Fracture and fatigue in wood-based materials

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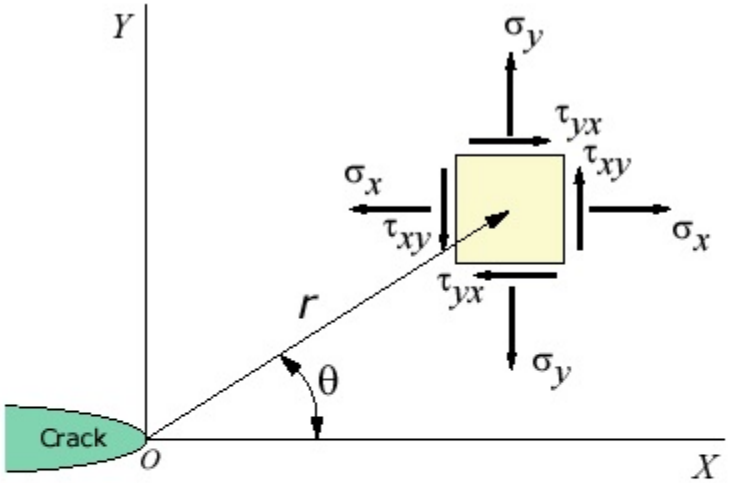
An emerging consensus in the structural materials science is that fracture properties are a much better indicator of real-world durability than more commonly measured properties such as modulus (MOE), strength (MOR), or qualitative failure tests.

http://www.nairaland.com/495832/real-reasons-titanic-sank-noahs

Intro to fracture mechanics

Stress intensity approach

Stress intensity approach is a mathematical solution to map stresses, strains and displacements ahead of the crack using Hook's law



$$\lim_{r\to 0}\sigma_{ij}^{(I)} = \frac{K_I}{\sqrt{2\pi r}} f_{ij}^{(I)}(\theta)$$

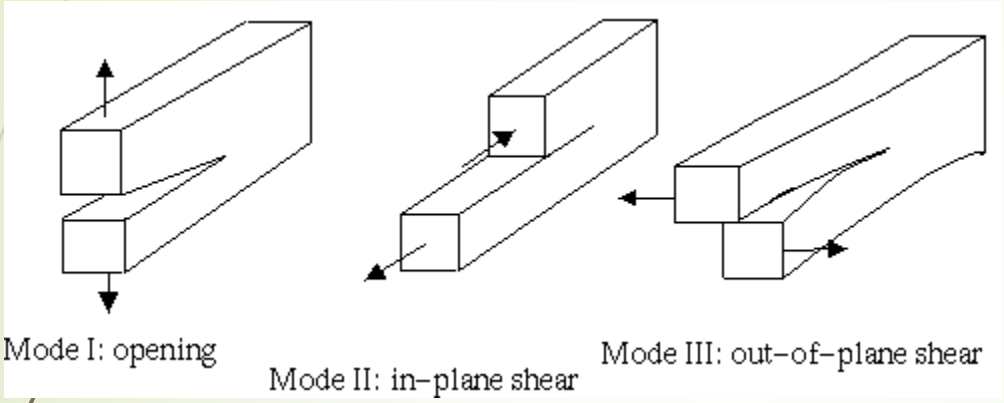
$$\lim_{r\to 0}\sigma_{ij}^{(II)} = \frac{K_{II}}{\sqrt{2\pi r}} f_{ij}^{(II)}(\theta)$$

$$\lim_{r\to 0}\sigma_{ij}^{(III)} = \frac{K_{III}}{\sqrt{2\pi r}} f_{ij}^{(III)}(\theta)$$

https://www.efunda.com/formulae/solid_mechanics/fracture_mechanics/fm_lefm_K.cfm

Intro to fracture mechanics

Modes of Fracture

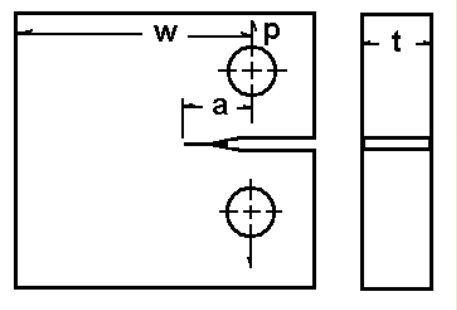


http://simscience.org/cracks/advanced/math1.html

$$K = Y\sigma\sqrt{\pi\, a}$$

Fracture tests for wood and wood composites

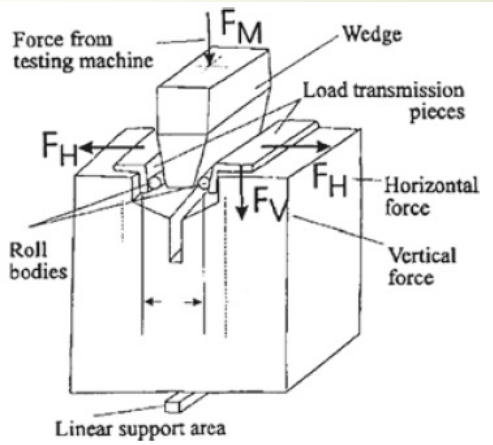
Commonly used methods:



