Suitability and Robustness of the SCB Fracture Toughness Test for Honeycomb Sandwich with Very Thin Face Sheets

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SCB Test Development – Background, Motivation

Problem, history

- Occurrence of in-service component failures associated with disbonding in honeycomb core sandwich in aircraft
- Structure integrity degradation due to disbonding
  affects continued operational safety
- Concern that such failures may discourage use of composites in future vehicles
- Methods for assessing propensity of sandwich to disbonding not fully matured, accepted and documented

Objective

Develop a methodology to assess face sheet/core disbonding in honeycomb sandwich components

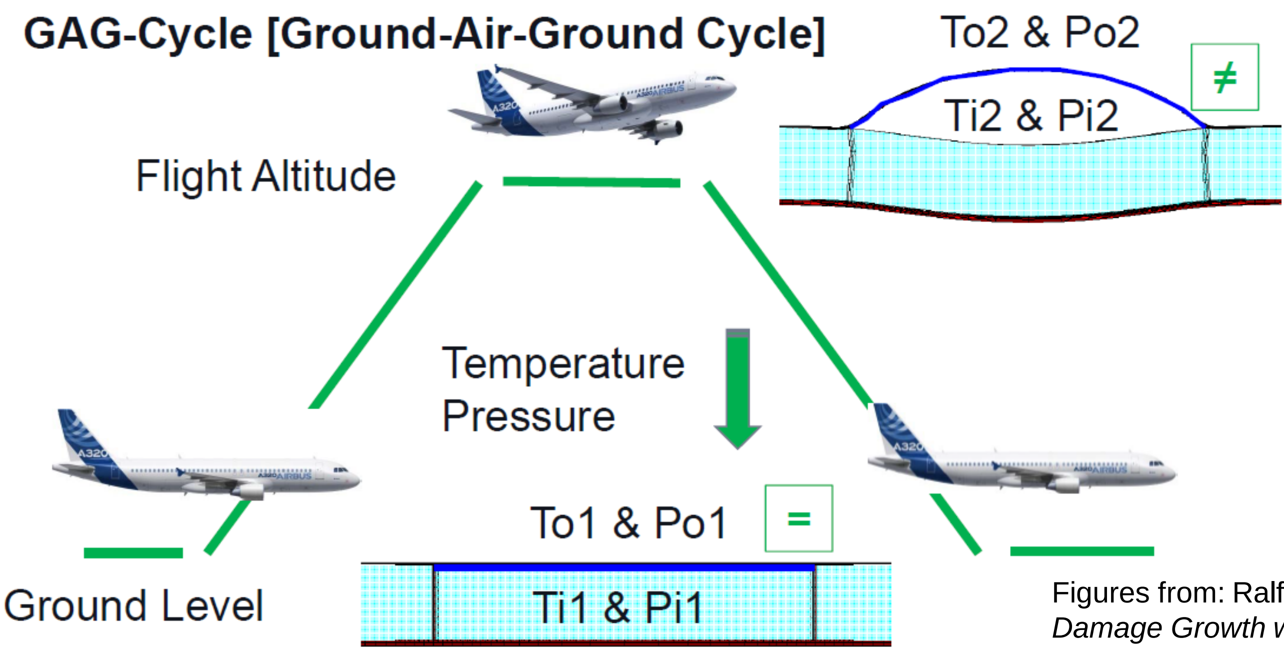
CMH-17 Sandwich Disbond Initiative [2011]

SCB Test Development – Background, Motivation

In-Service occurrences with the sandwich rudder triggered comprehensive studies

- Structural failure in flight
- Disbond detected due to contamination
- Disbond detected due to failed repair

The cause: Sandwich Damage Growth under GAG-cycle (Ground-Air-Ground)



Figures from: Ralf Hilgers, *Substantiation of Damage Growth within Sandwich Structures,* presented at CMH-17 meeting, Costa Mesa, 2010.

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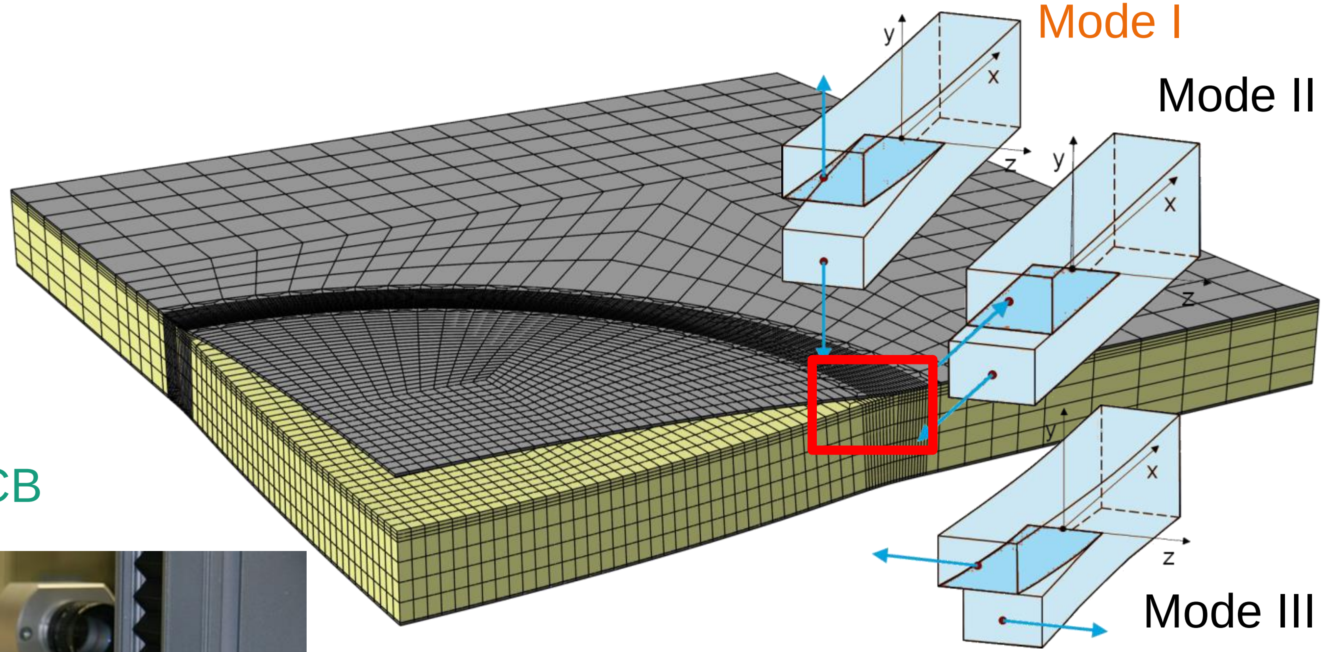
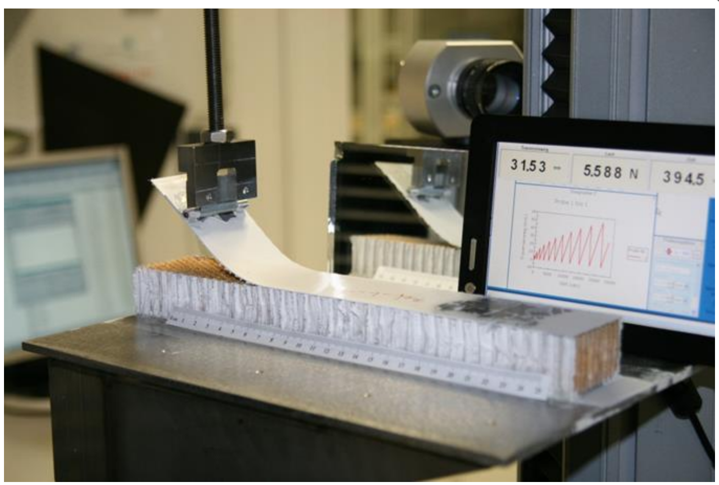
SCB Test Development – Background, Motivation

Mode I dominated fracture test

➔ G_{Ic}

➔ most simple: SCB





Criterion for disbond growth
$= f(G_I, G_{II}, G_{III}, G_{Ic}, G_{IIc}, G_{IIIc})$

➔ Mode I (opening mode) is assumed to be the most critical one (with regard to GAG, buckling etc.)

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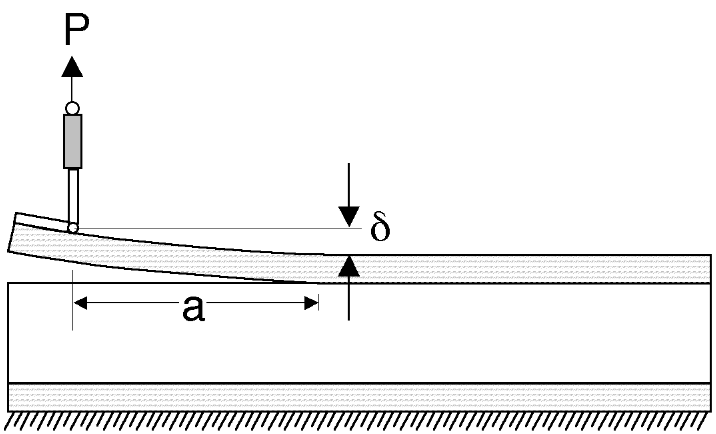
SCB Test Development – Background, Motivation

SCB test was derived from the well known DCB test (composite laminates) but is not symmetric (neither geometry nor material):

- Is fracture mode constant over a certain range of crack extension?
- Is it possible to define a test which is clearly mode-I dominated?
- Are there fracture mechanics and/or numerical modeling problems due to the bi-material interface between stiff CFRP face sheet and low density honeycomb core showing extreme mechanical anisotropy?
- ...

