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Fracture mechanics testing beyond LEFM:

Fracture mechanic testing to determine cohesive laws

Motivation - why measure cohesive laws?

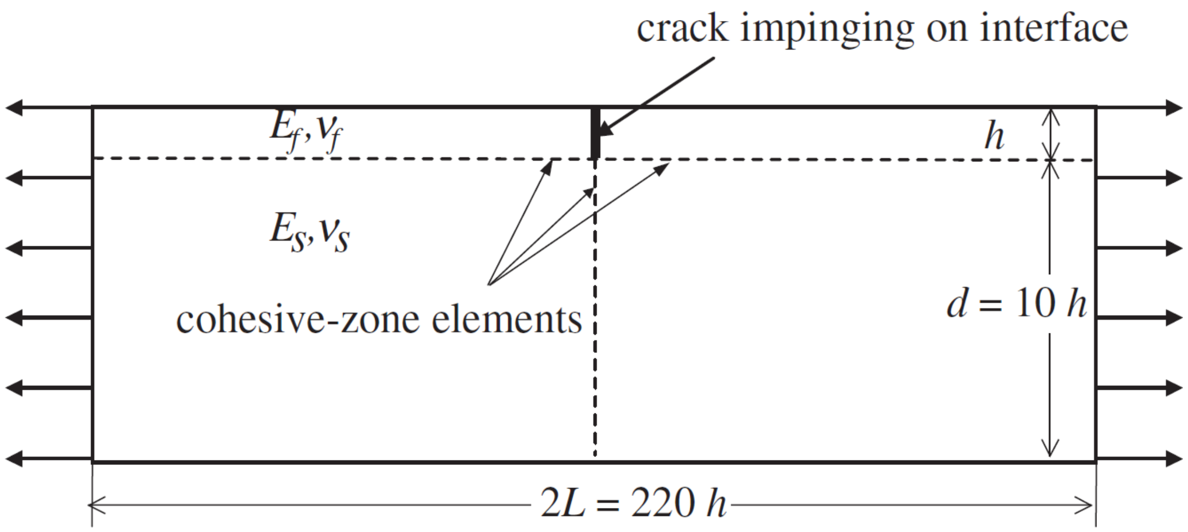
Rising fracture resistance (R-curve behaviour):

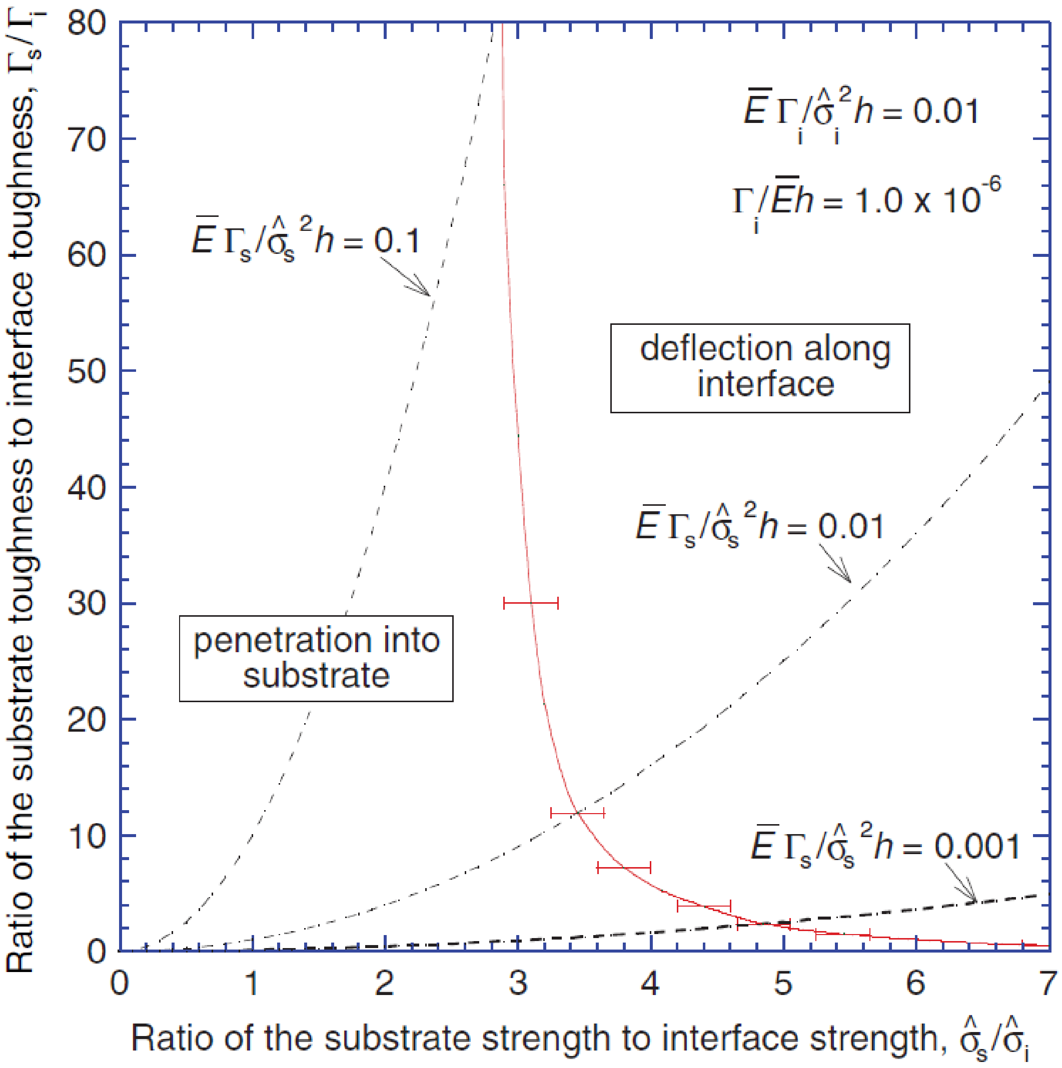
- Some composites show rising fracture resistance under delamination
- Rising fracture resistance is "beneficial" $\Rightarrow$ can stabilize or arrest cracks

