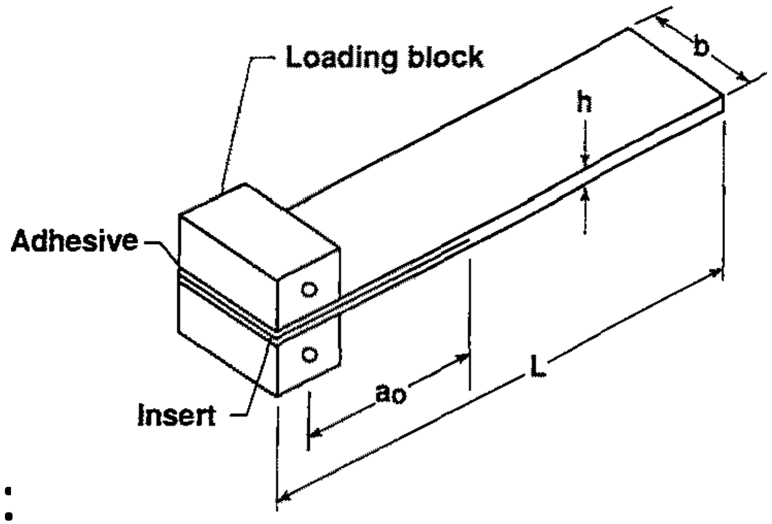
Empa
Materials Science and Technology

Does it really matter whether delamination toughness of polymer composites is a material parameter?

