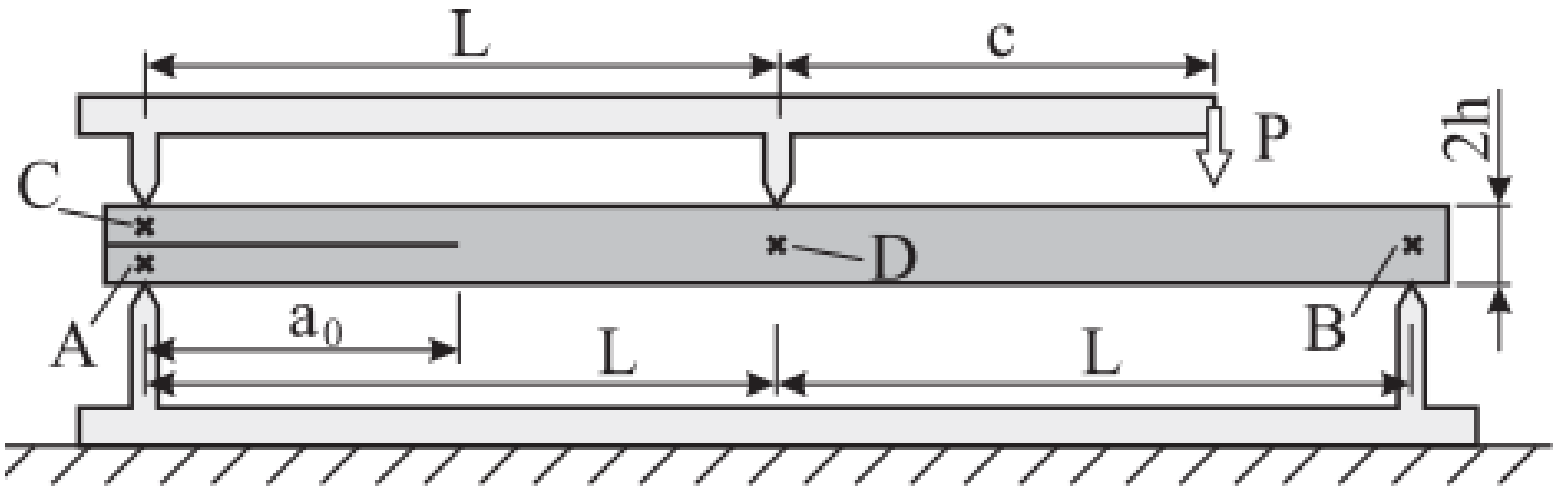
Mixed mode test setup design & in-situ durability test



- Edwin Meulman

- AMADE Day, Girona, 26th of January 2021

Source: Sarrado, et al. 2015

In-situ durability test

- Why in-situ durability testing for bonded joints?
  - Adhesives degrade over time due to environmental attack. To improve the durability and reliability of a structure containing bonded joints, the degradation properties of the bonded joints are required.

- What are the needs?
  - Knowing the crack growth rate in an adhesive, when a bonded joint is subjects to a certain energy release rate and harsh environment.

- What is the gap in literature?
  - A test method that applies a constant energy release rate to a bonded joint, providing the possibility to measure stable crack growth over time under influence of a harsh environment.

- Why are the existing test methods not optimal?

Mixed mode test setup

- Why testing a bonded joint in mixed mode?
  - If bonded joints in a structure is loaded in mixed mode, it is valuable to know what the properties are of that bonded joint loaded in mixed mode.

- What are the needs?
  - To be able to test a specimen in mixed mode over a wide range of mixed mode ratios, in which during the whole test, the mixed mode ratio and energy release rate remain constant.

- What is the gap in literature?
  - A relatively simple and accurate test method able to apply a constant energy release rate to a bonded joint for different mixed mode ratios.

- Why are the existing mixed mode test setups not optimal?

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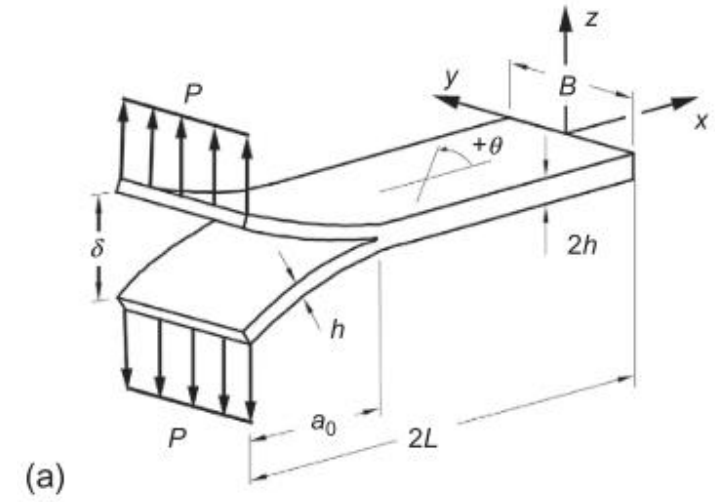
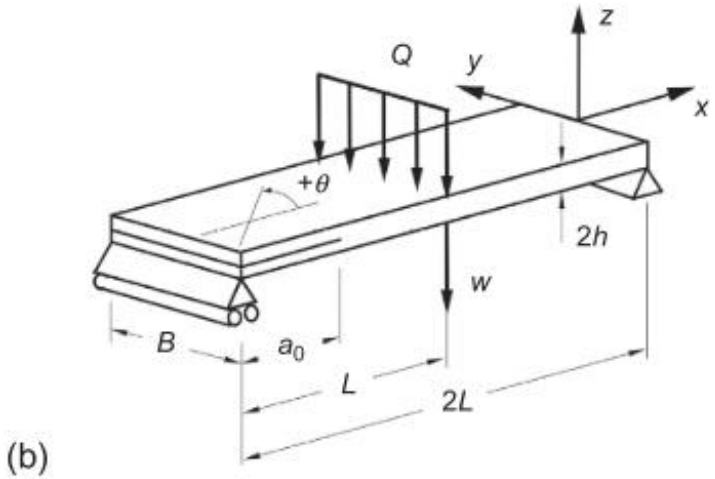
Mixed mode test setup

