MŰEGYETEM 1782

Budapest University of Technology and Economics (BME), Budapest

DEPARTMENT OF POLYMER ENGINEERING

ICCM22 MELBOURNE AUSTRALIA

11-16 AUGUST 2019

22nd International Conference on Composite Materials

University of BRISTOL

Bristol Composites Institute (ACCIS)

ADVANCED COMPOSITES COLLABORATION FOR INNOVATION & SCIENCE

THE COMBINED EFFECT OF MOISTURE AND TEST TEMPERATURE ON THE PSEUDO-DUCTILITY OF THIN-PLY HYBRID COMPOSITES

Gergely Czél (czel@pt.bme.hu)

Márton Bugár-Mészáros (marton.bugar.meszaros@gmail.com)

Michael R. Wisnom (M.Wisnom@bristol.ac.uk)

CONFERENCE HOSTS: ICCM ENGINEERS AUSTRALIA ACSS

CONFERENCE DESTINATION SUPPORTERS: MELBOURNE Victoria Australia MELBOURNE Convention Bureau

#ICCM22

Carbon/epoxy composites: STIFF, STRONG

and LIGHTWEIGHT!

BUT failure is CATASTROPHIC

DUCTILITY is needed for safety

High **Per**formance

Ductile **C**omposite **T**echnology-

HiPerDuCT Programme

Introduction

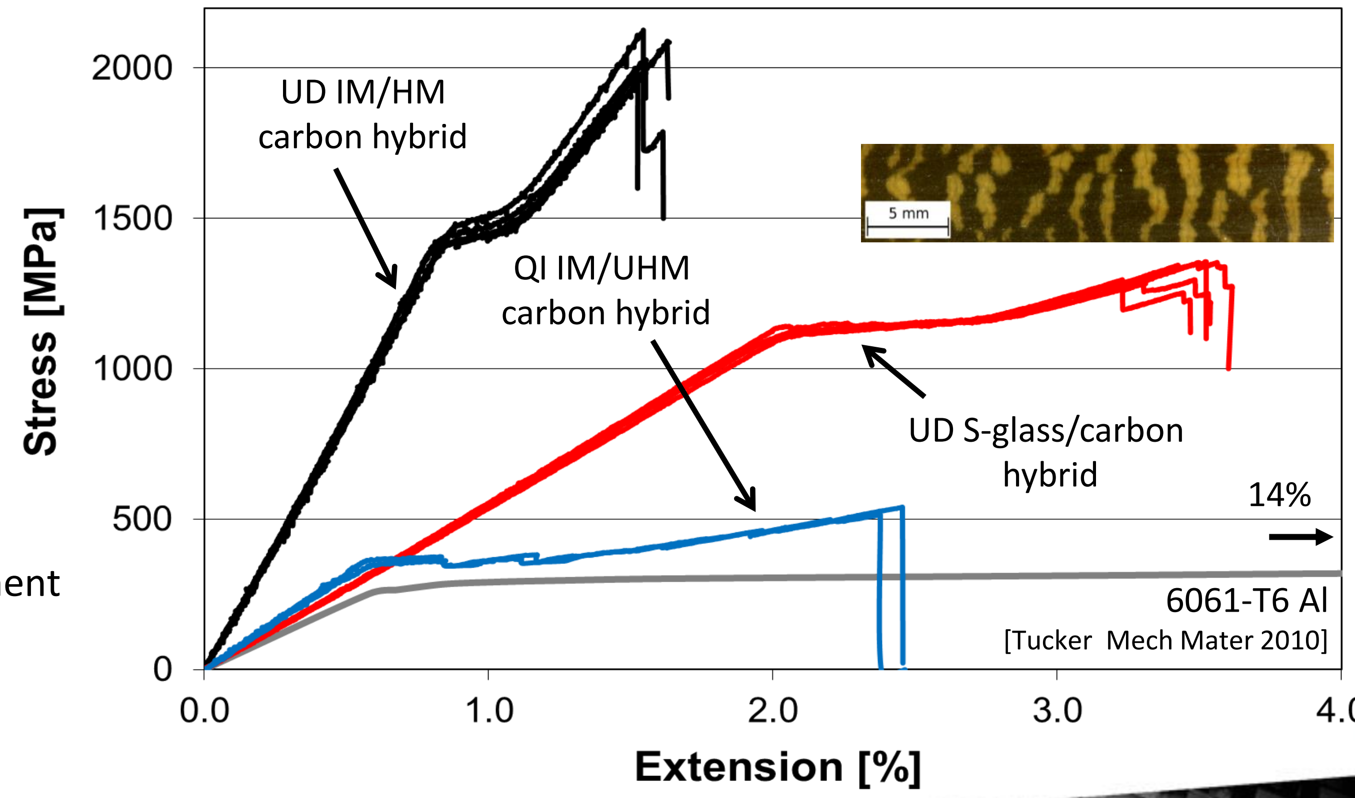
- **High performance composites**: **stiff** and **strong**, but **failure is sudden and brittle** with **little warning** and **poor residual strength**
- **Pseudo-ductility** with an **intrinsic safety margin** could **change design** approach and offer **major benefits**
- Excellent **pseudo-ductility demonstrated first with UD glass/carbon interlayer hybrids in tension** [1,2]*
- **Visible damage:**