- ASTM E399

actually developed for brittle, isotropic and homogeneous materials

- Only initiation toughness
- For self-similar crack growth (propagating straight with constant process zone size)



- Total work of fracture (usually wedge splitt

integration of load displacement envelop

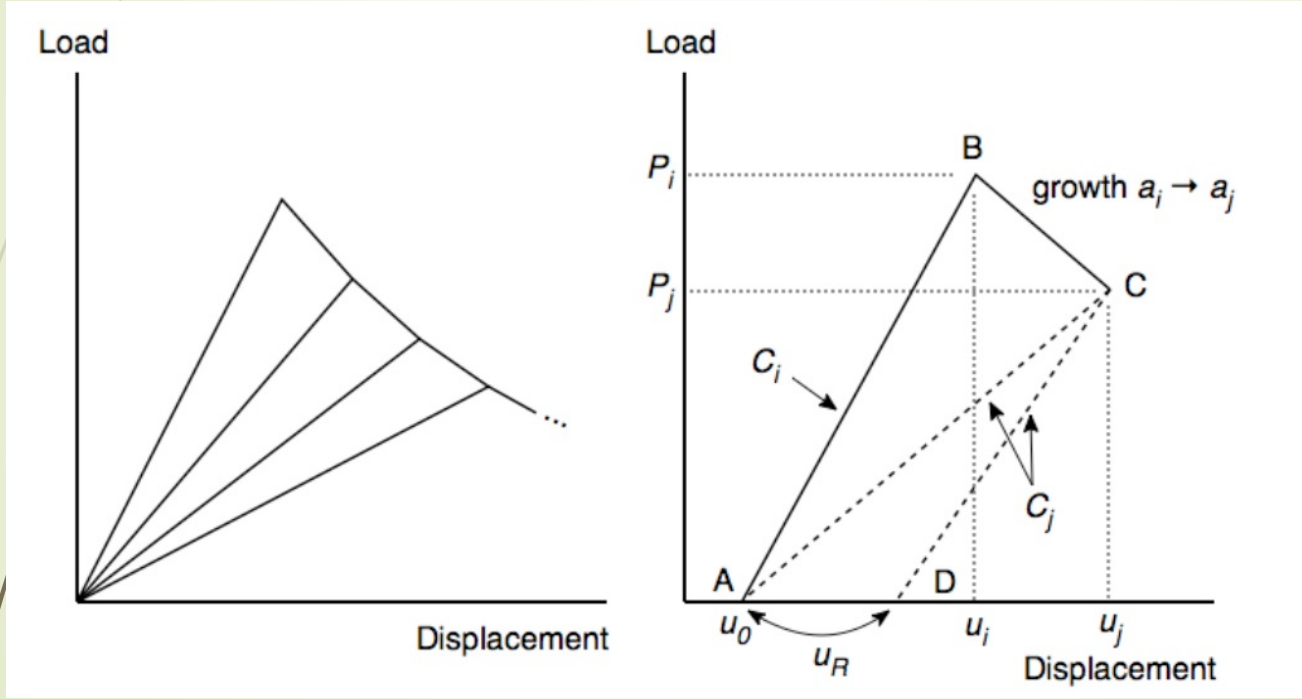
- Simple but not real fracture mechanics
- An average at best