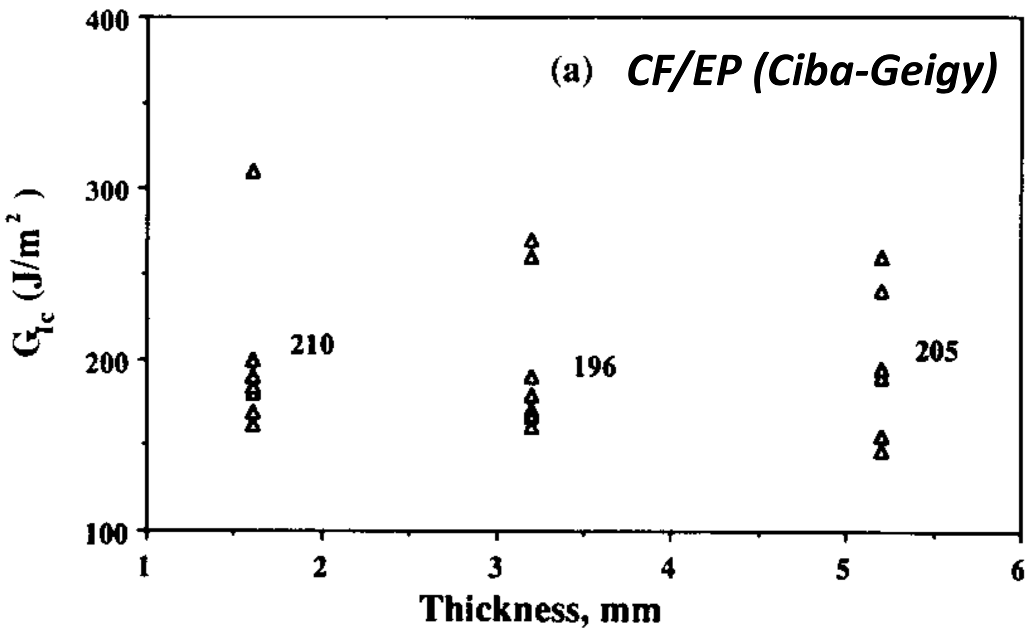
Andreas J. Brunner

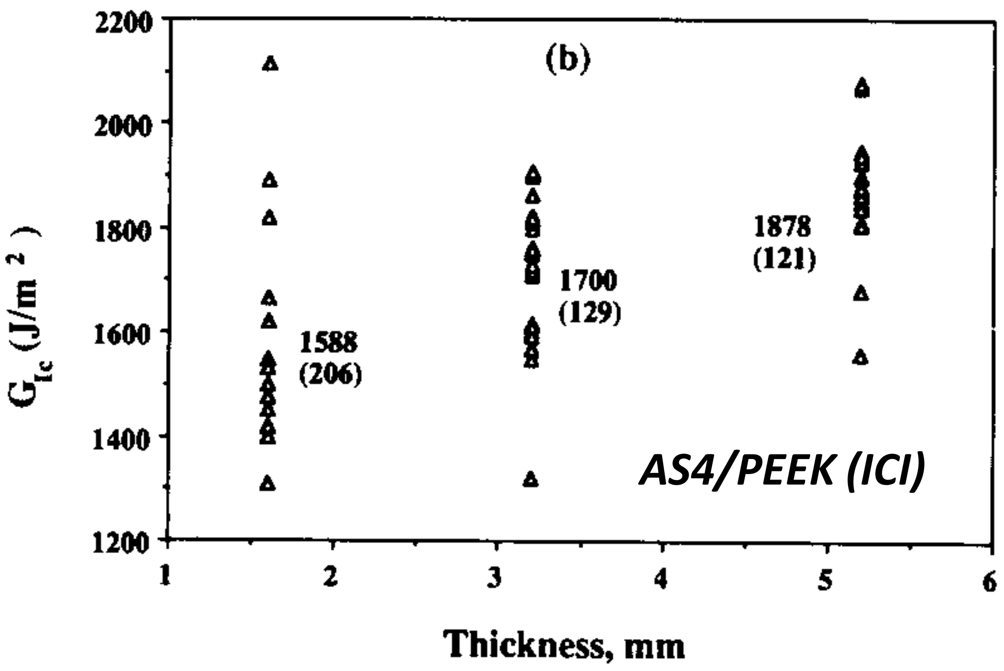
***retired from Empa**, Swiss Federal Laboratories*
for Materials Science and Technology, Dübendorf, Switzerland

Experimental evidence I



Is there a thickness effect «h»? Was investigated ≈ 1990 in Mode I delamination test development [1]:



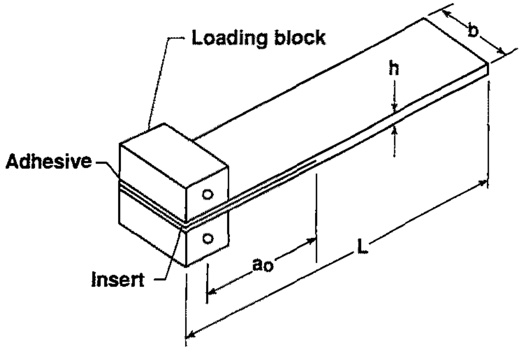


no clear thickness effect for CF/EP

possible effect for CF/PEEK

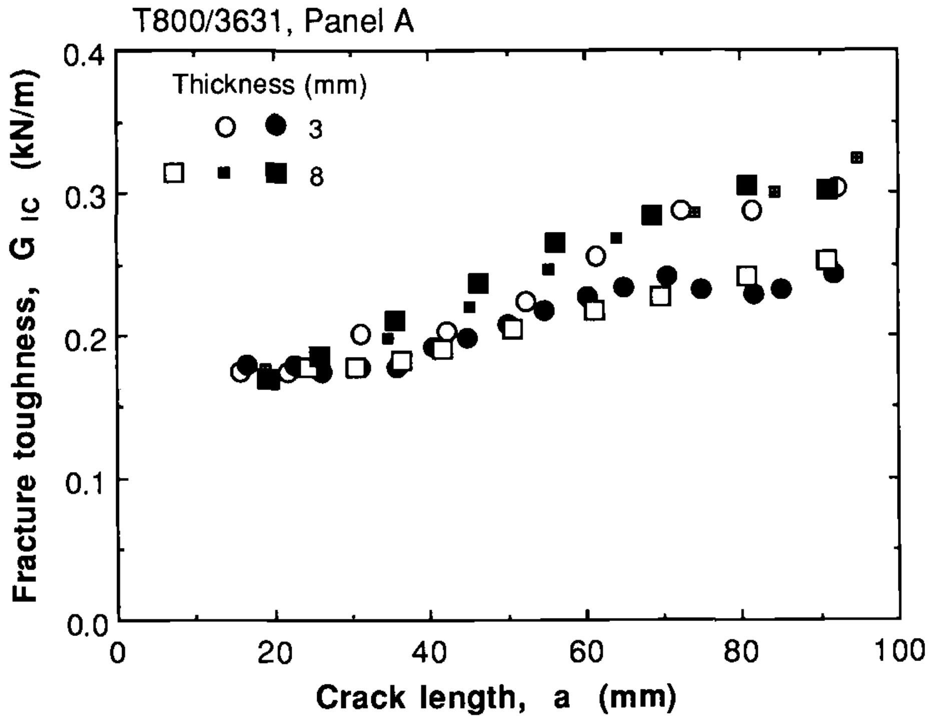
[1] Davies et al. Composites Science and Technology 43 (1992) pp. 129-136

