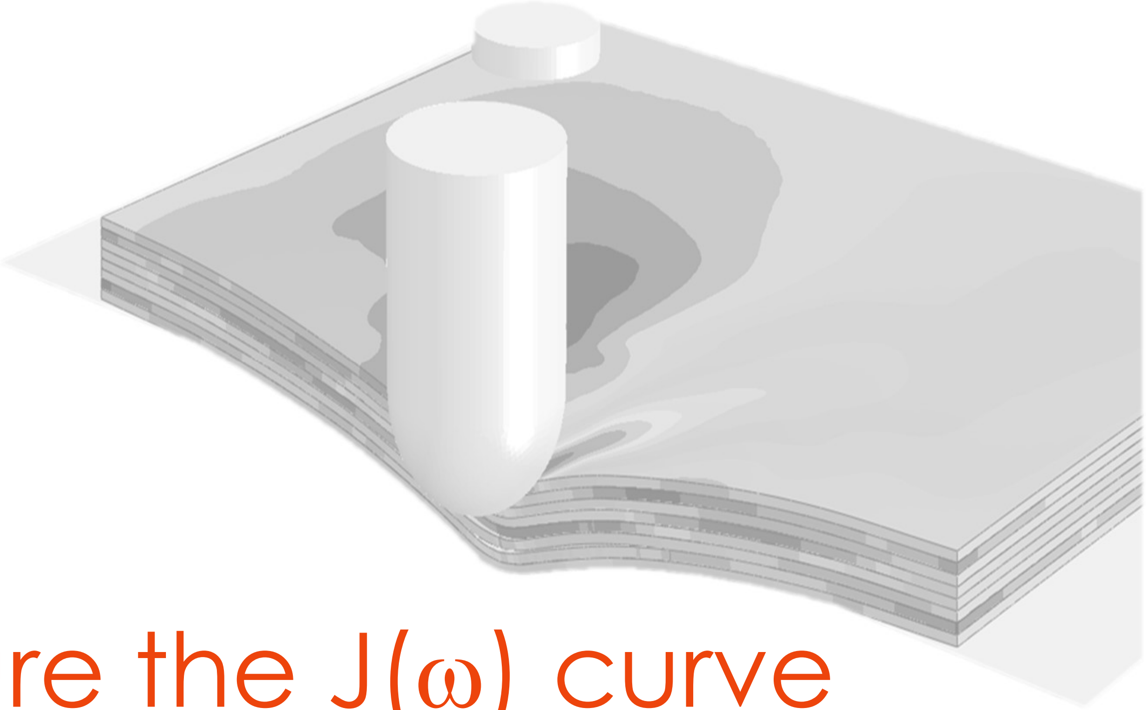
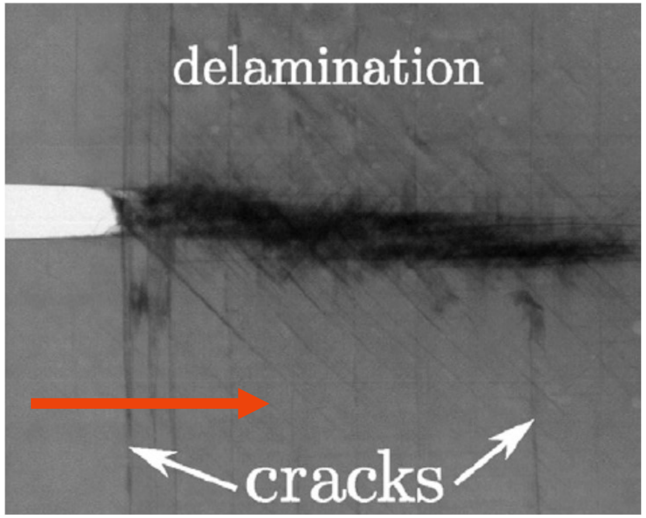


Four ways to measure the J(ω) curve

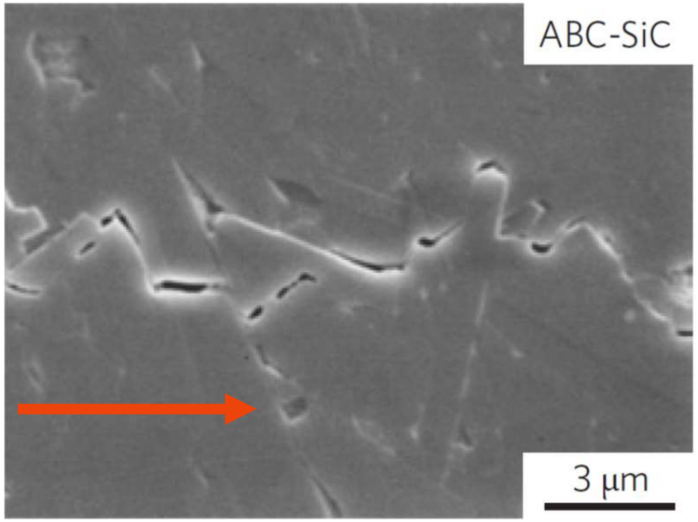
Pere Maimí

Introduction

- When a crack grows complex physical phenomena happens…



Ortega et al. 2017 (10.1016/j.compscitech.2017.02.029)