Can be modelled by cohesive zone modelling:

- Cohesive zone modelling (CZM) is widely implemented in finite element codes
- Using "real" (measured) cohesive laws will enable more accurate strength predictions

Motivation - does accuracy of cohesive law matter?



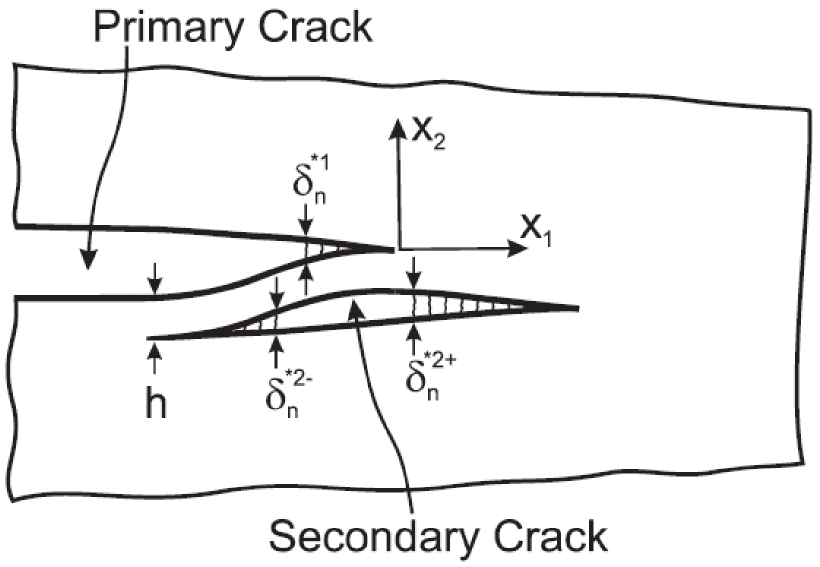


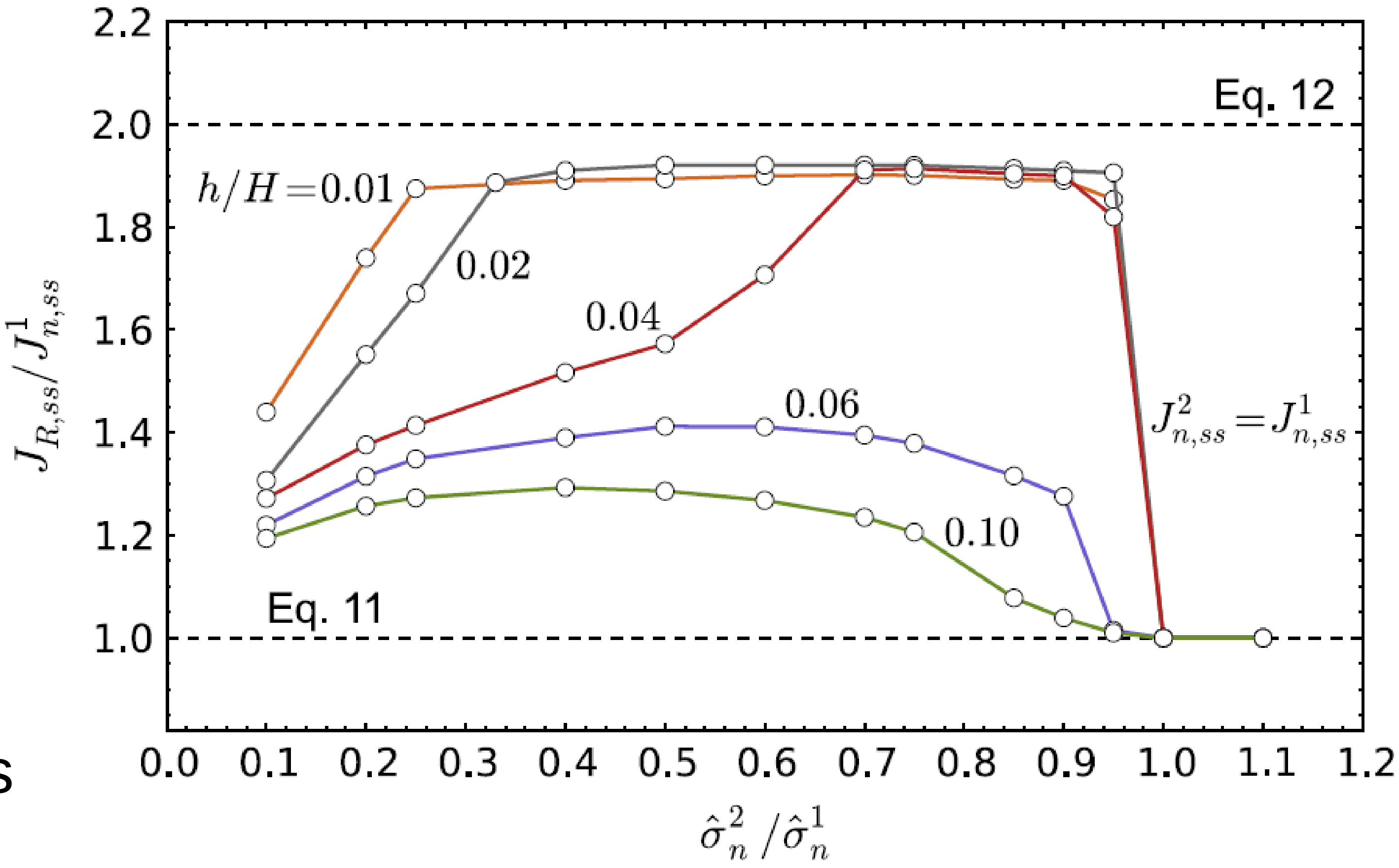
<u>Crack deflection</u>:

- Crack deflection/penetration at interface depends on both toughness and peak traction values

Parmigiani and Thouless, 2006, *Journal of the Mechanics and Physics of Solids*, **55** 266-87

Motivation - does accuracy of cohesive law matter?





Secondary crack formation:

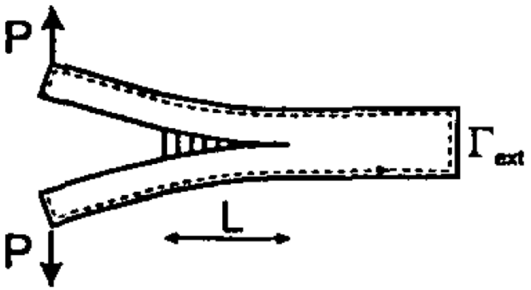
- The formation of a secondary crack at a neighbouring interface depends on the peak traction values

