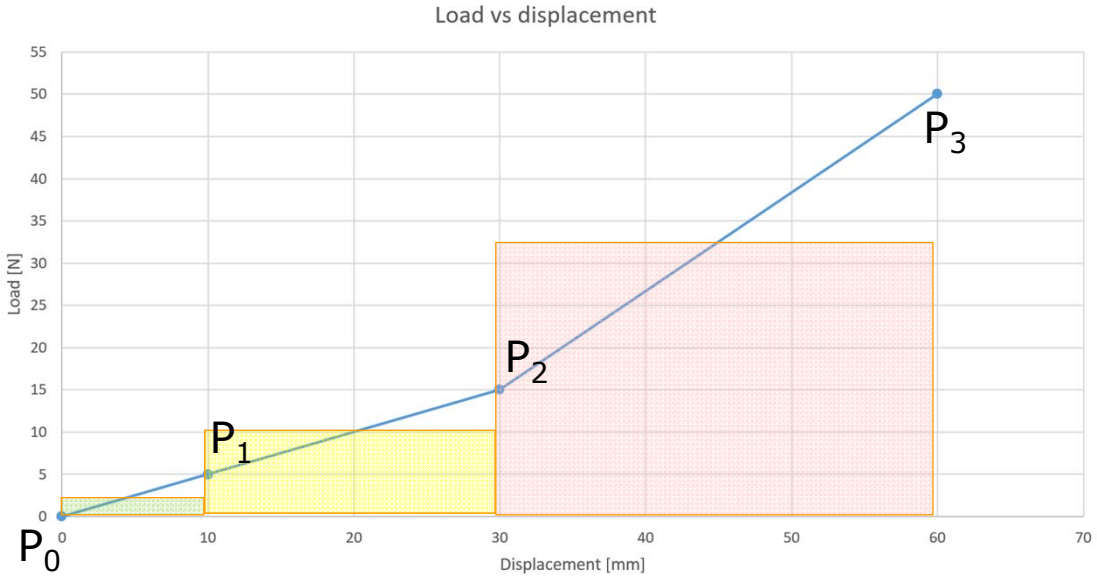
- **Six load cycles:** ~10mm crack growth per cycle, achieved through fixed displacement intervals.



- **Data reduction:** Area method.

Round Robin – SCB Test Procedure

- Area method



$$\left(\frac{L_0 + L_1}{2}\right) * (D_1 - D_0) = \mathrm{U}_1$$

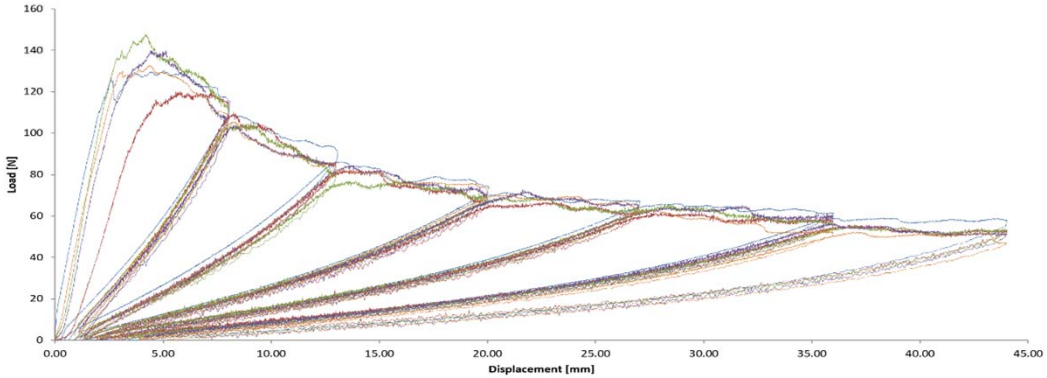
$$\left(\frac{L_1 + L_2}{2}\right) * (D_2 - D_1) = \mathrm{U}_2$$