Experimental evidence II



(b) with loading blocks

Are thickness effects in PEEK process-related [2] ?



8 mm laminates **milled to 3 mm, 4 mm and 5 mm**: *"The initiation values of the fracture toughness were independent of the specimen thickness both for AS4/PEEK laminates and T800/3631 laminates."*

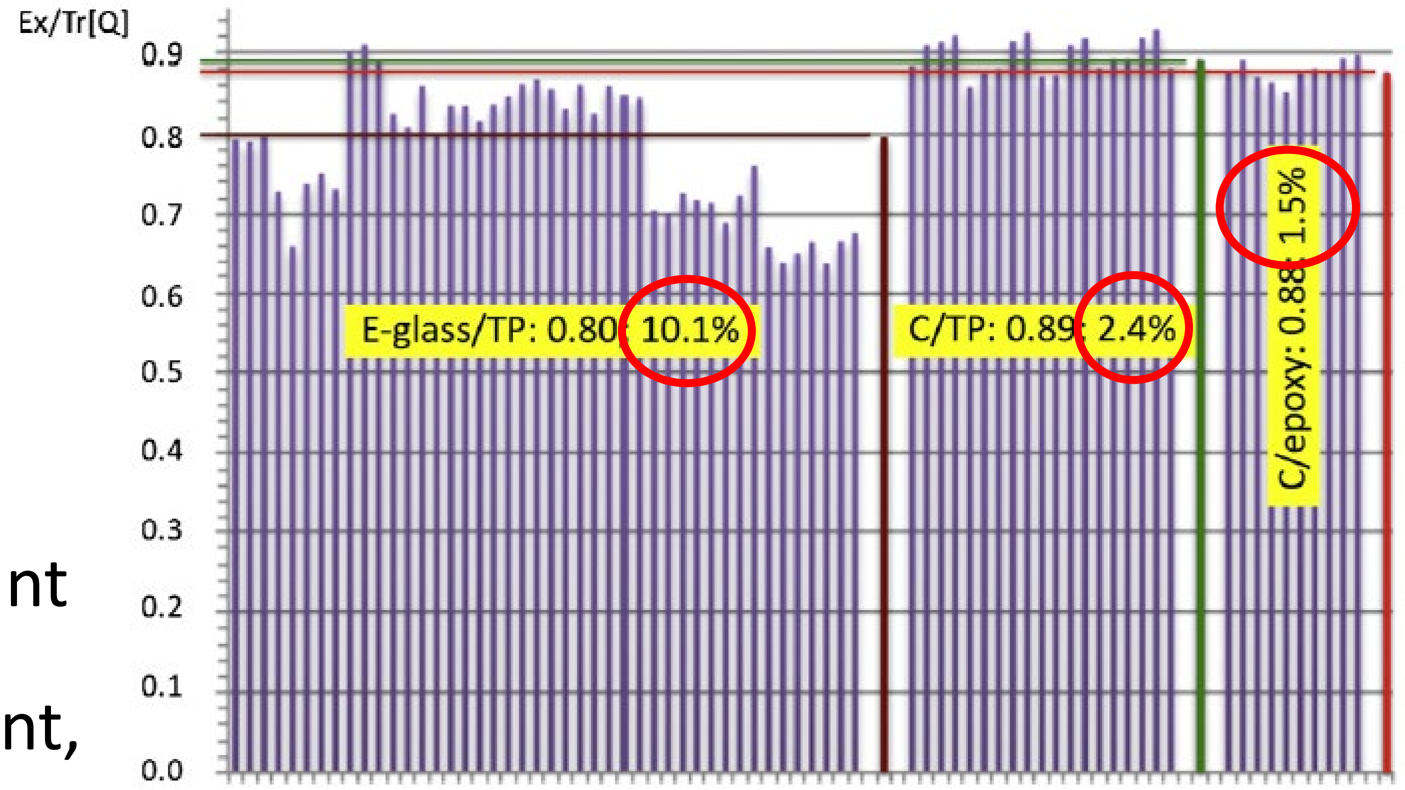
For AS4/PEEK: *"The genuine thickness effect on the propagation values obtained here was much smaller than the effect resulting from molding laminates of different thickness."*