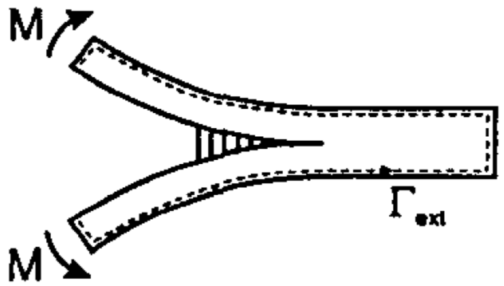
Goutianos and Sørensen, 2016, *Engineering Fracture Mechanics* **151** 92–108

Measurement of cohesive laws (J integral approach)

<u>J integral solutions</u>:

- Valid for large-scale bridging



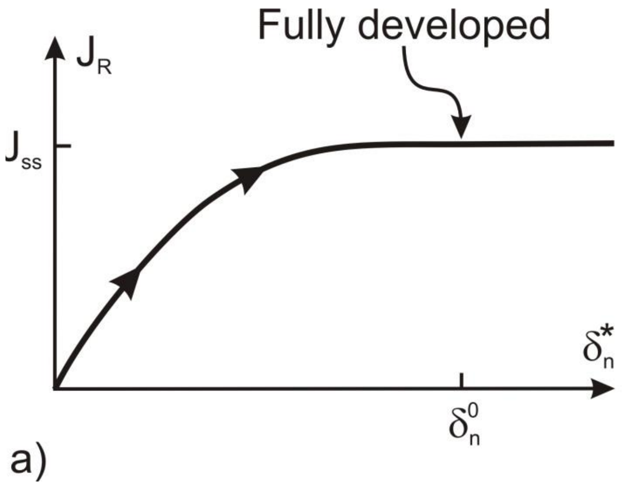


$$J_{ext} = 2\frac{P}{B}\theta$$

$$J_{ext} = \frac{12M^2}{B^2H^3E_{11}}$$

<u>J integral result</u>:

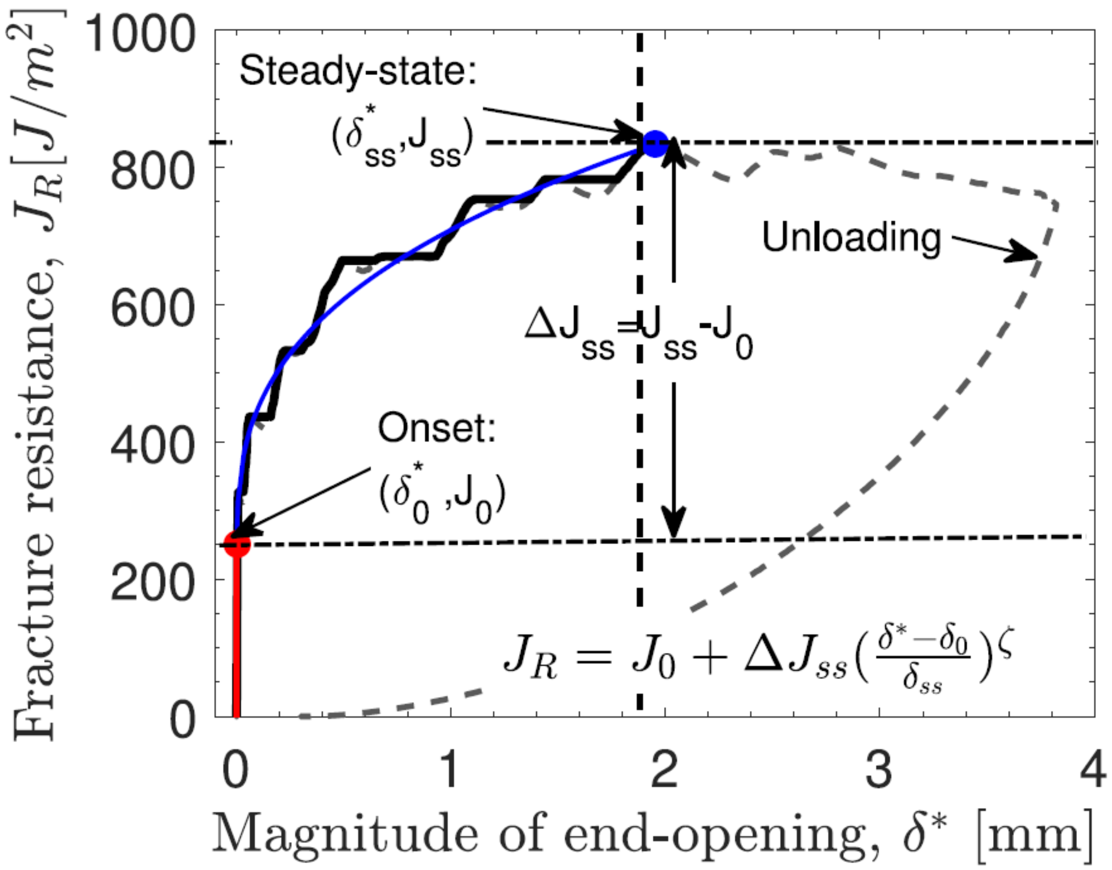
$$J_R = \int_0^{\delta_n^*} \sigma_n(\delta_n)\,d\delta_n$$



