Experimental and Computational Exploration of the Fracture Energy in Fiber Composites When Subject to Crack Parallel Compression

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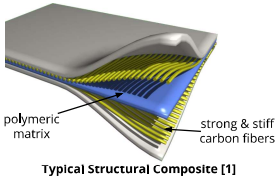
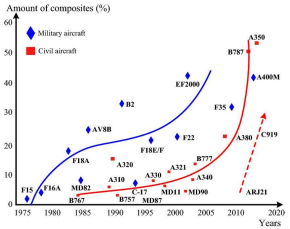
Motivation

- Composite Material: combination of two or more materials that are distinct at a physical scale > ~1 μm
- Used ubiquitously due to superior strength-to-weight, corrosion resistance, energy adsorption, and fatigue performance as well as having tailorable mechanical properties



Typical Structural Composite [1]



% weight of composite used in commercial and military aircraft [2]

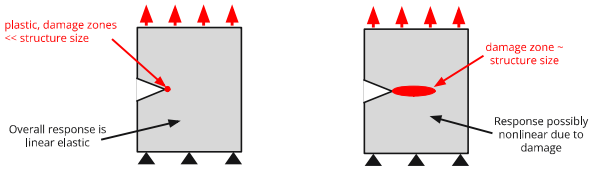
Commercial Aircraft Wingskin made of Carbon Fiber

- Composite fracture is a formidable challenge that is still a very active research area, despite their prevalence in industry.

It is the duty of the academic community to develop accurate, reliable, and efficient composite fracture analysis tools

Supporting Theory

- Foundational assumptions of the most developed fracture theory (LEFM) are too restrictive to apply to composites, must use a newer, developing theory (QBFM)

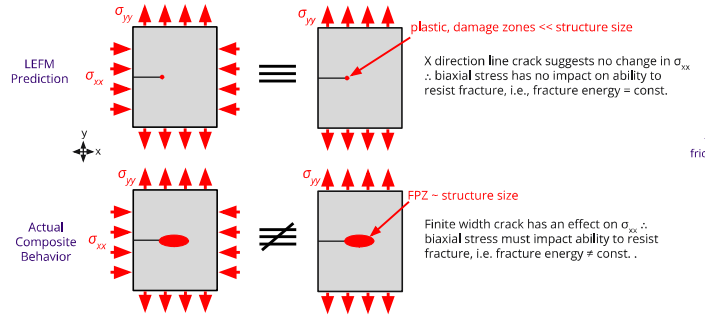


Linear Elastic Fracture Mechanics
- Accurate for brittle fractures: glass, ceramics, beryllium, etc.
- Assumes infinitely sharp cracks, global response linear elastic
- Studied since ~1920

Quasi-Brittle Fracture Mechanics
- Composites, concrete, shale, etc.
- Cracks have finite dimensions and global response can be nonlinear due to damage
- Studied in composites since ~1995

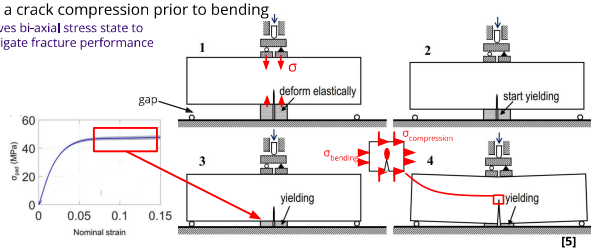
The Gap Test

- LEFM leverages a single parameter description of failure - fracture energy, G_f, is used to predict fracture and is assumed to be a constant material property
- Presence of a finite width FPZ in composites questions the constancy of fracture energy

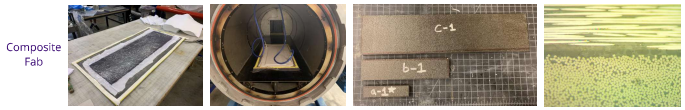


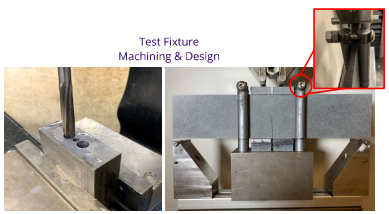
Manufacturing and Experimentation

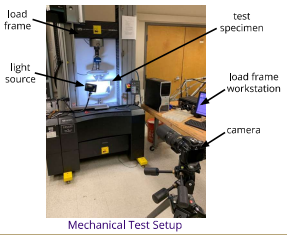
- Simple modification to standard 3PB test where plastic pads with a perfect yield plateau generate a crack compression prior to bending
  - Achieves bi-axial stress state to investigate fracture performance