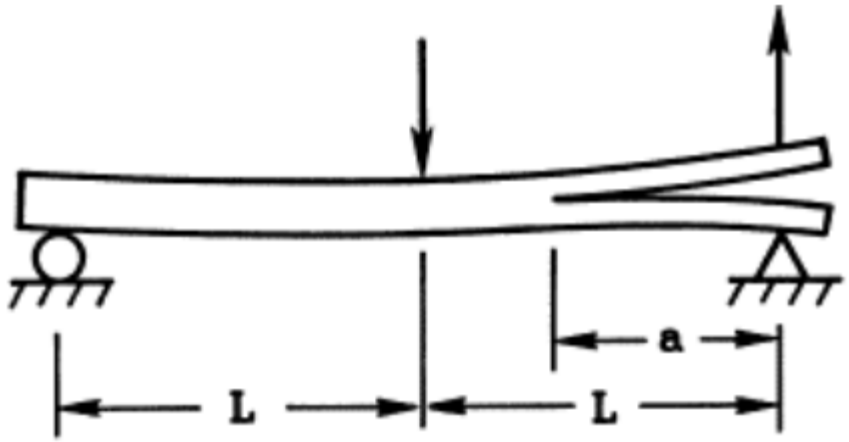




(Krueger, 2015)

DCB – mode I

ENF – mode II



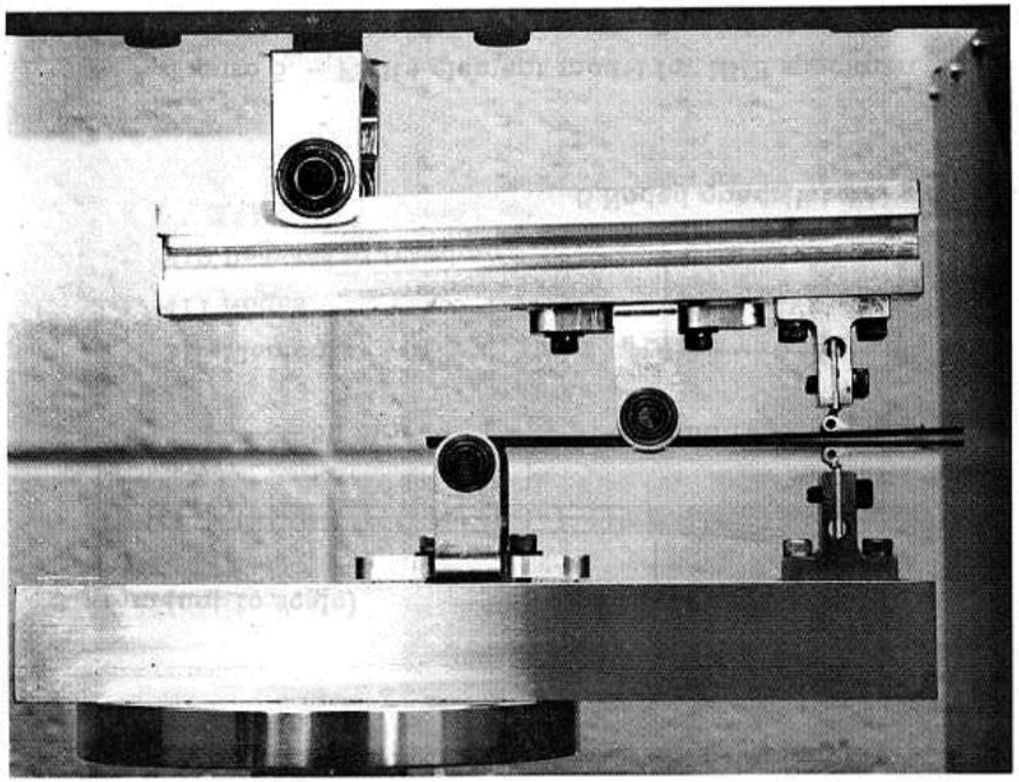
MMB – mixed mode

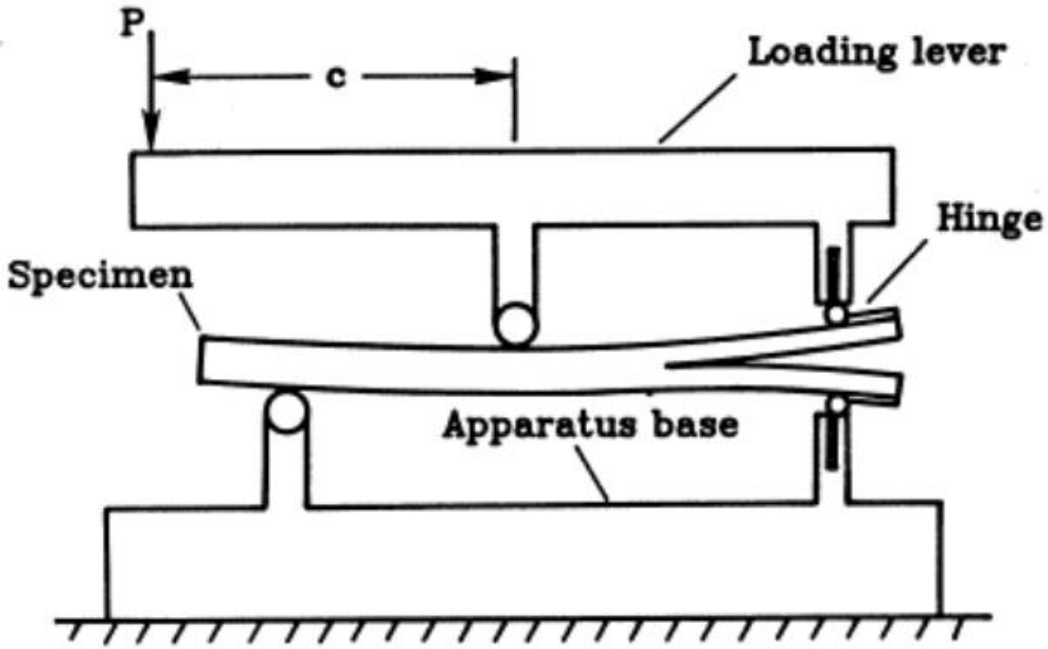
DCB = Double cantilever beam / ISO 25217
ENF = End-notched flexure / ASTM D7905
MMB = Mixed-mode bending / ASTM D6671

(Crews and Reeder, 1988)

Mixed mode test setup

The mixed-mode bending (MMB) test setup





(Crews and Reeder, 1988)

Mixed mode test setup

Comparison – main disadvantages

Test setups \ Disadvantage	Mode mixity at the crack tip is not constant	Limited range of mode mixity	Relatively large or complex test setup required	Not able to maintain a constant energy release rate

Mixed mode test setup

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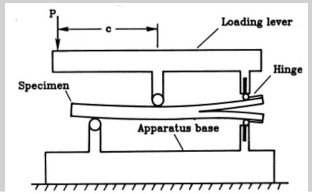
MMB 	X			X