<u>None of them take into account the incremental effect of crack growth</u>

Intro to fracture mechanics

Energy approach

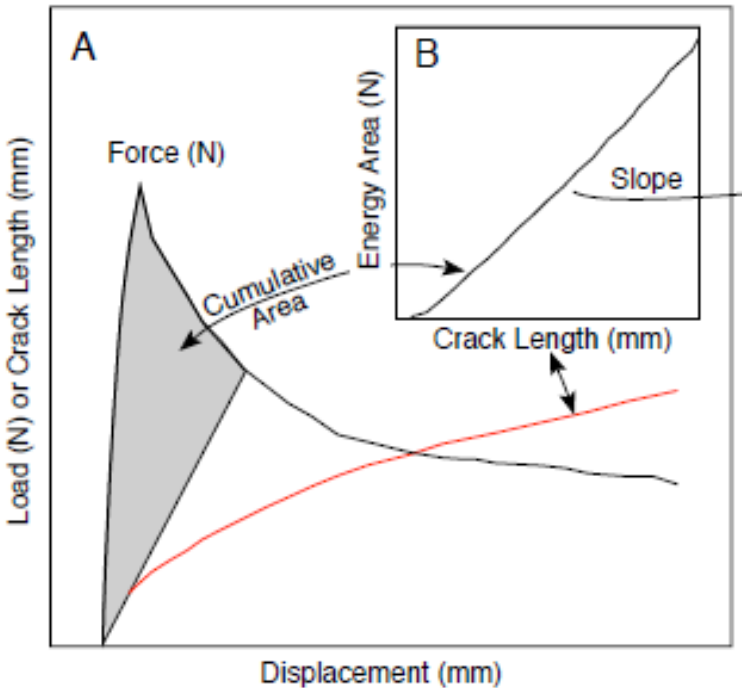
The fracture toughness is the energy per unit fracture area

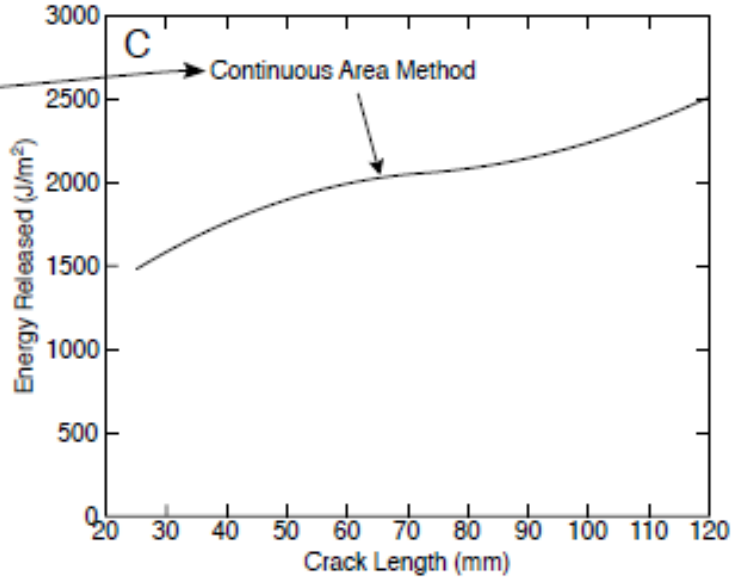


Left: load displacement curve for elastic fracture where the test is periodically stopped and unloaded. Right: A single loading and unloading envelop. Elastic fracture follows path ABC. Fracture with residual displacements follows path ABCD.

From: Noah Matsumoto and John A. Nairn, "The Fracture Toughness of Medium Density Fiberboard (MDF) Including the Effects of Fiber Bridging and Crack-Plane Interference," Engr. Fract. Mech., 76, 2748-2757 (2009).

