JOINT ADVANCED MATERIALS & STRUCTURES
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Certification of Discontinuous Composite Material Forms for Aircraft Structures

Marco Salviato, Seunghyun Ko, Jinkyu Yang, Mark Tuttle

University of Washington

JAMS 2017 Technical Review
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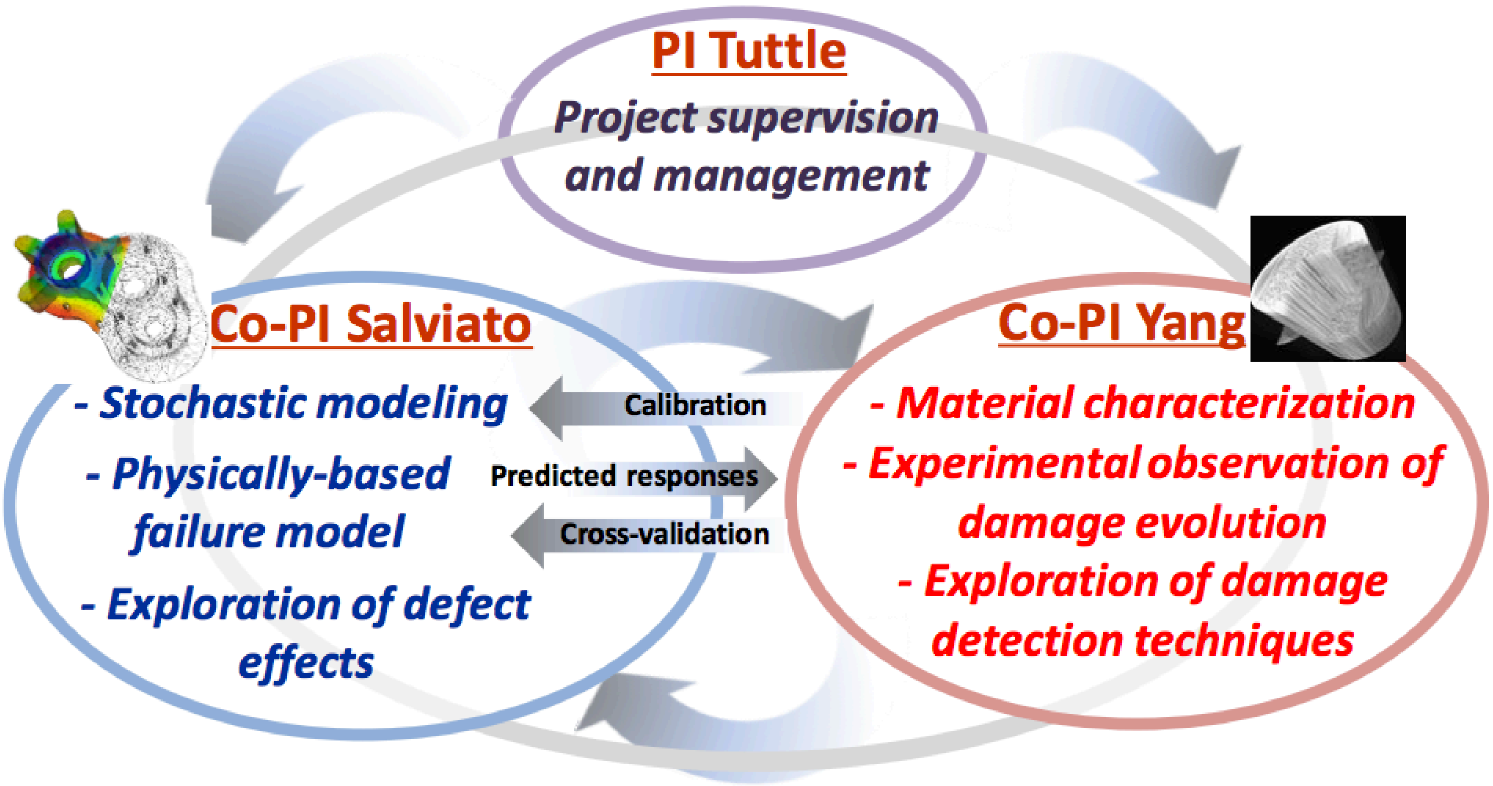
Research team outline



Research team outline

- Seunghyun Ko (PhD student);

- Reed Hawkins (Master student)
- Reda El Mamoune (Master student)
- ZT Yang (Master student)