A special situation:

Very thin face sheets **and**
very low density honeycomb core **and**
high resistence against disbond growth
(high fracture toughness)



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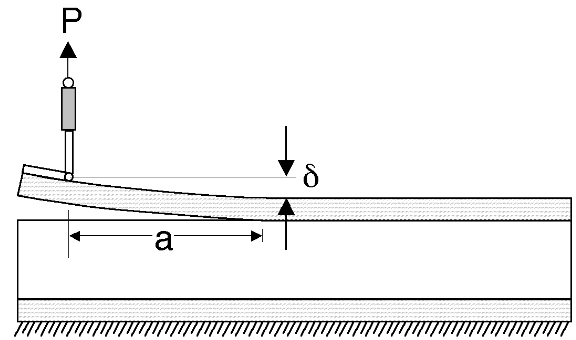
SCB Test Principle

Procedure and data reduction method

... according to the ASTM Draft Standard:

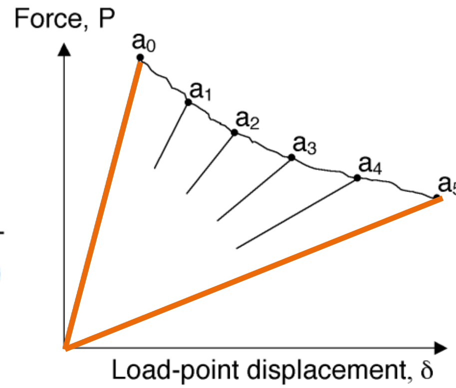


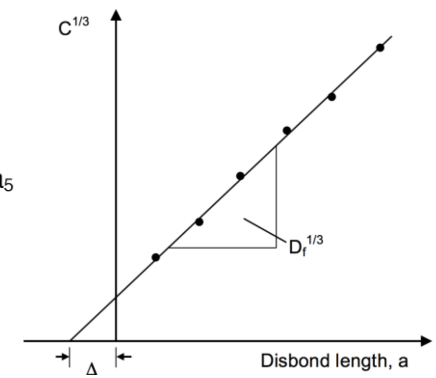
Interfacial Fracture Toughness of Peel Loaded Sandwich Construction. Date of Rev. 2014

MBT is based on linear-elastic deformation and constrained to small deflection and rotation:

$$G_c = \frac{3P\delta}{2b\left(a + |\Delta|\right)}$$

➔ Applicable as long as the load/displacement curve remains linear

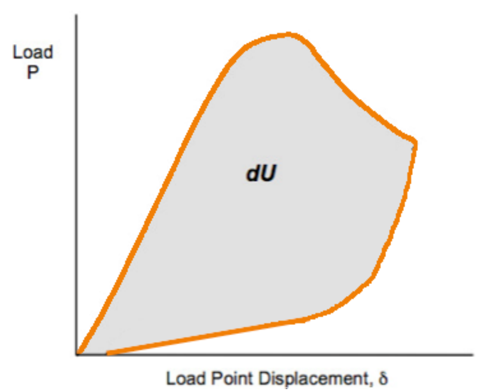


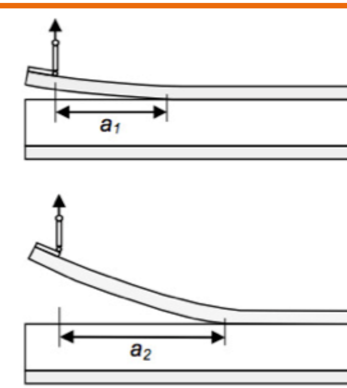


More generally applicable:

Areas Method

$$G_c = \frac{dU}{dA}$$





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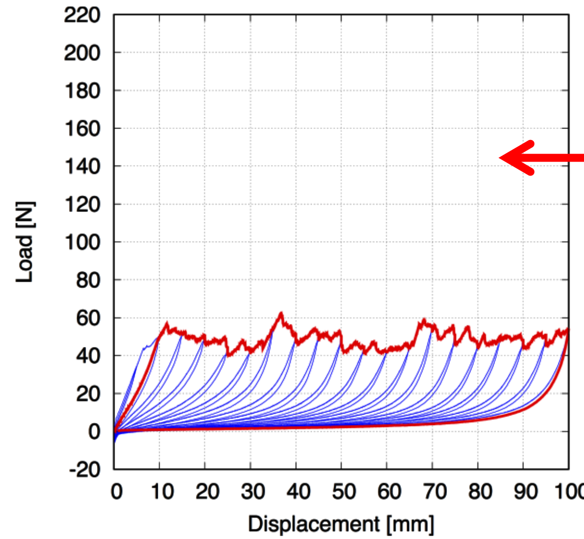
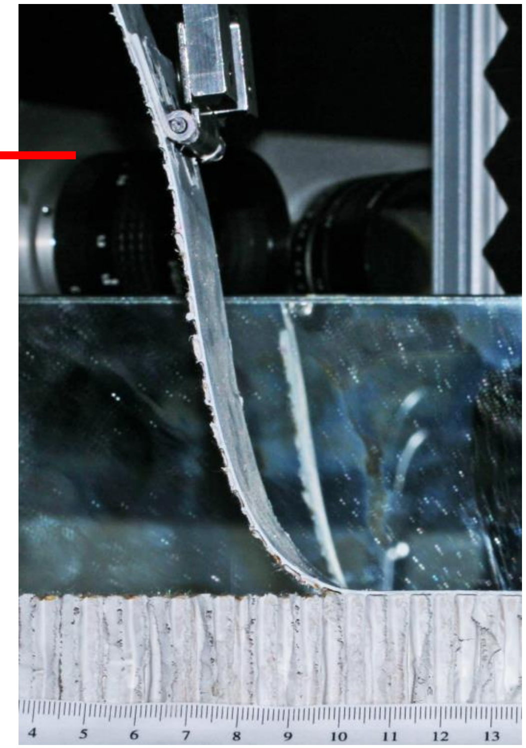
Specifics of Honeycomb Sandwich with thin Face Sheets

... and high G_C

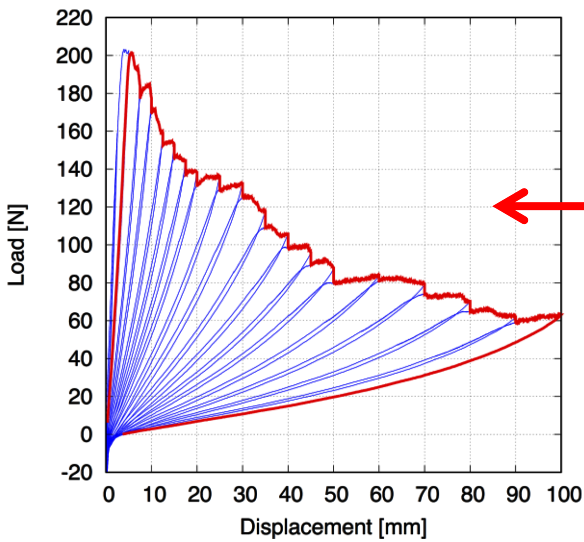
SCB Test variant with doubler compared to original specimen

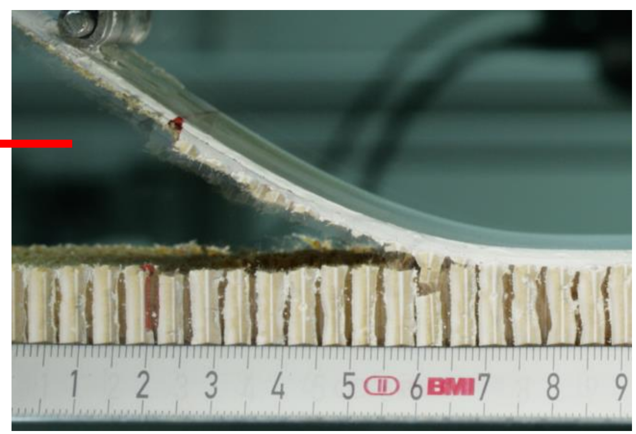
Characteristic load displacement curves





Original thin CFRP face sheet





Face sheet stiffened by GFRP reinforcement plate to limit deflection and rotation

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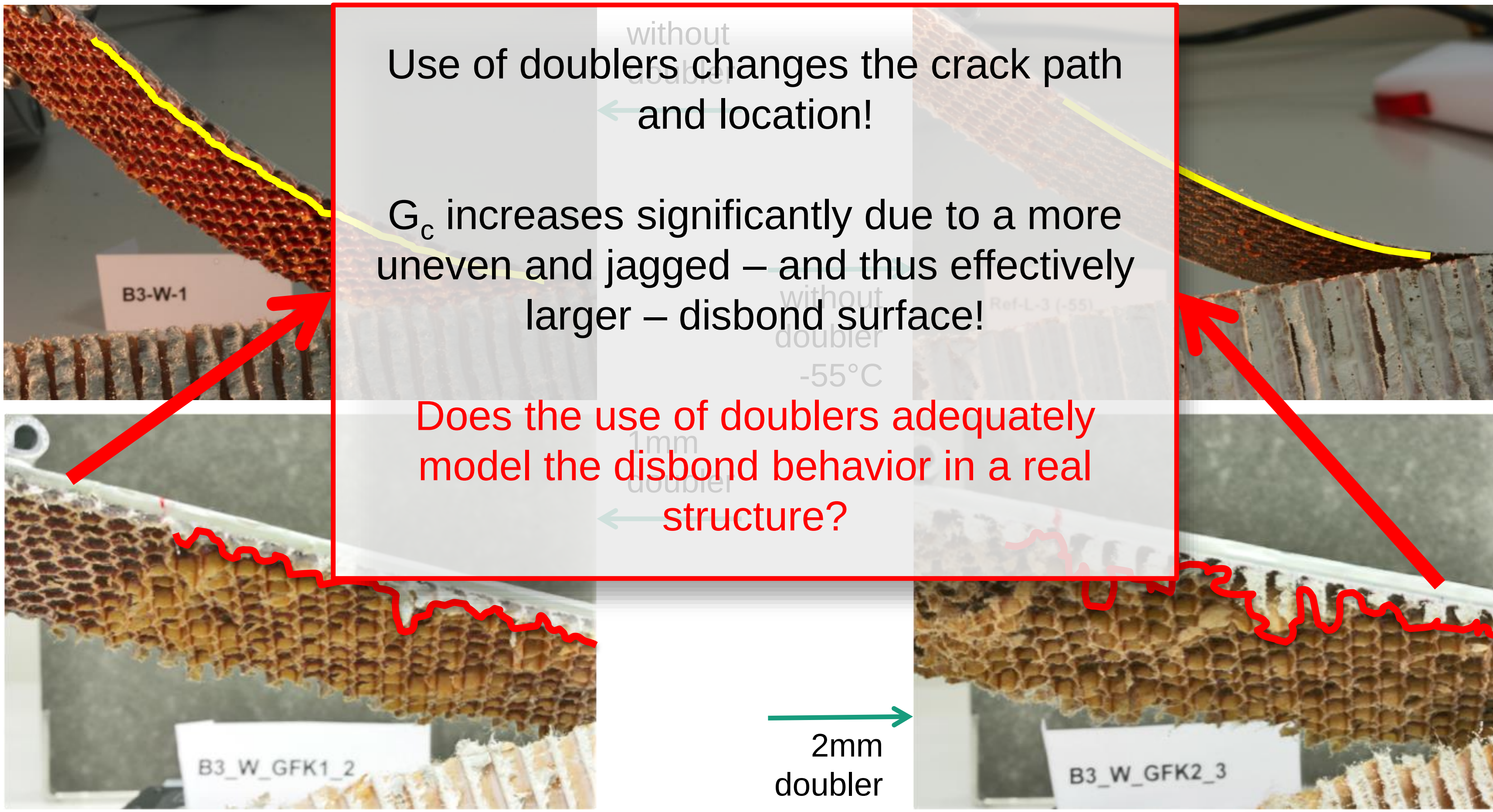
Specifics of Honeycomb Sandwich with thin Face Sheets