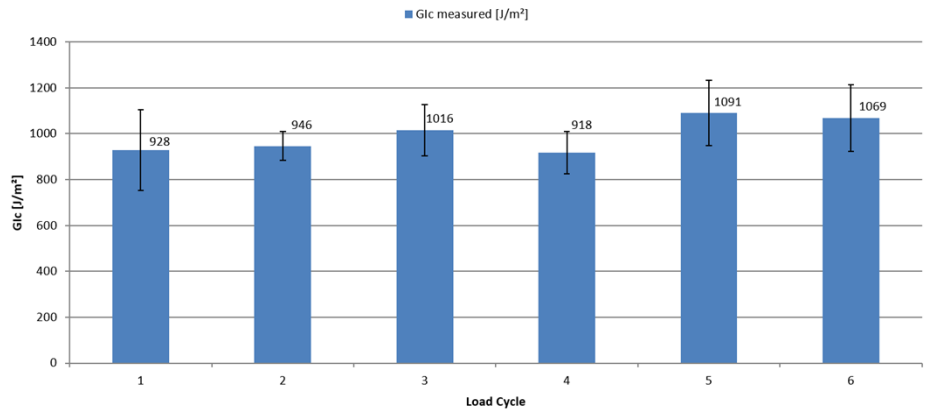
$$\left(\frac{L_2 + L_3}{2}\right) * (D_3 - D_2) = \mathrm{U}_3$$

$$U_1 + U_2 + U_3 = Loading\ energy$$

$$G_C^{AM} = \frac{Loading\ energy - Unloading\ energy}{b * \Delta a}$$

Round Robin – Baseline results (DTU)





G1c average per cycle.

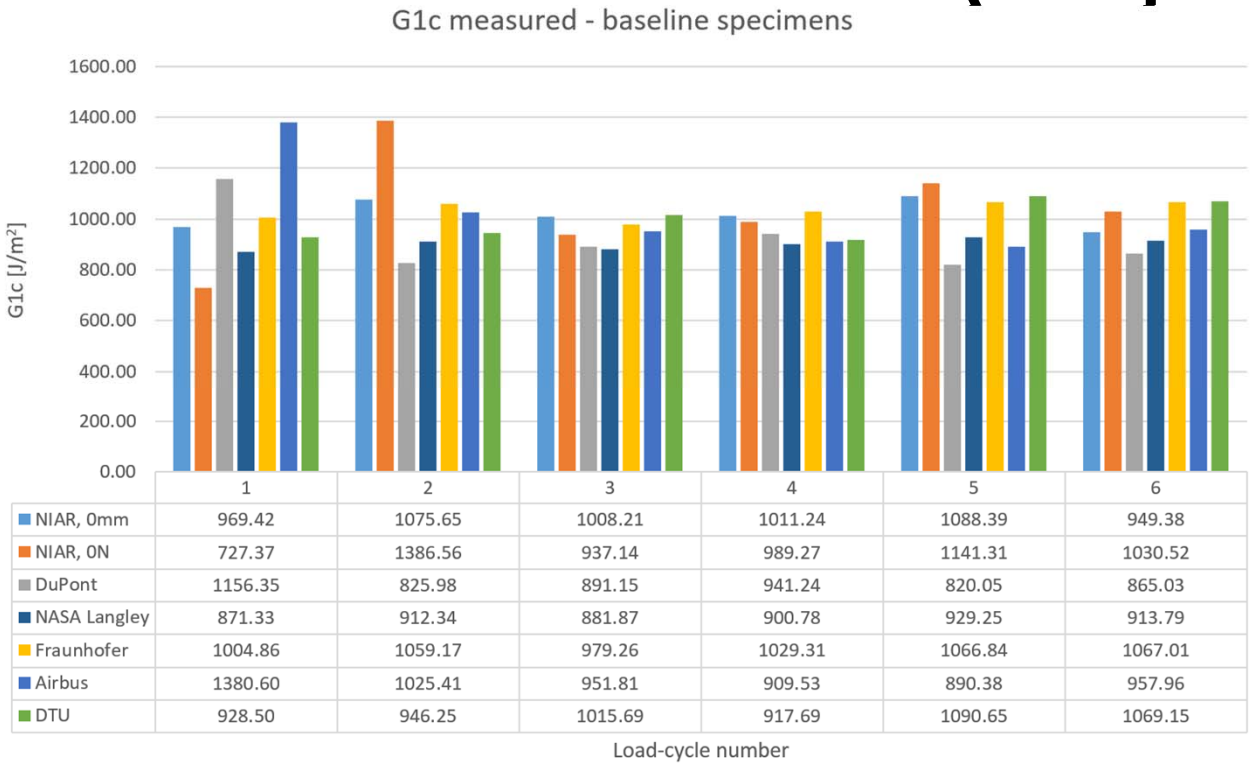
Baseline results:

load vs displacement diagrams, superimposed.