Revised energy method

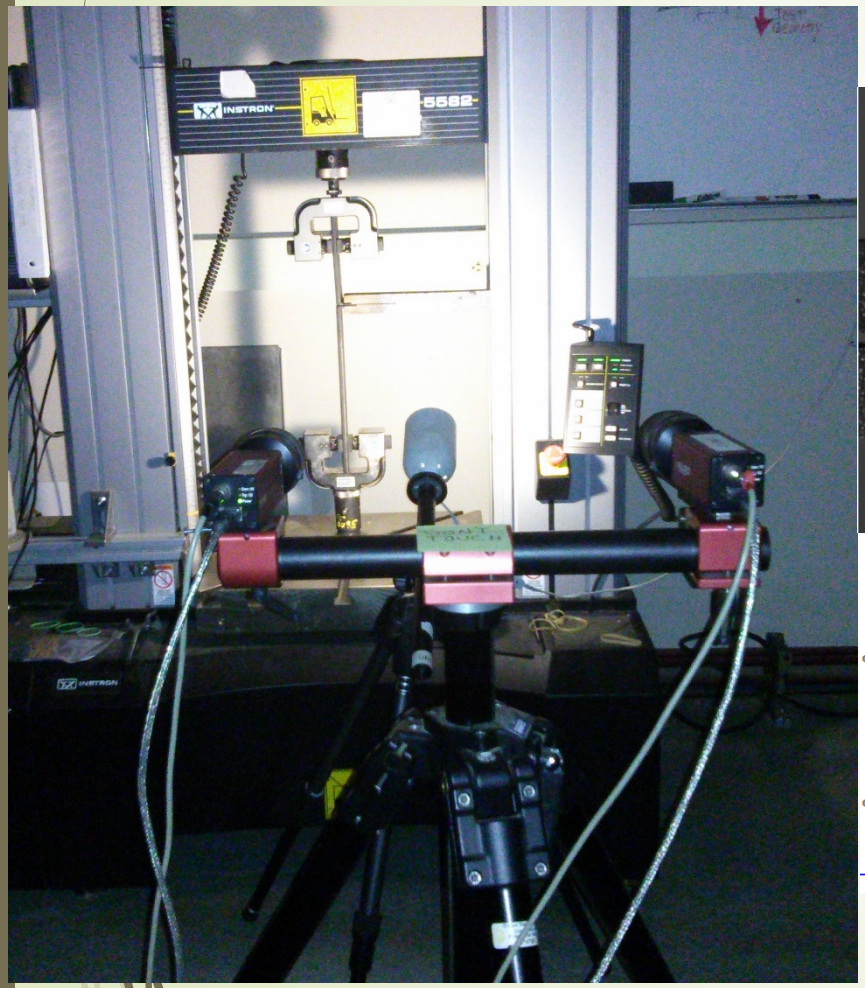


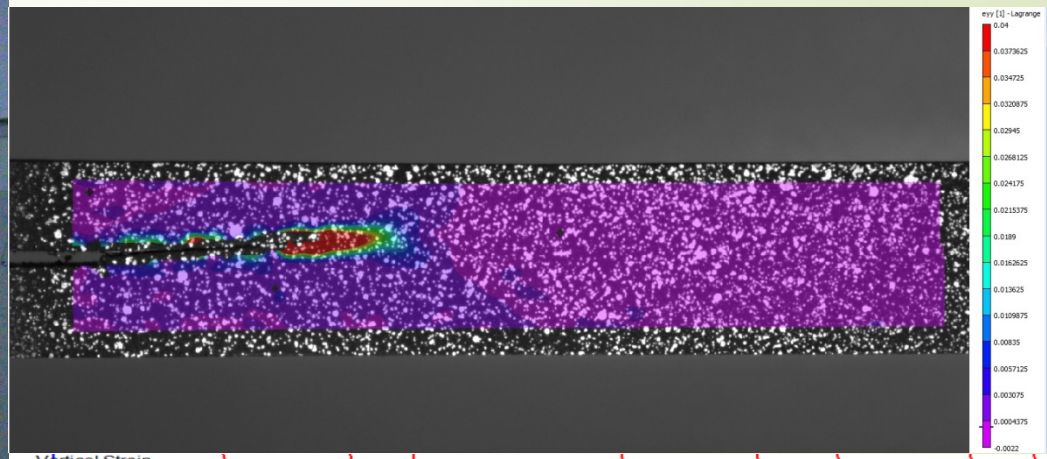


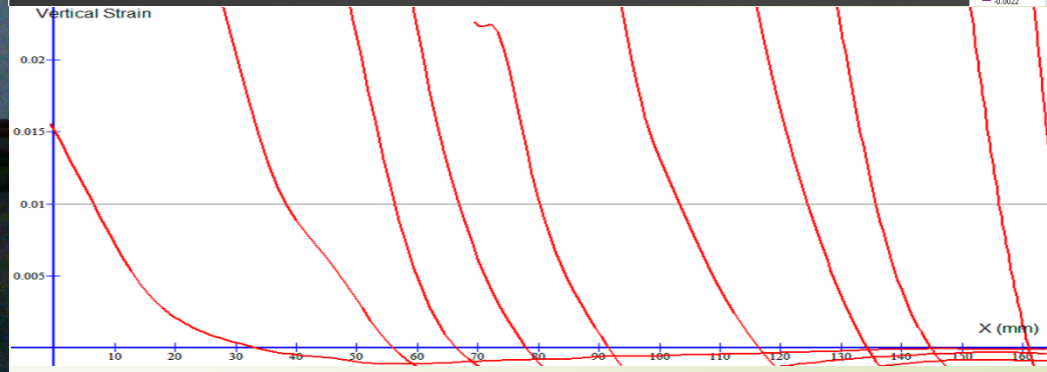
$$U(d) = \frac{1}{B}\left(\int_0^d F(x)dx - \frac{1}{2}F(d)d \right)$$

From: Matsumoto N. and Nairn J. (2009) The fracture toughness of medium density fiberboard (MDF) including the effects of fiber bridging and crack–plane interference. Engineering Fracture Mechanics 76:18

