

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE Technical Papers		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER 2302	
				5e. TASK NUMBER MIG 2	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048				8. PERFORMING ORGANIZATION REPORT	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT A	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Leilani Richardson
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) (661) 275-5015

PC 1 2 1 1

36 separate files are enclosed

TP-FY99-0144

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✓ Spreadsheet
✓ DTS

MEMORANDUM FOR PRS (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO)

15 June 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0144
Tim Miller, "Mixed-Mode Fracture in a Rubbery Particulate Matrix"

6th Annual International Conference on Composites
Vu/Graphs

(Public Release)



Mixed-Mode Fracture in a Rubbery Particulate Composite

Timothy C. Miller
Air Force Research Laboratory

Sixth Annual International Conference on Composites
Engineering
Orlando, Florida
June/July 1999

[20021119 130]



Outline of Presentation

- Introduction
 - ▶ What is the problem?
 - ▶ How do we solve the problem?
- Experimental Procedure
 - ▶ Procedure Followed
 - ▶ Difficulties Encountered
- Results
 - ▶ Crack Initiation Toughness Results
 - ▶ Kink Angle Results
 - ▶ Crack Growth Results
- Conclusions and Recommendations for Future Work



Problem Statement

Reasons for Examining Mixed-Mode Cracking

- Damage During Manufacture or Handling May Cause Cracks That Are Later Subjected to Mixed-Mode Loading
- Cracks Near or at Interfaces Are Inherently Mixed-Mode Cracks
- Analysis of Mixed-Mode Cracking is Substantially More Complicated Than for Mode I Cracks



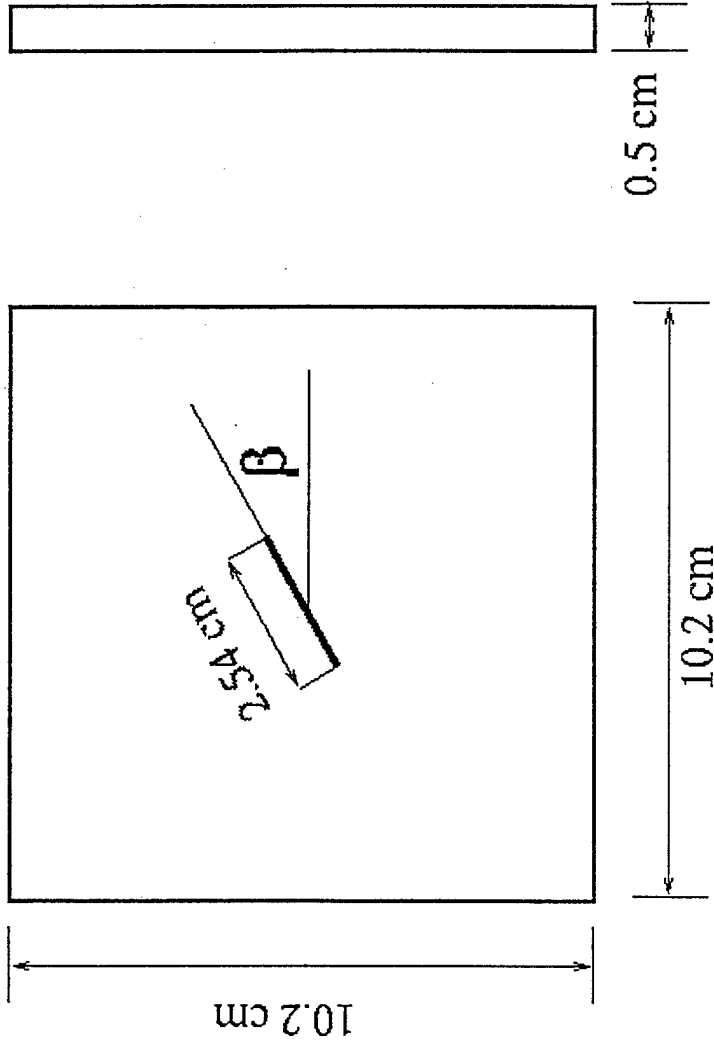
Method of Solution

- Test Various Mixed-Mode Specimens
 - ▶ Measure Load at Initiation
 - ▶ Measure Crack Length (Simplified Manner) Versus Time
 - ▶ Measure Kink Angle
- Use Finite Elements and Experimental Load Measurements to Determine Fracture Parameters at Initiation of Growth
- Use Crack Length Versus Time to Determine Simplified Crack Growth Model
- Use Kink Angle Measurements to Determine if Available Theories Can Adequately Predict Growth Direction