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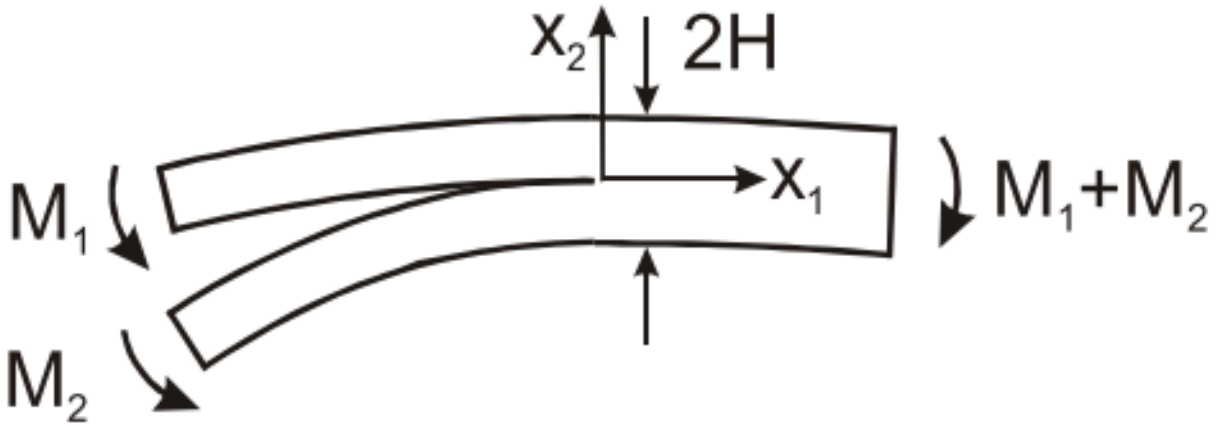
Mixed mode test setup

Uneven bending moments

Test setup with uneven bending moments

A DCB-specimen loaded with bending moments

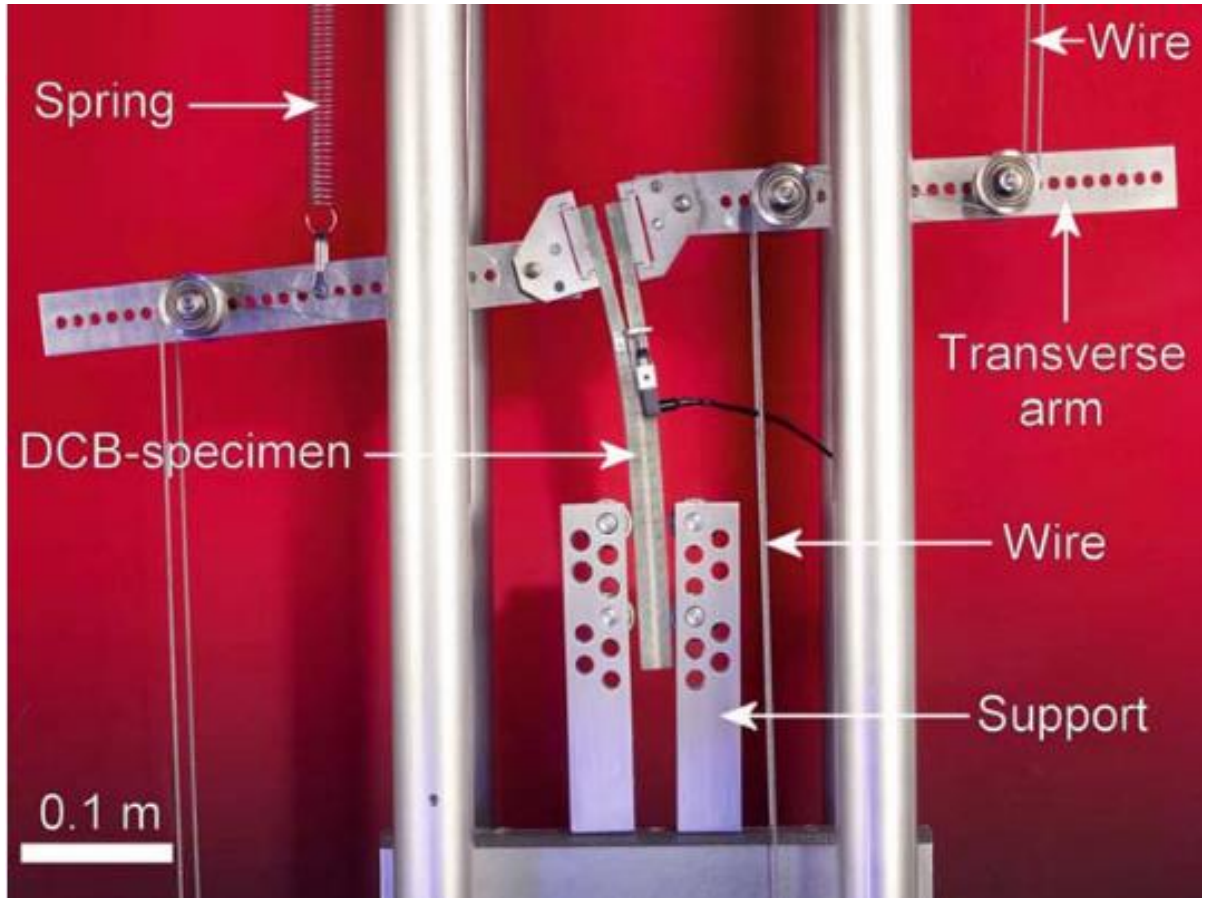


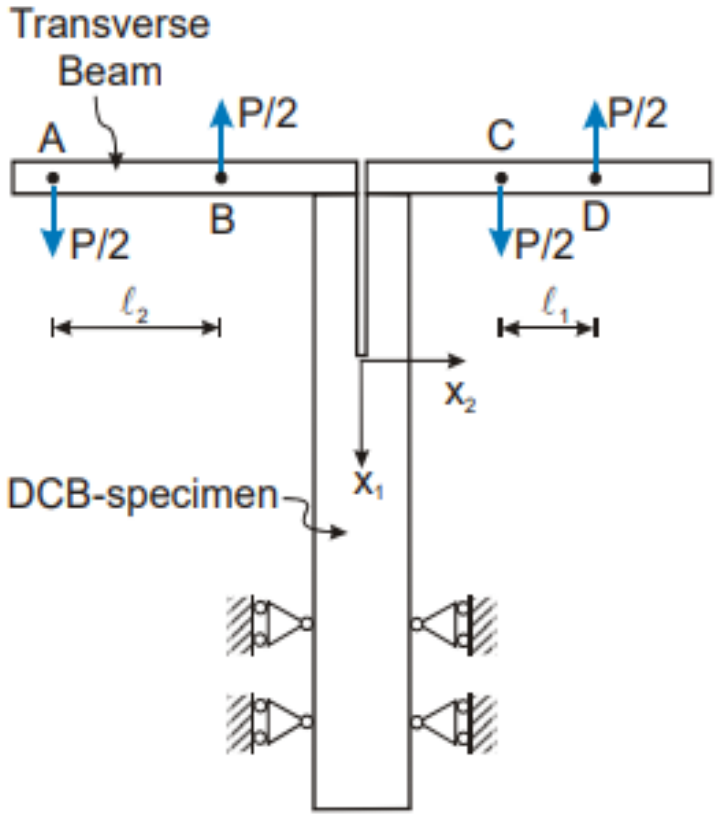
$$\downarrow M_1 \neq \downarrow M_2 \quad Mixed\ mode \quad (M_2 > M_1)$$