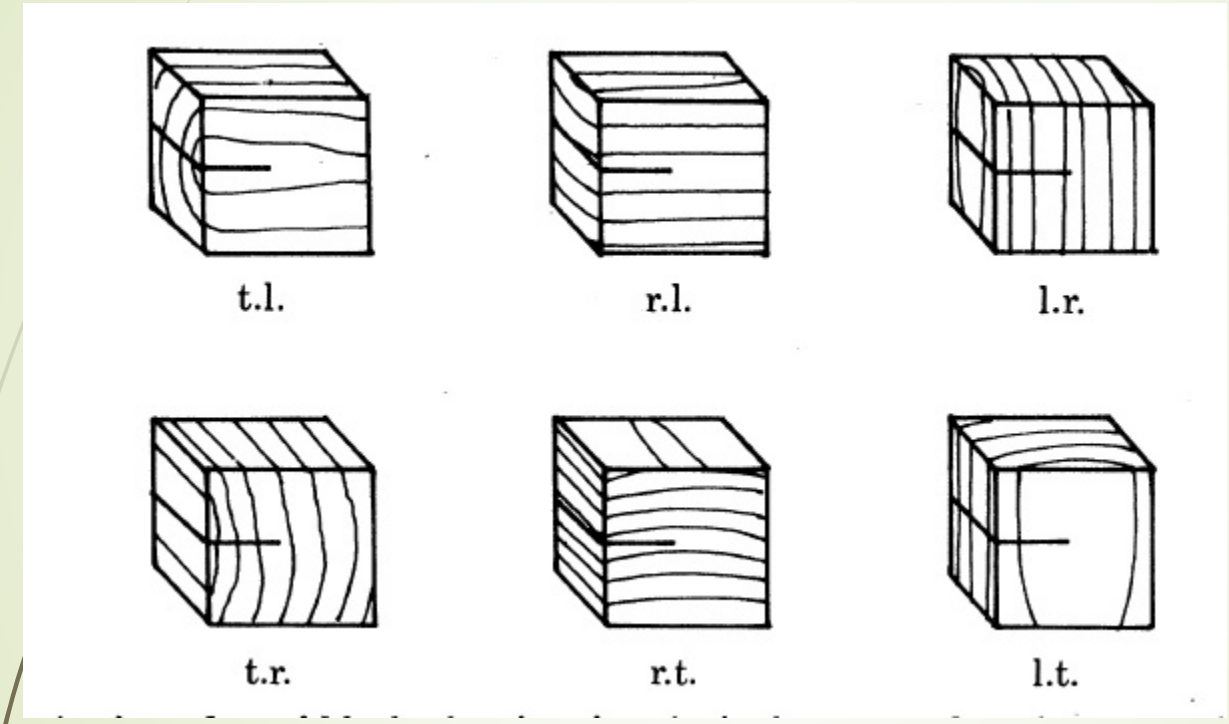
DIC crack measurement





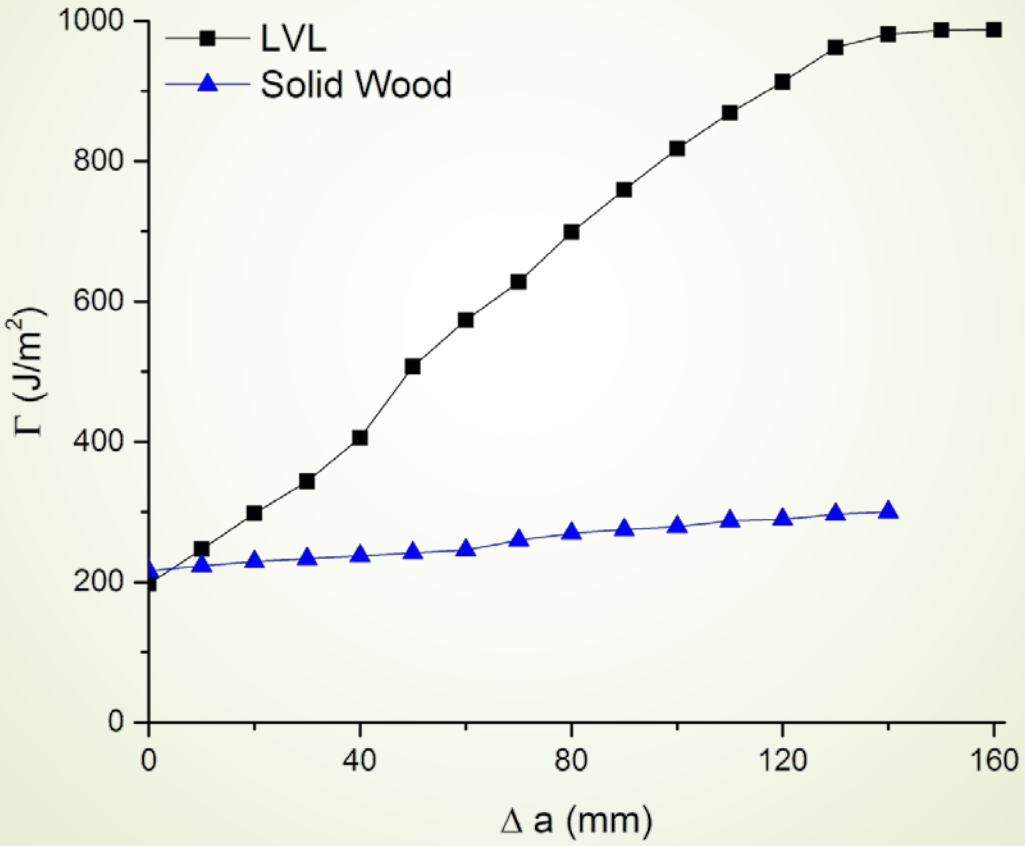


Fracture orientations relative to wood growth axis



BARRETT, B. J. D., 1981. Fracture mechanics and the design of wood structures. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences,* pp. 217-226.