Specimen Geometry for Mixed-Mode Testing

Crack Angles Used Are 0 (Mode I), 15, 30, 45, and 60 Degrees



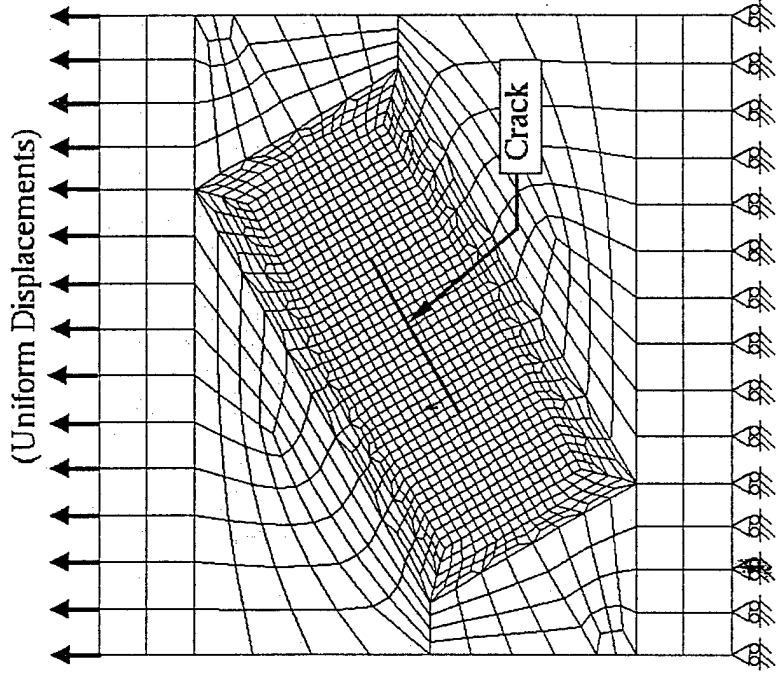
$$K_I = \sigma \sqrt{\pi a} \cos^2 \beta$$

$$K_{II} = \sigma \sqrt{\pi a} \sin \beta \cos \beta$$



Sample Finite Element Mesh for Computational Models

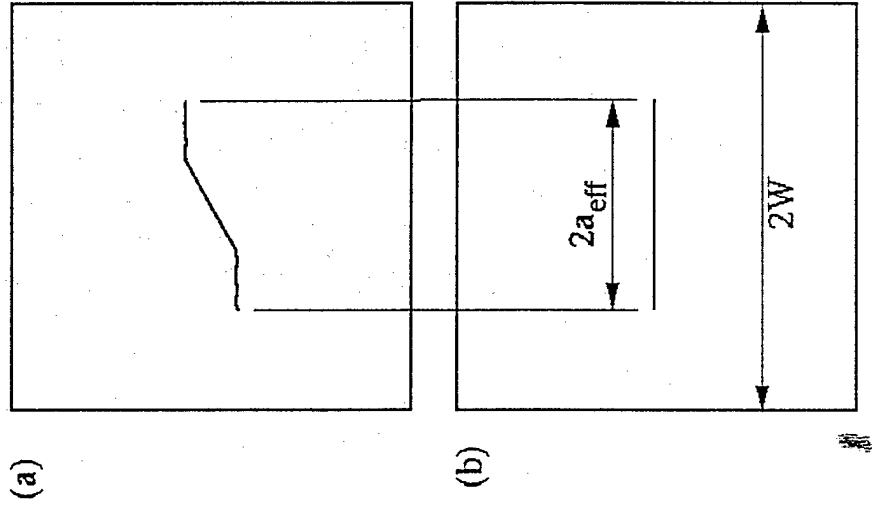
Displacement Boundary Conditions Are Used, Crack
Orientation Shown Here is 30 Degrees