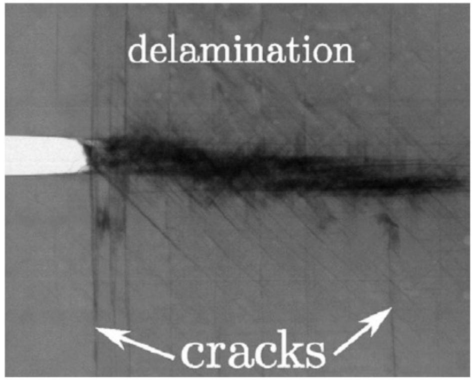


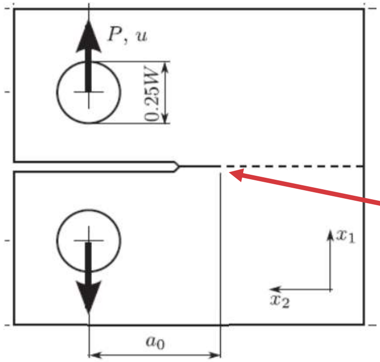
Ritchie 2011 (10.1038/NMAT3115)

But engineers like simple solutions, preferably a number (G_C), to characterize a material

Linear Elastic Fracture mechanics

because reality is too complex ... …we like to work with idealized problems





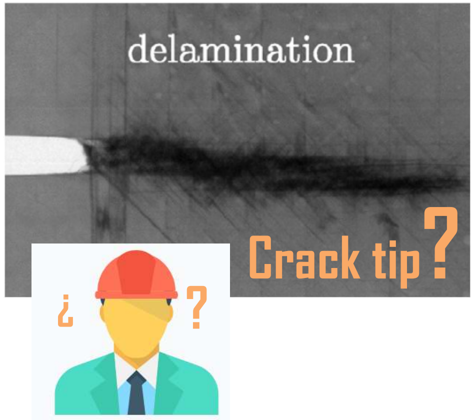
The material is elastic and have a magic point: the **Crack tip**

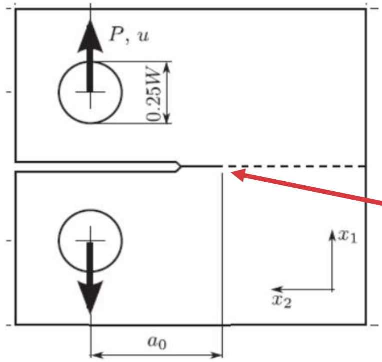
we have a theory, LEFM!!!!

- We need to measure the crack length: a

Linear Elastic Fracture mechanics

because reality is too complex ...   …we like to work with idealized problems





The material is elastic and have a magic point: the **Crack tip**

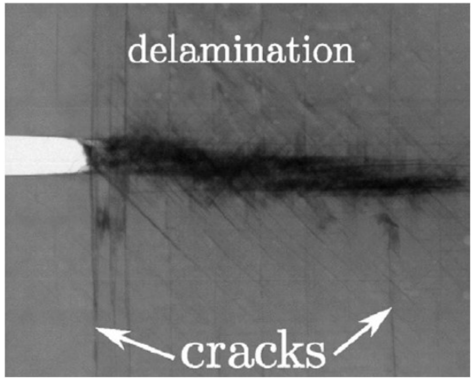
we have a theory, LEFM!!!!

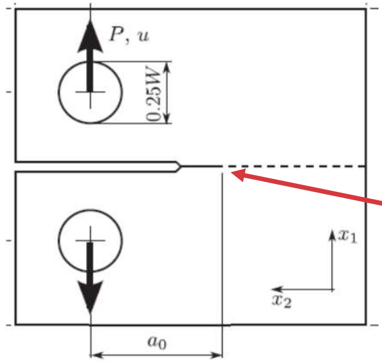
- We need to measure the crack length: a
  - We can try to measure a optically
  - The compliance method: $C_{experimental} = C_{ideal}(a)$

- We can determine $G_C=P^2/(EW)\ f(a/W)$

Linear Elastic Fracture mechanics

because reality is too complex … …we like to work with idealized problems





The material is elastic and have a magic point: the **Crack tip**

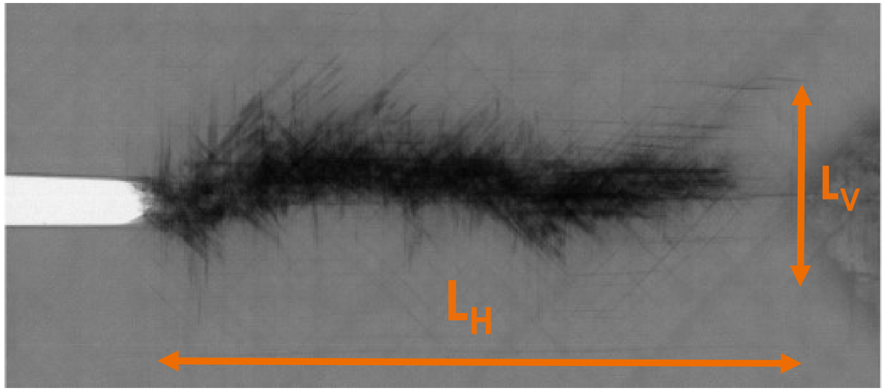
we have a theory, LEFM!!!!

- We need to measure the crack length: a
- We can determine G_C=P^2/(EW) f(a/W)

Both a and G are only defined in the idealized problem, not in the real problem

We obtain a very strange response: **R(Δa)** curve.

Does Linear Mechanics of Elastic Fracture Work?