(Sørensen et al. 2006)

Test setup with uneven bending moments

Wire & Lever arm (W&L)

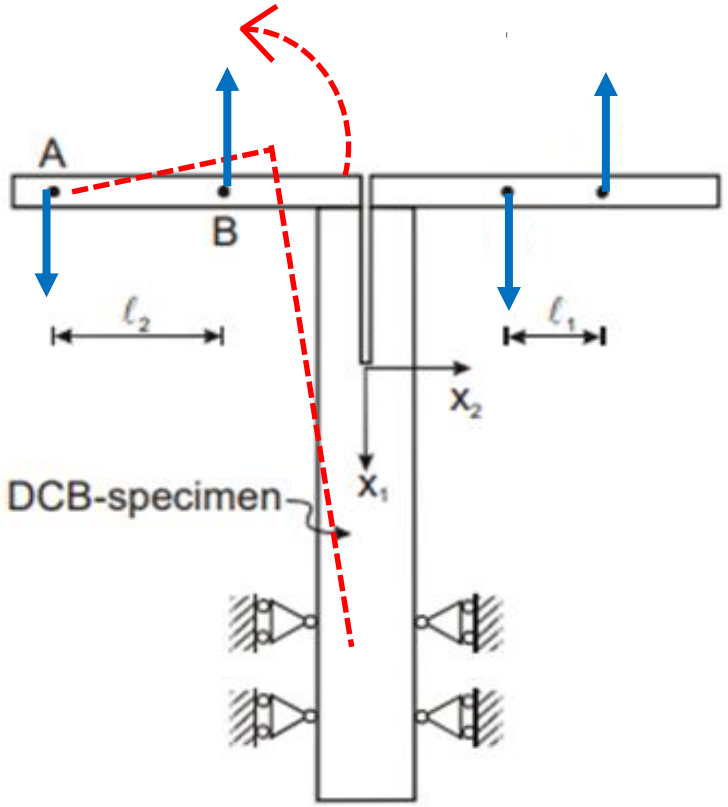


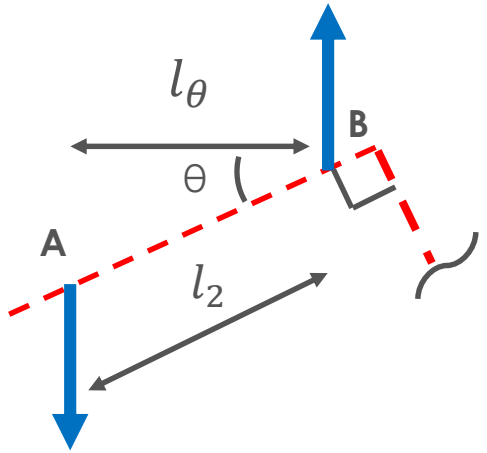


(Sørensen et al. 2006)

Test setup with uneven bending moments

Wire & Lever arm (W&L) – effect of lever arm rotation on applied moment

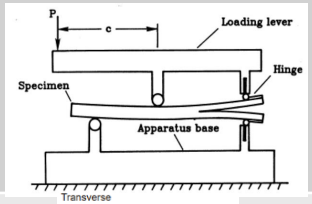
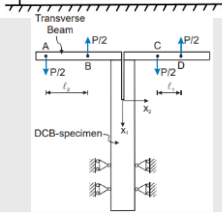




At an angle (θ) range from 0° to 15° rotation, the error in applied moment M increases up to about 3%. As a result the error in energy release rate goes up to about 7%.