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DFCs overview

HexMC Material,(450mm wide Roll),~2000 gsm,~2 mm thick

50mm x 8mm 8552/AS4 UD 150 gsm, 38% RC, Controlled Random Distribution

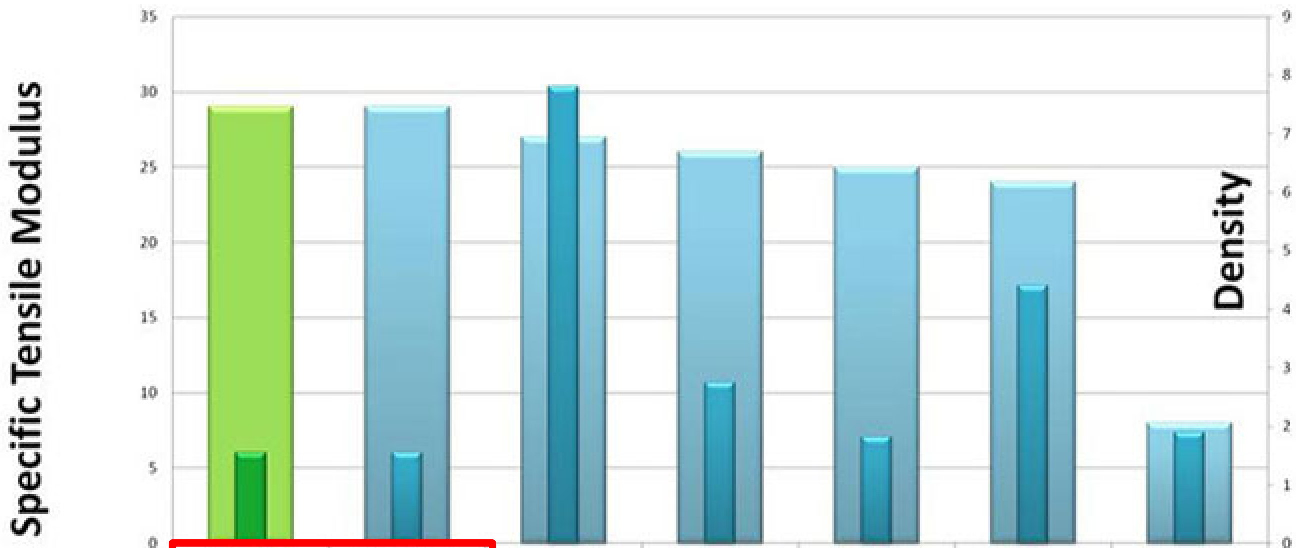
Source: www.hexcel.com

DFC structural components

(almost) Net shape design

Source: www.hexcel.com

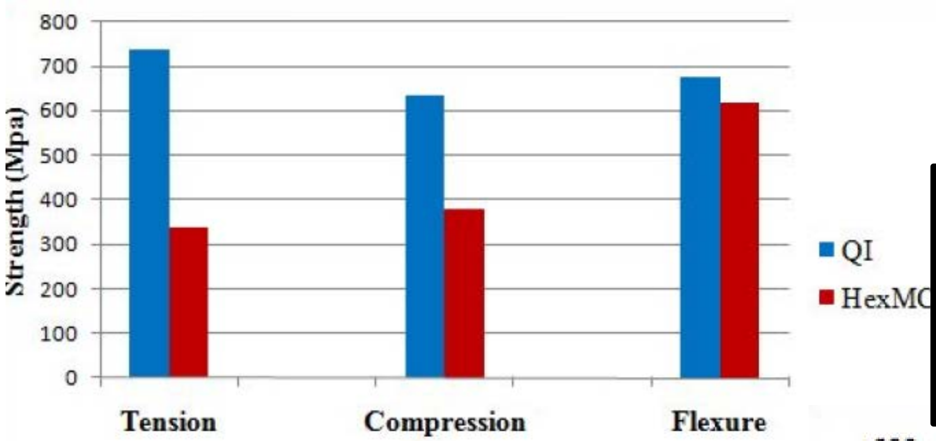
DFC performance

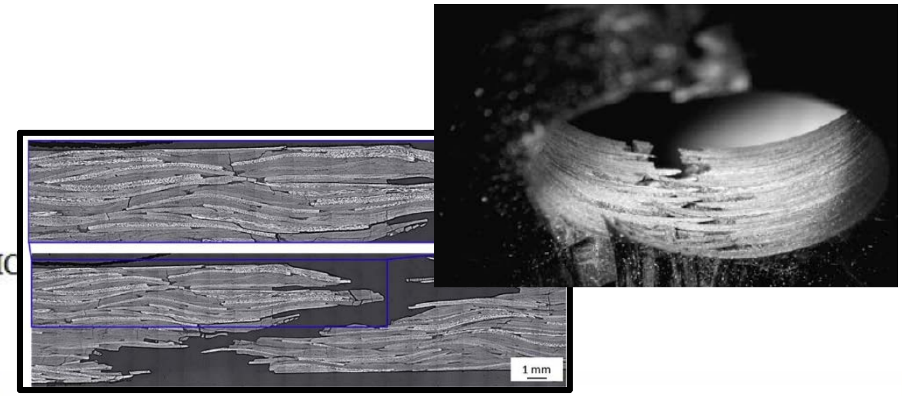


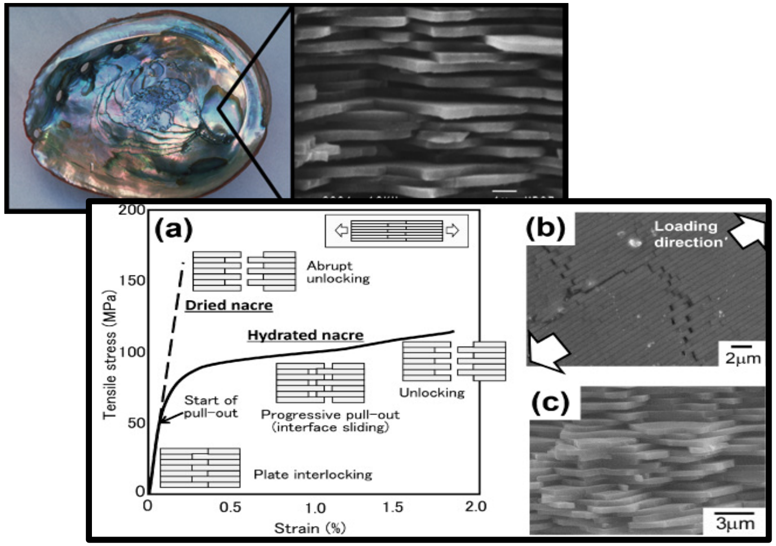
	HexMC®	Quasi-Iso Prepreg	Steel	Aluminum	Magnesium	Titanium	SMC (50% weight glass)
Specific Tensile Modulus	29	29	27	26	25	24	8
Density (g/cm3)	1.55	1.55	7.8	2.74	1.81	4.4	1.9