Works if the ideal problem is similar to the real problem…

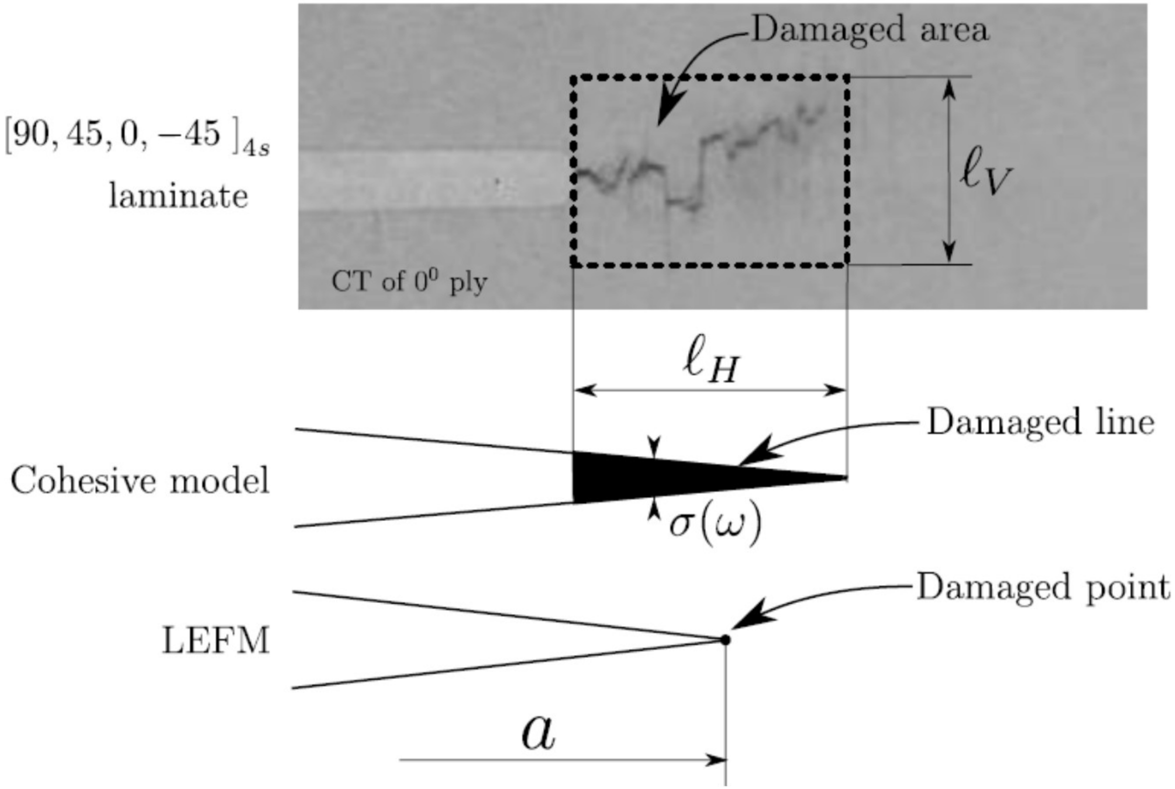
If the lengths L_H and L_V that defines the failure process zone are small enough:
The nonlinear zone is small compared to the specimen dimensions

According to ASTM "small" is defined as

$$\ell_M < 0.4(W - a) \qquad \ell_M = \frac{G_{Ic}E'}{\sigma_u^2}$$

Condition known as <u>Small Scale Bridging or Yielding</u>

A better idealitzed model: The cohesive zone model



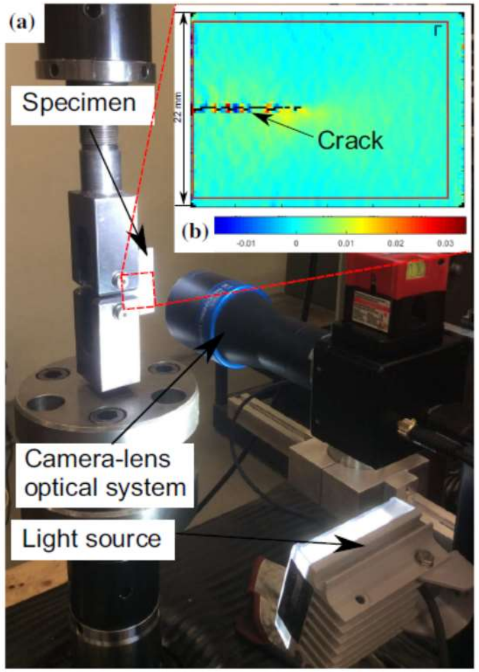
Cohesive zone model defines a law between stress and crack opening: σ(ω), its integral is the J(ω)

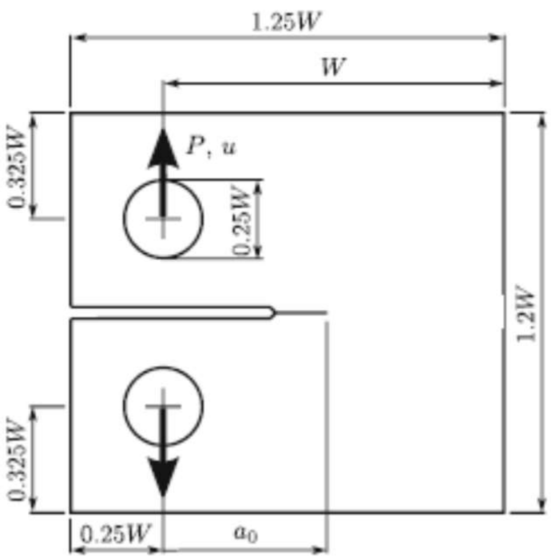
$$\mathcal{J}(\omega) = \int_0^{\omega} \sigma(\omega) d\omega$$