- Consistent;
- Curve progresses as expected.

Avg. G_{1c} (load-cycle 2-6)=1008 J/m^2

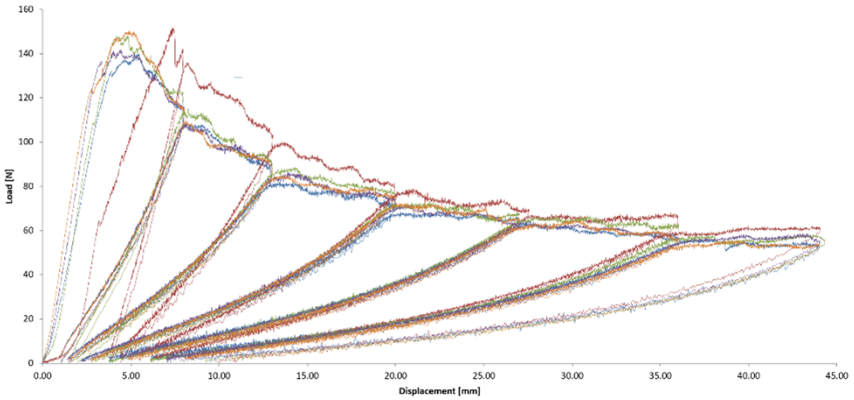
Round Robin – Baseline results (comparison)

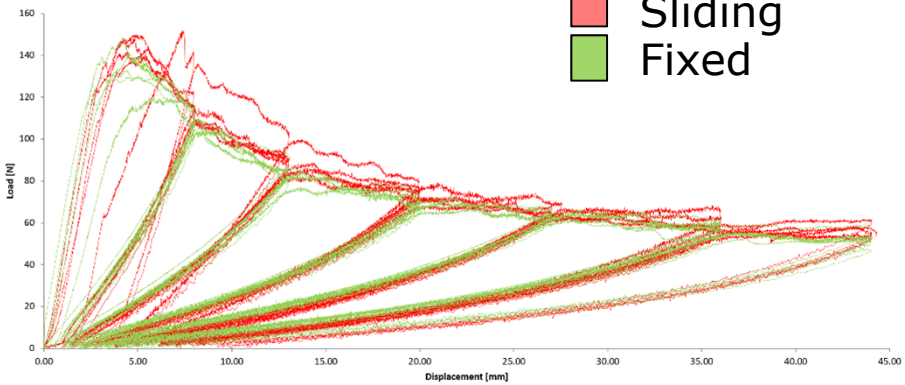


	1	2	3	4	5	6
NIAR, 0mm	969.42	1075.65	1008.21	1011.24	1088.39	949.38
NIAR, 0N	727.37	1386.56	937.14	989.27	1141.31	1030.52
DuPont	1156.35	825.98	891.15	941.24	820.05	865.03
NASA Langley	871.33	912.34	881.87	900.78	929.25	913.79
Fraunhofer	1004.86	1059.17	979.26	1029.31	1066.84	1067.01
Airbus	1380.60	1025.41	951.81	909.53	890.38	957.96
DTU	928.50	946.25	1015.69	917.69	1090.65	1069.15

- Results are consistent (small results difference between laboratories);
- The first load-cycle has to be discarded due to a high scatter of the results.