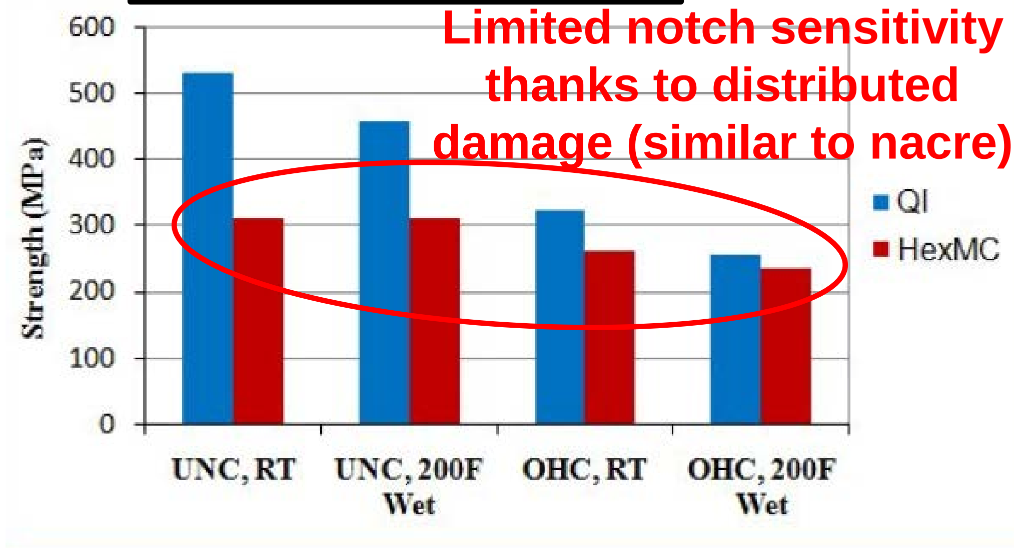
Source: www.hexcel.com

DFC performance









B. Boursier, 22nd SAMPE European conference, March 2001

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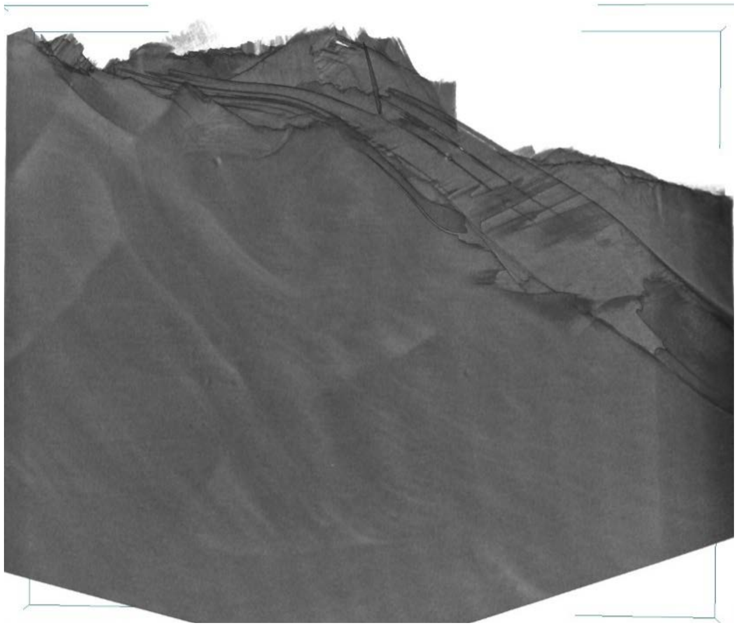
Challenges for certification

- The main mechanisms of damage in the presence of multi-axial loading, notches and defects are not clearly understood;
- The multi-axial behavior of un-notched and notched DFC structures has not been characterized yet. This is key for design and certification;
- The effects of defects on the overall structural performance has not been quantified. This is important to provide guidelines for certification and maintenance of DFC parts;
- All the above issues have to be considered keeping in mind the thickness effect which was shown to highly affect the overall mechanical behavior

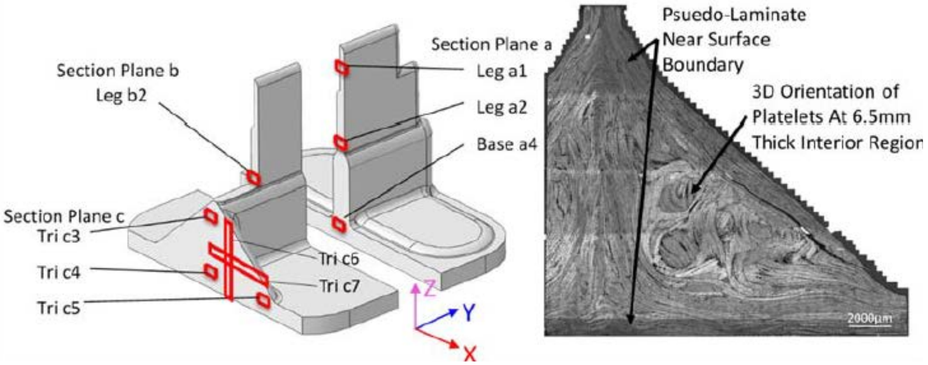
Proposed methodology and research plan

- **Damage mechanism investigation**

Extensive 3D analysis of damage progression by micro-Computer Tomography



Source: UW team



Denos, Pipes, 31st ASC conference, 2016

North Star Imaging X5000 Industrial 2D Digital X-ray and 3D Computed Tomography (CT) System: Nominal part envelope: 32' (dia.) x 48' tall, Overall system resolution: 3 μm. X-ray energy: 10-450 kV. Geometric magnification: 2000x.

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Proposed methodology and research plan

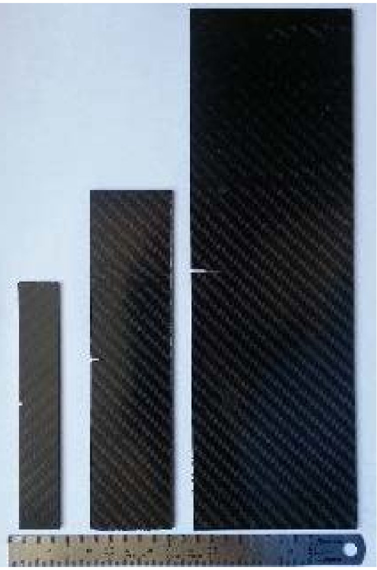
- **Defect analysis**

Experimental and computational analysis of size effect in DFC structures to find critical defect sizes keeping in mind the highly stochastic behavior

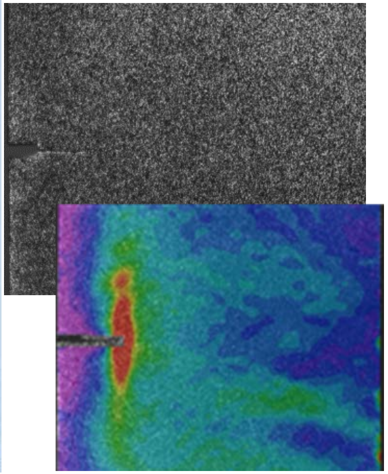
Types of defects:

- ***Molded-in defects* (e.g. 1.27 cm x 1.27 cm brass covered with Teflon) imbedded between HexMC plies;**
- **Visible damage from impact**
- **Incidental damage: cuts made with a saw and/or visible surface damages**