Modeling Mixed-Mode Crack Growth Using a Simplified Approach

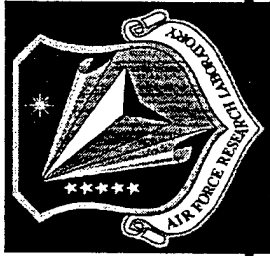
Simplified Geometry Can Be Used to Analyze Crack Growth Rates Successfully





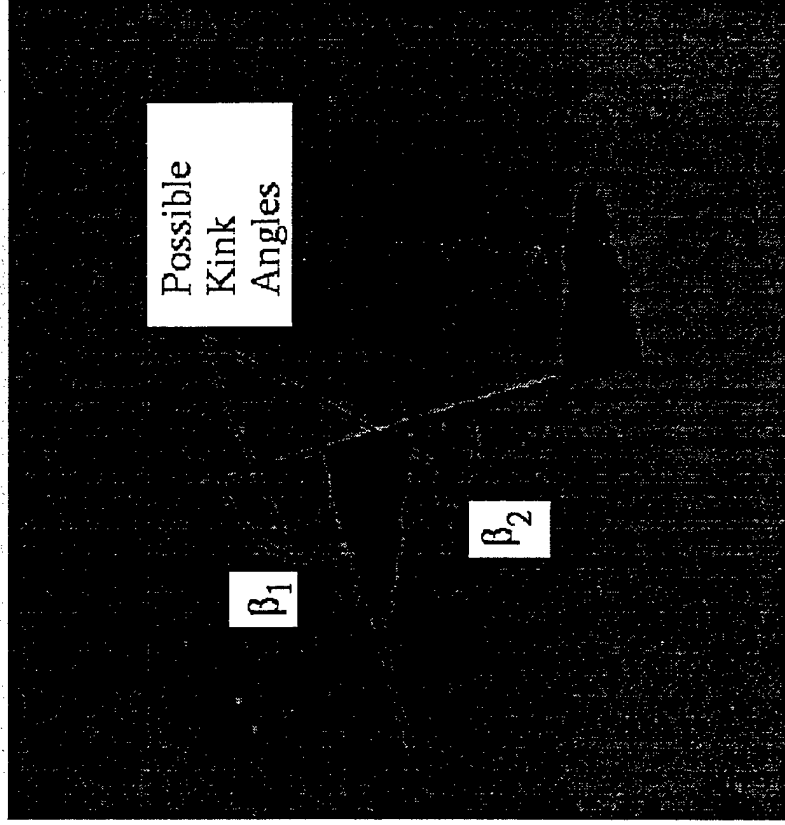
Difficulties Encountered

- Large Deformations Make In-Situ Determination of Kink Angles Difficult
- Mixed-Mode Initiation Toughness Locus is Linked to Micromechanisms That Are Poorly Understood
- Linear Elasticity May Not Be Valid