Fiber bridging in monotonic loading



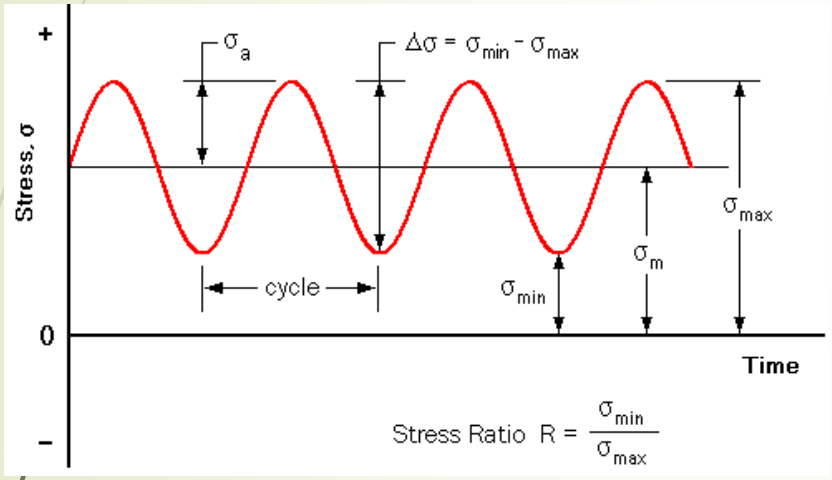
TL Fracture Surfaces
Wood vs. LVL

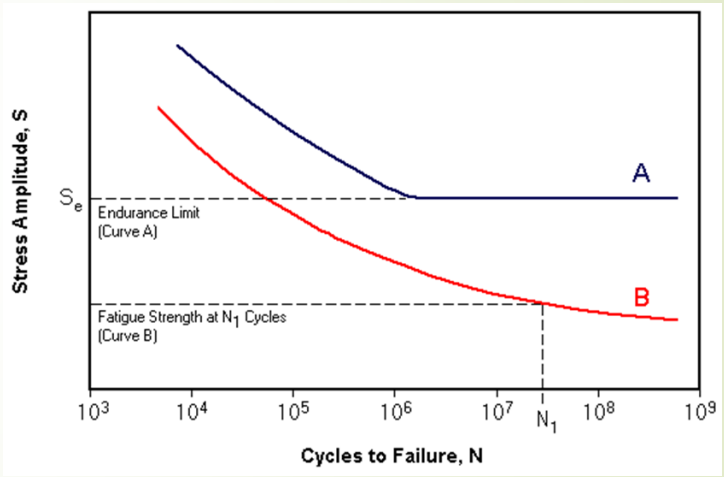
Fatigue

Fatigue

Empirical relations

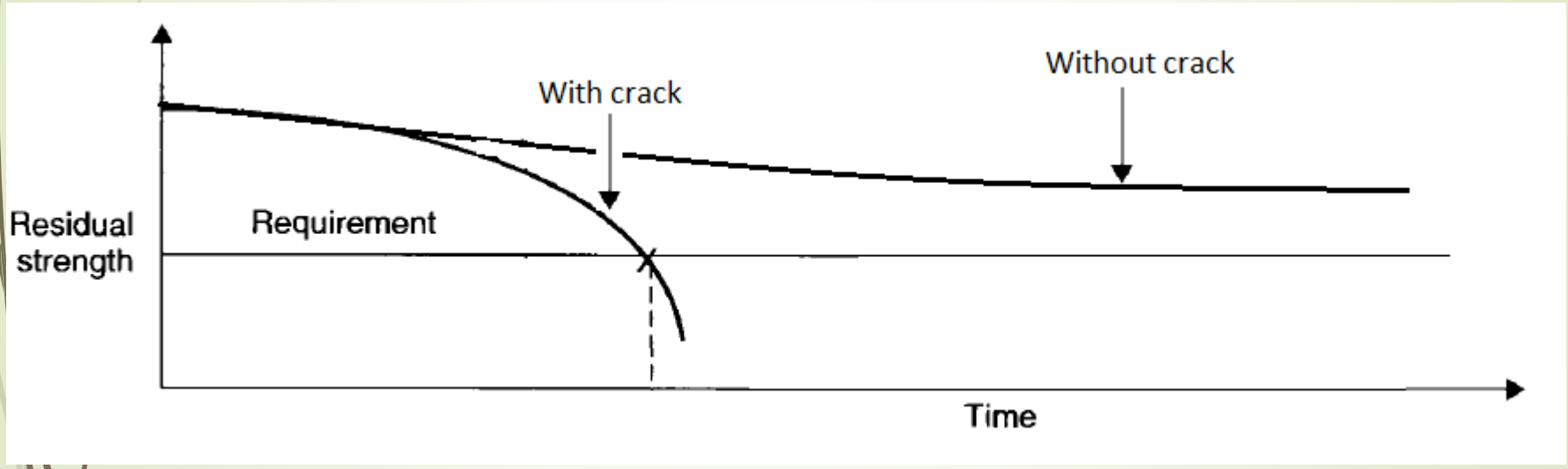
Uncertainty is a problem with S/N approach to fatigue