Round Robin – Slider results (DTU)



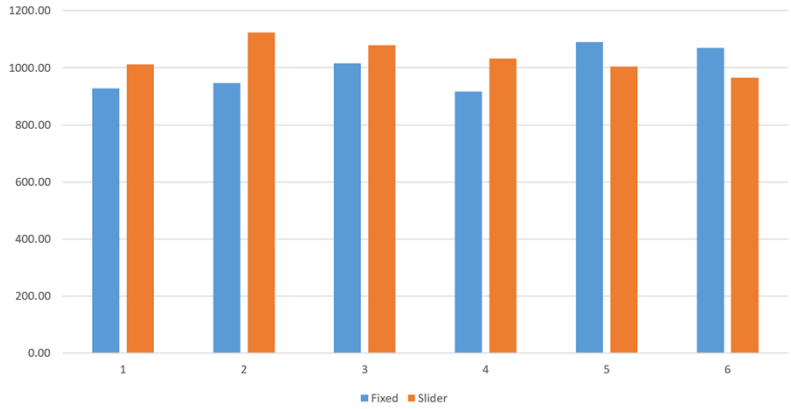


Slider results:

load vs displacement diagrams, superimposed.

The overall higher energy might be due to the friction effect obtained when the table slides.

Avg. G_{1c} (load-cycle 2-6)=1041.54 J/m^2

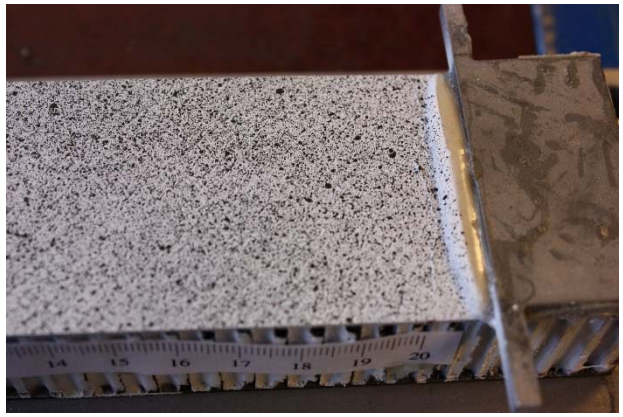


Digital Image Correlation

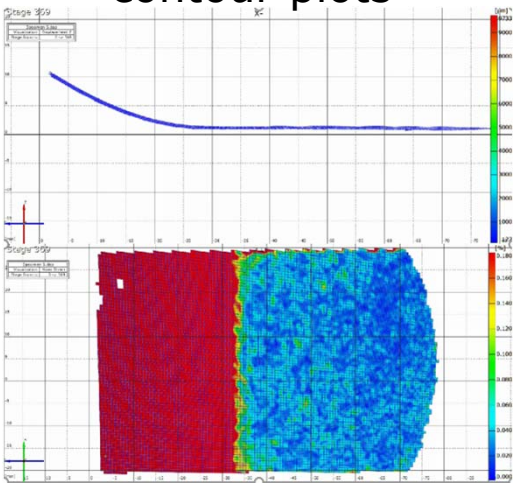
- 3D, non-contact optical technique to measure contour, deformation, vibration and strain on almost any material.
- Uses a high-contrast mono-chromatic dotted pattern painted on the surface of the specimens to detect **strain** and **damages** of the facesheet during the experiments.