Representative fracture surface

... out of some hundred tests under varied conditions on different materials.



Use of doublers changes the crack path and location!

G_c increases significantly due to a more uneven and jagged – and thus effectively larger – disbond surface!

Does the use of doublers adequately model the disbond behavior in a real structure?

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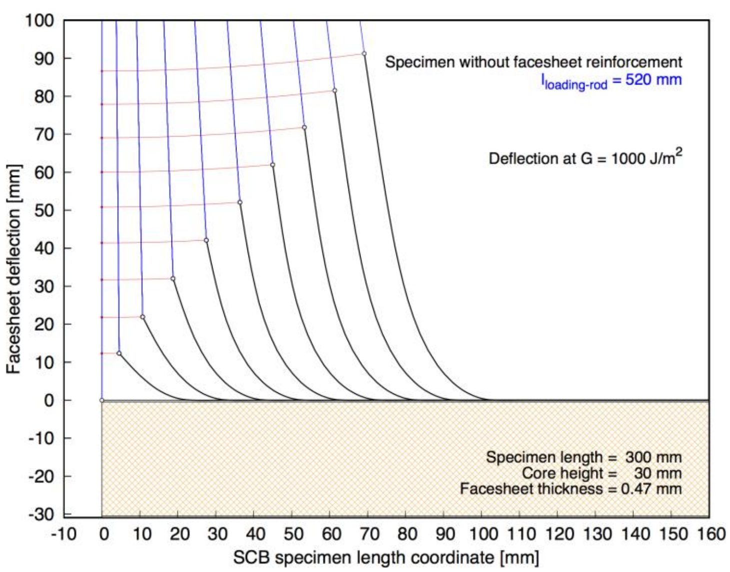
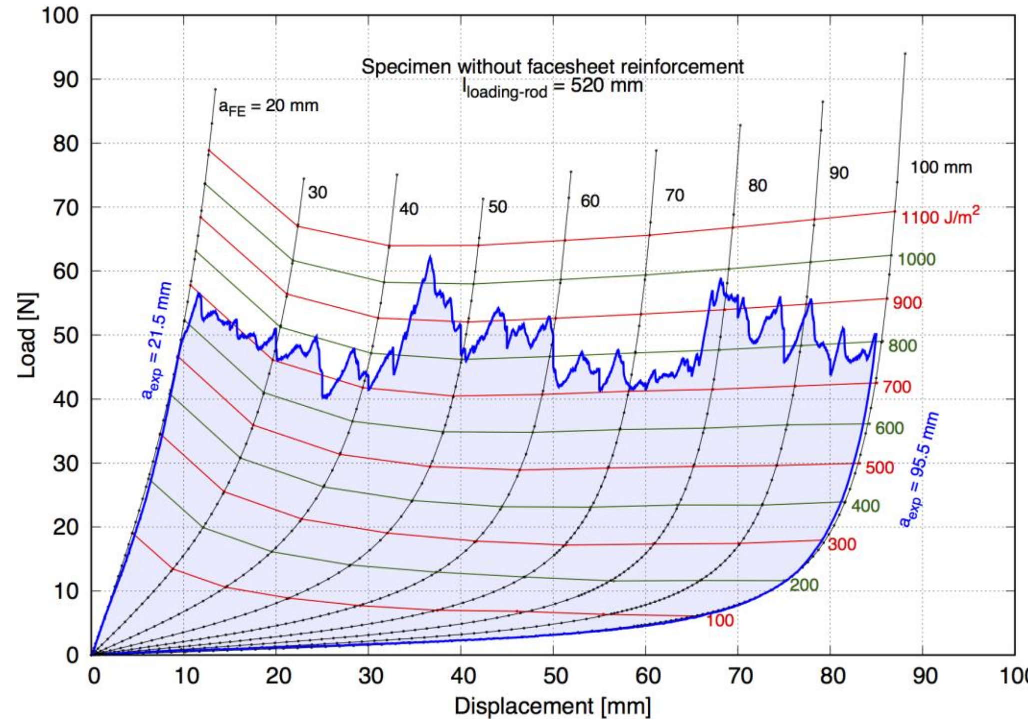
Honeycomb Sandwich SCB Test

Structural and Fracture Mechanics Analysis – Fixed Table

Objectives:
- Basic understanding the essential effects of test conditions
- Optimal test definition
- Determination of fracture modes
- Adaption of data reduction procedure
- etc.

Example:
Honeycomb Sandwich with thin face sheet:
Loading rod length and crack propagation extent affecting G and fracture modes





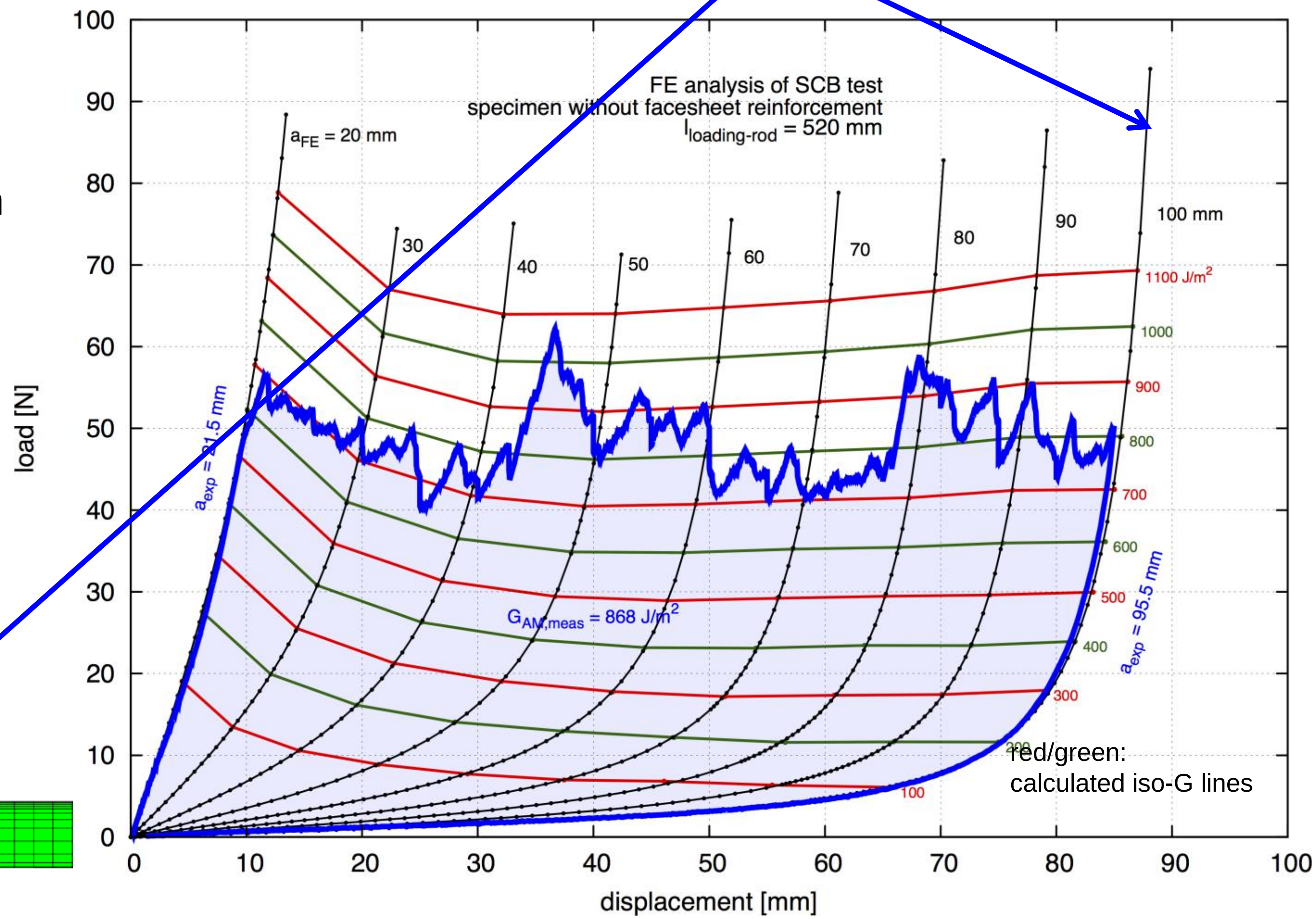
SCB Test Analysis

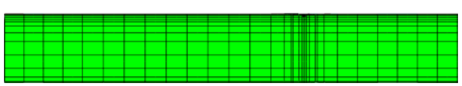
Fixed specimen

(without doubler)

Load-displacement curve of the load application point for a = 100 mm

Experimental and simulated load/displacement curve of a specimen with 0.47 mm thick CFRP facesheet, Aramid paper honeycomb, cell size of 4.8 mm (diameter) and a density of 32 kg/m^2.