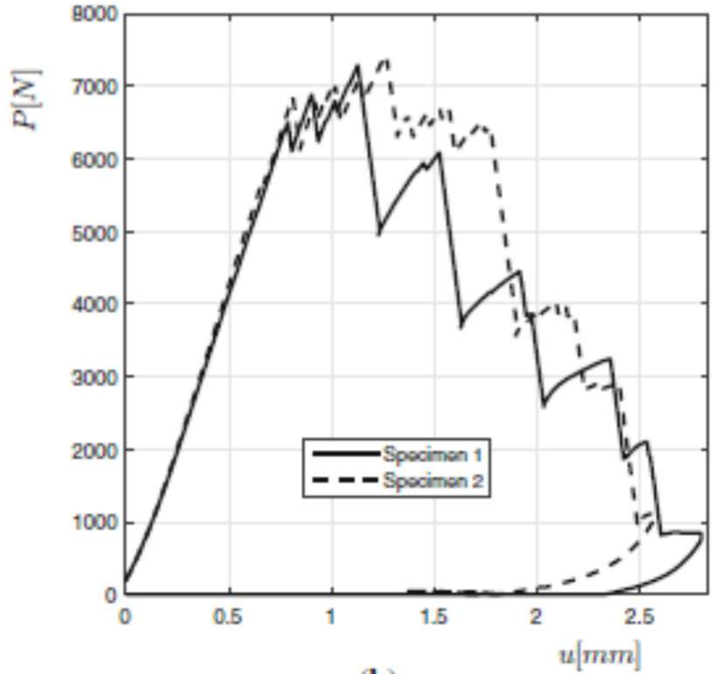
It represents better the real problem, it only requires the length L_V to be small (this is typical of quasi-brittle materials: concrete or composites)

How can we get the σ(ω) or J(ω)?

Experimental test: Translaminar crack







(b)

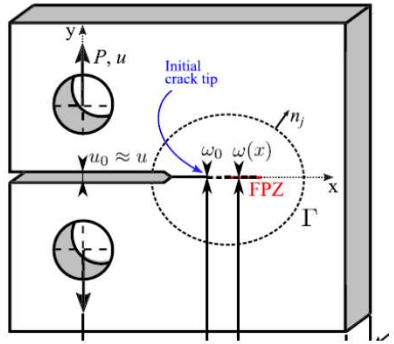
Laminate	h (mm)	W (mm)	a_0 (mm)	E (GPa)	ν_{12}	σ_{uT} (MPa)
$[90/45/0/-45]_{3s}$	4.44	51	21	48.8	0.312	671.1

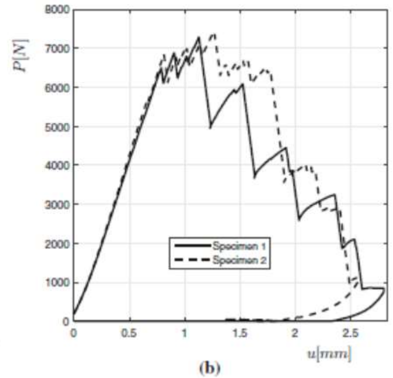
Method 1: J-integral and ω_0

- Measure ω_0 at crack tip
- Compute the J-intregral

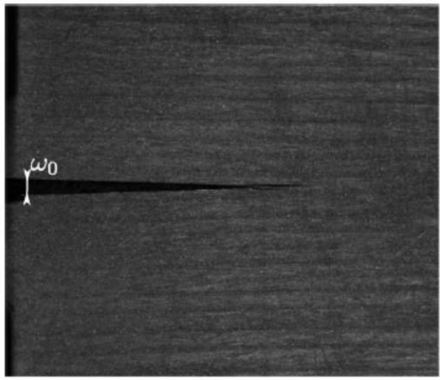
$$\mathcal{J}_\Gamma = \int_\Gamma \left(\Phi dy - t_i \frac{\partial u_i}{\partial x} ds \right)$$

(for CT specimen a DIC is required, for a DCB it is very simplified)