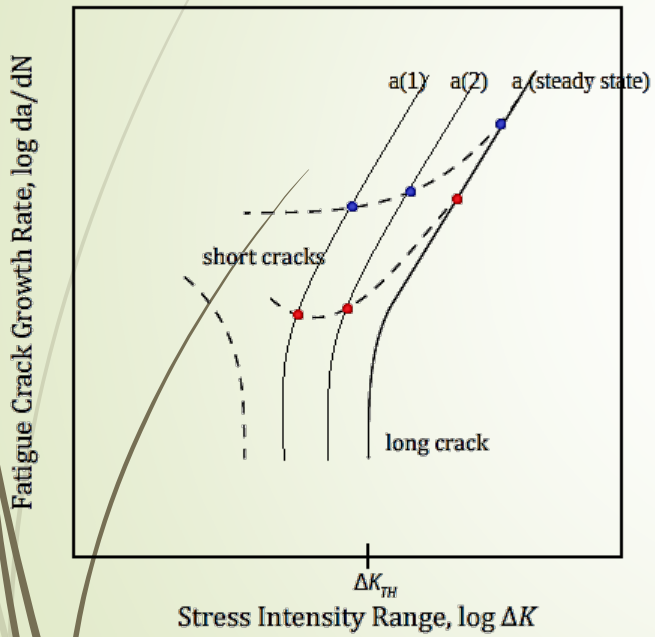


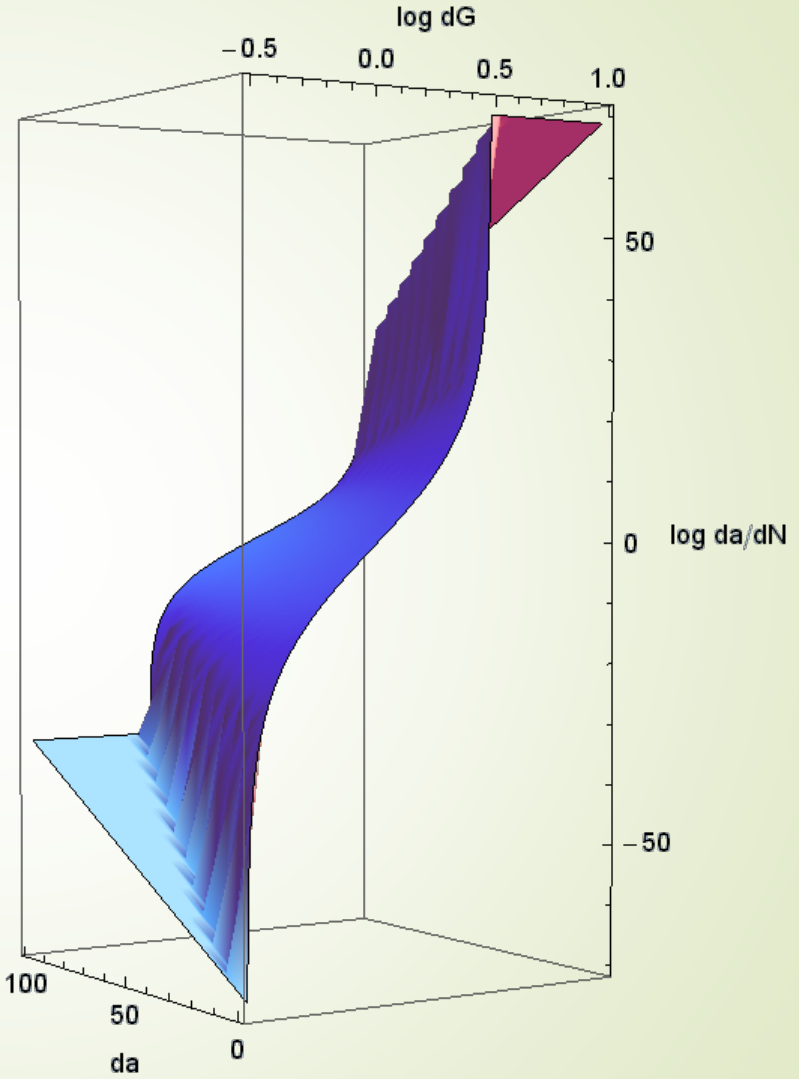
Typical cyclic loading parameters
www.fea-optimization.com

Effect of crack presence on lifespan

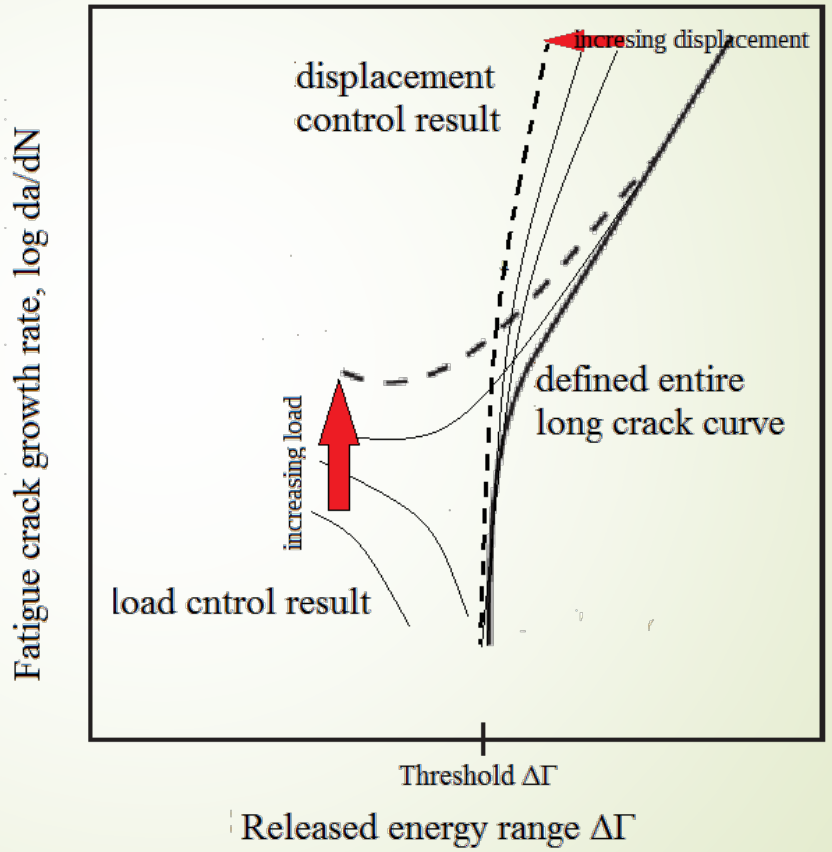


Effect of crack bridging on fatigue





Defining long crack fatigue



- Fatigue crack analysis has been extended to other bridging materials such as fiber reinforced PMC and bridging ceramics, but not to wood-based materials,

- Wood-based material has very long bridging zone, which demands certain considerations.

- Wood composites are more homogeneous than solid wood,

But,

cracks, voids and checks are always present, which makes the application of crack-based fatigue analysis a proper approach.