-Overload indicator [3]

The concept is then adopted for:

- **UD IM/HM carbon hybrids** [4]
- **QI IM/UHM carbon hybrids** [5]

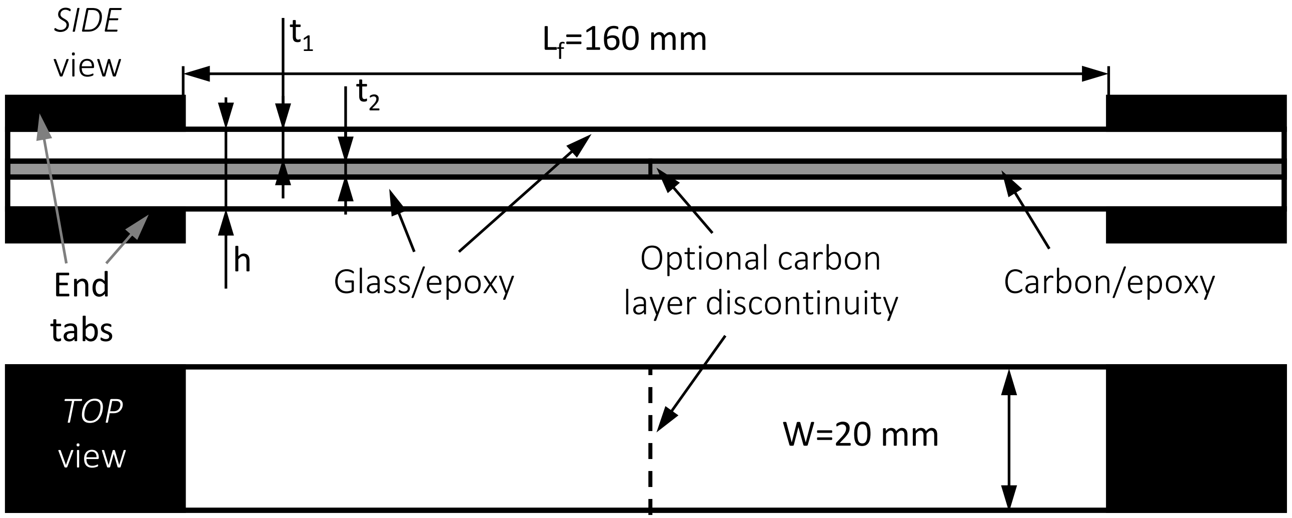
*See references at the end of the document



Key challenges

- To study the effect of **test temperature and moisture** on the ductility mechanisms in UD carbon/glass hybrids in tension
- **Fragmentation** and **delamination** to be assessed separately

Specimen design



Delamination:

$$G_{II} = \frac{\varepsilon_{2b}^2 E_2 t_2 \left(2E_1 t_1 + E_2 t_2\right)}{8E_1 t_1}$$

Glass layer thickness:

$$t_1 > \frac{\varepsilon_{2b} E_2 t_2}{2E_1\left(\varepsilon_{1b} - \varepsilon_{2b}\right)}$$

Lay-up sequence	Carbon layer	Nominal thickness	Energy release rate at carbon fibre failure strain (1.6%)[a]	Minimum vs. nominal glass/epoxy layer thickness	Initial modulus[a]
		[mm]	[N/mm]	[mm]	[GPa]
[S-glass$_1$/TC35$_2$/ S-glass$_1$]	Continuous	**0.358**	**0.480**	0.045/0.155	54.7
[S-glass$_2$/TC35$_4$/ S-glass$_2$]	Discontinuous	**0.716**	**0.959**	0.090/0.310	54.7