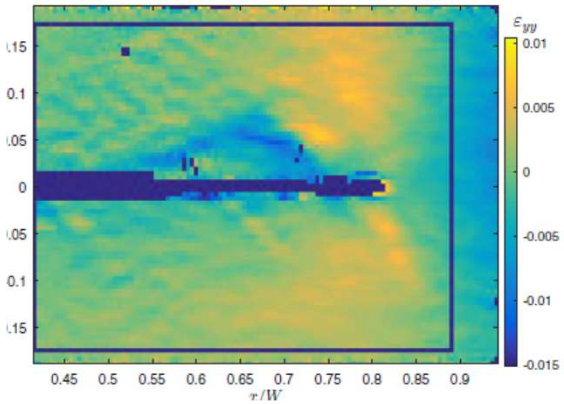


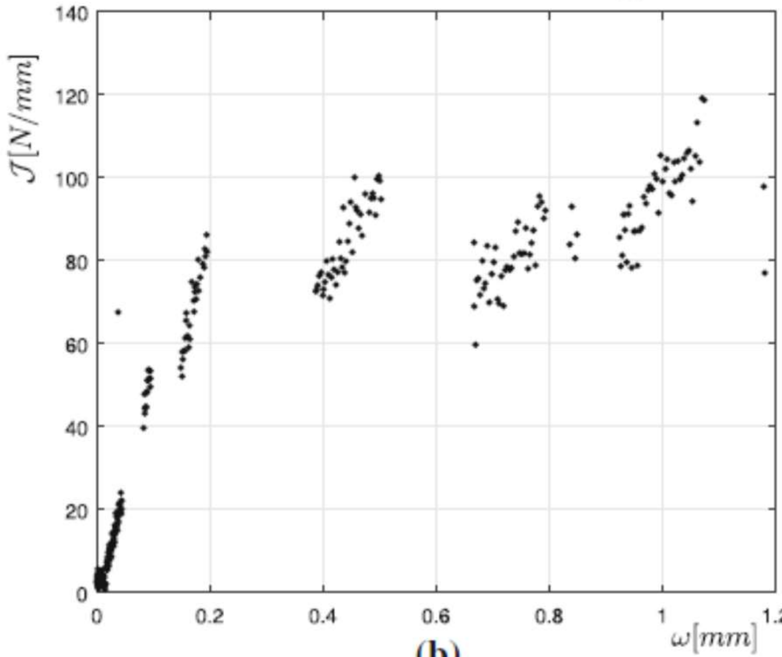


(b)



(a)



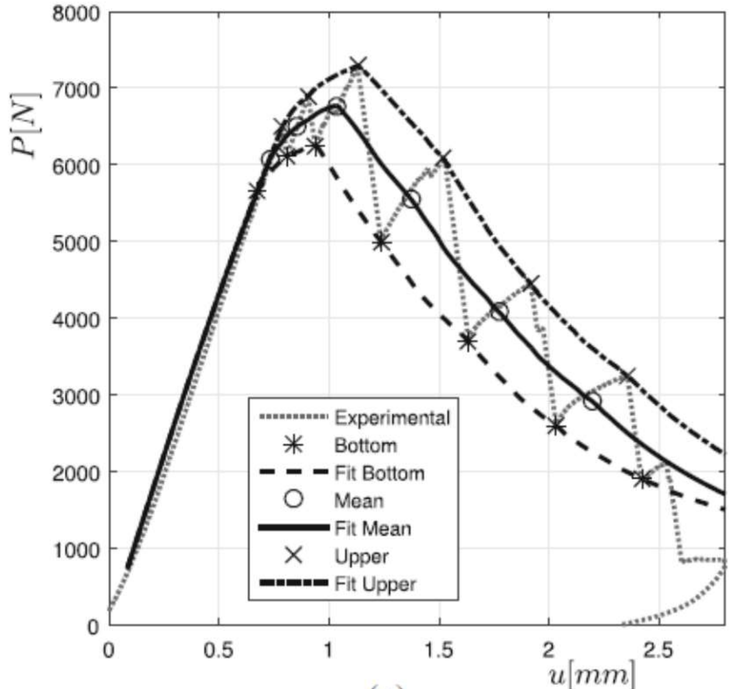


(b)

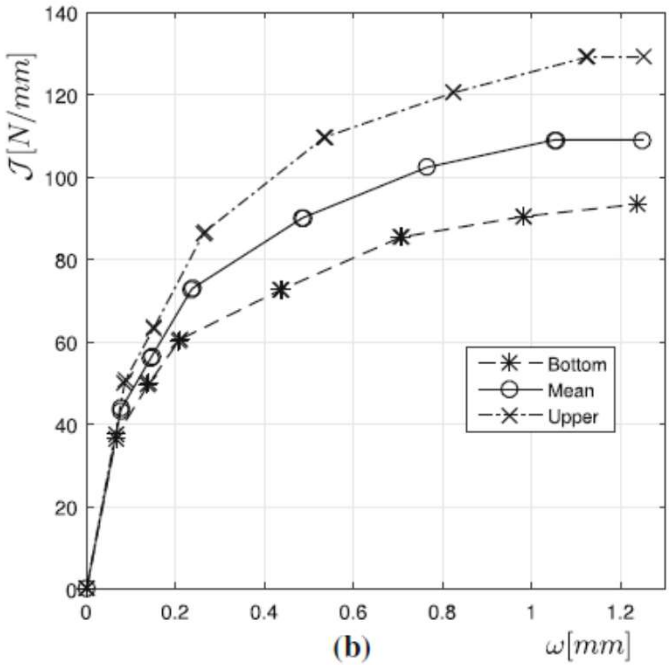
This method was used by C. Sarrado PhD for beam-like geometries

Method 2: Optimization or fitting algorithm

- To minimize the error between experimental data and a numerical model.
- A set of experimental P-u points are selected and the cohesive law is defined to fit these points



(a)