Crack in a Propellant Specimen Shortly After Initiation of Crack Growth

Large Deformations Make Kink Angle Determination
Ambiguous





Ligament Bridging Near the Crack Tip in a Rubbery Composite Specimen

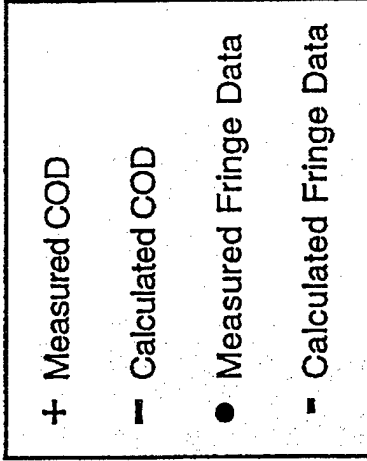
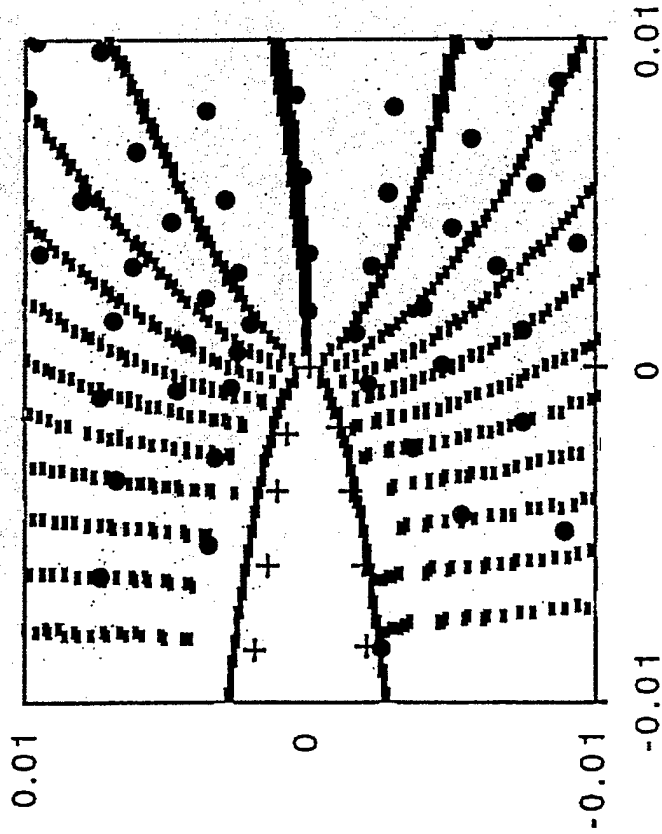
Mechanisms Such as Ligament Bridging May Account for Shape of
Mixed-Mode Failure Locus in a Rubbery Particulate Composite





Experimental and Computed Moiré Fringes and Crack Opening Displacements for a Rubbery Particulate Composite

Good Agreement Shows That Linear Elastic Fracture Mechanics Works Well



Handed
CLARITY
FRM METRICS TO SHOW
FRONTIERS HAS
STUDY WILL BE REMOVED



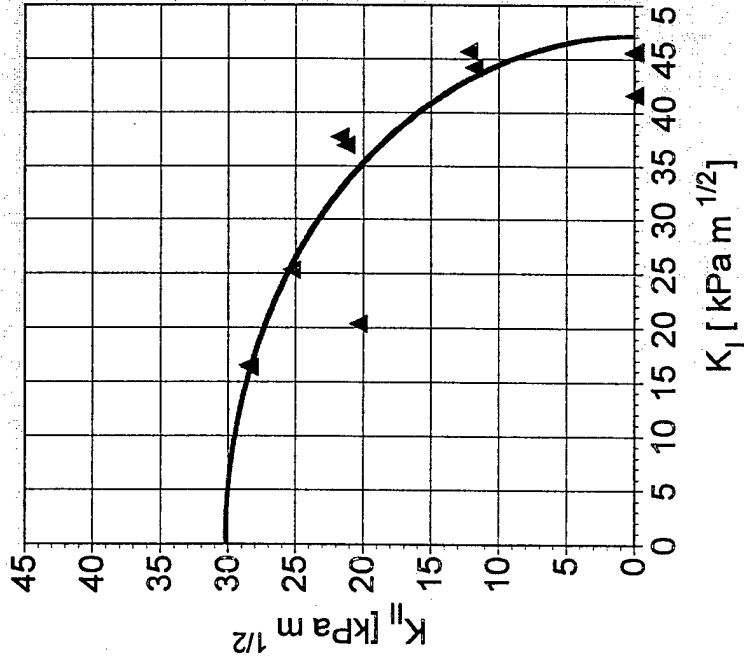
Results

- Results for Initiation Toughness Show That Elliptical Curve Fit Works Well
- Results for Kink Angle Determinations Show More Deviation From Theory Than Expected
- Use of Simplified Approach to Predict Crack Growth Rate Works Well



Elliptical Failure Locus for Initiation of Crack Growth

Unlike the Failure Locus for Metals, the Mode I Fracture Toughness is Higher Than its Mode II Counterpart