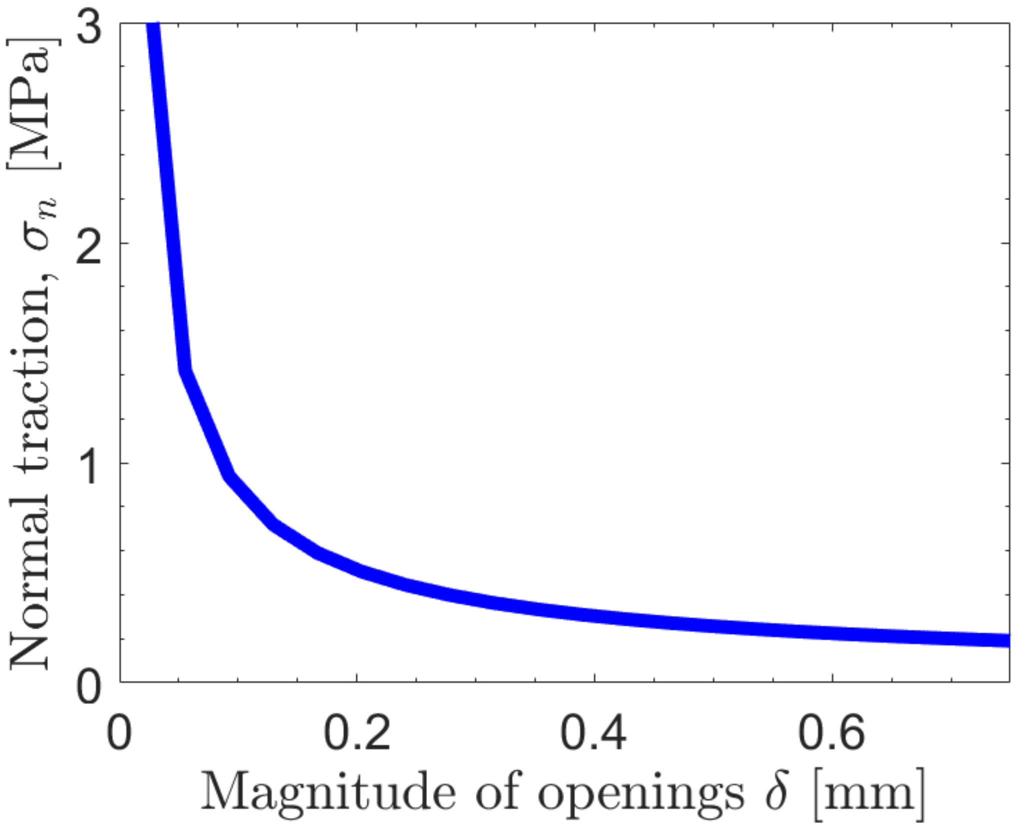
Jabobsen and Sørensen, 2000, *Plastics, Rubber and Composites*, **26** 119-33

Measurement of cohesive laws - an example

Large scale bridging region:



Derived cohesive law:

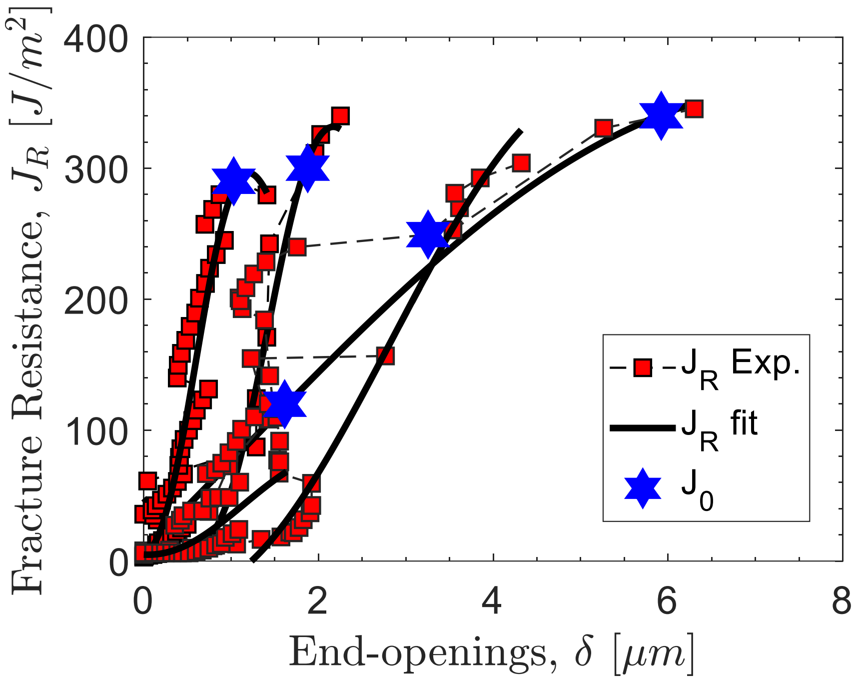


Erives, Sørensen and Goutianos, 2023, *Composites Part A*, **165** 107346

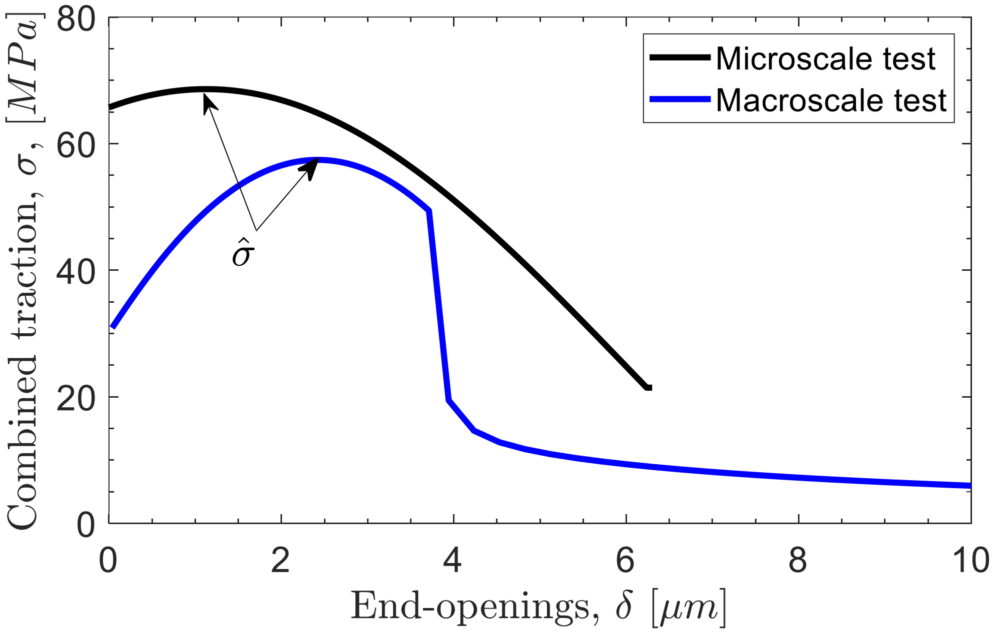
Measurement of cohesive laws - an example

Crack tip fracture resistance:

Fracture test conducted in SEM



Derived crack tip cohesive law:



Erives and Johansen, 2023, Proc. ICEM20, 20th Int. Conf. on Experimental Mechanics, Porto 2-7 July 2023

Challenges and outlook

Difficulties:

- Measurement of crack tip cohesive laws requires care (high resolution displacements and narrow specimen to have straight crack front)

Reward:

- The fracture can be modelled accurately, also transition from stable to unstable crack growth before "fully developed" cohesive zone
- Materials can be developed or chosen to a given crack problem to provide best behaviour (e.g. highest load-carrying capability)

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