Interlaminar Fracture and Fatigue Characterization of Laminated Composites

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Project Goals

Develop Methodologies and Validated Analysis Tools for Fatigue Life and Residual Strength Prediction for Composite Rotorcraft Structures

(1) Improved Safety - Certification by Analysis
(2) Improved Durability - Reduced Life Cycle Costs
(3) Improved Accept/Reject Criteria

Approach

Collaborative research between NASA and U.S. Rotorcraft Companies with the Center for Rotorcraft Innovation, CRI, to design, test and analyze representative validation test articles

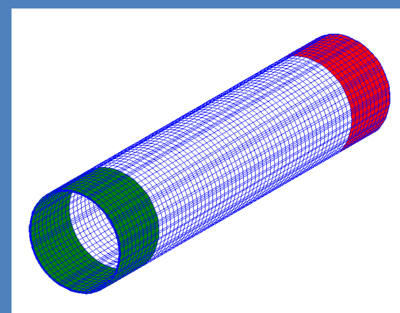
(1) Representative problems and designs developed with partners
(2) Validation articles and characterization specimens manufactured by partners
(3) Analysis done using specific data and commercial codes

Durability and Damage Tolerance Validation Articles

Representative Loading	Representative Geometry	Potential Application Area

Composite Tube

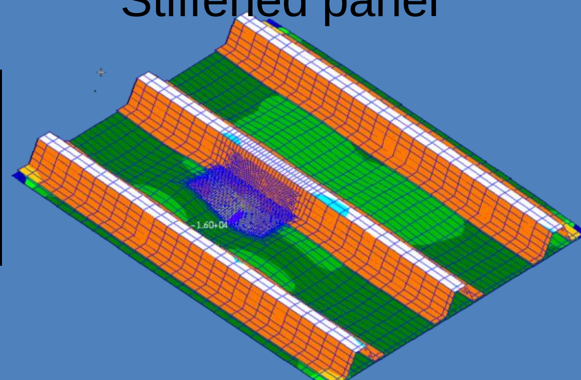
Tension/Torsion Fatigue Loading With Teflon Insert



Helicopter Rotor Blade Spar

Stiffened panel

Compression Fatigue Loading
Post Impact (BVID)



Tilt Rotor Wing

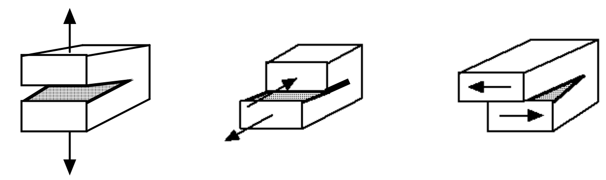
Background - Delamination Characterization