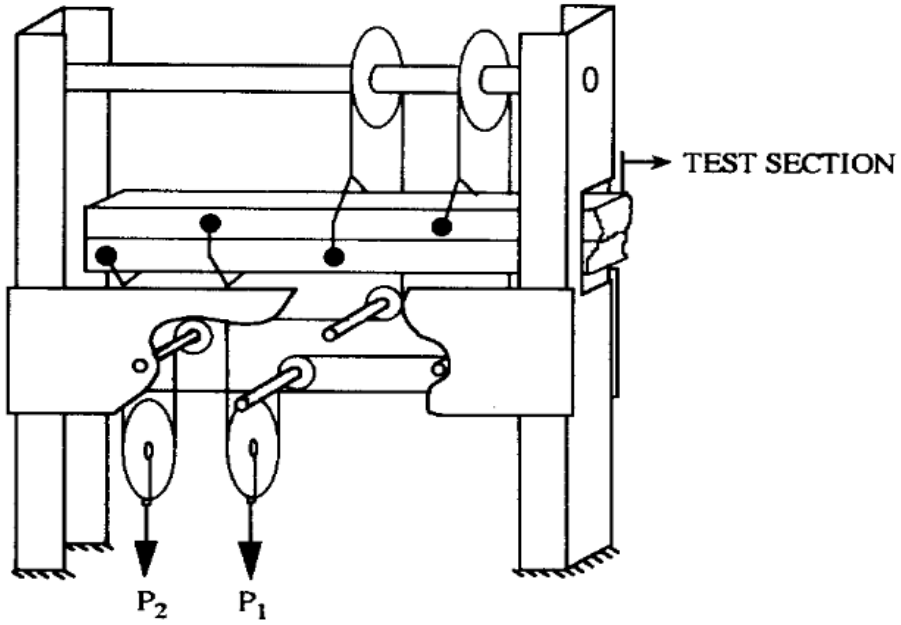
Mixed mode test setup

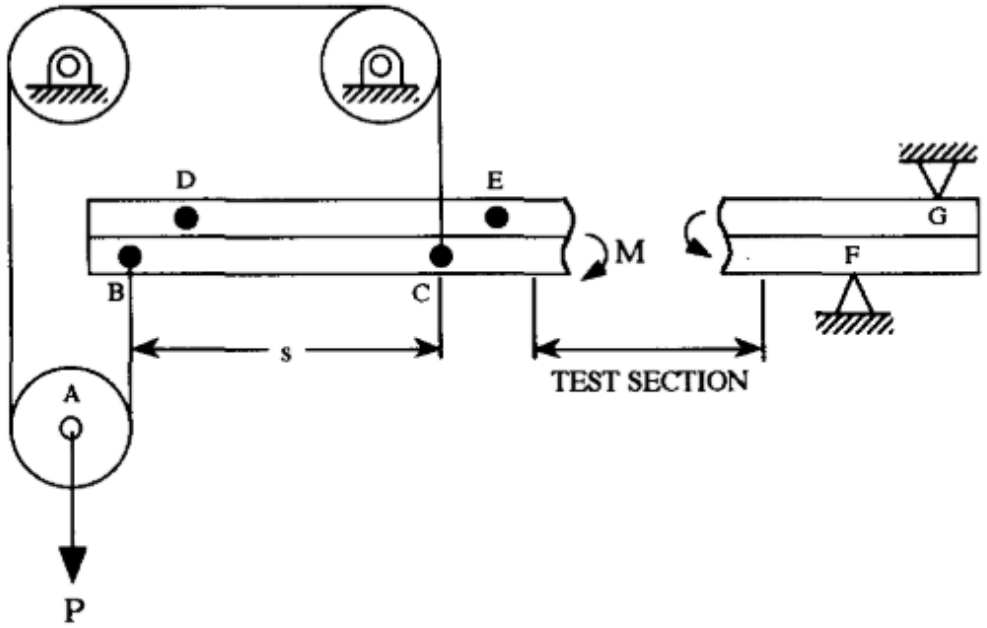
Comparison – main disadvantages

Disadvantage / Test setups	Mode mixity at the crack tip is not constant	Limited range of mode mixity	Relatively large or complex test setup required	Not able to maintain a constant energy release rate
MMB 	X			X
W&L 		X	X	X

Test setup with uneven bending moments

Wire & Weight (W&W)





(Plausinis et al. 1995)

Mixed mode test setup

Comparison – main disadvantages

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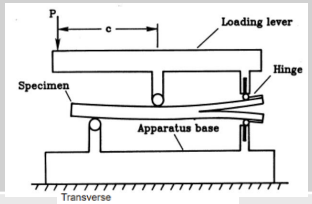
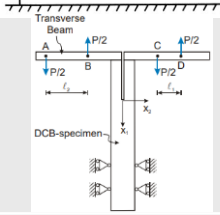
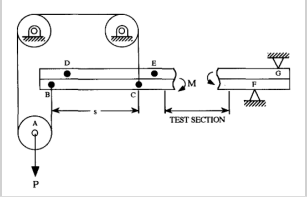
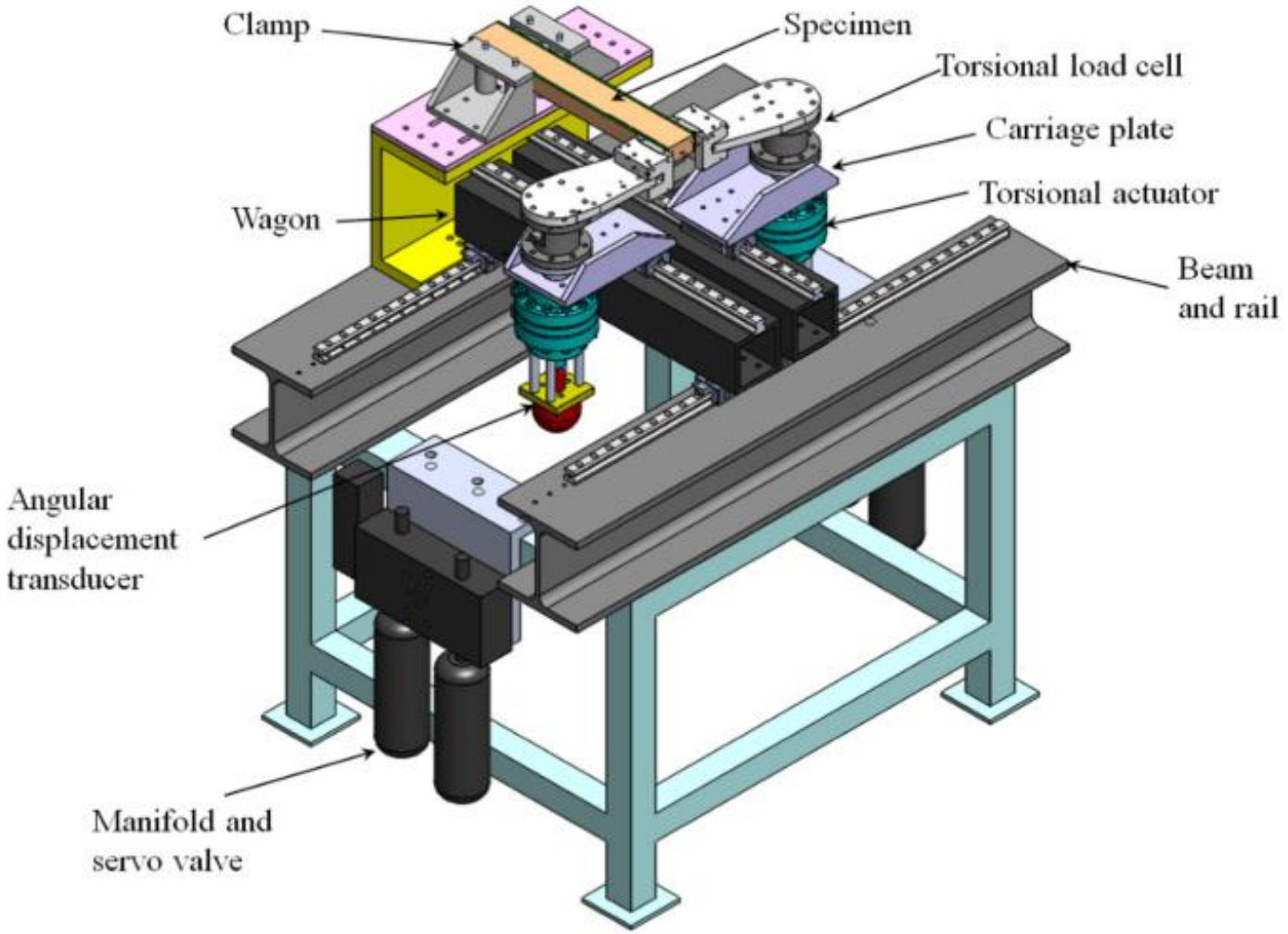
MMB 	X			X
W&L 		X	X	X
W&W 		X	X	X