[a]Calculated using manufacturer's data

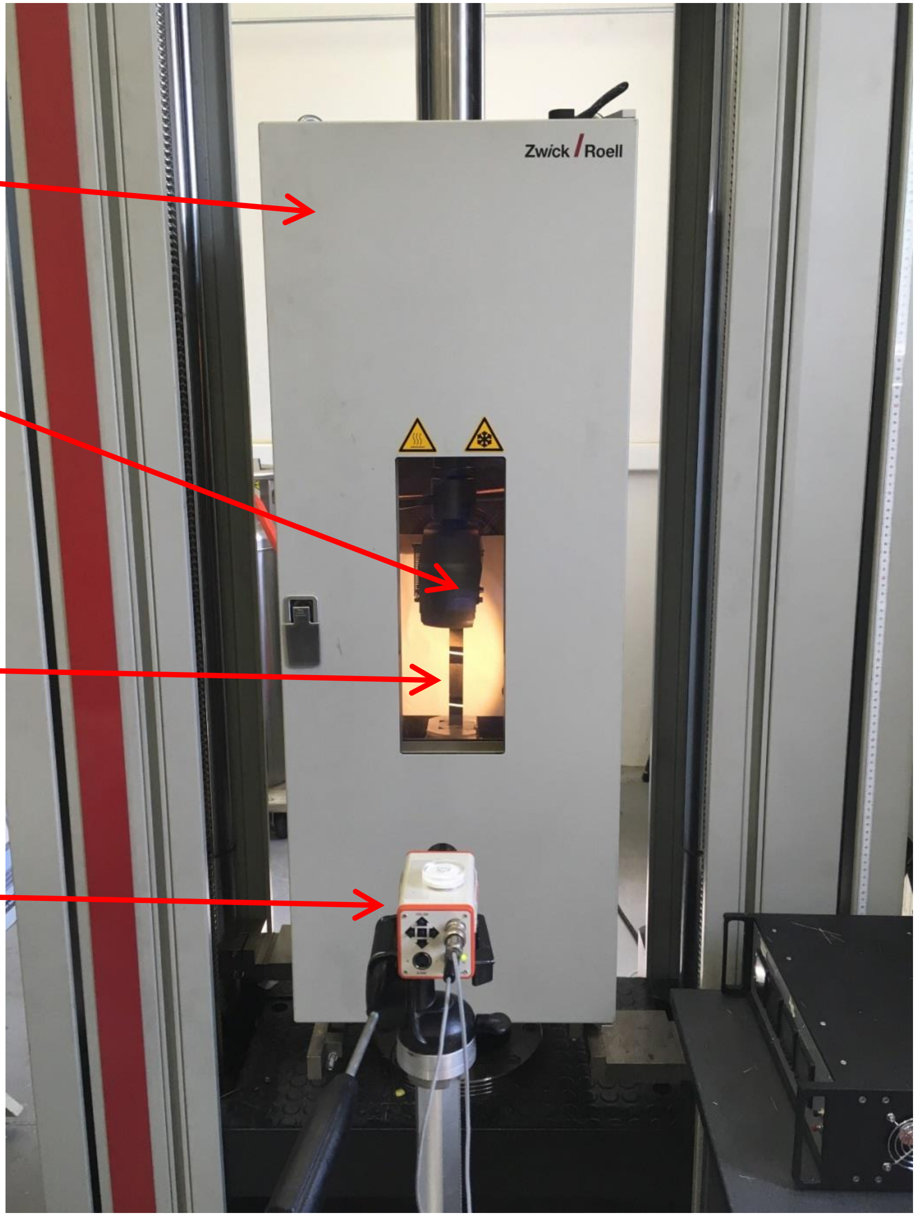
Test method

Environmental chamber

Mechanical wedge grip

Test specimen with markers for strain measurement

Video-extensometer



Test temperatures:

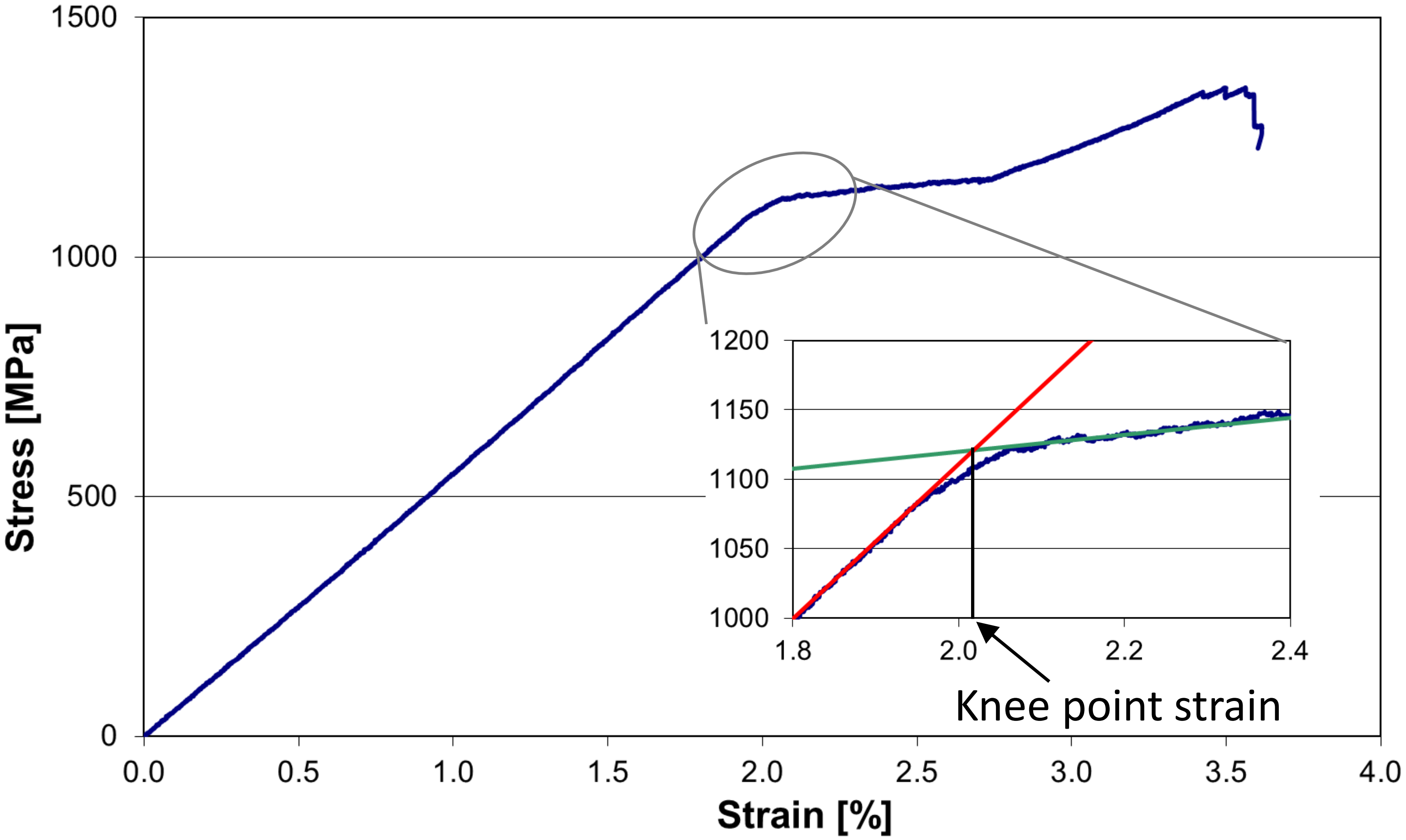
-50°C, 25°C, 80°C

Wet conditioning:
60°C, 90% RH

Hybrid specimens:
1500 hour conditioning

S-glass/epoxy:
125/500/1000/1500 h conditioning

Evaluation of pseudo-ductility

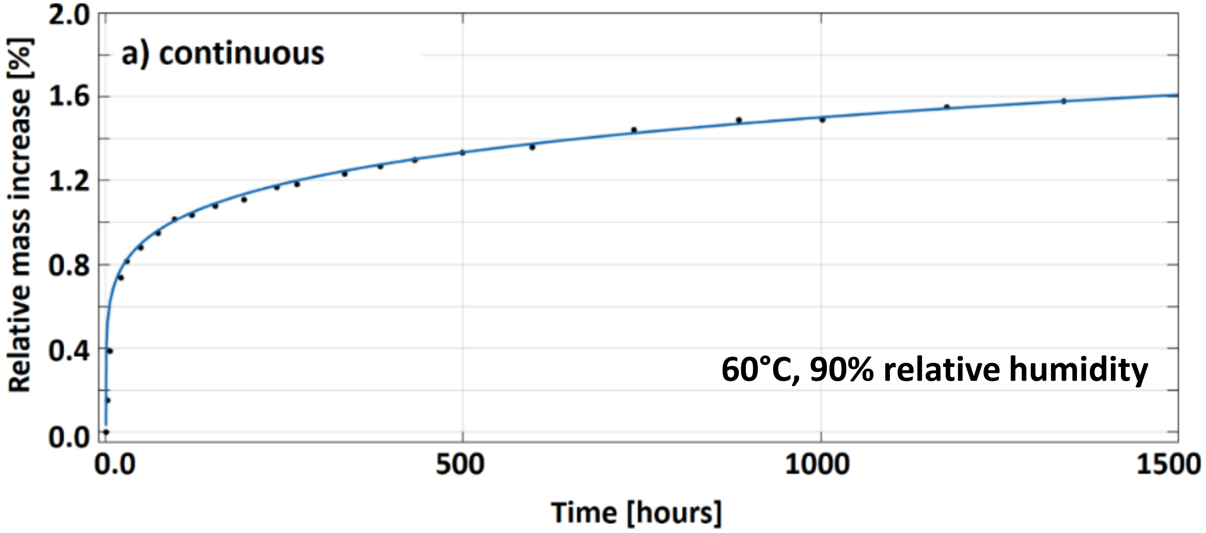