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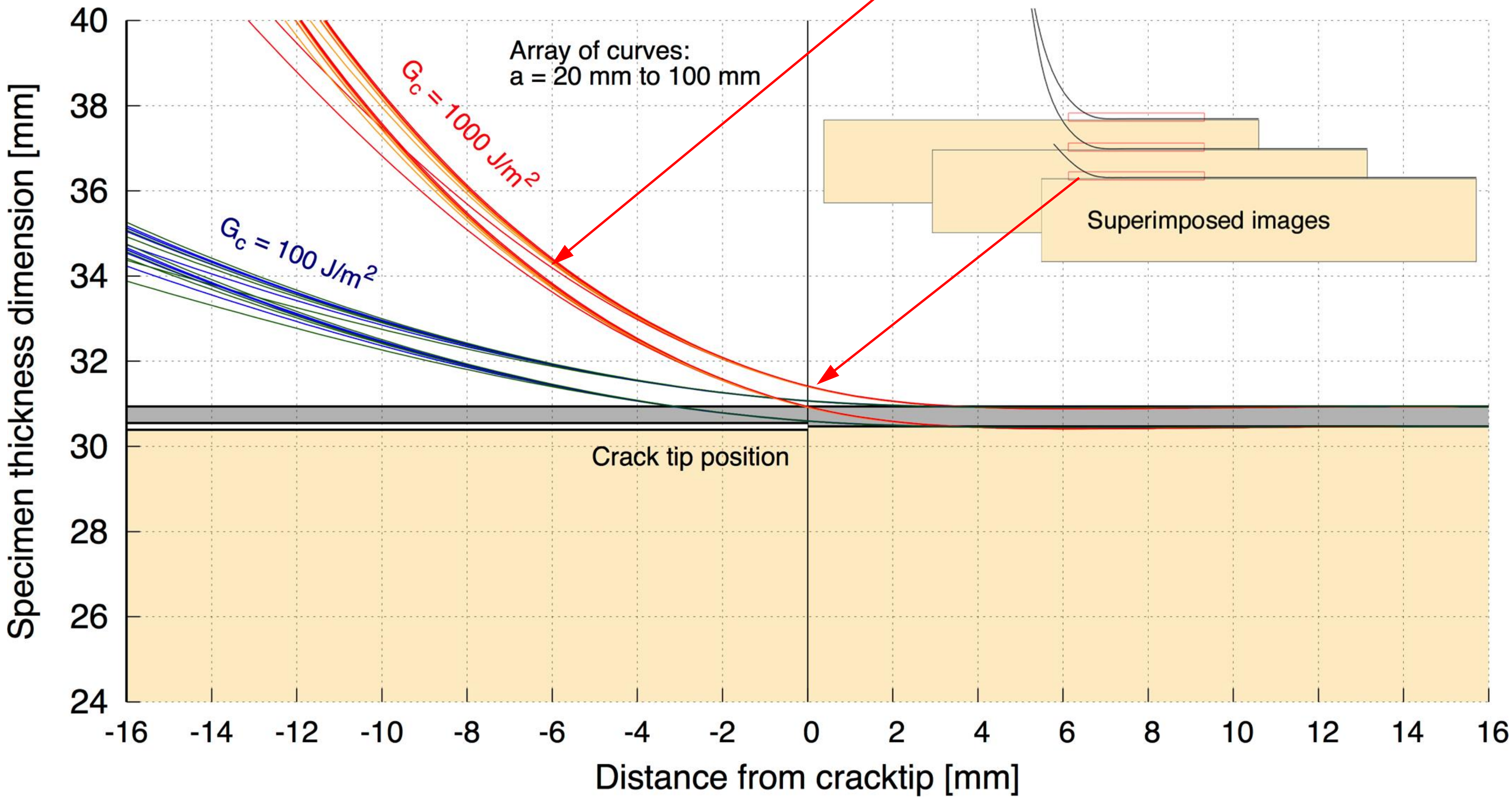
SCB Test Analysis

Fixed specimen

(without doubler)

set of superimposed facesheet upper edge shapes
(crack length a = 20, 30, ... , 90, 100 mm)



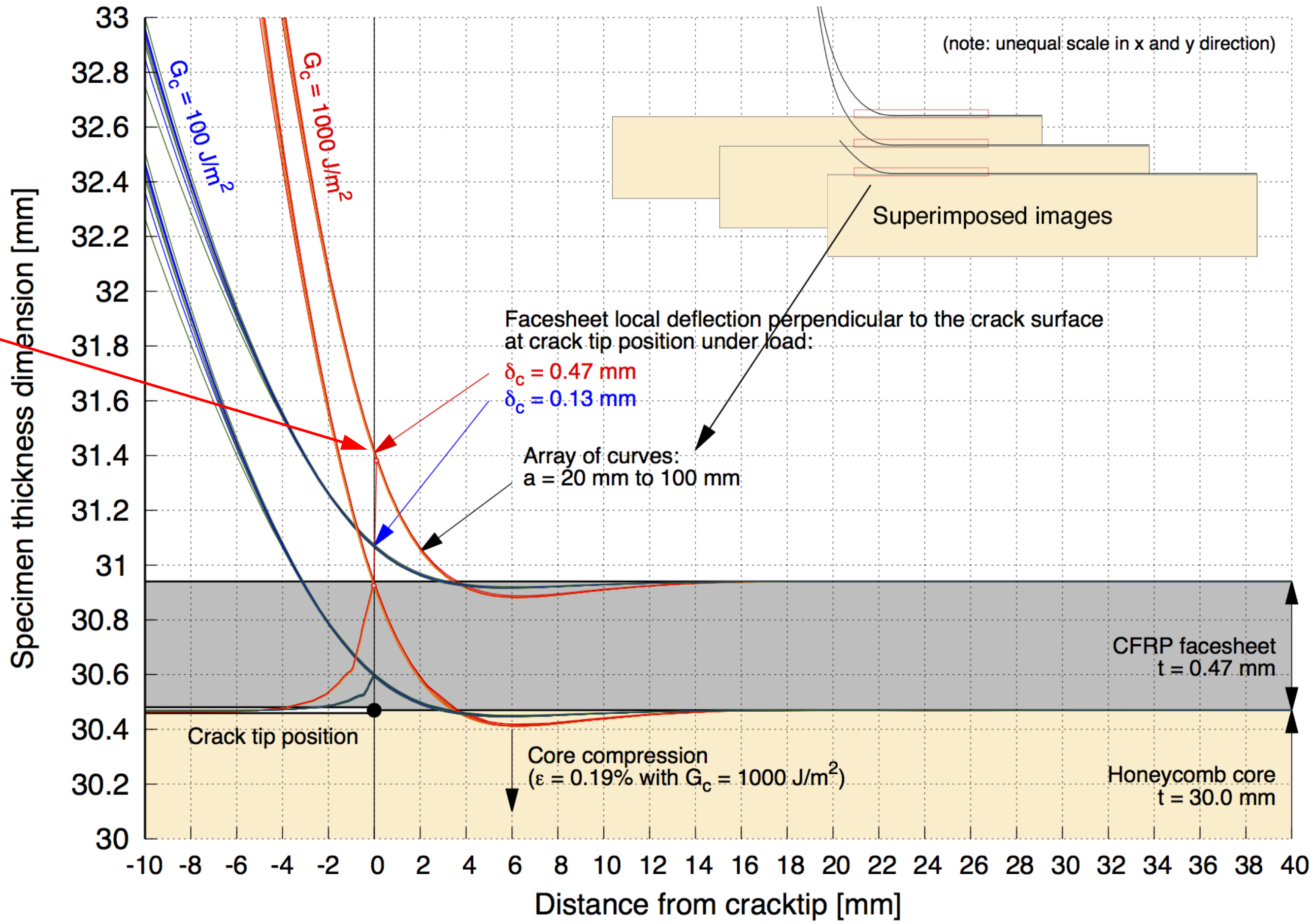
SCB Test Analysis

Fixed specimen

(without doubler)

set of superimposed facesheet upper edge shapes
(a = 20, 30, ... , 90, 100 mm)

- Edge deformation shapes for different crack lengths coincides well
- Vertical displacement of the upper facesheet edge above the crack tip is constant for all crack lengths, thus can be used for automatic cracktip recognition ...
- Slightly varying deformation in the vicinity of the tip in the case of shorter cracks ...