- **SENT**



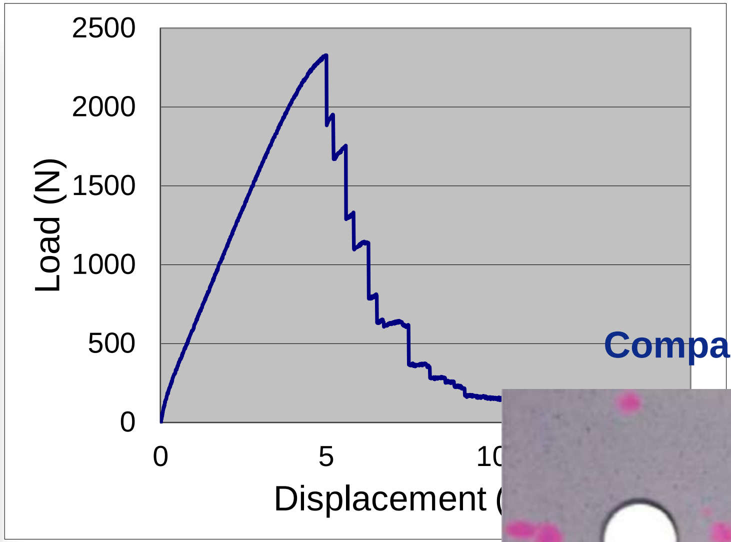
DIC investigation



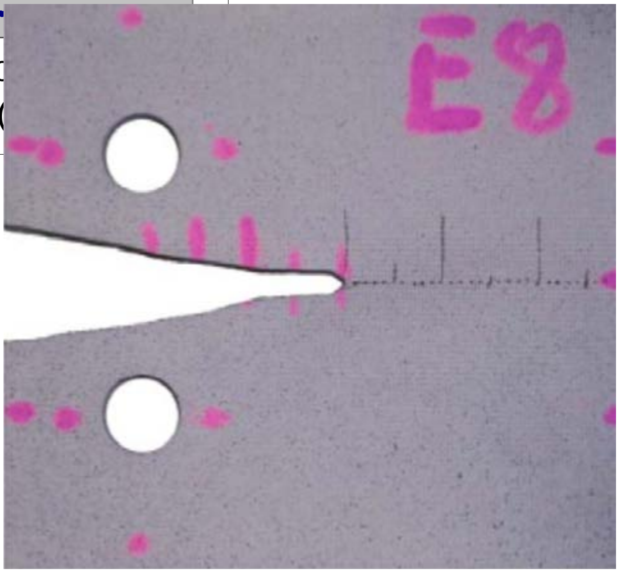
Salviato et al., Composite Science & Technology, 2016

Proposed methodology and research plan

- **Compact Tension**



Compact Compression



Salviato et al., Composite Science & Technology, 2016

Salviato et al., JAM, 2016

Pinho, Doctoral dissertation, London, 2005

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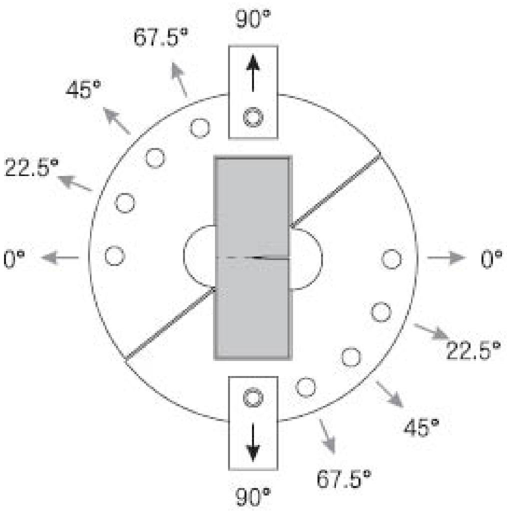
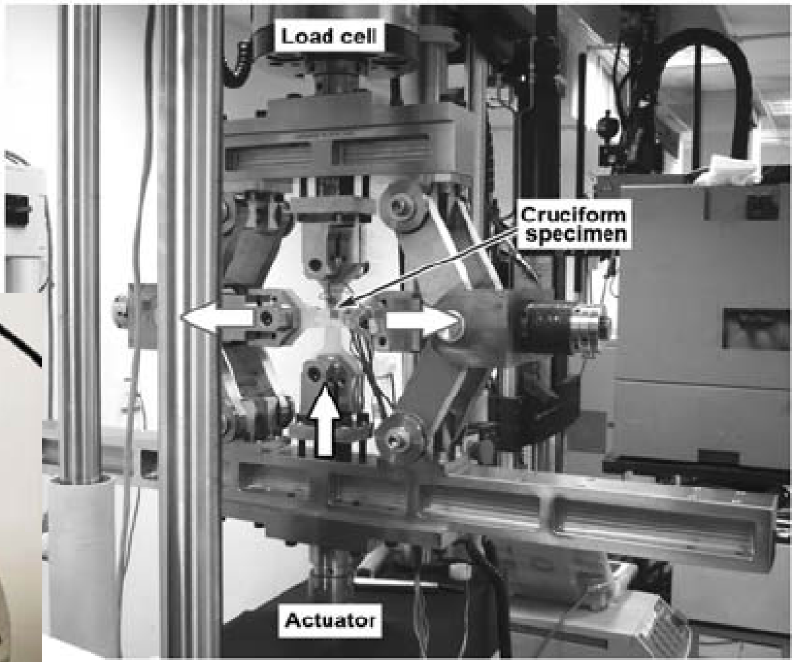
Proposed methodology and research plan

- **Multi-axial behavior**

Comprehensive experimental campaign on un-notched and notched specimens under biaxial loading with various thicknesses





Sun et al., Journal of Composites, 2012

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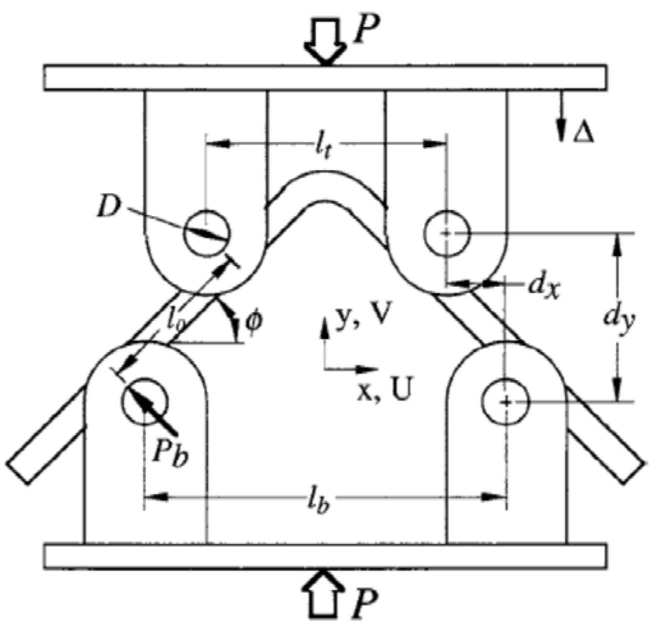
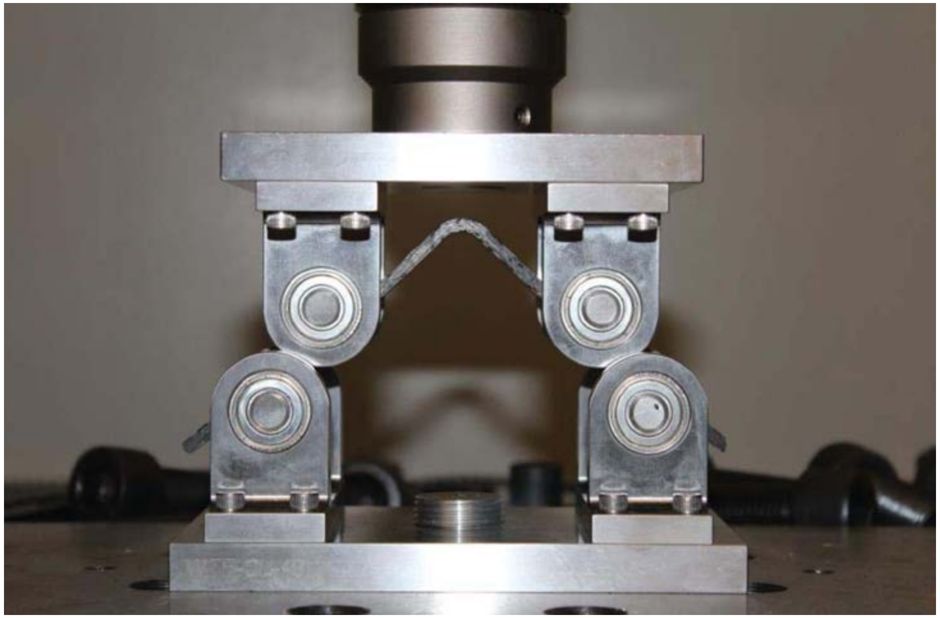
Proposed methodology and research plan