Results- Water uptake

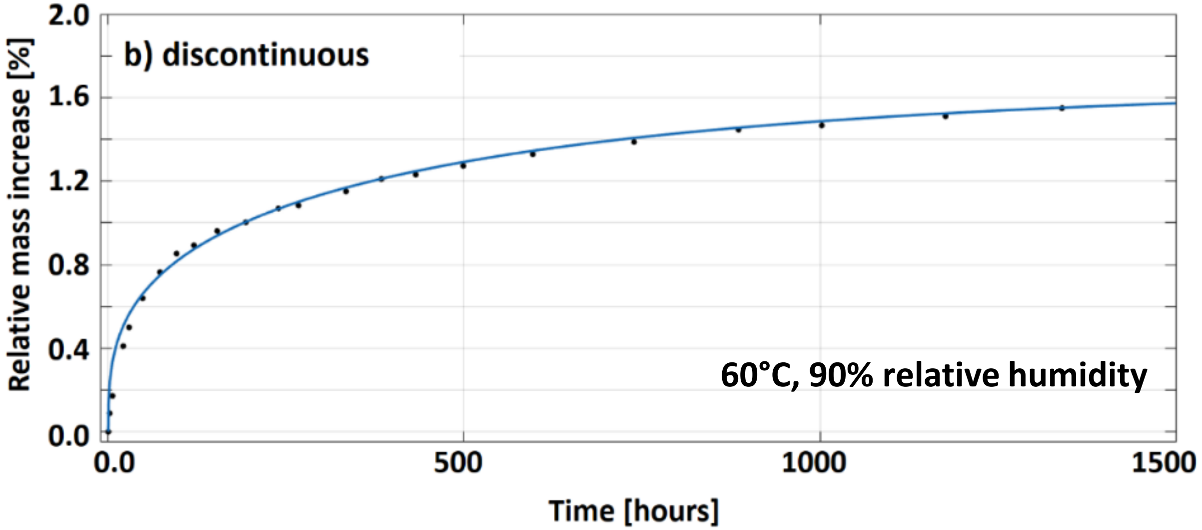
Process modelling:

$$\Delta m(t) = \Delta m_\infty \cdot \left(1 - e^{(-A\cdot t)^{\left(\frac{1}{2K}\right)}}\right)^K$$

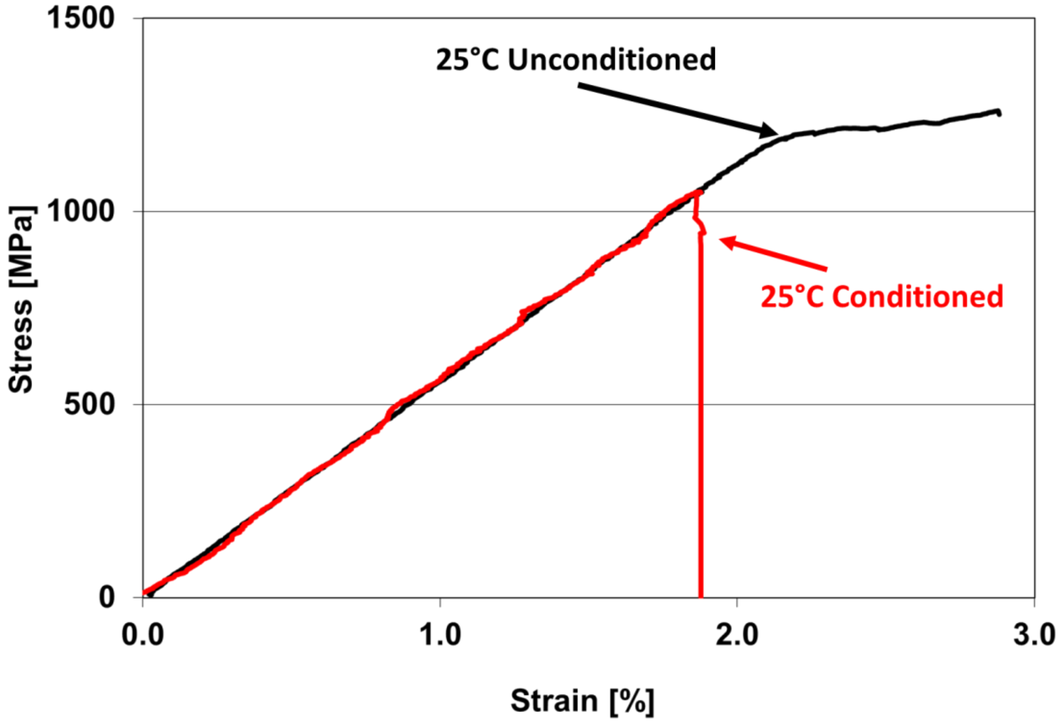
Continuous hybrid
(average of 16 specimens)