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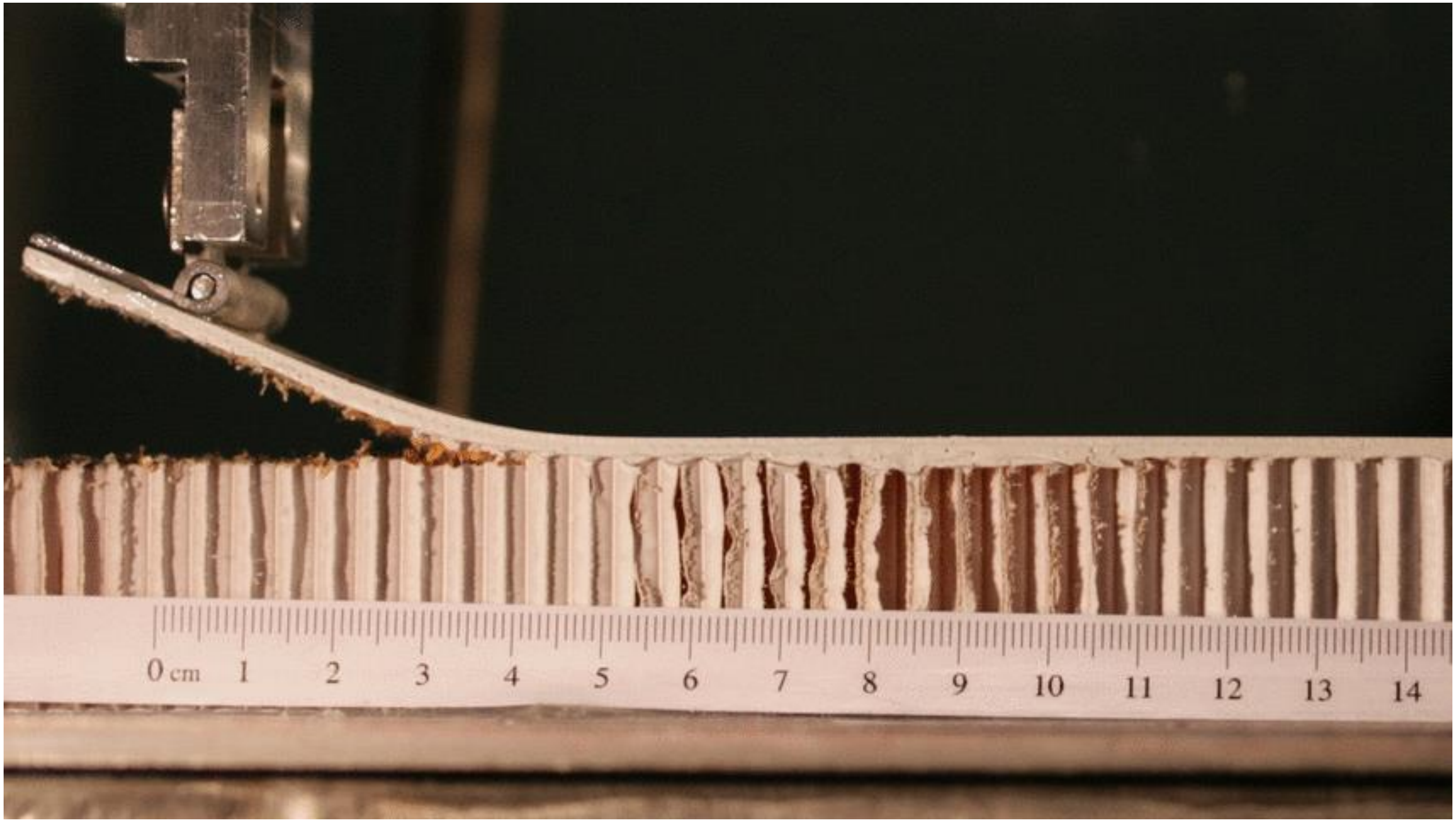
Honeycomb sandwich SCB test
Core compression in front of the crack ...



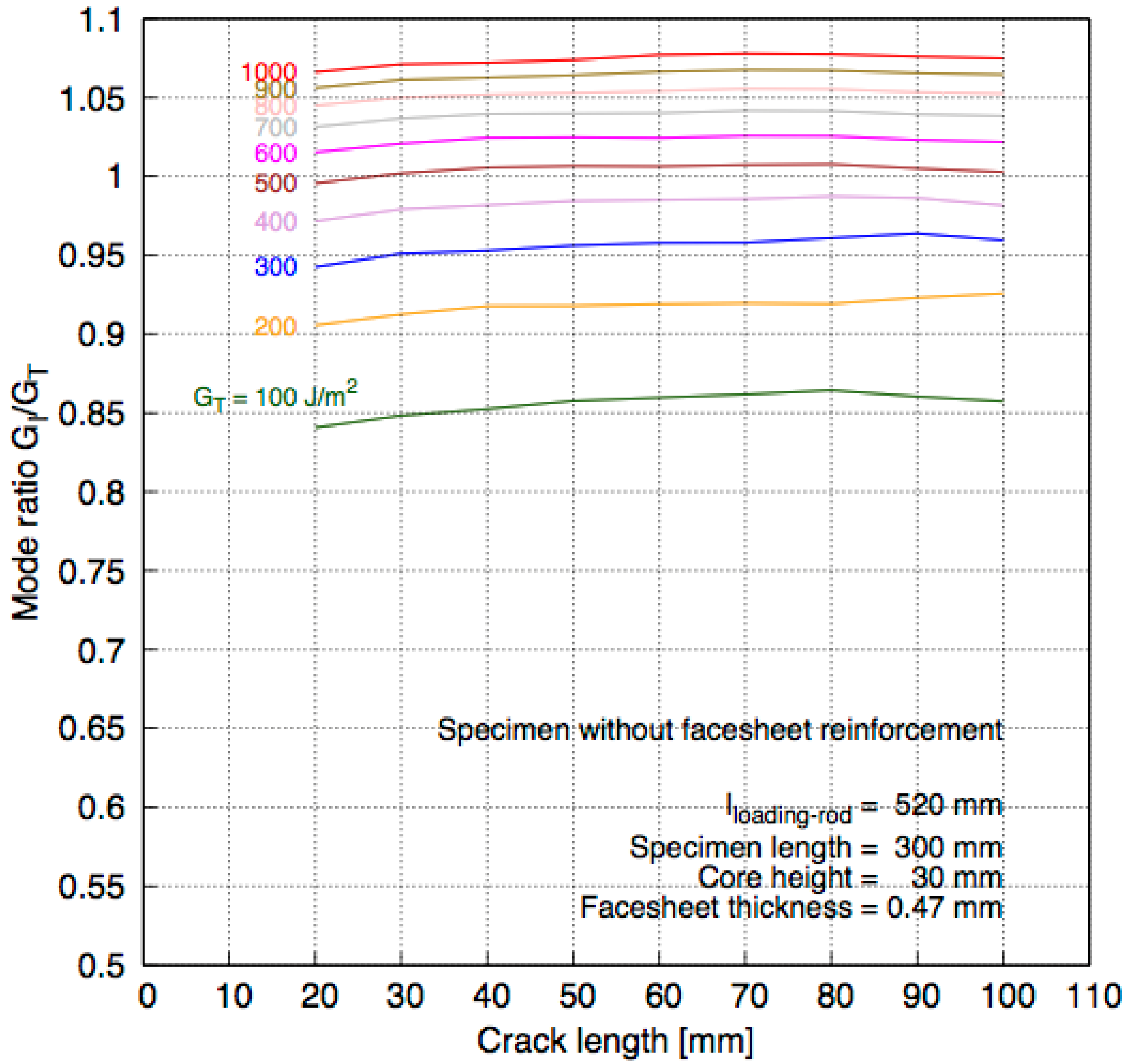
SCB Test Analysis

Fixed specimen

(without doubler)

VCCT results, mode mixity:

- Facesheet deflection with G_c=1000 J/m^2
- Mode ratio (G_I/G_{II}) slightly changes with crack growth, but becomes more constant for larger cracks
- Mode I predominance at higher G_c



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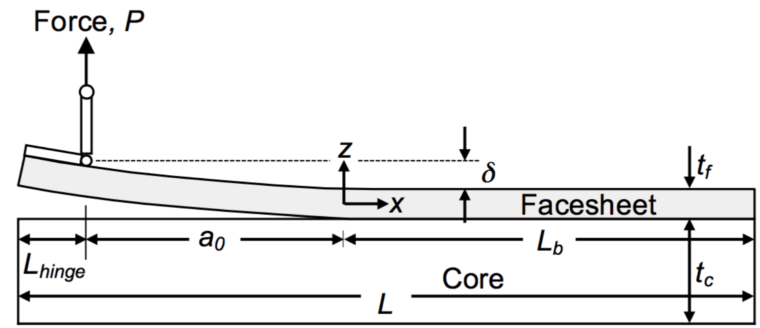
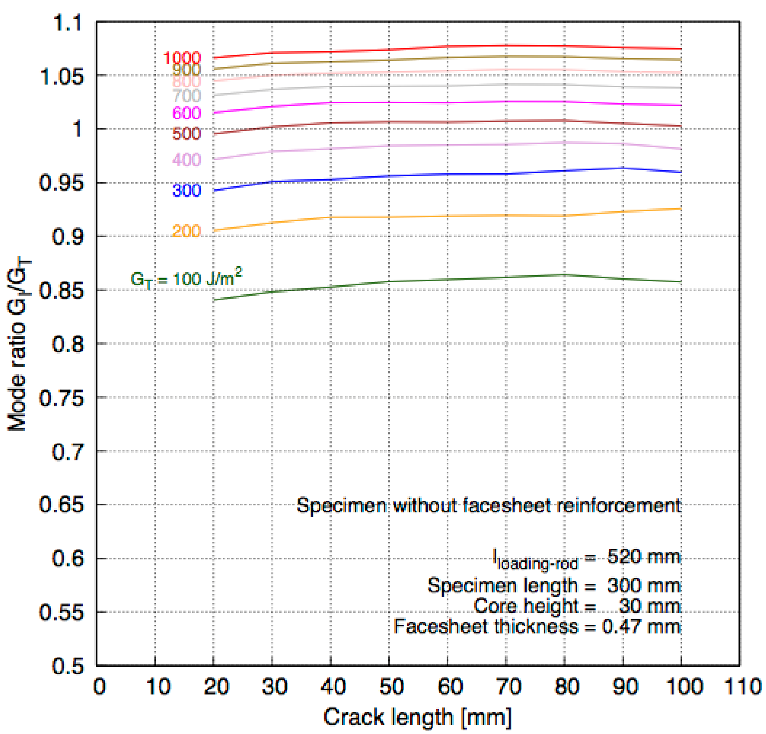
SCB Test Analysis