For CF/EP: *"The effect of specimen thickness on the propagation values at a certain crack length was smaller than the scatter of the data points for the two panels tested here."*

[2] Hojo & Aoki 4th ASTM Symp. STP 1156 (1993) pp. 281-298

Experimental evidence III

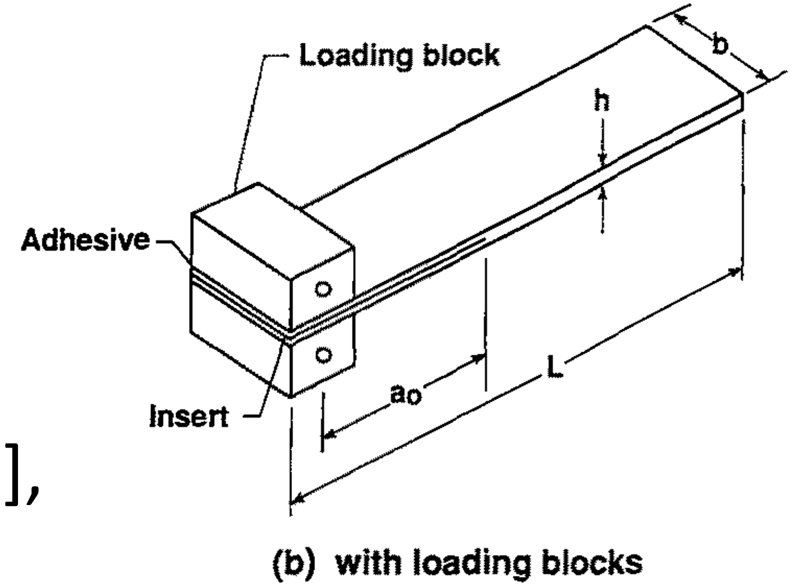
- Round robin repeatability and reproducibility 10-20%
- Material variability yields intrinsic scatter, ≈ 1-3% for CFRP, ≥ 3-5% for GFRP [3,4]
- Measurement resolution scatter estimate is ≤ 6% [3]
- Additional sources of significant scatter are human operator actions in set-up, measurement, and data analysis [3]



[3] Brunner, Engineering Fracture Mechanics, 264 (2022) 108340

[4] Tsai and Melo, Composites Science and Technology, 100 (2014) pp. 237–243

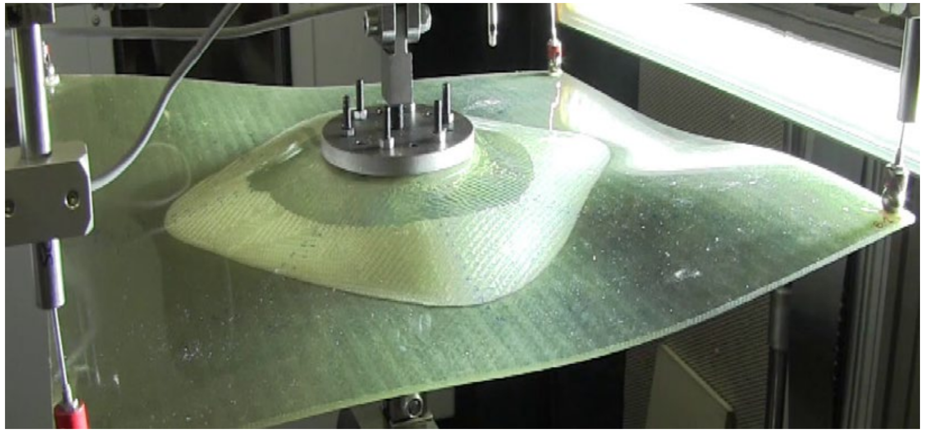
Experimental evidence IV



Is there a width effect «b»? Was investigated ≈ 1990 in Mode I delamination test development [5], widths 12.5 mm, 25.0 mm and 37.5 mm tested

"Because no significant width effect was discovered …. 20-25 mm wide specimens were tested in the 4th and 5th rounds."