- **Curved beam testing**

Comprehensive experimental campaign on curved beam specimens with various thicknesses





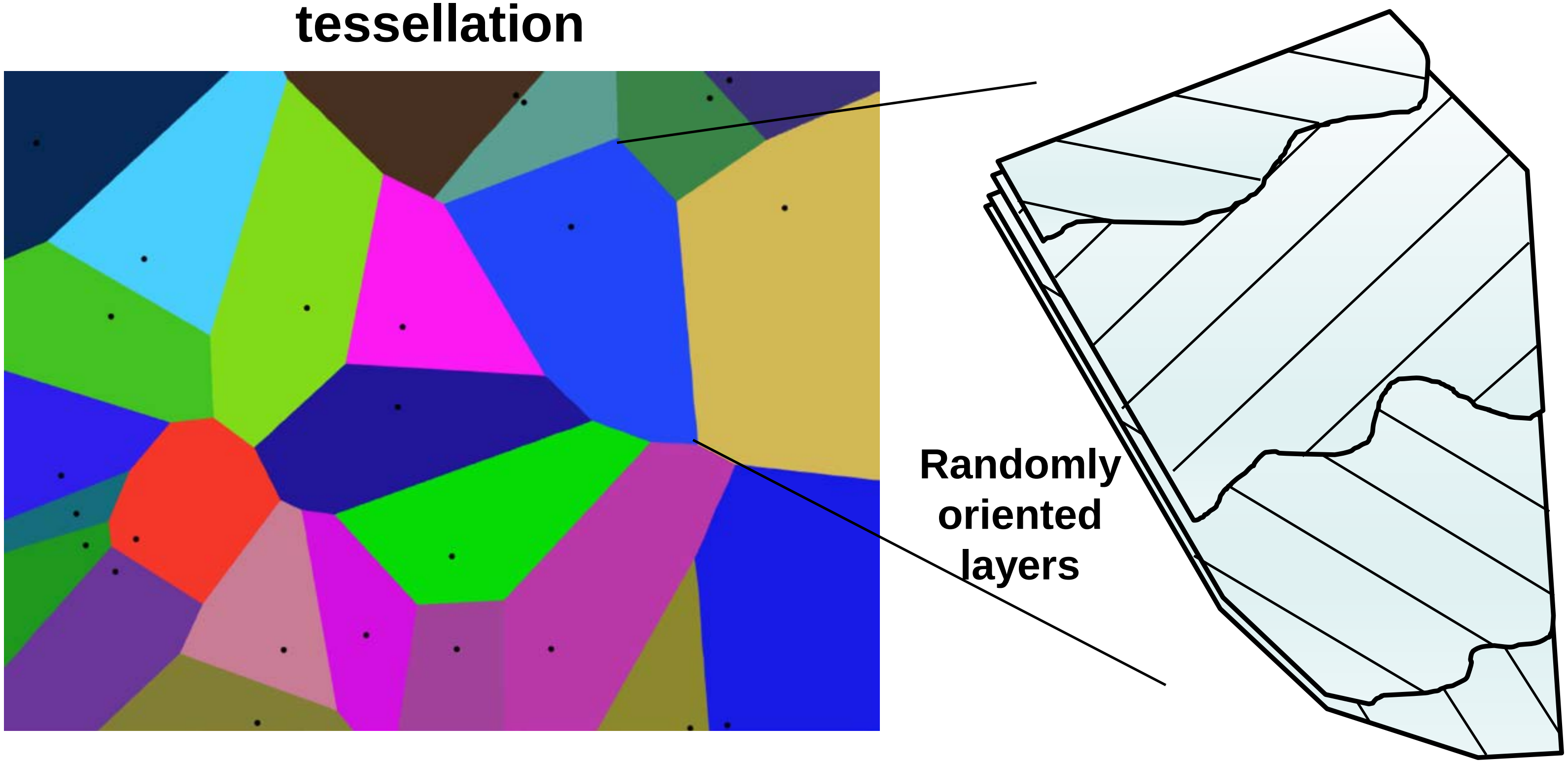
ASTM D6415

An example of size effect study to identify the critical defect size of DFC structures

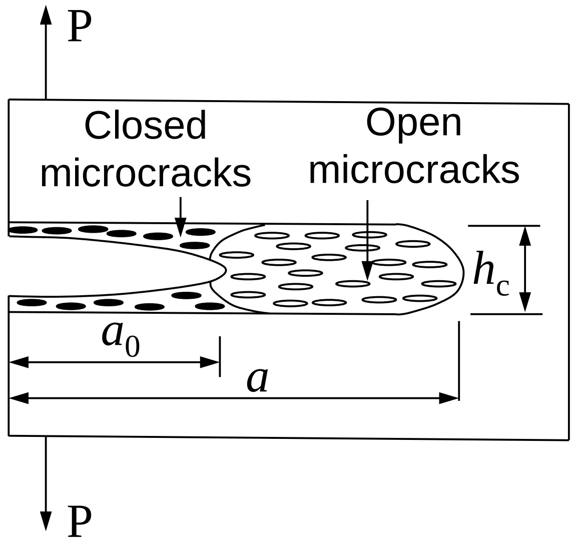
Stochastic Laminate Analogy

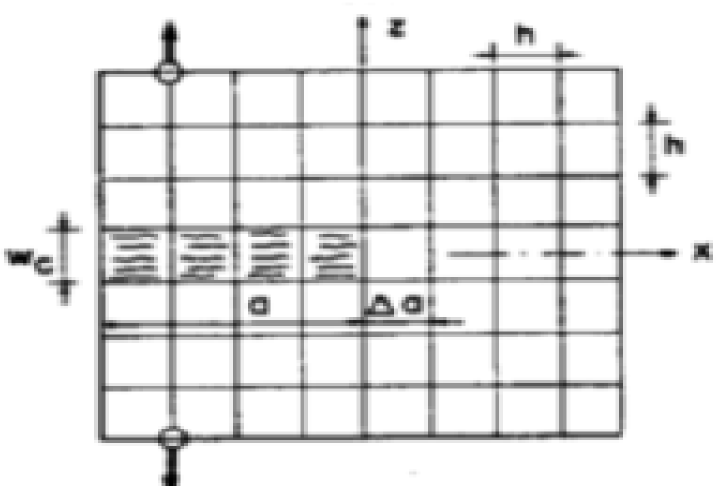
Discretization into RLVEs by Voronoi tessellation