Test setup with uneven bending moments

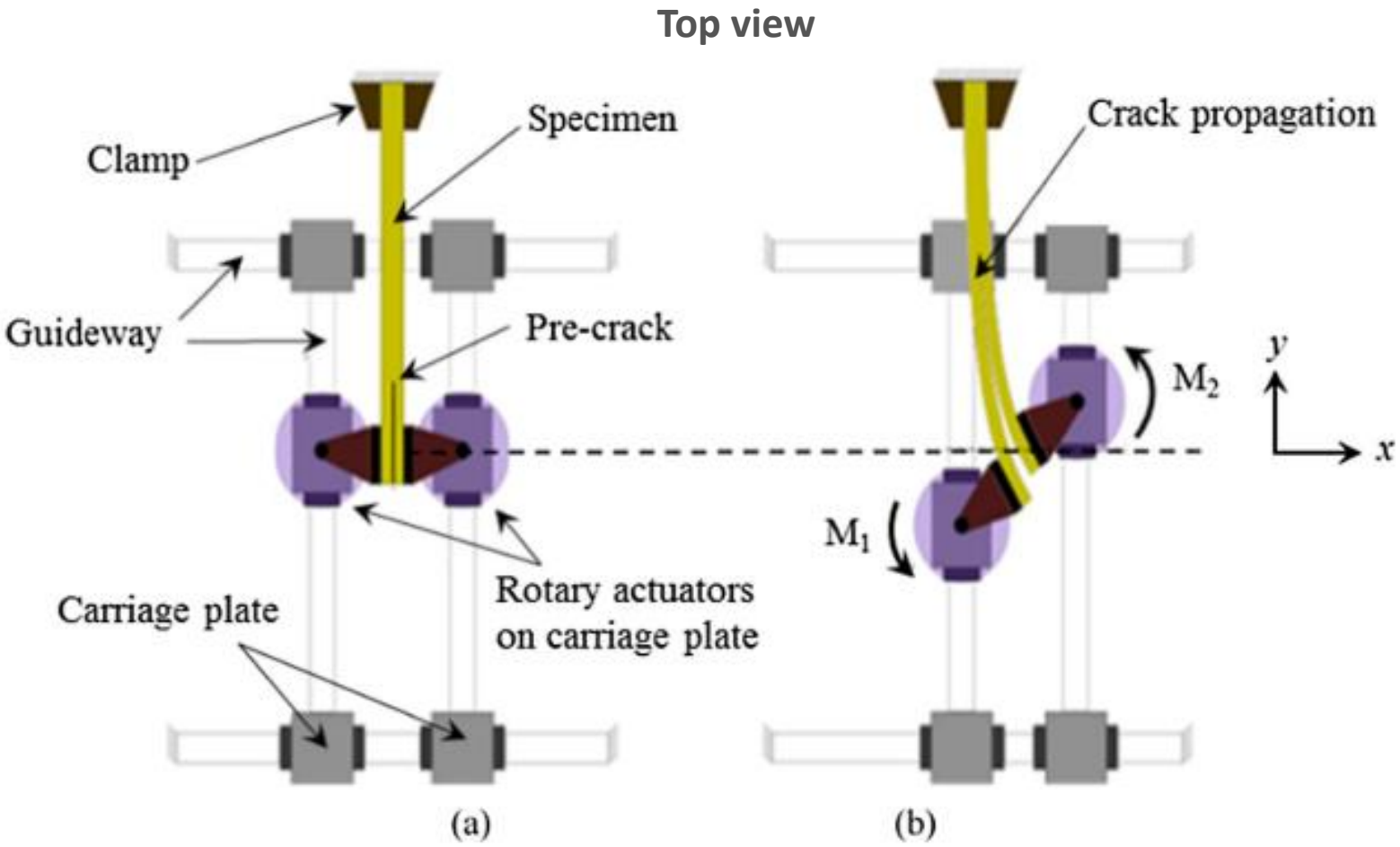
Torsional Actuator (TA)



(Berggreen et al. 2018)

Test setup with uneven bending moments

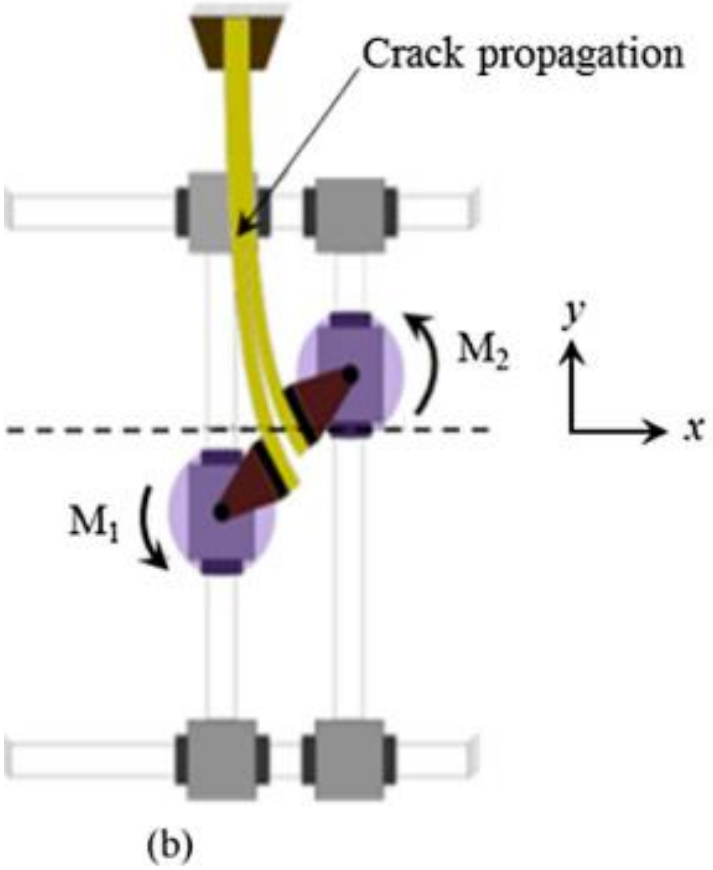
Torsional Actuator (TA)



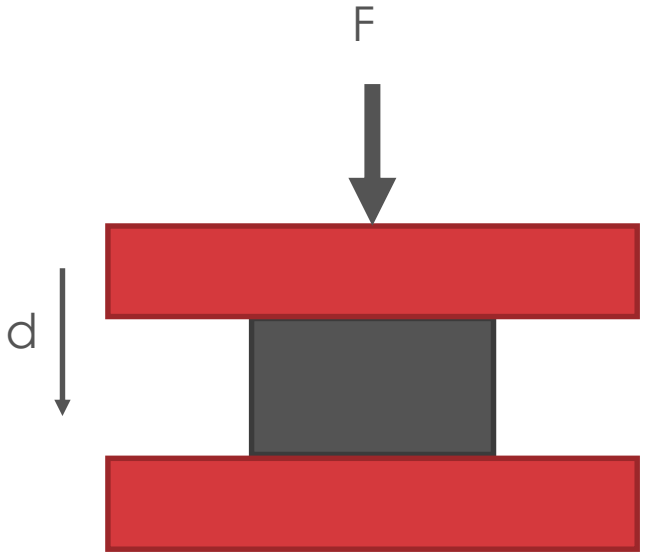
(Berggreen et al. 2018)