Needed Properties

- *Fracture Toughness*
- *Fatigue Onset*
- *Fatigue Crack Growth*

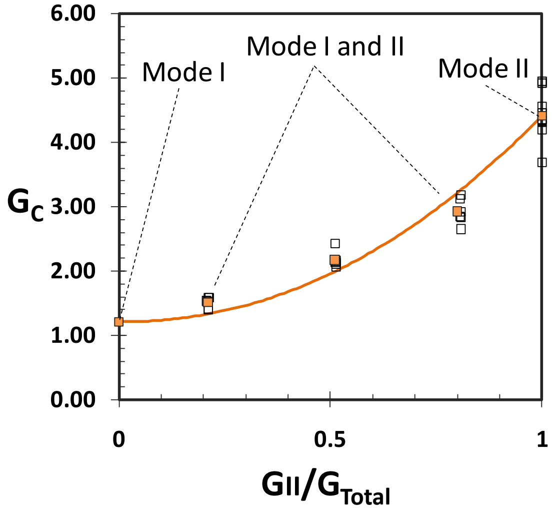
Energy Release Rate

$$G = \frac{P^2}{2B}\frac{dC}{da}$$

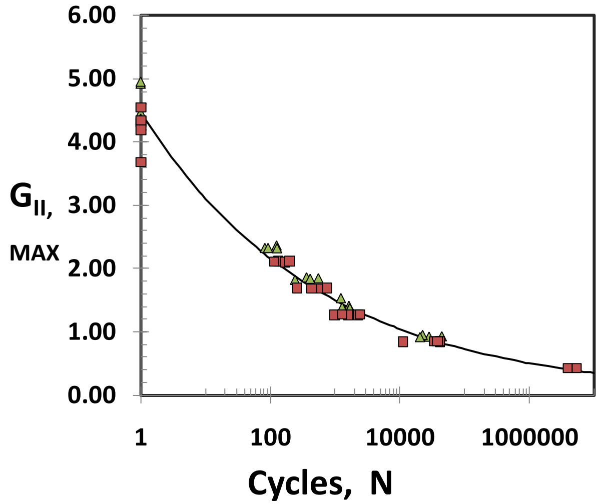


crack opening Mode I | in plane shear Mode II | Tearing Mode III

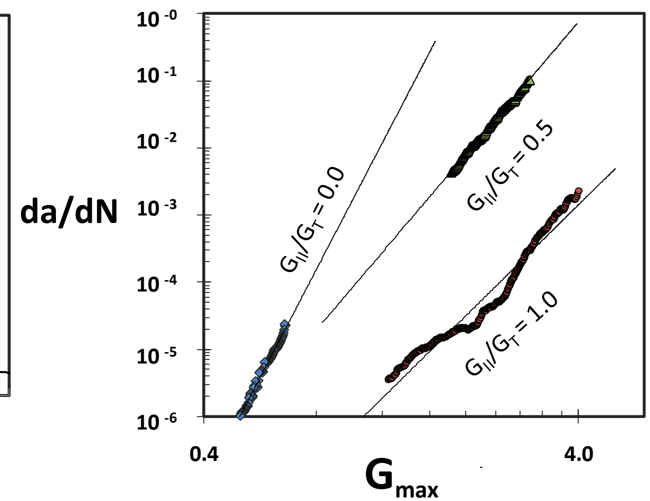
Mode I, II, I&II Static Fracture Toughness



Fatigue Onset



Mode I/II Fatigue Growth



Interlaminar Characterization Objectives

•Provide material properties for input to validate delamination modeling in test articles (IM7/8552)

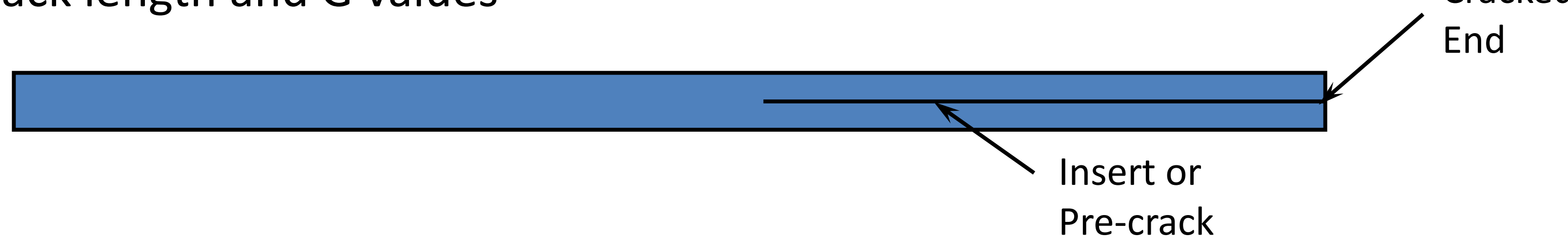
•Develop test methods and refine existing standards for evaluating interlaminar fatigue and fracture in laminated composites

•Understand the mechanics of delamination failure during testing to ensure that valid, applicable, and reliable mechanical property data is developed

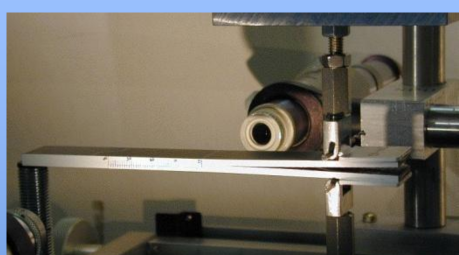
Specimens and Interlaminar Test Methods

•Test specimen consists 24 ply unidirectional laminate of IM7/8552 with Teflon (PTFA) insert embedded in mid-plane at one end as starter crack

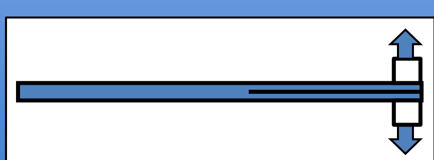
•Relationship between compliance and crack length used to determine crack length and G values