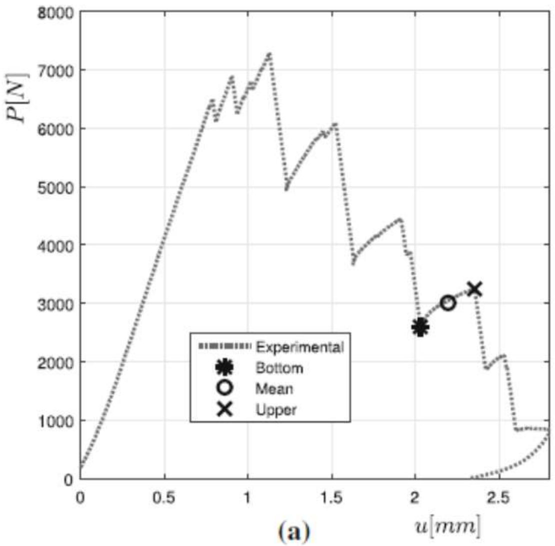


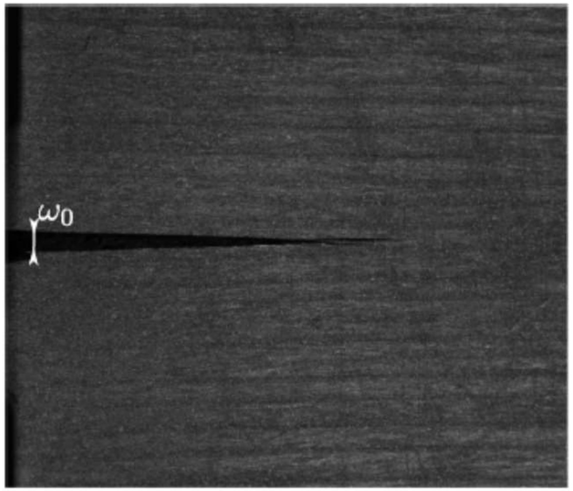
(b)

Details of this method are explained in A. Ortega and Said Monsef PhDs

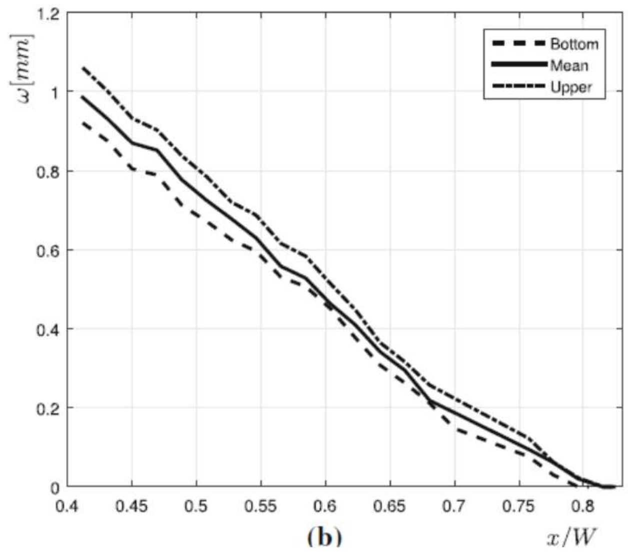
It is possible to obtain the J curve from a single point?

- The previous two methods requires the complete load-displacement curve to obtain the J curve.

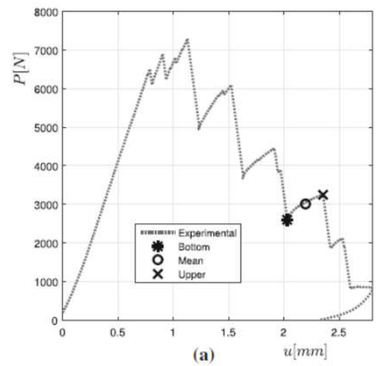




(a)

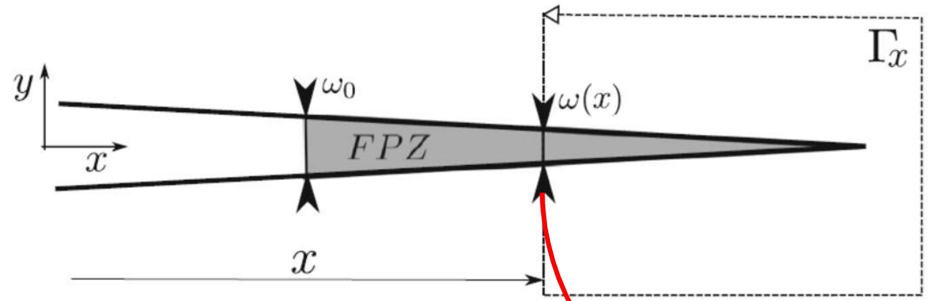


- It is possible if the profile of crack opening displacement can be measured: ω(x)