Stochastic Laminate Analogy



Damage progression modeling



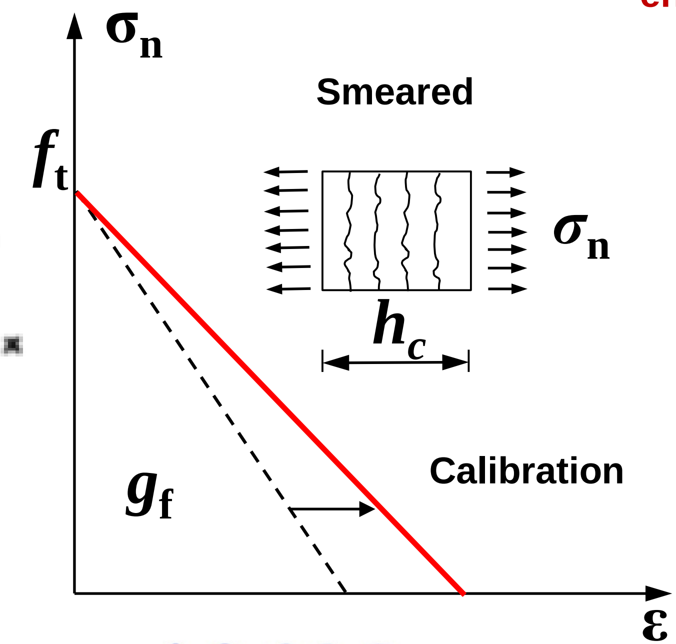


The crack is modeled as a *smeared crack band* with fixed width

$$h_c$$

the crack opening, W, is calculated as the product of average strain and band width

The post-peak softening response of the model is recalibrated to match the experimental fracture energy!



$$G_f = \int_{\varepsilon} \sigma(\varepsilon') h_c \mathrm{d}\varepsilon'$$

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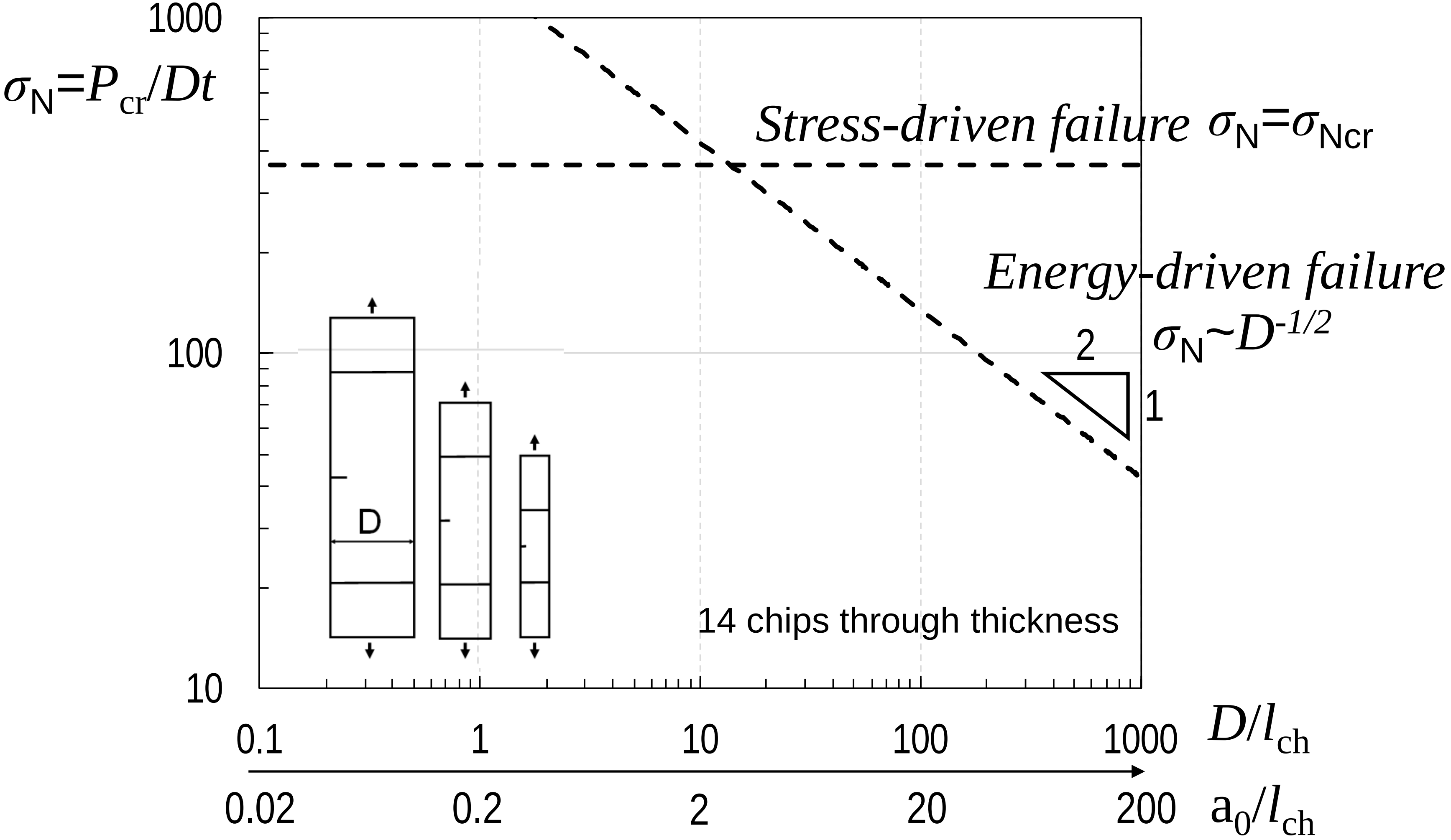
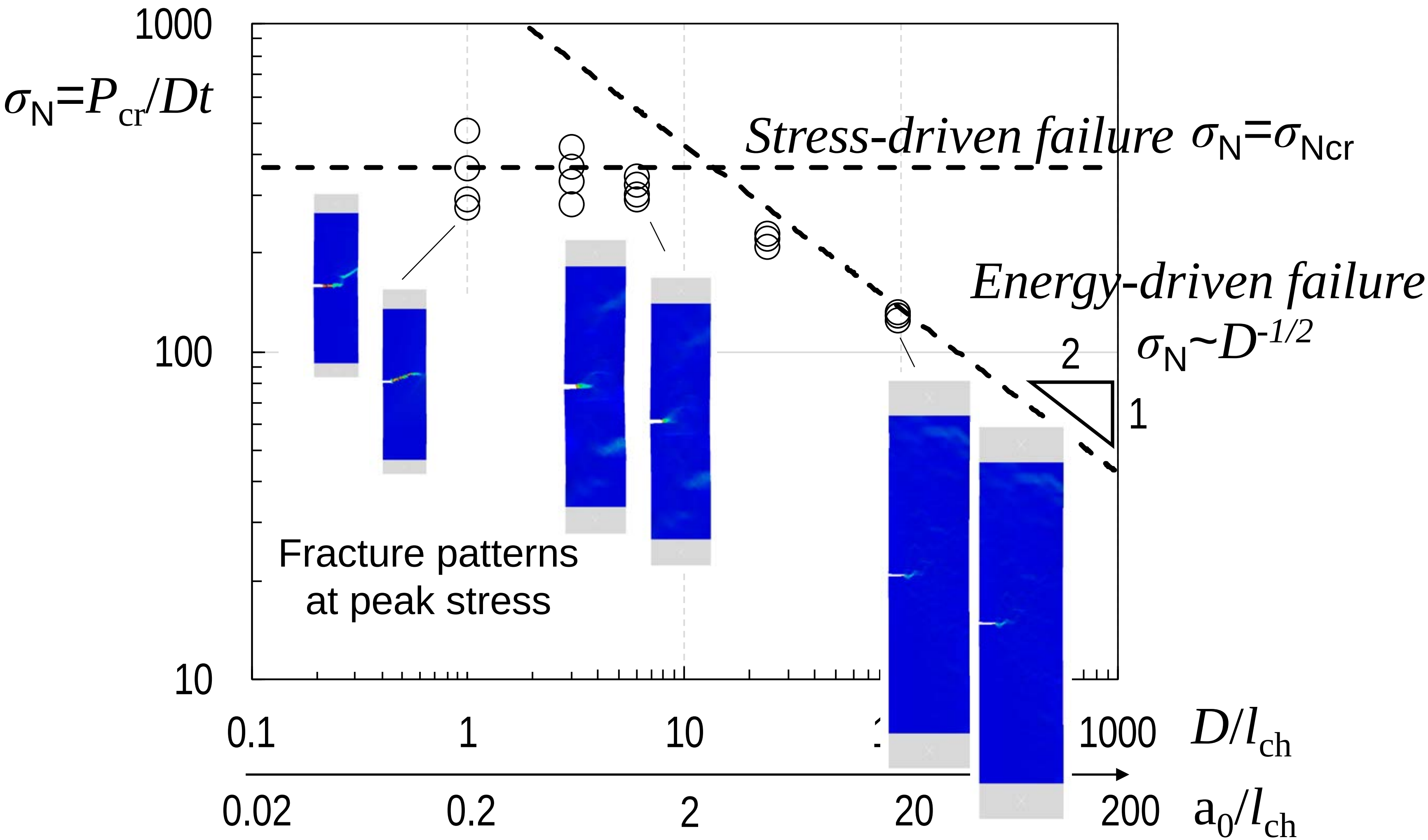
Critical defect size for DFCs