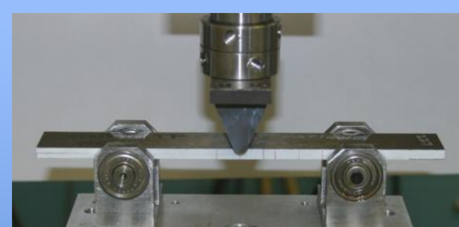
Mode I



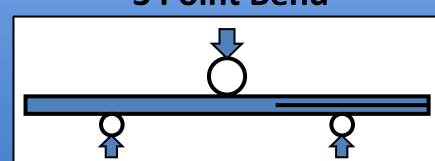
Double Cantilever Beam (DCB)



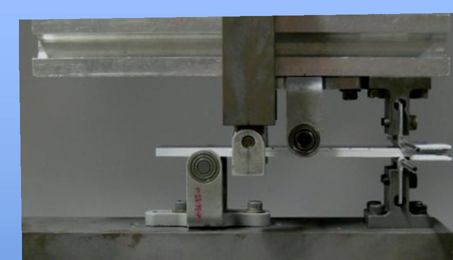
Mode II



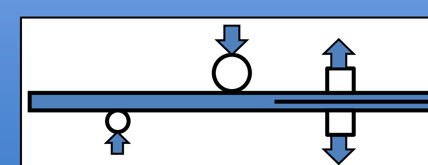
End Notch Flexure (ENF)
3 Point Bend



Mixed Mode I/II



Mixed Mode Bending (MMB)



Interlaminar Test Standards

Characterization Methods

- *Established Standards*
- *Draft Standards*
- *Internal Methods*

Related ASTM Activities

- *Evaluating Draft Standards*
- *Round Robin Testing*
- *Developing Procedure for Future Test Standards*

ASTM Standards	Mode I (DCB)	Mode II (ENF)	Mode I&II (MMB)
Fracture Toughness	D 5528	Draft	D6671
Fatigue Onset	D 6115	None	None
Fatigue Crack Growth	Draft	None	None

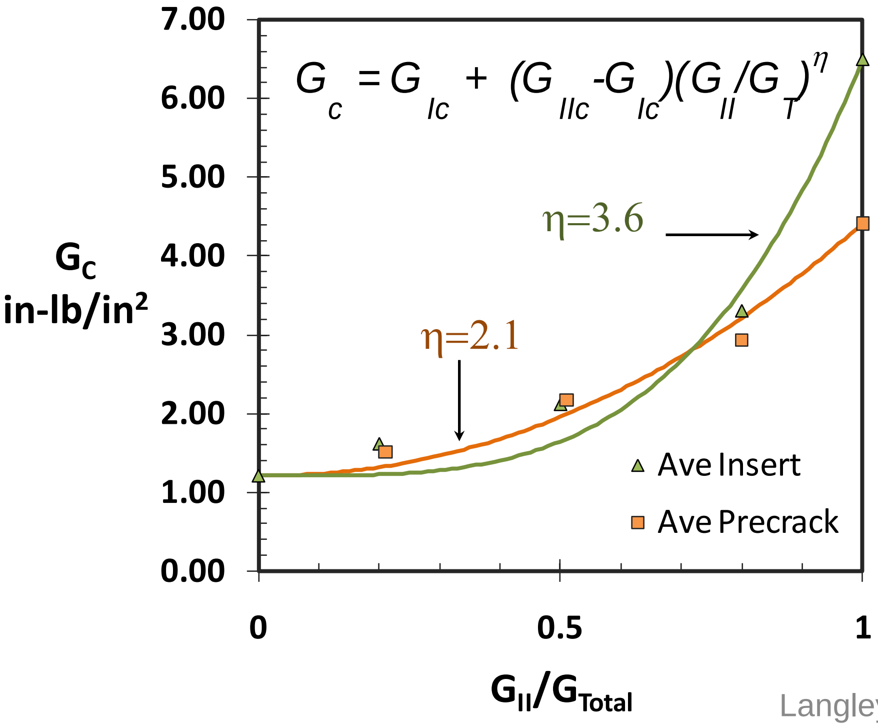
Developed internal methods, when none were available, based on experience and existing test standards and draft standards.