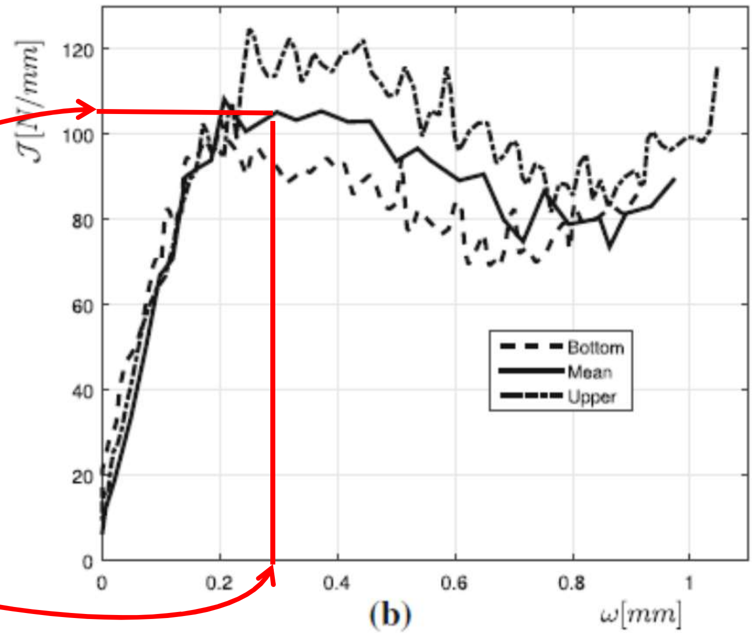


Method 3: J(x)-integral

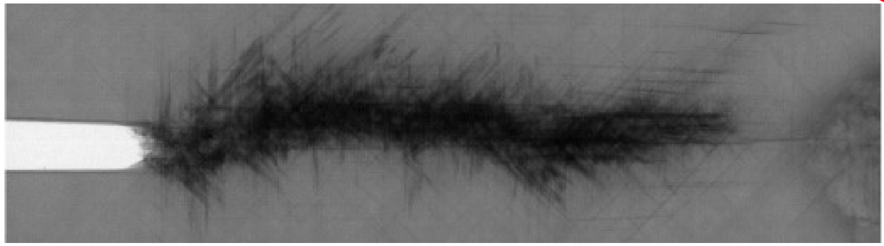
- Compute the J-integral in a path:



$$\mathcal{J}_{\Gamma_x} = \mathcal{J}(\omega_x).$$



Drawback: To compute J integral that cross the FPZ. In our ideal material it works but in the real material:



Method 4: Stress profile at FPZ required to obtain ω(x)

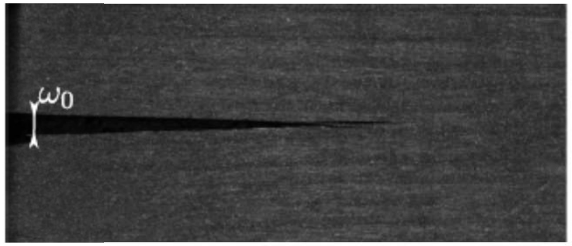
- Obtain stress profile at FPZ that produce the measured crack opening profile:

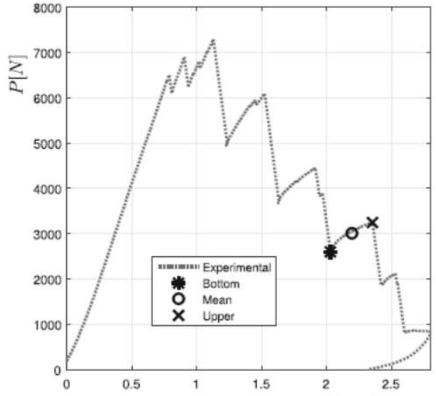
$$\begin{bmatrix} w_1 \\ \vdots \\ w_{n-1} \\ P \end{bmatrix} = \begin{bmatrix} F_{11} & \cdots & F_{1n} \\ \vdots & \ddots & \vdots \\ F_{n1} & \cdots & F_{nn} \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \vdots \\ \sigma_n \end{bmatrix}$$

Experimental data

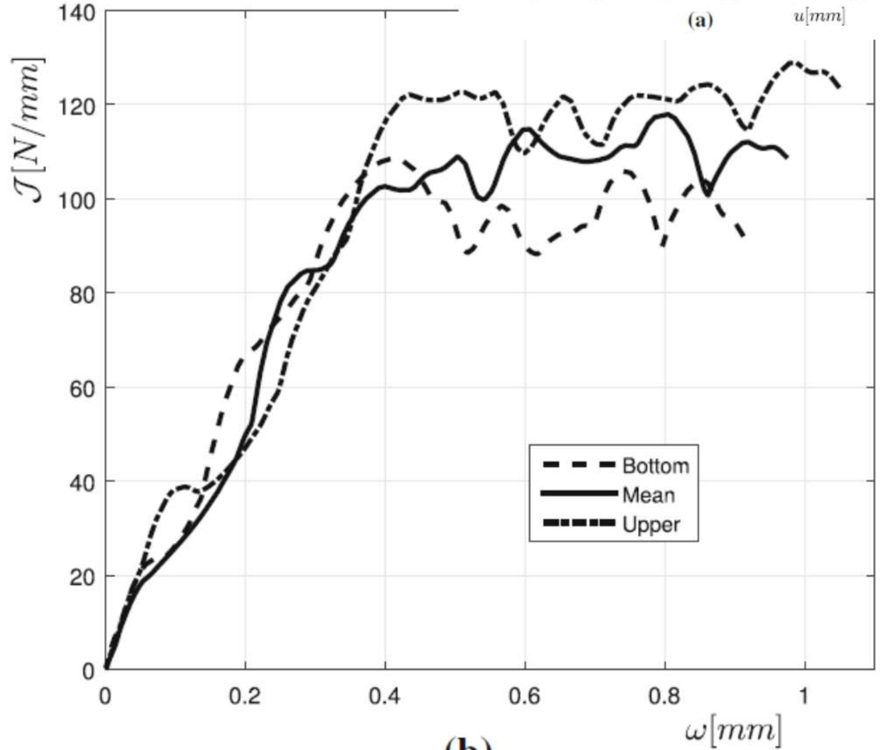
Geometry

????