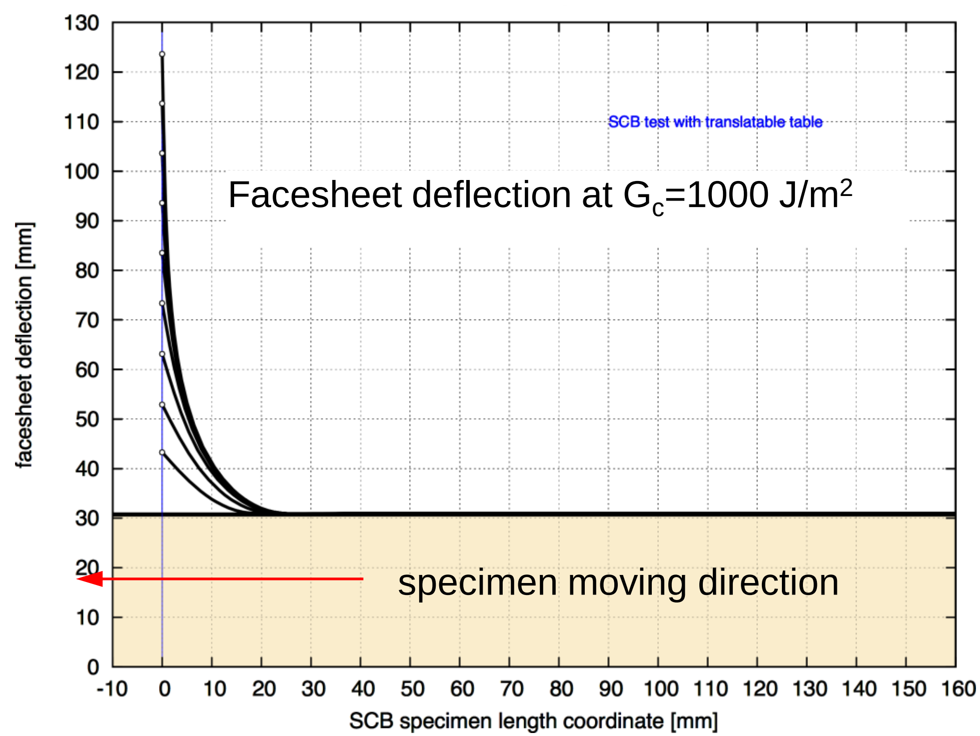
Translatable table

(without doubler)

results in same crack tip load as with fixed table with loading rod of proper length ... but is not as robust as the fixed specimen test jig!







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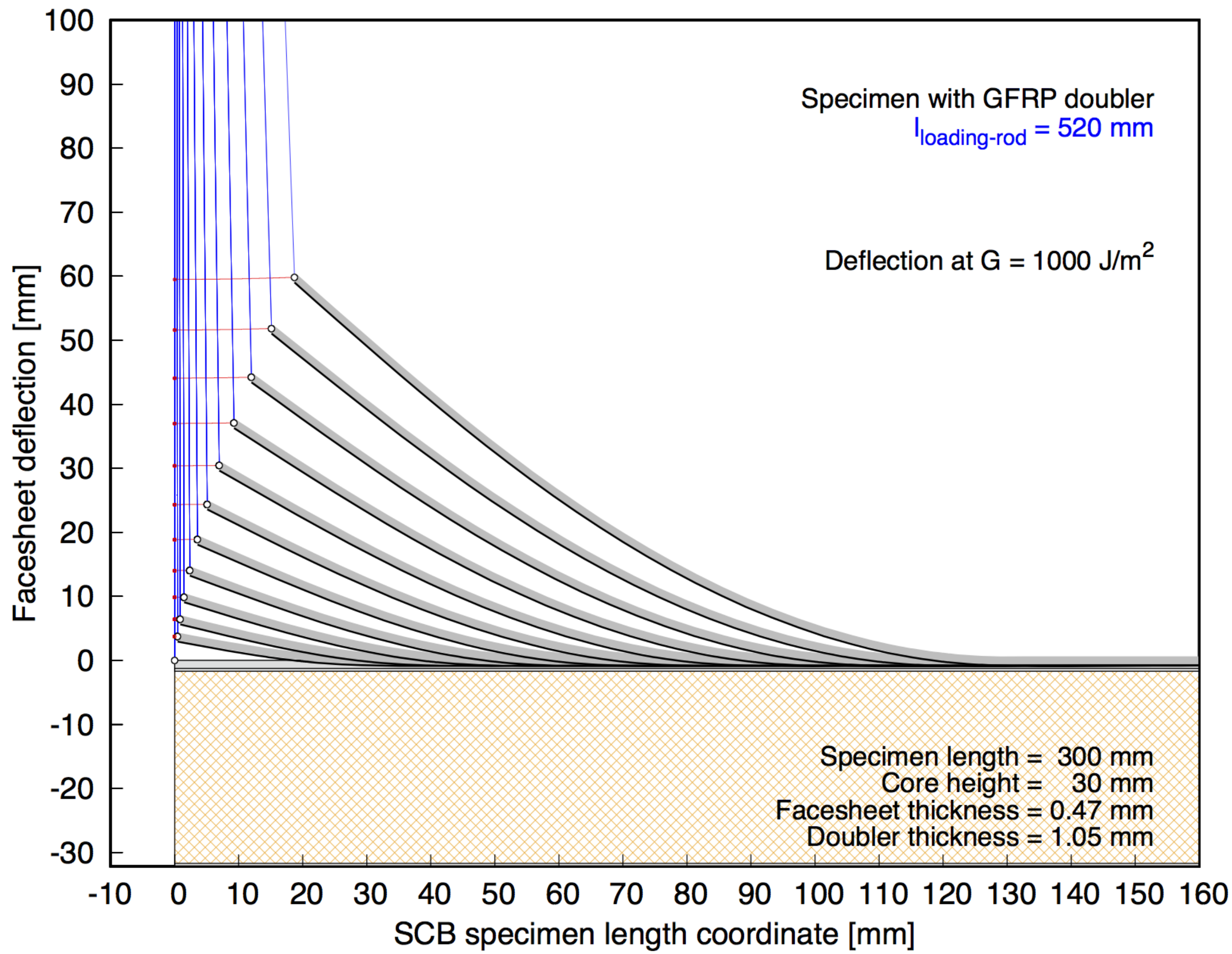
SCB Test Analysis