DIC 12M system

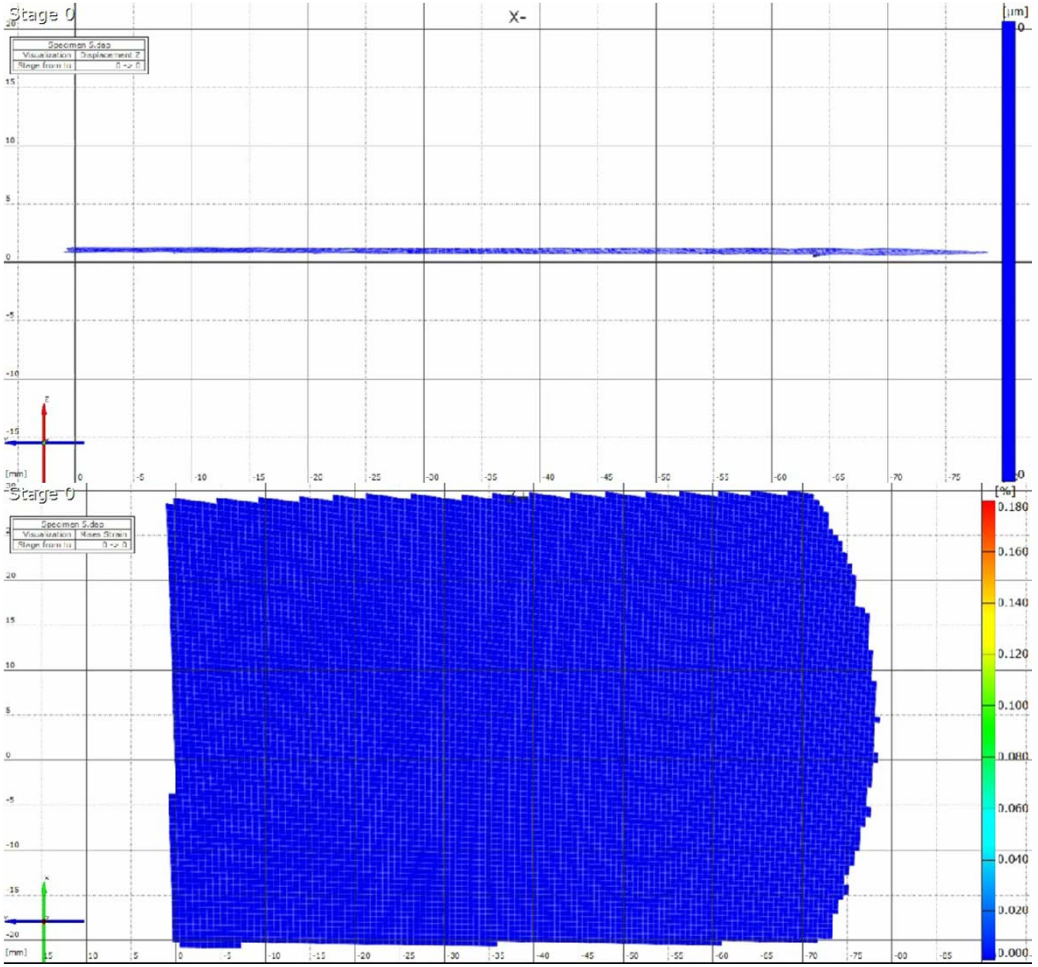
High-contrast dotted pattern



DIC output – contour plots



Digital Image Correlation



Conclusions

- The **test rig** is a robust and reliable machine to assess the fracture toughness in sandwich-structured composites.
  - Requires low maintenance;
  - is solid and durable;
  - relatively cheap to manufacture.

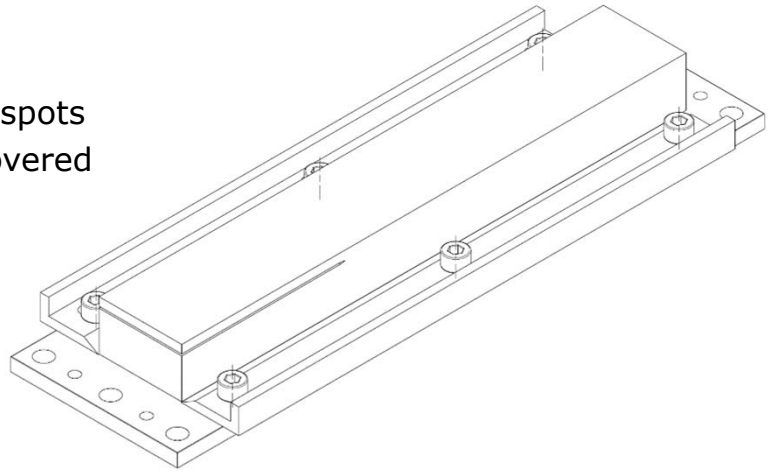
- The **results** obtained are:
  - consistent within the ten specimens tested thus far in DTU;
  - comparable results obtained from other laboratories.