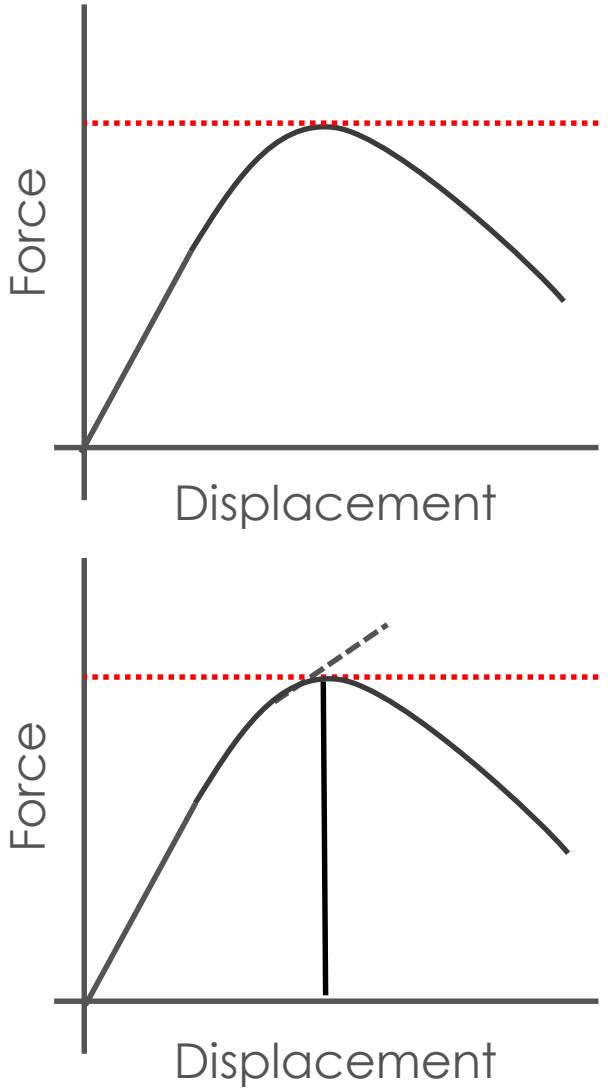
Test setup with uneven bending moments

Torsional Actuator (TA) – Moment/Force control



(Berggreen et al. 2018)





Mixed mode test setup

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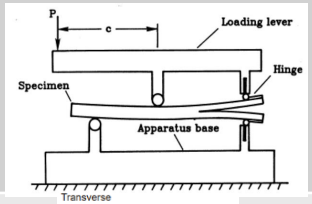
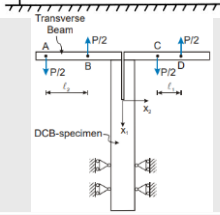
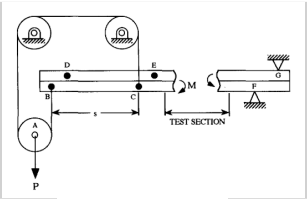
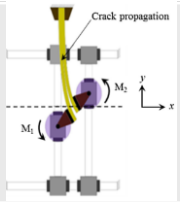
MMB 	X			X
W&L 		X	X	X
W&W 		X	X	X
TA 			X	X

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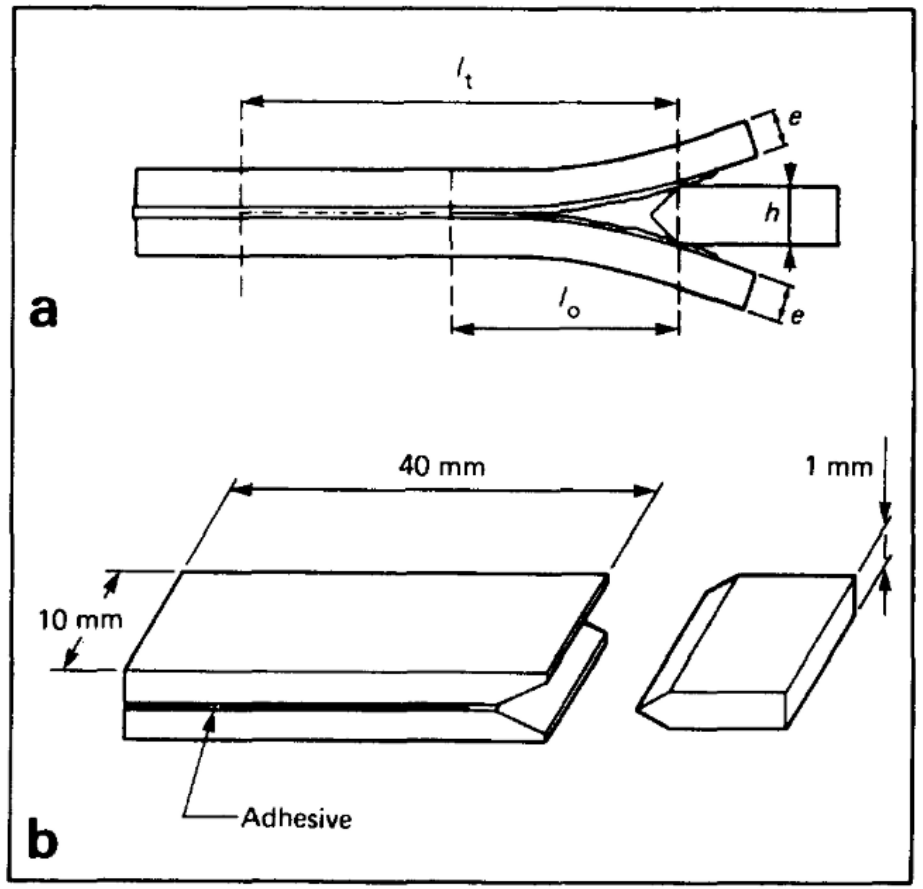
In-situ durability test

In-situ durability test

Durability test for adhesively bonded joints, also known as the Boeing wedge test