Fixed specimen with doubler

Face sheet doubler reduces the deflections and rotations



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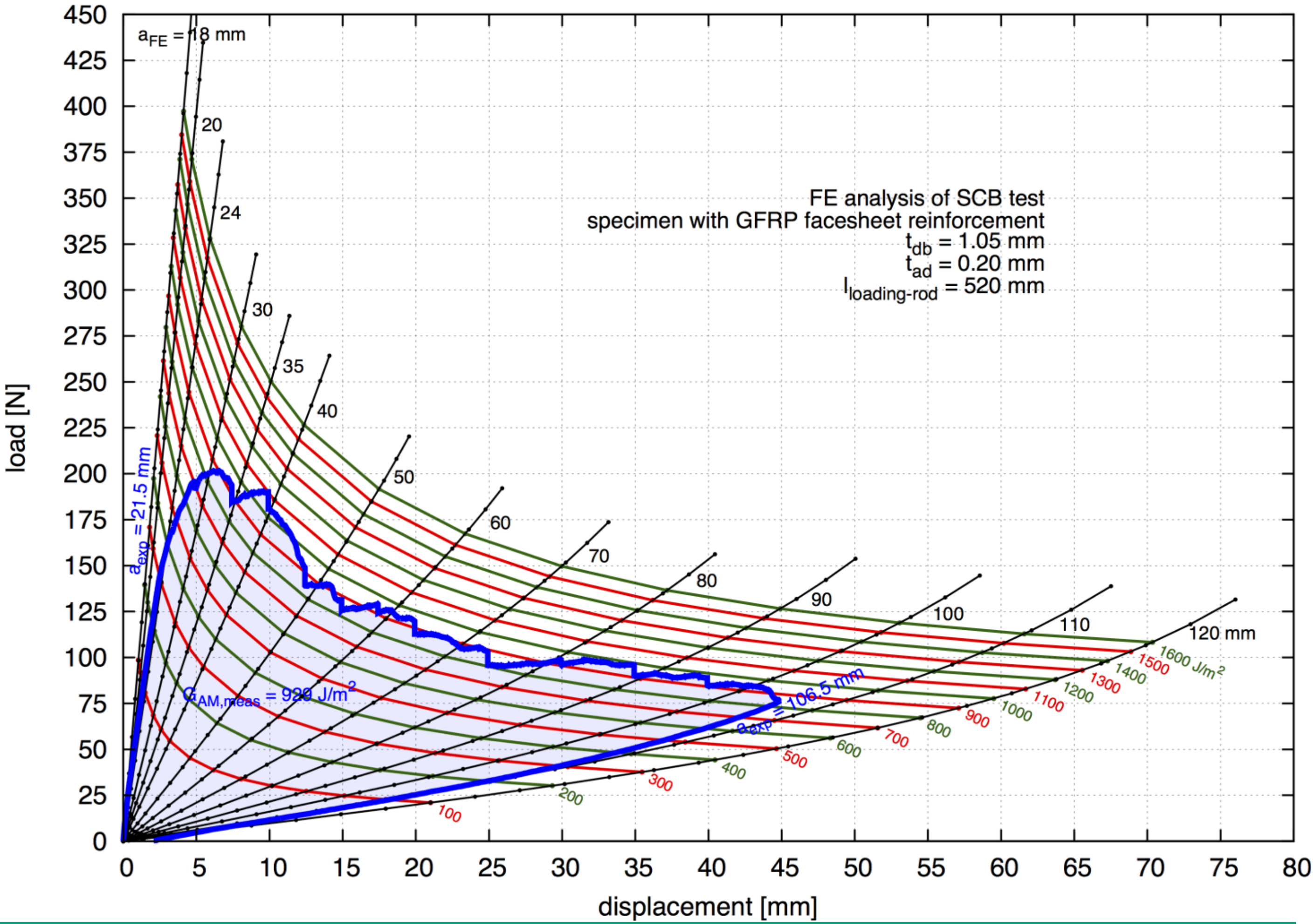
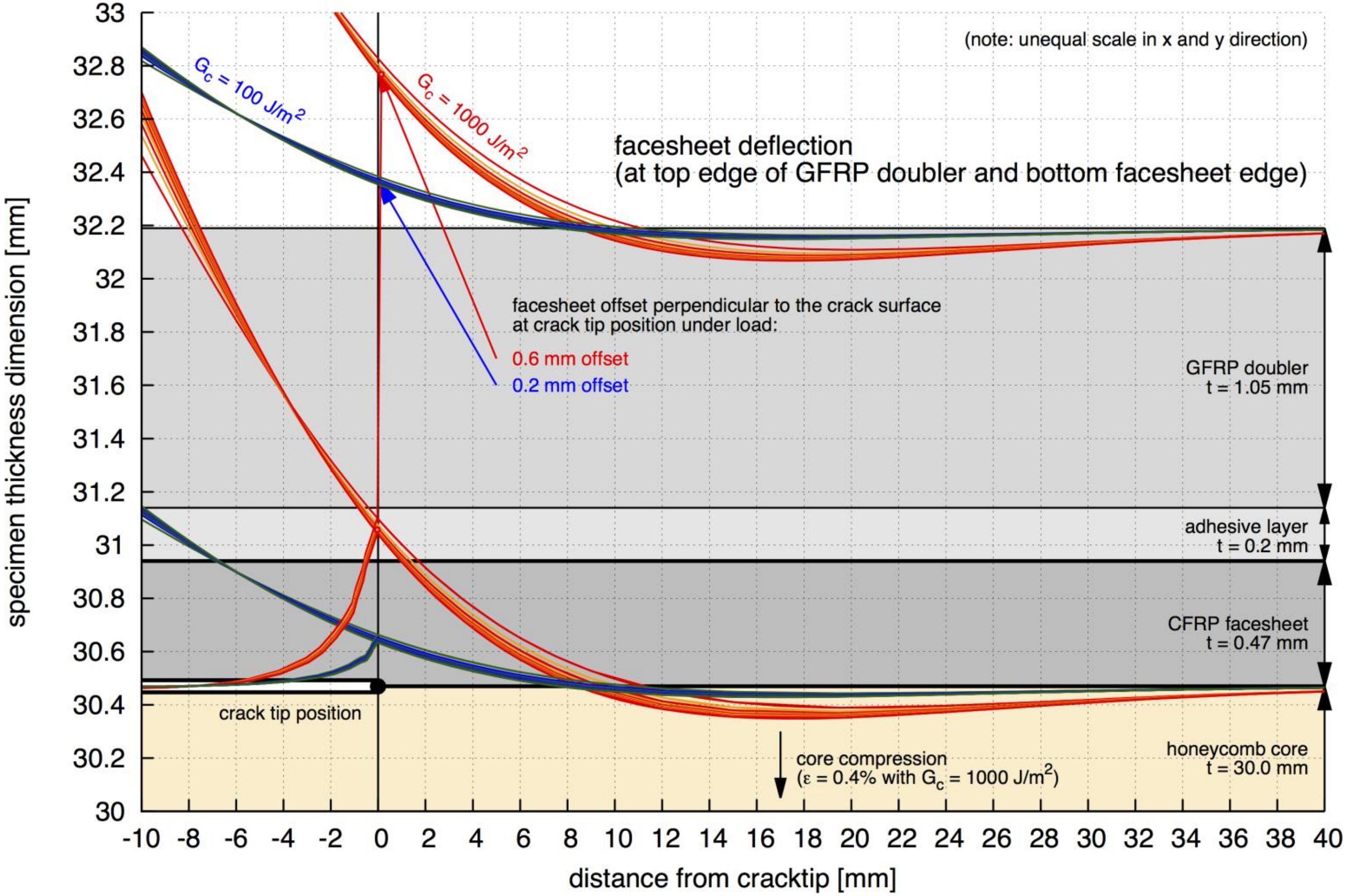
SCB Test Analysis
Fixed specimen with doubler

Experimental and simulated load/displacement curve of a specimen with 0.47 mm thick CFRP facesheet, reinforced by a 1.05 mm thick GFRP plate, Aramid paper honeycomb, cell size of 4.8 mm (diameter) and a density of 32 kg/m².



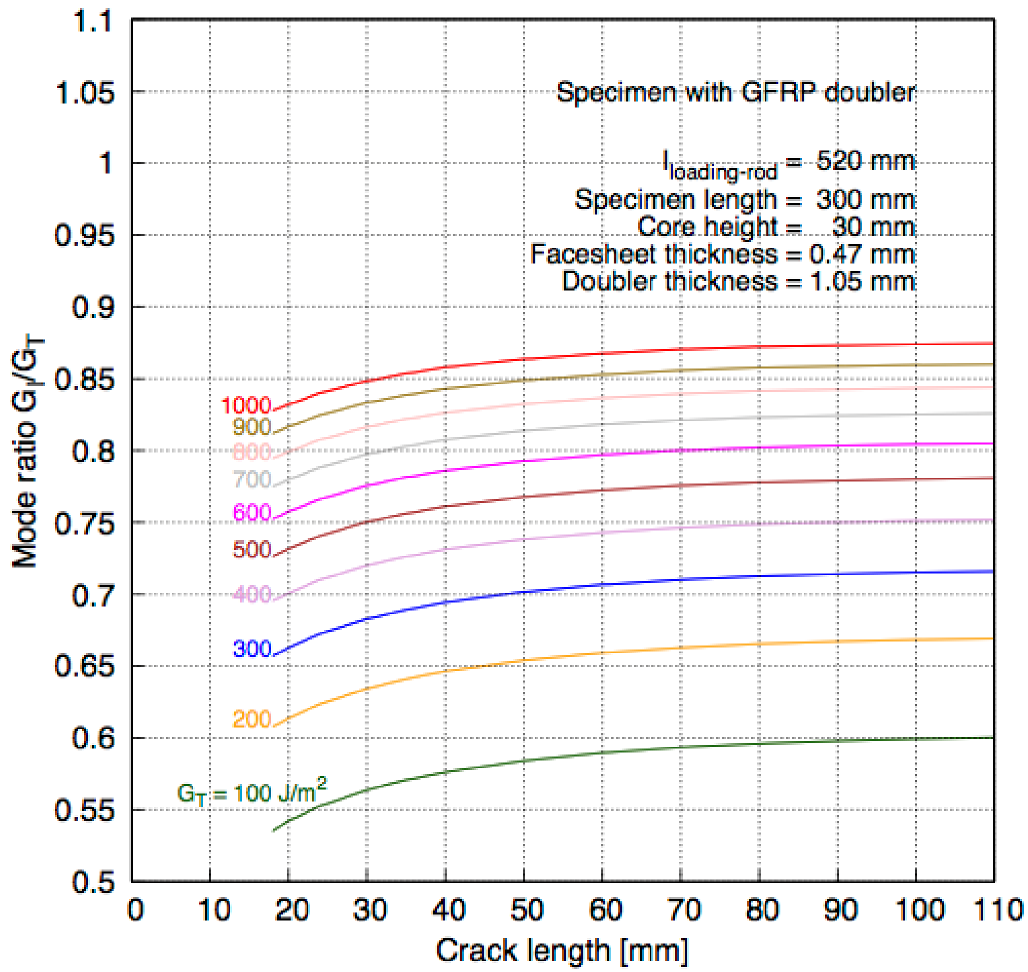
SCB Test Analysis
Fixed specimen with doubler



SCB Test Analysis
Fixed specimen with doubler

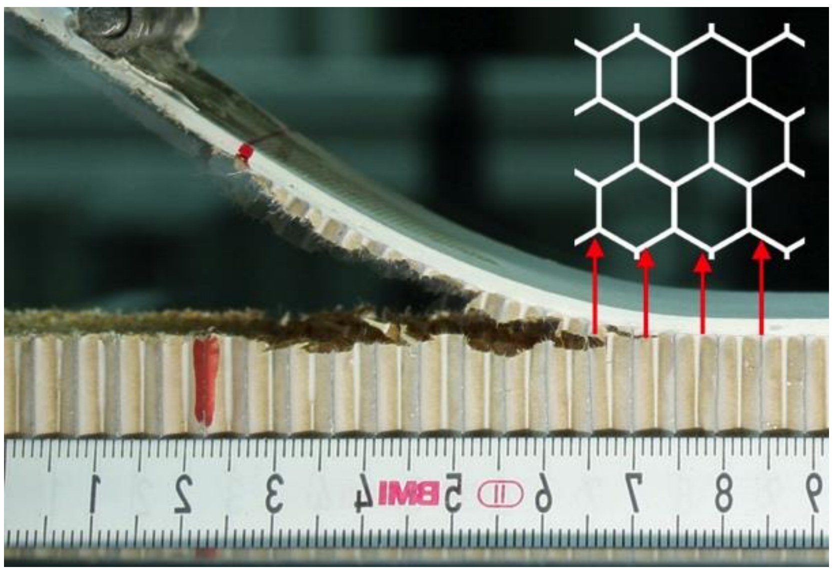
VCCT results:

- Mode ratio (G_I/G_T) slightly changes with crack growth, but becomes more constant for larger cracks
- Significant Mode I predominance only for larger cracks
- Mode II portion causes the crack path to switch towards the pure core region

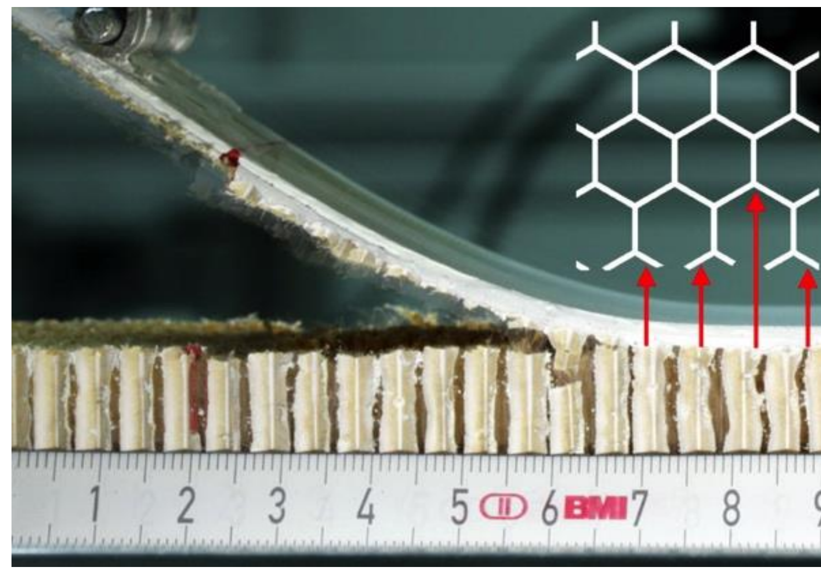


Honeycomb Sandwich SCB Test Development
Crack Length Observation

Reading errors are in the range of about one cell diameter!