Fracture Toughness of IM7/8552

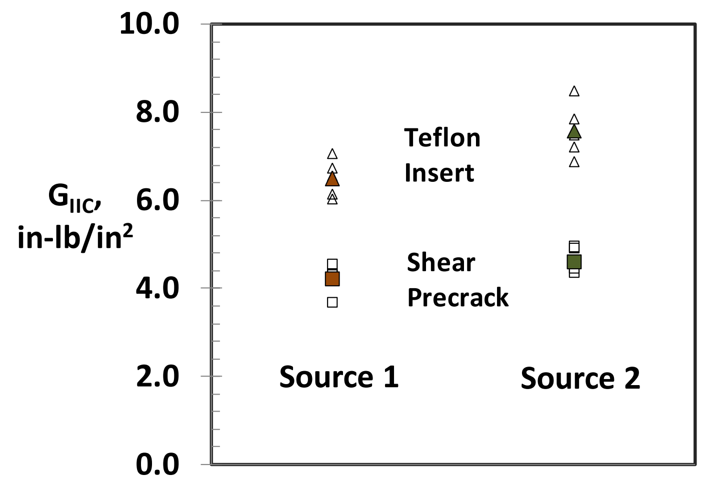
Test Matrix

- Tested mixed mode ratios from Mode I to Mode II (G_{II}/G_C = 0.0, 0.2, 0.5, 0.8, 1.0)
- Tested specimens form 2 different manufacturers for Modes I and Mode II
- Mode II specimens tested from insert and precrack

Fracture Toughness Mode I/II



Mode II Fracture Toughness



Results

- Similar toughness values form 2 different manufacturers for Mode II
- Mode II produced relatively low scatter (CV<10%) compared to other characterizations in literature
- Specimens yield higher toughness values from insert than from precrack in the Mode II dominated cases

Fatigue Onset of IM7/8552

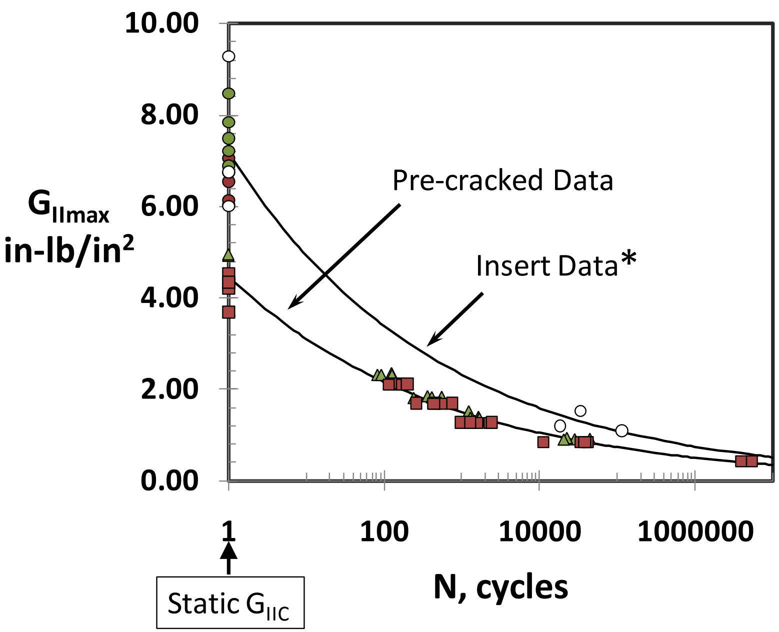
Test Matrix

•Tested from Mode I to Mode II (G_{II}/G_C = 0.0, 0.2, 0.5, 0.8, 1.0)

•Tested at initial loading for G_{max} = 50%, 40%, 30%, 20% and 10% of G_c

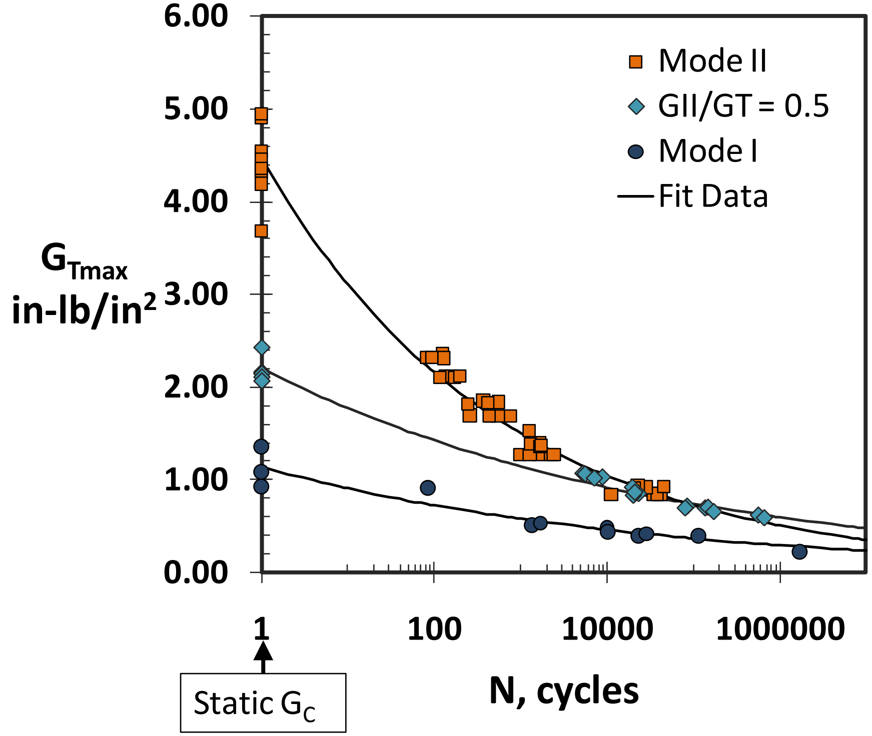
• Tested specimens from 2 different manufacturers for Modes I and Mode II