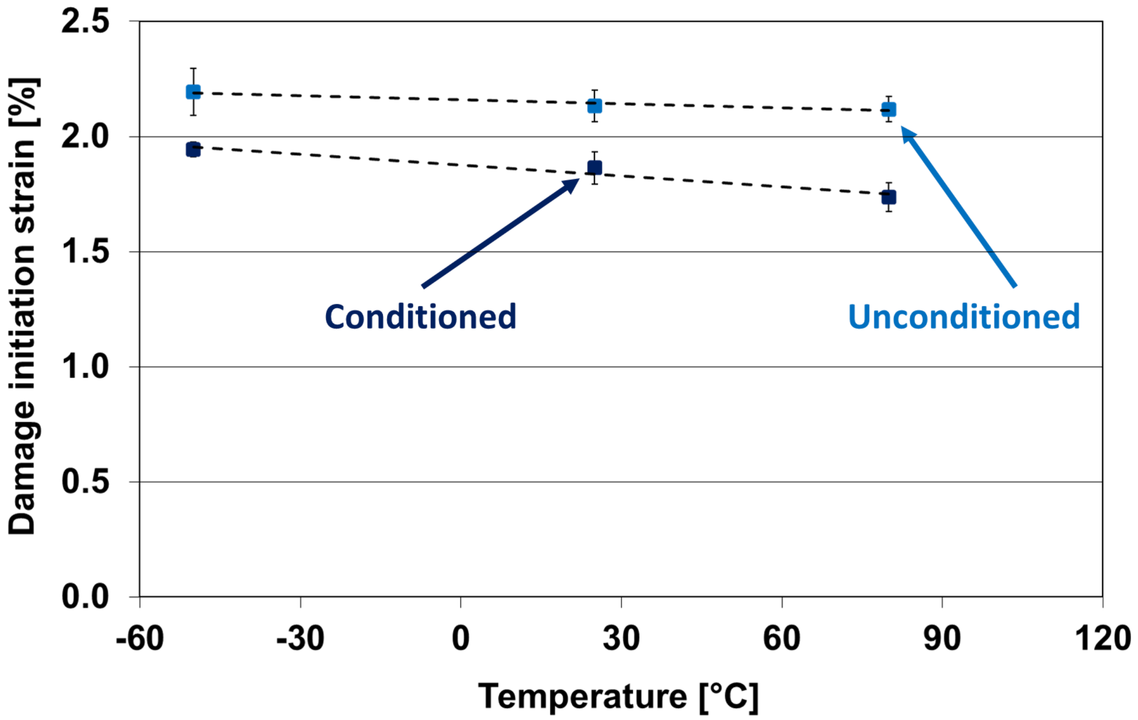


Discontinuous hybrid
(average of 16 specimens)