Clear view to load carrying cell walls



View is shielded by cell wall remainders

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Honeycomb Sandwich SCB Test Development

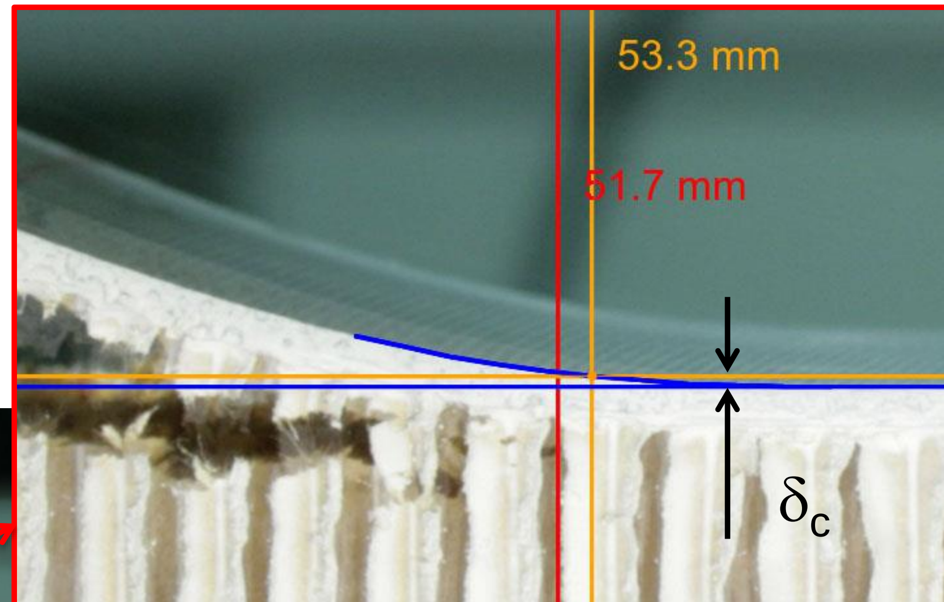
Automated Crack Length Measurement

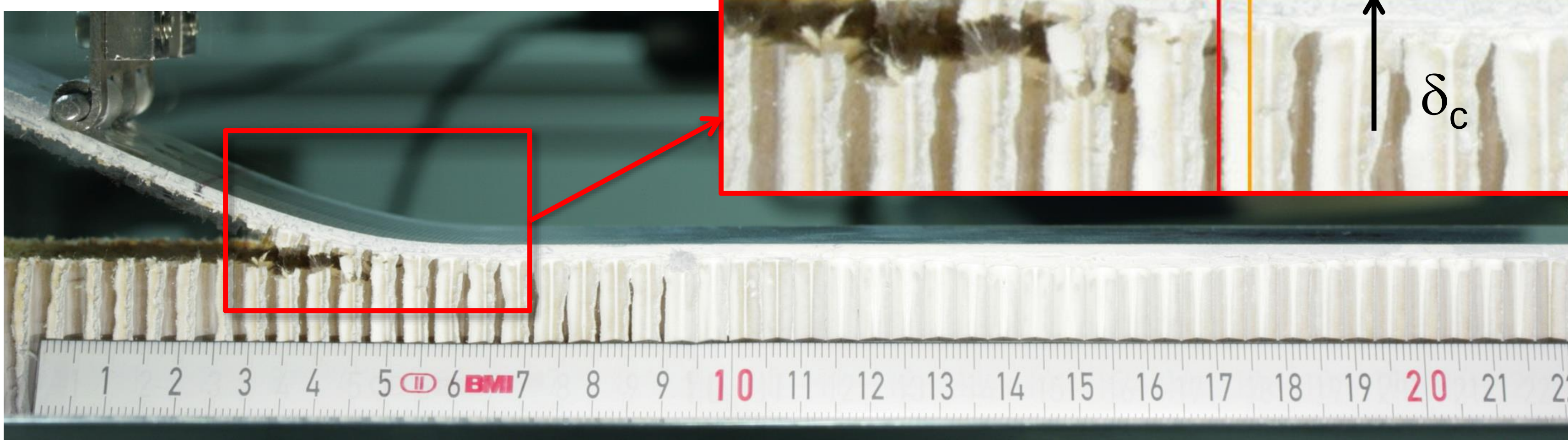
- ➔ reduces measuring inaccuracy
- ➔ massive time saving when analysing large data sets

Principle of crack tip recognition:

- ➢ automated edge detection of the deformed face sheet
- ➢ real crack tip location is supposed to be aligned with a constant face sheet deflection δ_c above the crack tip
- ➢ δ_c is material dependent

Underestimation of crack length by visual inspection due to hidden crack tip





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SCB Honeycomb Sandwich
X-Ray CT-Scan

SCB specimen scanned by means of X-ray CT after test – face sheet slightly deflected

The crack lengths determined at the outer side slices (CT) and observed by visual inspektion are matching

The actual crack front at the center region runs about 11mm ahead

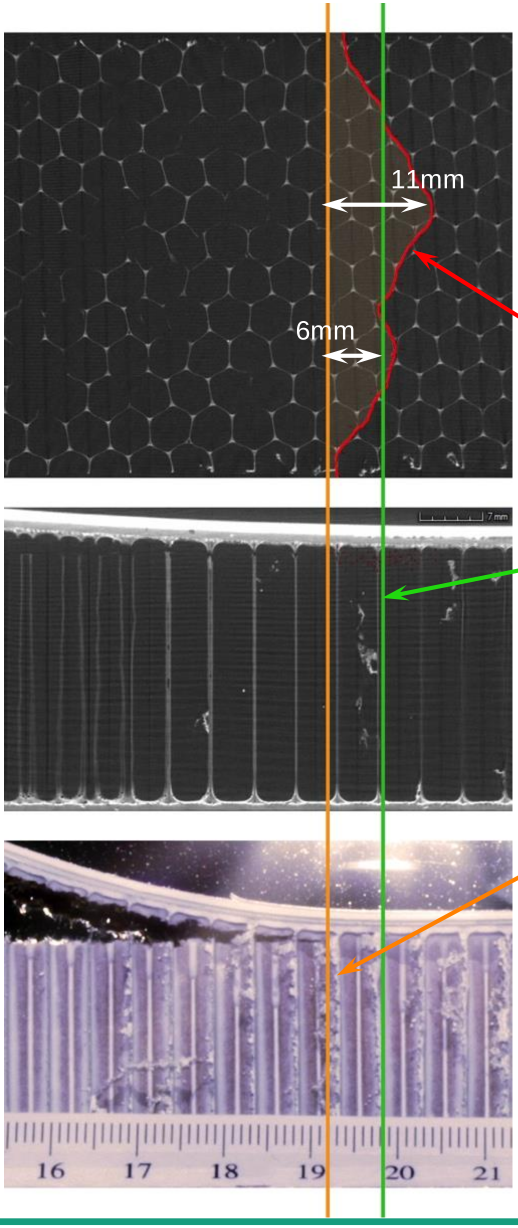
Possible solution for analysis of G_{IC}: adjust crack length as a straight line in such a way that it represents the total fracture surface

(here: ca. 6mm to add)

CT-scan top view

CT-scan side view

camera image side surface



red line:
actual crack front along the CT –scan marks

green line:
effective crack length adjusted by corresponding fracture surface

orange line:
crack length by visible observation

Summary, Concluding remarks

- The use of (well defined) doublers can limit the face sheet deflection and rotation to an appropriate extent. This way, linear theory based data reduction is applicable and the SCB test will act like a „familiar fracture mechanics test“ even in the case of originally very thin face sheet.
  - On the other hand the artificial stiffening of the cantilever beam causes a change in mode mixity, an enlargement of the „process zone“ and thus a change of the crack path and crack surface. This yields higher G_C!
- By using the Areas Method in data reduction, also excessively deflected and rotated thin face sheets can be handled properly. The G_c results seem to be more representative for a real structure and more conservative.
  - On the other hand the Area Method overestimates the G_C in principle, as any other portion of dissipated energy that may appear is counted to contribute in crack extension only.
- The initial crack length should not be too small to guarantee constant mode mixity and dominating fracture mode I.
- Crack length measurement could be done indirectly by identifying a predefined small displacement of the upper edge of the face sheet using optical camera images
- Not only the thickness of the facesheet is influencing the test conditions but also the absolute value of G_C of a given core/skin interface.

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Thank you for your attention!

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CMH-17 COMPOSITE MATERIALS HANDBOOK

Sandwich Disbond Growth Task Group