- In house fab of composite test specimens, test fixture machining, and mechanical testing



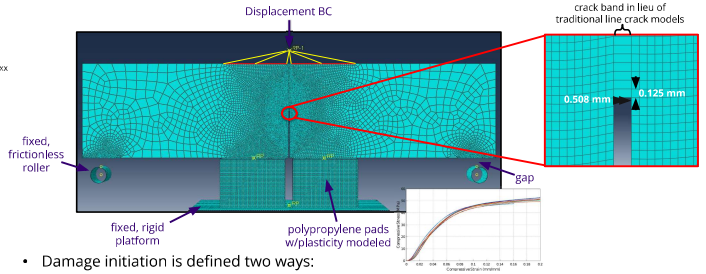




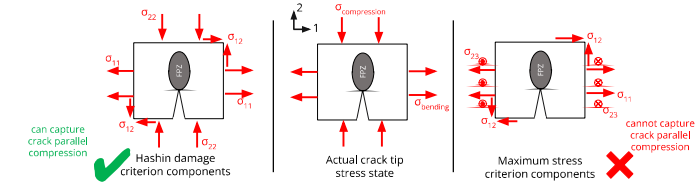
Mechanical Test Setup

Computational Framework

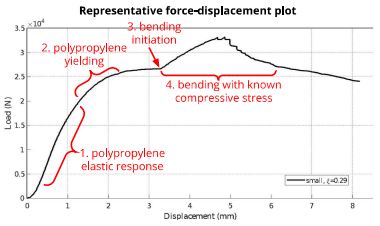
- Computational framework allows practicing engineers to appropriately model and predict a composite structure's behavior when crack parallel compression is experienced
- Correct modelling definition also obviates the need to undertake a large experimental effort

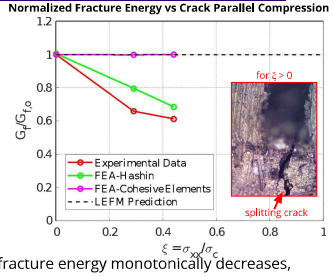


- Damage initiation is defined two ways:
  1) Hashin Damage Criterion, which is captures all the crack tip stresses (fully tensorial)
  2) Cohesive Elements + Maximum stress criterion, which does not capture all the crack tip stresses (reduced tensorial)



Results & Conclusions





1) As crack parallel compression is increased the fracture energy monotonically decreases, proving that fracture energy may be non-constant in composites
2) Crack parallel compression leads to a change in fracture morphology which expedites catastrophic failure, explaining the observed weakening effect
3) To capture the effects of crack parallel compression in composites a crack band model with a fully tensorial damage law must be used, otherwise specious results are obtained
4) Further investigation is required for: crack parallel tension and shear, in-plane and out of plane, mixed mode and fatigue loading, and differing layup sequences and geometries

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References

[1] en.wikipedia.org/wiki/Composite_material
[2] Zhang, L., Wang, X., Pei, J. et al. Review of automated fibre placement and its prospects for advanced composites. J Mater Sci 55, 7121–7155 (2020). https://doi.org/10.1007/s10853-019-04090-7
[3] www.newscientist.com/article/dn12951-composite-aircraft-may-hide-dangerous-flaws/
[4] Beaumont, P.W.R. The Structural Integrity of Composite Materials and Long-Life Implementation of Composite Structures. Appl. Compos. Mater. 27, 449–478 (2020). https://doi.org/10.1007/s10443-020-09822-6
[5] Nguyen, H. T., Pathirage, M., Cusatis, G., and Bažant, Z. P. (May 29, 2020). "Gap Test of Crack-Parallel Stress Effect on Quasibrittle Fracture and Its Consequences." ASME. J. Appl. Mech. July 2020; 87(7): 071012