However, some improvements are to be considered…

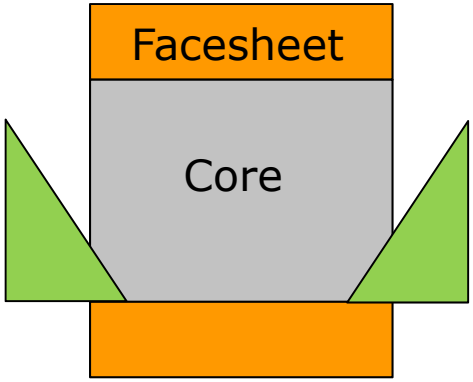
Further developments

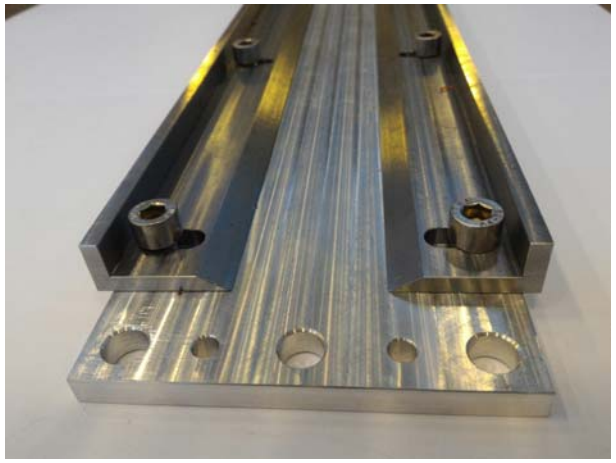
The further developments suggested address the weak spots of the rig and the test procedure which have been discovered during the tests and are highlighted below:

- Specimens setup: new specimen plate design.
  - Quick specimen setup;
  - environmentally friendly.



New specimen plate's blades

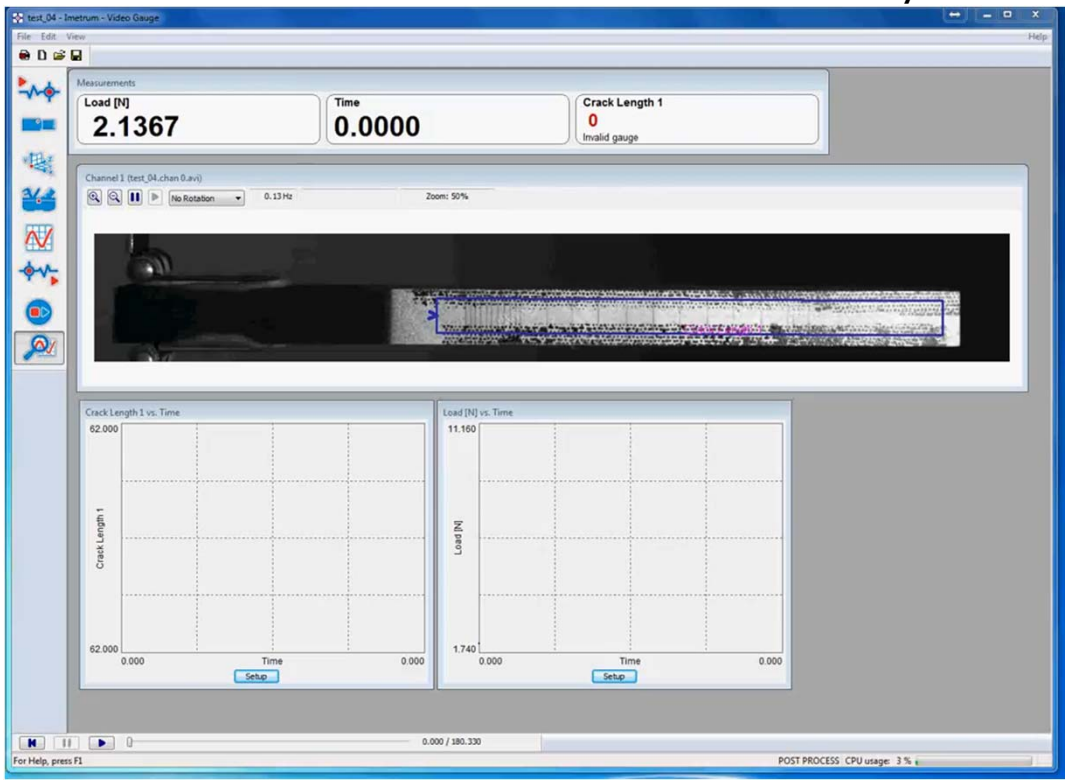




Further developments

- Crack monitoring: crack length detection.
  - Avoid reading mistakes;
  - consistent readings.

Imetrum System




Thank you for your attention!
Questions?