(a)



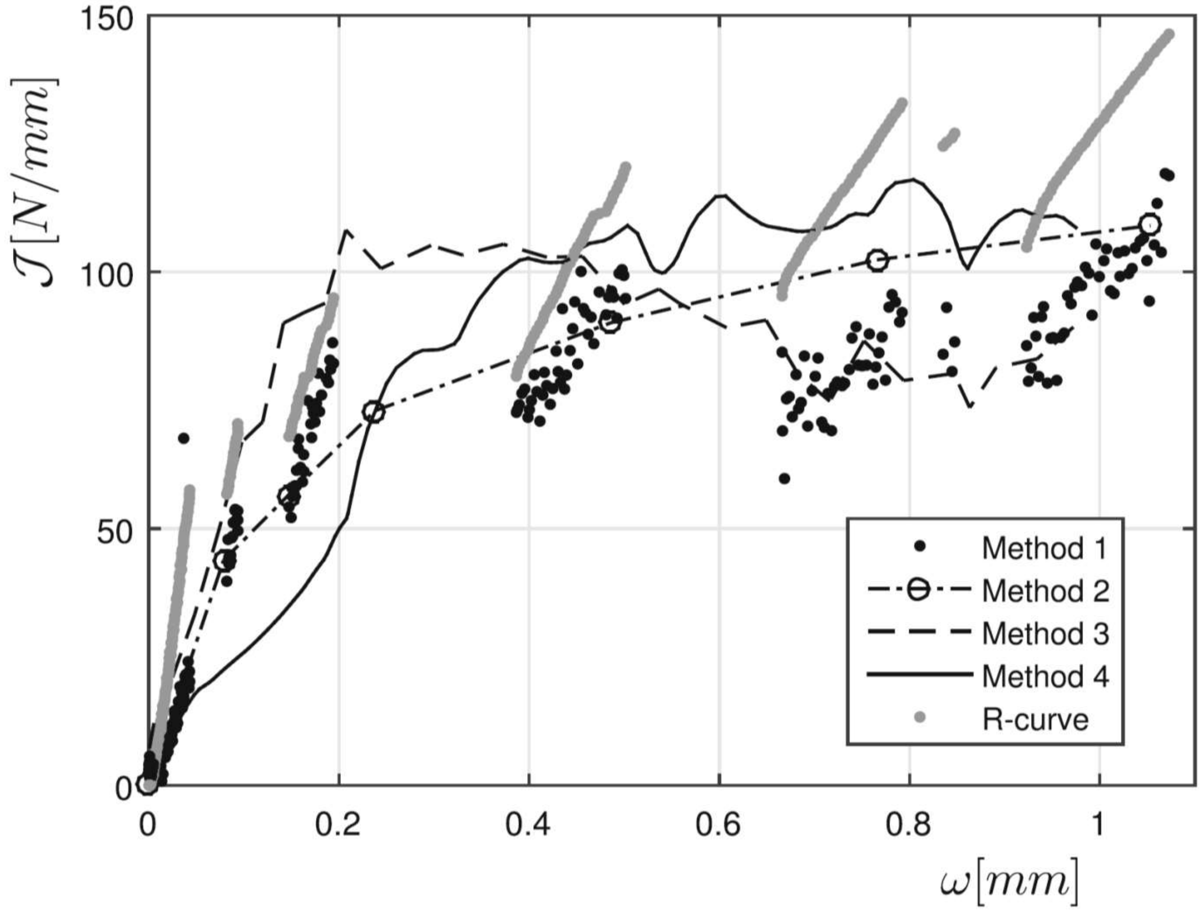
(b)

Comparison of the four methods (and LEFM)

- What is the best method?

I don't know, but…

- Method 2 is the cheaper once it is implemented
- Method 1 is cheap for beam-like geometries because J-integral is simple.
- Methods 3 and 4 does not depends on the initial notch but crack opening profile is required
  - Method 3 is a bad idea
  - Method 4 is beautiful.



Time for **easy** questions

For difficult questions you can read the paper:

Int J Fract
https://doi.org/10.1007/s10704-020-00456-0

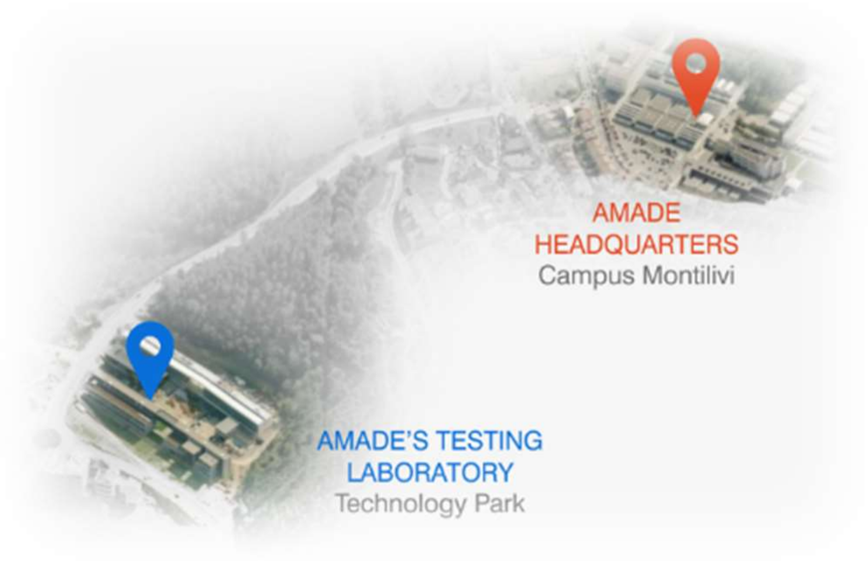
Check for updates

ORIGINAL PAPER

On the experimental determination of the $\mathcal{J}$-curve of quasi-brittle composite materials

Pere Maimí · Ahmed Wagih · Adrián Ortega · José Xavier · Norbert Blanco · Pedro Ponces Camanho

and C. Sarrado, A. Ortega and S. Monsef PhDs



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