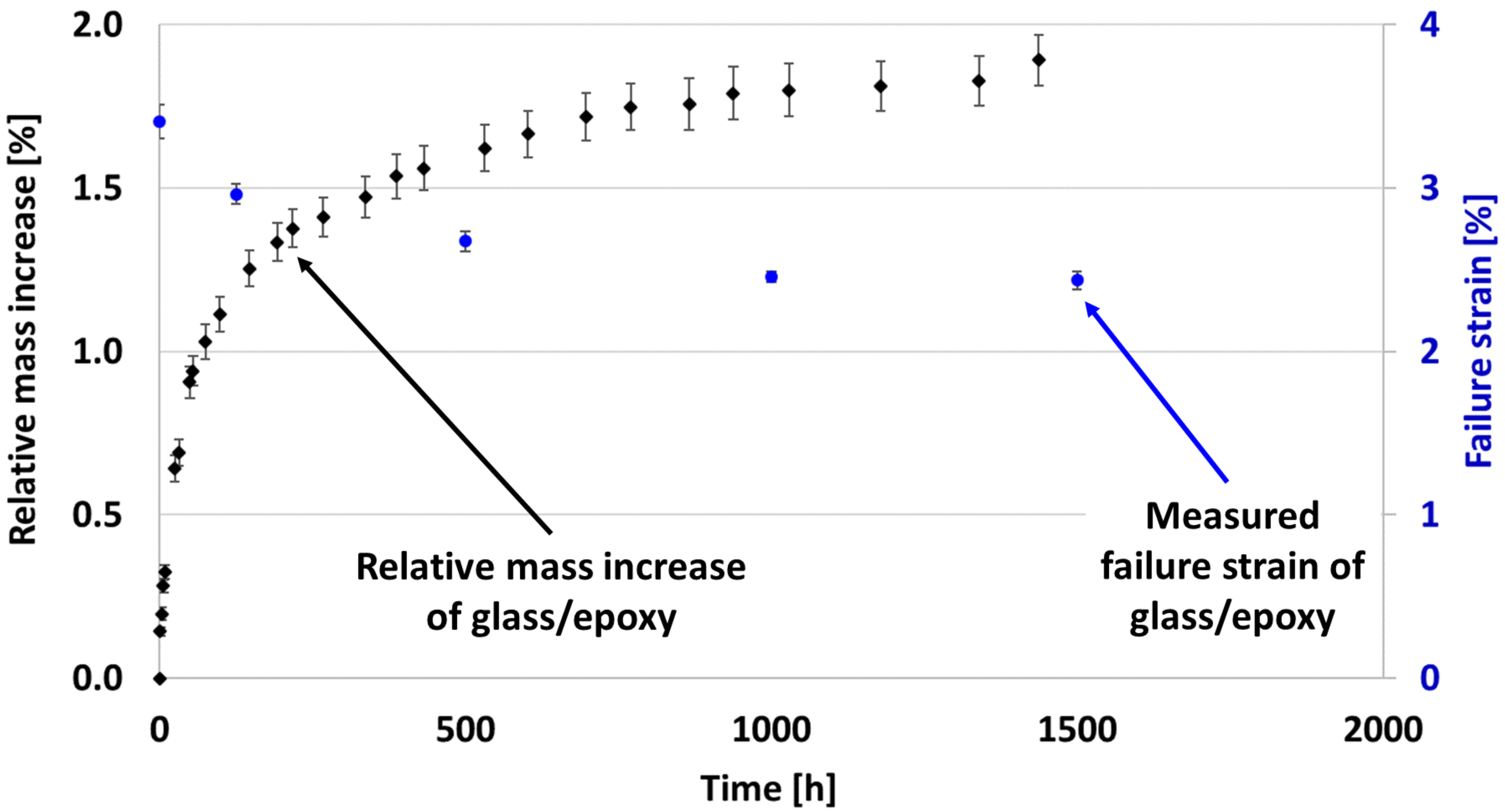
Results- Continuous hybrid specimens





- Change of failure mode due to conditioning
- Significant drop in damage initiation strain