But Mode I 2D delamination involves membrane stresses and depends on fiber lay-up and size and shape of loading device and precrack [6,7]



[5] O'Brien & Martin NASA TM 104222, 1992
[6] Cameselle Molares et al. Engineering Fracture Mechanics 203 (2018) pp. 152–171
[7] Wang et al. Engineering Fracture Mechanics 250 (2021) 107787

Modelling and prediction

Blind modelling prediction of damage, e.g., open hole fatigue strength, yields up to 70% scatter depending on fiber orientation [8]

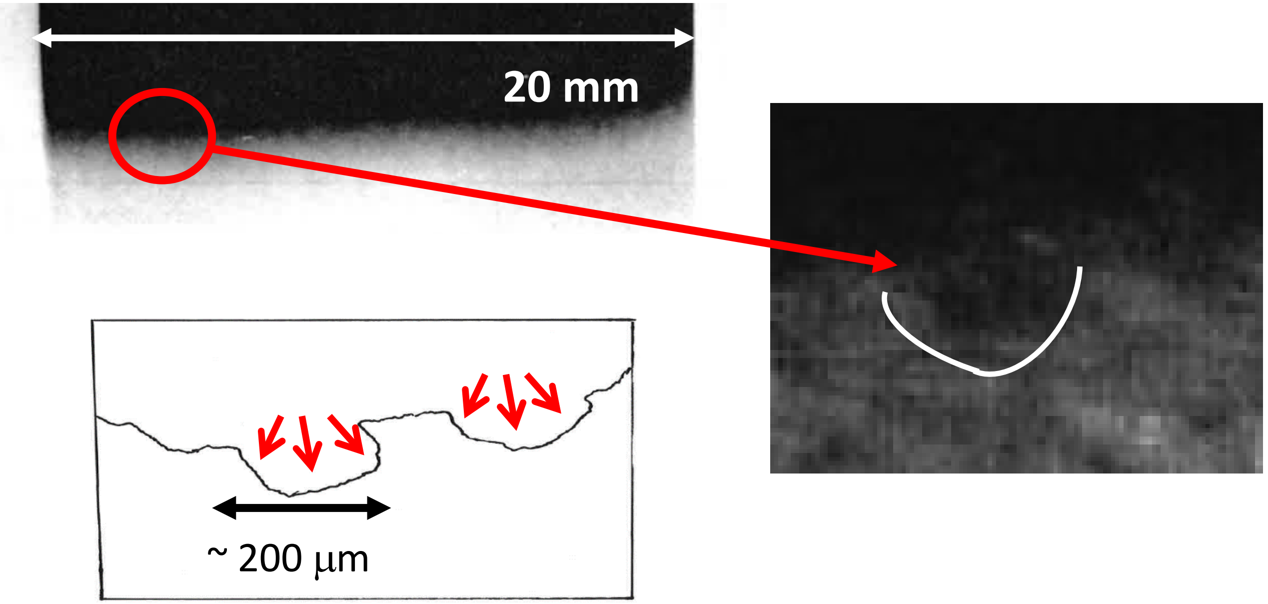
Table 2. Overall blind predictions summary of stiffness and residual strength.