Critical defect size for DFCs



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Size effect law

Let's define the nominal stress in the specimen as:

$$\sigma_N = P/(tD) \qquad \begin{matrix} P = \text{applied load} & D = \text{width} \\ t = \text{thickness} & \end{matrix} \qquad (1)$$

the following expression holds for the initial fracture energy:

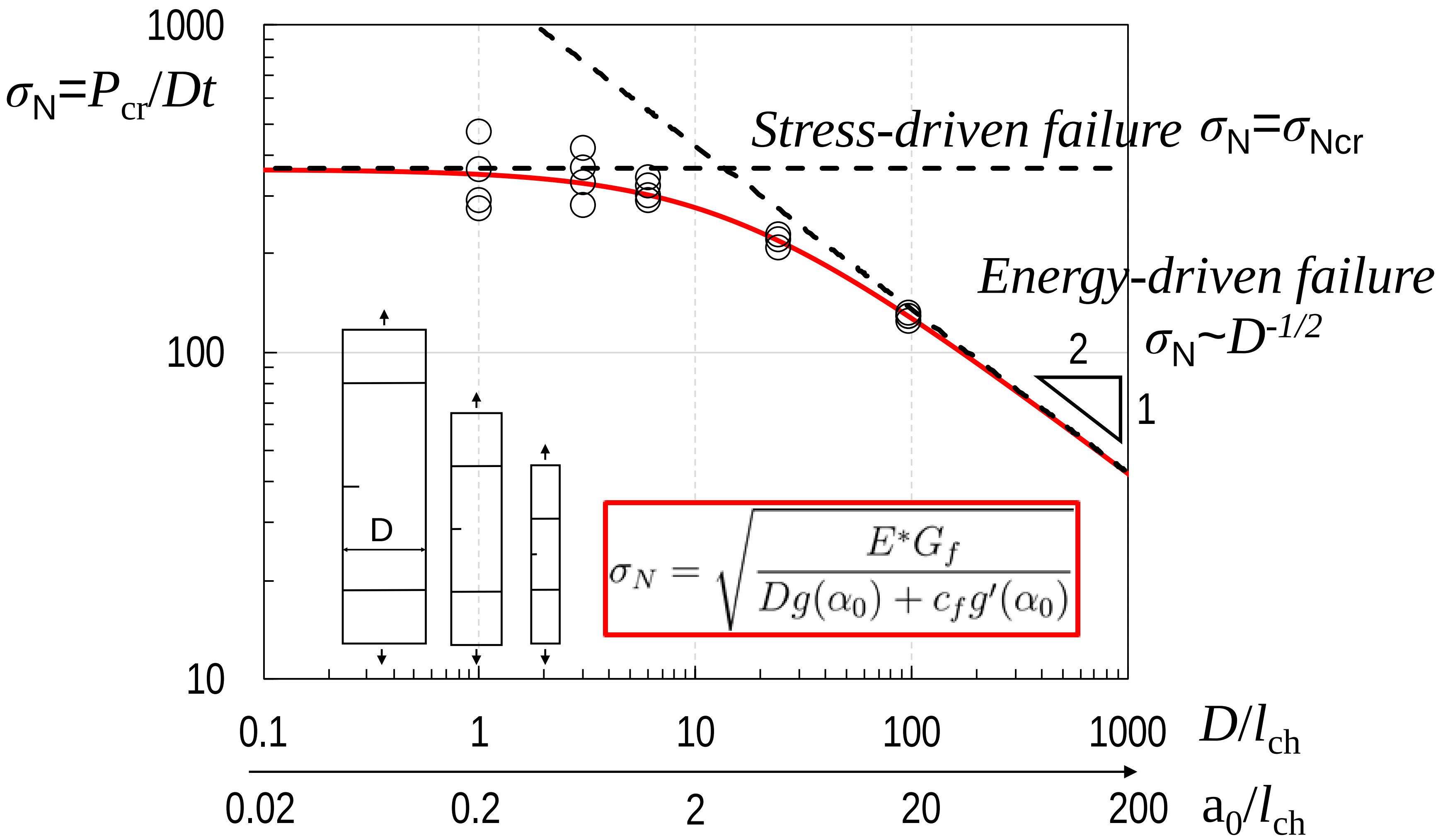
$$G_f(\alpha) = \frac{\sigma_N^2 D}{E^*} g(\alpha) = \frac{\sigma_N^2 D}{E^*} g(\alpha_0 + c_f/D) \qquad \begin{aligned} \alpha &= a/D \\ E* &= \text{effective modulus} \\ g &= \text{dimensionless energy release rate} \end{aligned} \qquad (2)$$