Results- Monolithic S-glass/epoxy specimens

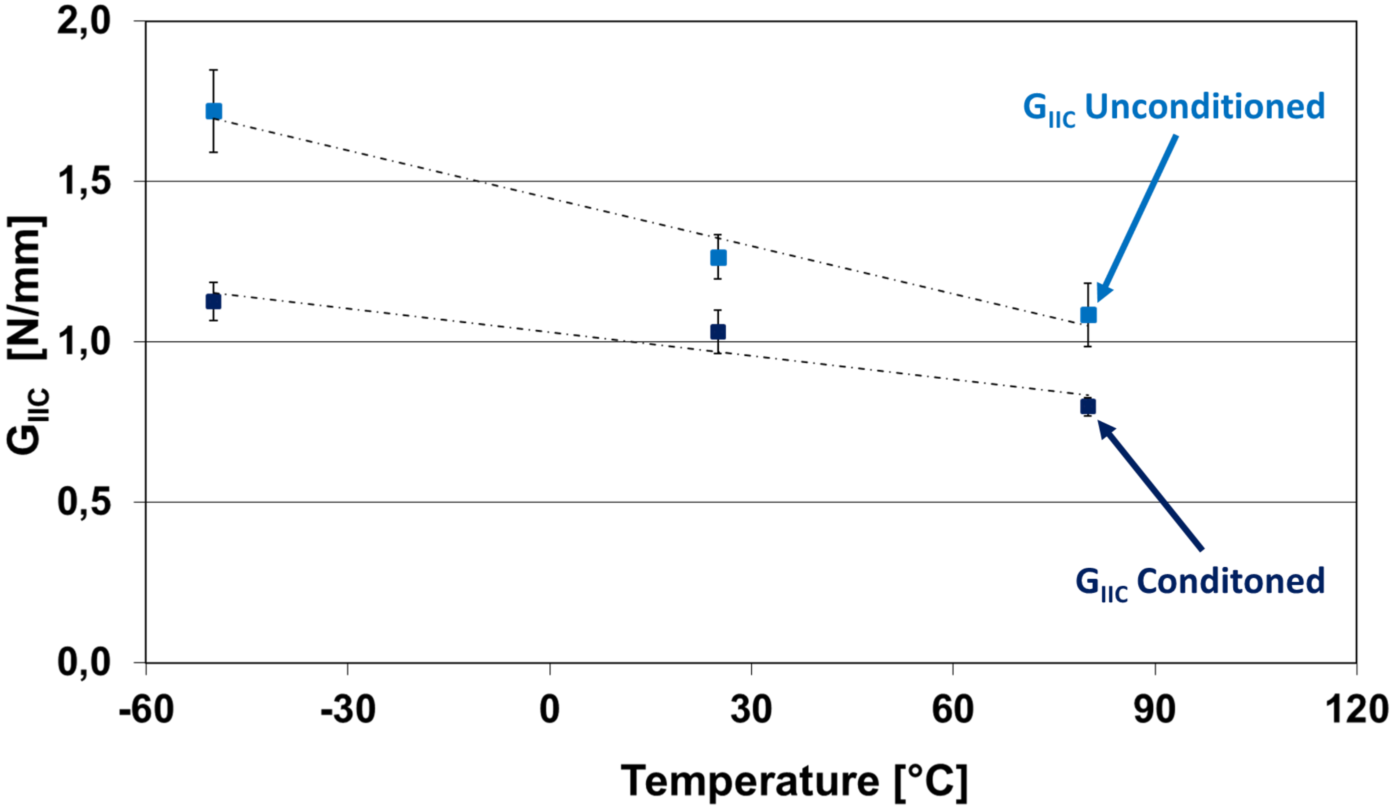


- Water uptake of S-glass/epoxy is higher than that of the hybrids
- Failure strain is reduced by 30% after 1000 hours

Hot-wet conditioning: 60°C, 90% relative humidity, 125/500/1000/1500 hours

Tensile testing at room temperature (25°C)

Results- Discontinuous hybrid specimens



- Failure became less stable due to moisture
- Glass layer strength reduced

Conclusions

- Unconditioned hybrid specimens showed pseudo-ductile stress-strain response between -50°C and 80°C: the continuous specimens fragmented, the discontinuous specimens showed stable delamination between the glass and carbon layers
- Water uptake processes of monolithic S-glass/epoxy and both hybrid specimen types were investigated in detail
- A suitable function was found to model the water uptake process that fitted well to the experimental data
- Wet conditioning changed the damage mode of the continuous hybrid specimens from pseudo-ductile to catastrophic failure
- Moisture sensitivity of glass/epoxy layers was found to be responsible for the lack of pseudo-ductility in the case of continuous hybrids
- Increasing test temperature decreased the mode II fracture toughness of the discontinuous specimens
- Wet conditioning decreased the mode II fracture toughness further at all temperatures

References

[1] G. Czél, M.R Wisnom. Demonstration of pseudo-ductility in high performance glass-epoxy composites by hybridisation with thin-ply carbon prepreg. Composites Part A: Applied Science and Manufacturing, 52:23-30, 2013.

[2] G. Czél, M. Jalalvand, M.R Wisnom. Design and characterisation of advanced pseudo-ductile unidirectional thin-ply carbon/epoxy-glass/epoxy hybrid composites. Composite Structures, 143:362-70, 2016.

[3] T. Rev, M. Jalalvand, J. Fuller, M. R. Wisnom, G. Czél. A simple and robust approach for visual overload indication - UD thin-ply hybrid composite sensors. Composites Part A: Applied Science and Manufacturing. 121:376-385, 2019.

[4] G. Czél, M. Jalalvand, M.R Wisnom, Czigány T. Design and characterisation of high performance, pseudo-ductile all-carbon/epoxy unidirectional hybrid composites. Composites Part B: Engineering, 111:348-356, 2017.

[5] G. Czél, T. Rev, M. Jalalvand, M. Fotouhi, M.L. Longana, O. J. Nixon-Pearson, M.R. Wisnom. Pseudo-ductility and reduced notch sensitivity in multi-directional all-carbon/epoxy thin-ply hybrid composites. Composites Part A: Applied Science and Manufacturing,104:151-164, 2018.

Acknowledgement

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE

EPSRC
Engineering and Physical Sciences Research Council

This work was funded by the Hungarian National Research, Development and Innovation Office - NKFIH through grant ref. OTKA K 116070, NVKP_16-1-2016-0046 and by the UK Engineering and Physical Sciences Research Council through Grant EP/I02946X/1 in collaboration with Imperial College London. Gergely Czél acknowledges the Hungarian Academy of Sciences for funding through the János Bolyai scholarship and NKFIH for funding through grant ref. OTKA PD 121121.