	Experiment σ_{max} (MPa)	GENOA σ_{max} (MPa)	DCN σ_{max} (MPa)	MDS-C σ_{max} (MPa)	BSAM/MIC σ_{max} (MPa)	MAC/GMC* σ_{max} (MPa)	Helius PFA* σ_{max} (MPa)	EHM* σ_{max} (MPa)	Average error %
Residual strength after fatigue (200 K/300 K cycles)									
Open-hole tension									
$[0/45/90/-45]_{2s}$	544	498	450	498	684	342	475	522	16
$[60/0/-60]_{3s}$	675	468	0	0	828	237	0	0	74
$[30/60/90/-60/-30]_{2s}$	424	384	383	0	408	303	428	307	26
Average error (%)		16	42	69	17	44	38	44	39
Open-hole compression									
$[0/45/90/-45]_{2s}$	−317	−389	−295	−296	−325	−183	−282	−355	15
$[60/0/-60]_{3s}$	−378	−420	0	0	−362	−127	0	0	69
$[30/60/90/-60/-30]_{2s}$	−274	−380	−245	0	−332	−165	−249	−248	33
Average error (%)		24	39	69	9	50	40	41	39
	Experiment E (GPa)	GENOA E (GPa)	DCN E (GPa)	MDS-C E (GPa)	BSAM/MIC E (GPa)	MAC/GMC* E (GPa)	Helius PFA* E (GPa)	EHM* E (GPa)	Average error %

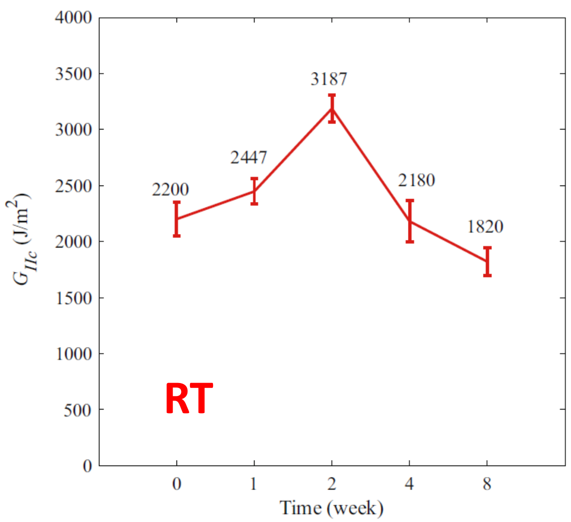
[8] Engelstad & Clay Journal of Composite Materials, 51, No. 15 (2017) pp. 2227-2249

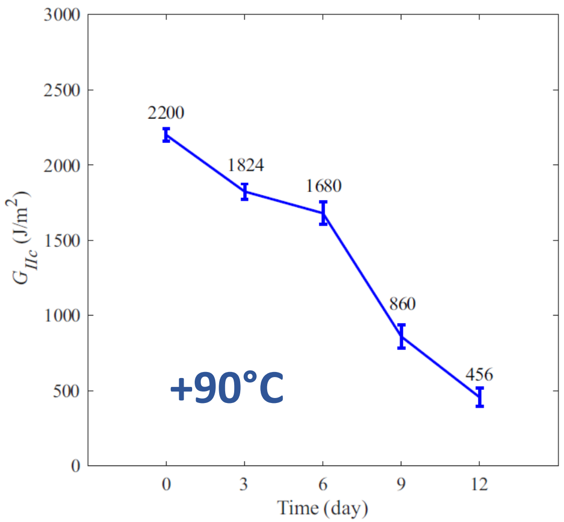
Micro-scale morphology effects

Morphology – scale estimate [9] and time-dependent behavior [10]



Average delamination damage size increment (diameter) from radiography: a few ten to few hundred micrometers, time-scale a few ten nanoseconds to a few microseconds





Toughness changes for constant media exposure at constant temperature: How to predict toughness for media exposure and temperature both varying at different time-scales?

[9] Brunner, Journal of Acoustic Emission, 33 (2016) pp. S41-S49
[10] Salamt-Talab et al. Science and Engineering of Composite Materials, 28 (2021) pp. 382–393

Conclusions

- Experimental toughness data and models both still suffer from significant scatter limiting comparison and predictions
- Multi-scale morphology, multiple delaminations, and time-dependent phenomena interacting on all scales yield effects on toughness observed in composite structures
- Understanding multi-scale morphology of composites and relevant interactions from micro-/nano-scale size and time up is essential for improving toughness prediction in composite structures from material test data
- Hence, in my opinion, it does not matter whether delamination toughness is a material parameter or not, you have to understand what you do when using experimental toughness data for whatever purpose

Thank you for your attention