Fatigue Onset Mode II



*US Army European Research Office Report Report# N68171-98-M-5177

Fatigue Onset Mode I/II

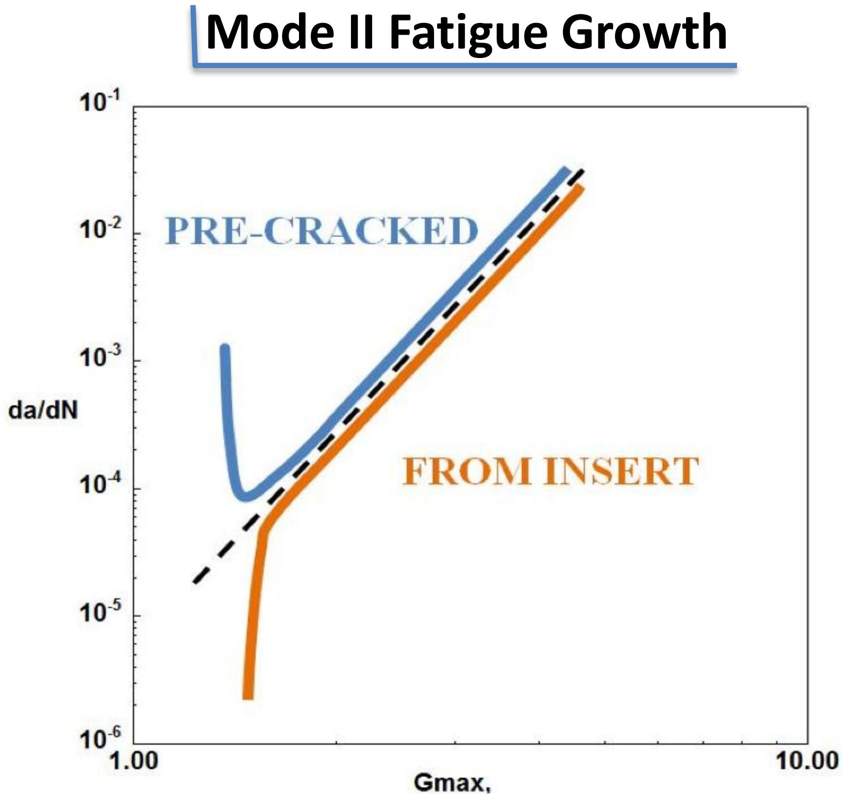


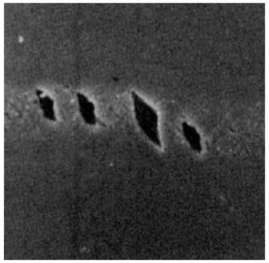
Results

•Later onset response in the precracked and insert data on mode II loading

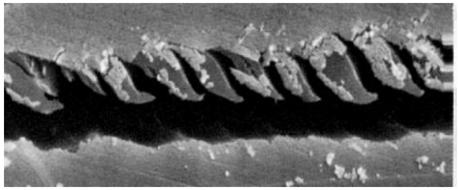
•Mode II data from both sources follow same trend

Fatigue Onset Response ENF Specimens





Fatigue causes formation of micro-tension cracks ahead of crack tip during shear loading