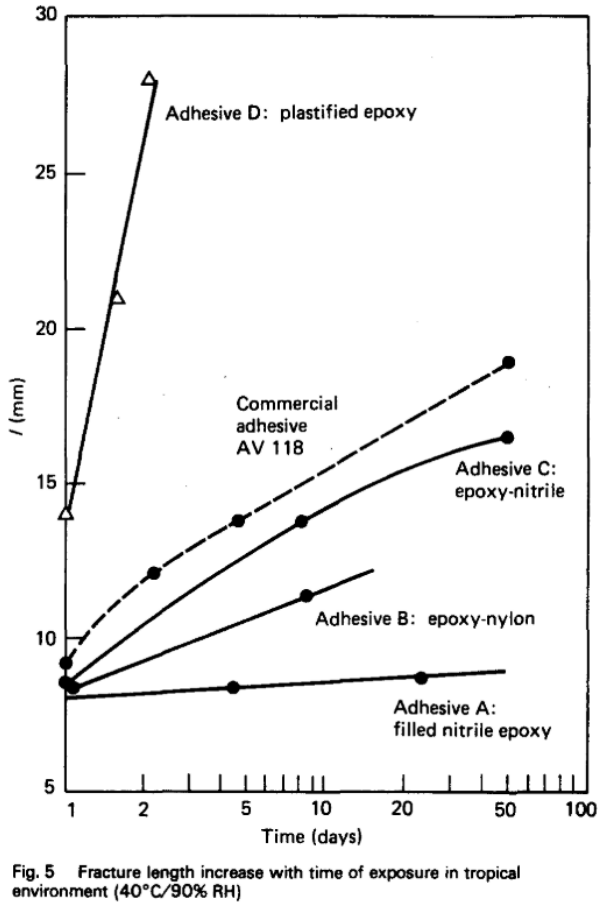
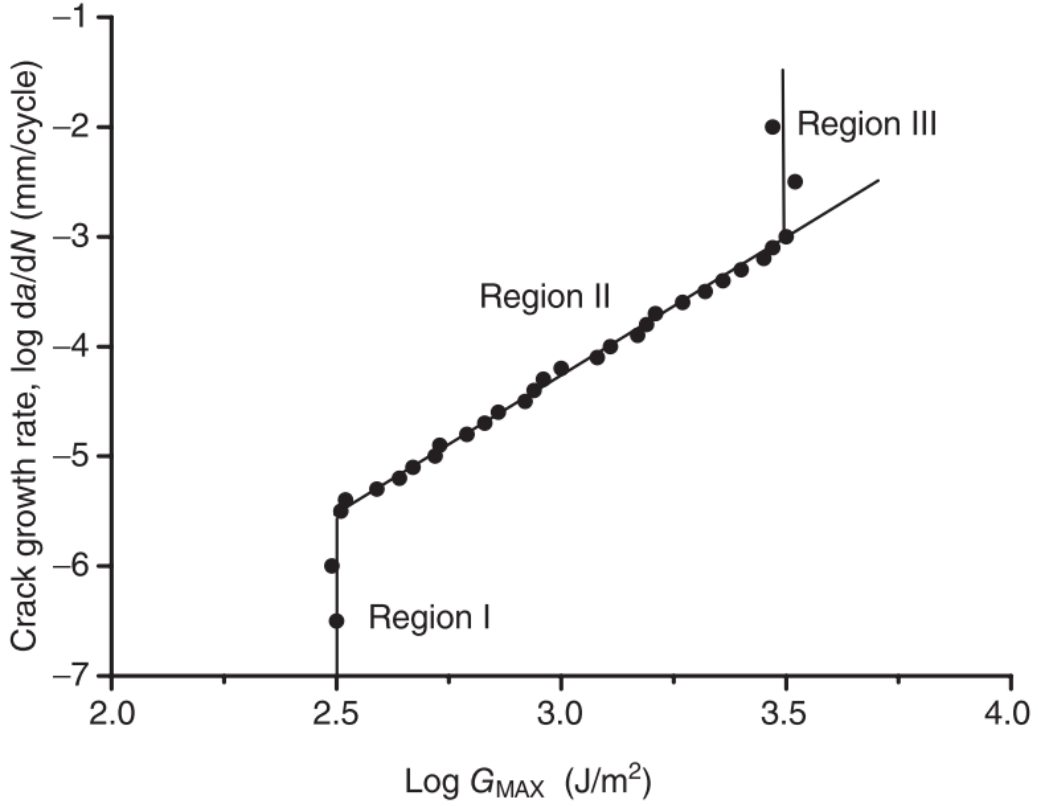


Fig. 5 Fracture length increase with time of exposure in tropical environment (40°C/90% RH)

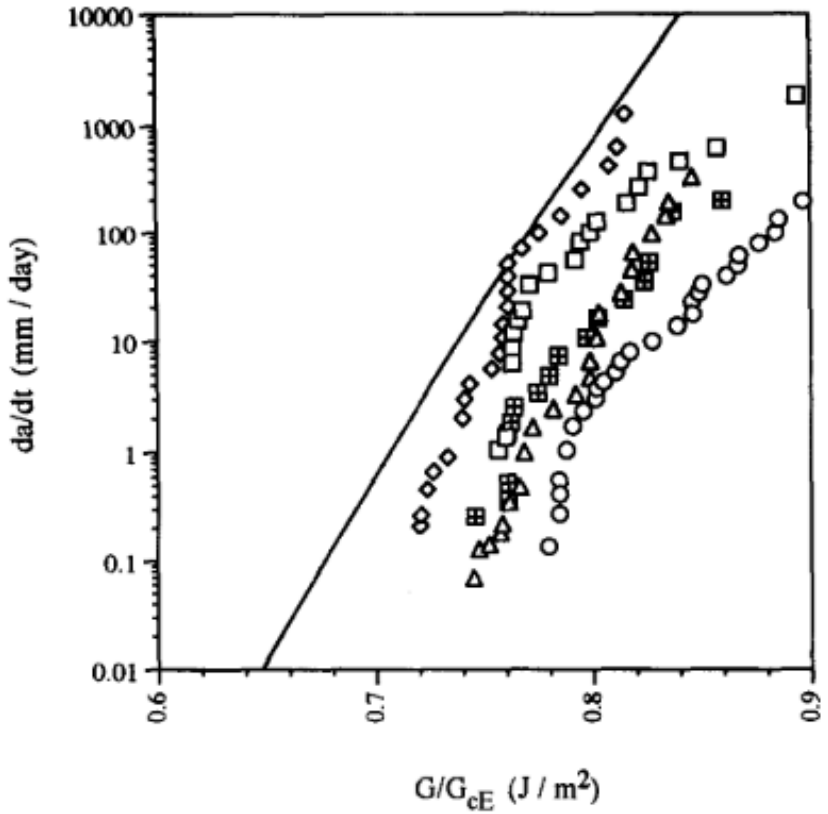
(Cognard et. al. 1986)

In-situ durability test - Constant energy release rate

Durability test for adhesively bonded joints – crack growth rate



(Broughton et. al. 2012)



(Spelt et. al. 1995)

Mixed mode test setup design & in-situ durability test

Questions & Discussion

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