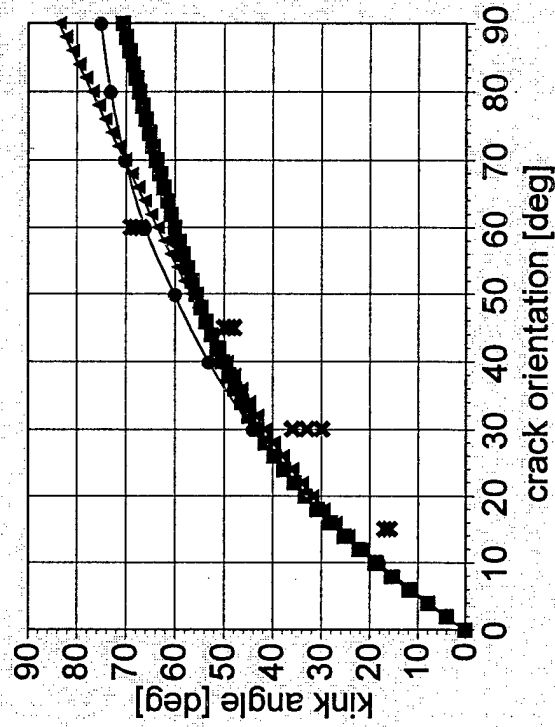


$$\left[\frac{K_I}{K_{IC}}\right]^2 + \left[\frac{K_{II}}{K_{IIC}}\right]^2 = 1$$



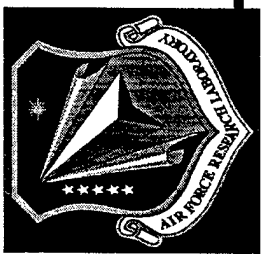
Kink Angles Plotted as a Function of Crack Orientation Angle

Experimental Results Show Some Deviation From Existing Theories

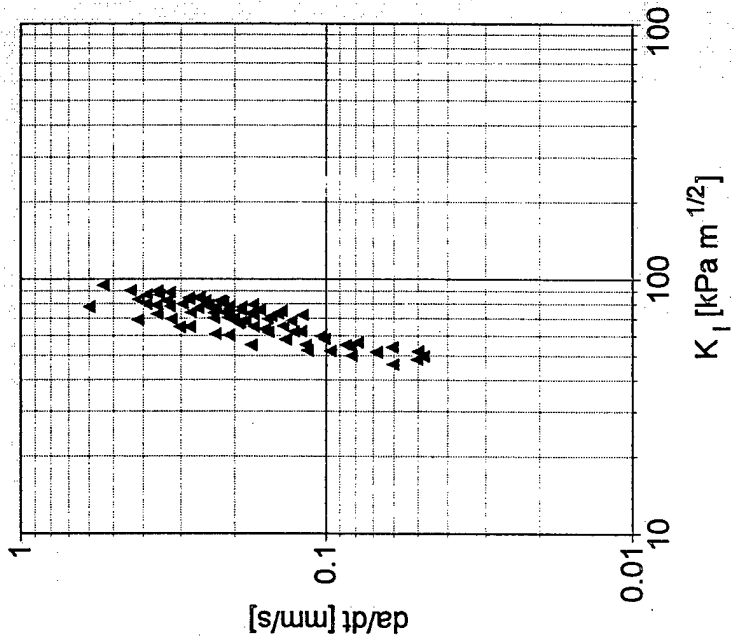


- max tensile stress theory
- max energy release rate theory
- ▲ max strain energy density theory
- × propellant experiments

Effective Crack Growth Rate for the Mixed-Mode Experiments as a Function of Stress Intensity



Use of Simplified Approach Shows Agreement Even With Different Levels of Mode Mixity



$$\frac{da_{eff}}{dt} = CK_I^m$$



Conclusions

- Although rubbery particulate composites have viscoelastic properties, high elongations, and complicated failure mechanisms, they can be studied, for a given nominal strain rate, using linear elastic fracture mechanics.
- The complex stress intensity factor failure locus is elliptical.
- The kink angles match available theories best at higher levels of mixity. The best theory appears to be Strain Energy Density Theory, but all of the theories made similar predictions.
- A simplified approach that uses an equivalent mode I crack can be used to predict the crack growth rate for mixed-mode cracks

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