By expanding g in Taylor Series, retaining only 1st order terms and re-arranging:

$$\boxed{\sigma_N = \sqrt{\frac{E^* G_f}{D g(\alpha_0) + c_f g'(\alpha_0)}}} \qquad (3)$$

Bažant's Size Effect Law (SEL) for quasi-brittle materials (extended to DFCs)

Size effect of DFCs



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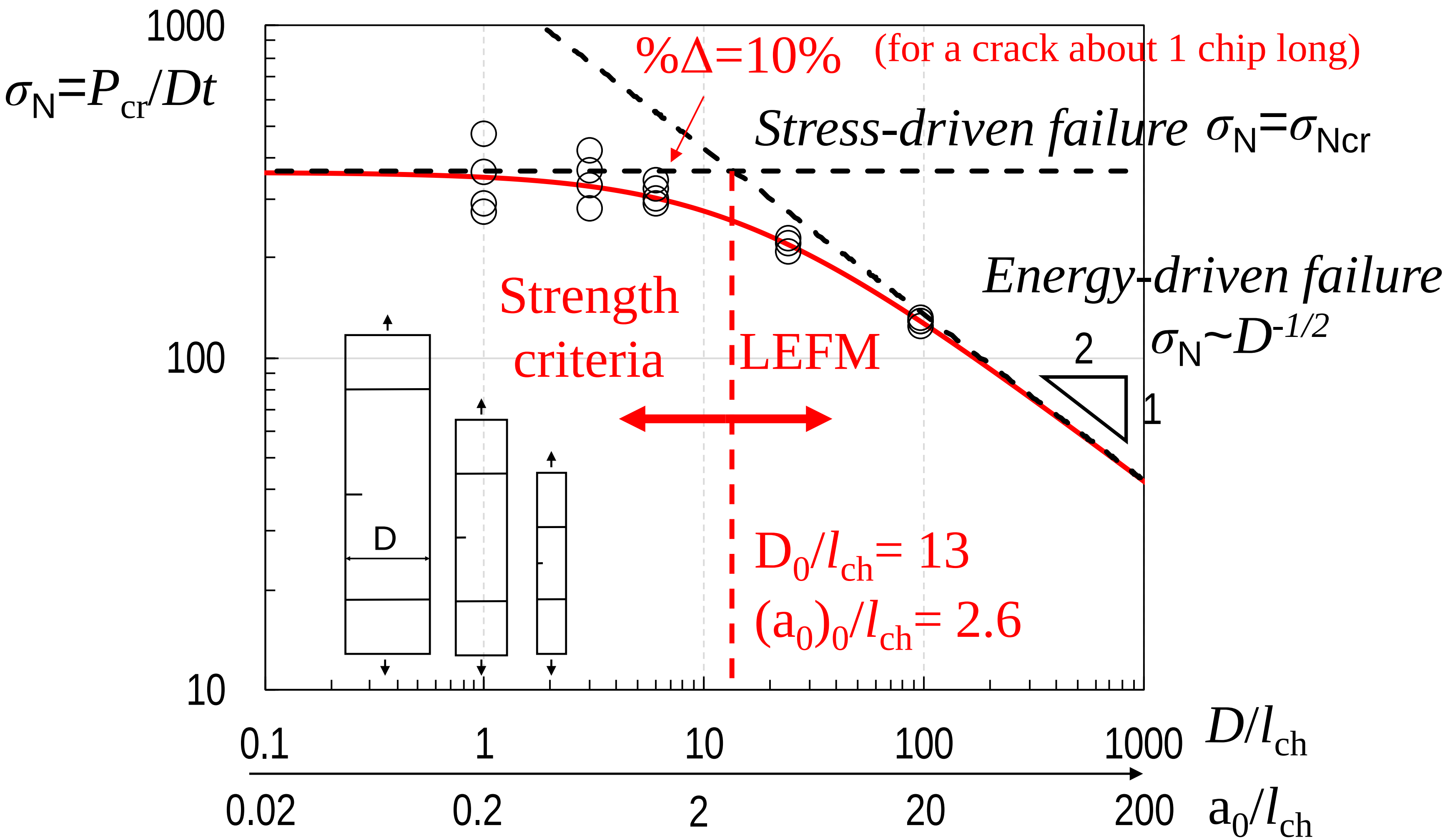
Critical defect size for DFCs



Conclusions

- The efficient design and certification of DFC structures urges the understanding of a) the main mechanisms of damage, b) the effects of multi-axial loading and c) defects and stress concentrators

- The proposed project aims at addressing the foregoing issues by coupling computer tomography, computational modeling and multi-axial experiments on notched and un-notched DFC structures

- An example of size effect study was provided. It was shown that a) the mechanical behavior of DFC structures strongly depend on the size of the structure compared to the chip size. Small structures behaves an quasi-ductile, larger structures as brittle; b) the transition between stress-driven failure and energy-driven failure occurs at crack lengths of about 2.6 chip size; c) for a crack about 1 chip long, the structural strength decreases of 10% only; d) this information is key for certification and for maintenance scheduling.

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