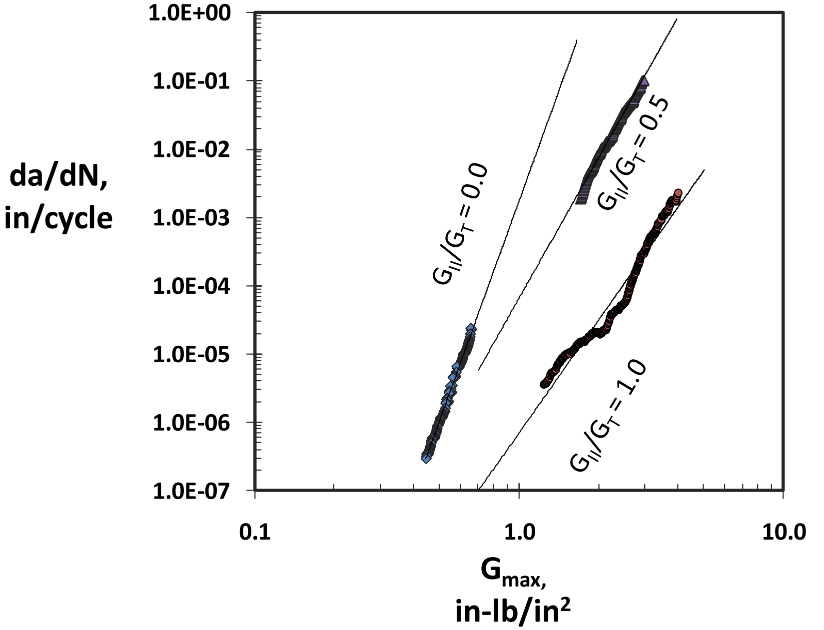
During growth micro-cracks coalesce to form the macroscopic crack

Fatigue Crack Growth of IM7/8552

Test Matrix

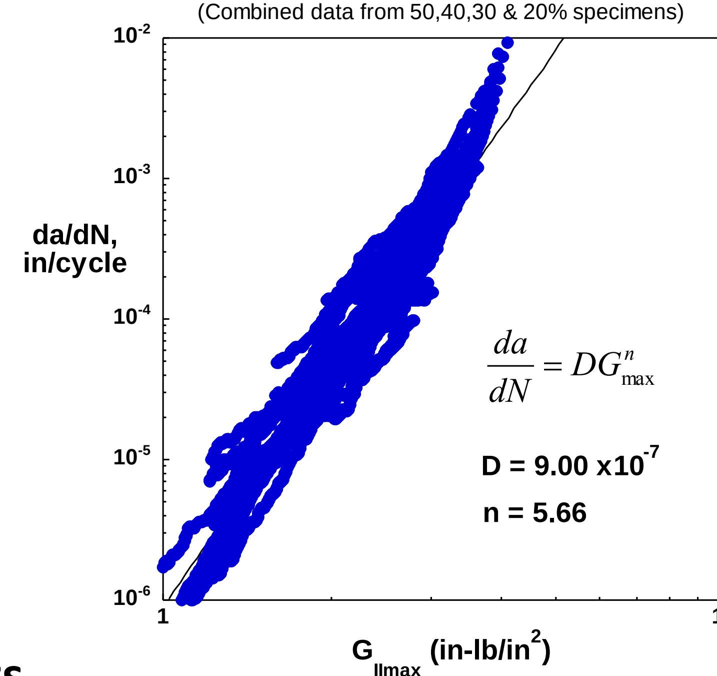
- Same specimens used for testing onset
- Test at Stress Ratio of R= 0.1 (R= P_{min}/P_{max})
- Tested in load control or displacement control with an automated system

Fatigue Growth Mode I/II



Fatigue Growth Mode II

(Combined data from 50,40,30 & 20% specimens)



Results

- Power law fit to results for all load levels have similar slopes
- Similar behavior between different manufacturers
- Mode I and Mode II data shows some shift with respect to test load

Summary

•Measured Mode I, Mode II and mixed mode interlaminar fracture toughness and delamination onset and growth characterization data for a IM7/8552 graphite epoxy composite
•Developed fatigue test methods and data reduction procedures for Mode II and Mixed Mode Bending (MMB) testing
•Developed an understanding of the effects of a Teflon insert on the measured values of fracture toughness, fatigue onset and crack growth rate

Future Work

•Development of Mode II and Mixed Mode Bending(MMB) fatigue crack growth standards for ASTM

•Material properties will be used for input to validate delamination fatigue life prediction methodology on representative rotor spar and tilt-rotor stiffened wing skin components