

REPORT DOCUMENTATION PAGE

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62

MEMORANDUM FOR IN-HOUSE PUBLICATIONS

FROM: PROI (TI) (STINFO)

1 Oct 98

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-
1998-169 Tim Miller "Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials
Under Plane Strain Conditions (Presentation for paper AFRL-PR-ED-TP-1998-075 cleared 5 May 98)
Presentation Only **(Statement A)**



Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials Under Plane Strain Conditions

T.C. Miller

**Air Force Research Laboratory
Edwards Air Force Base, California**

October 1998

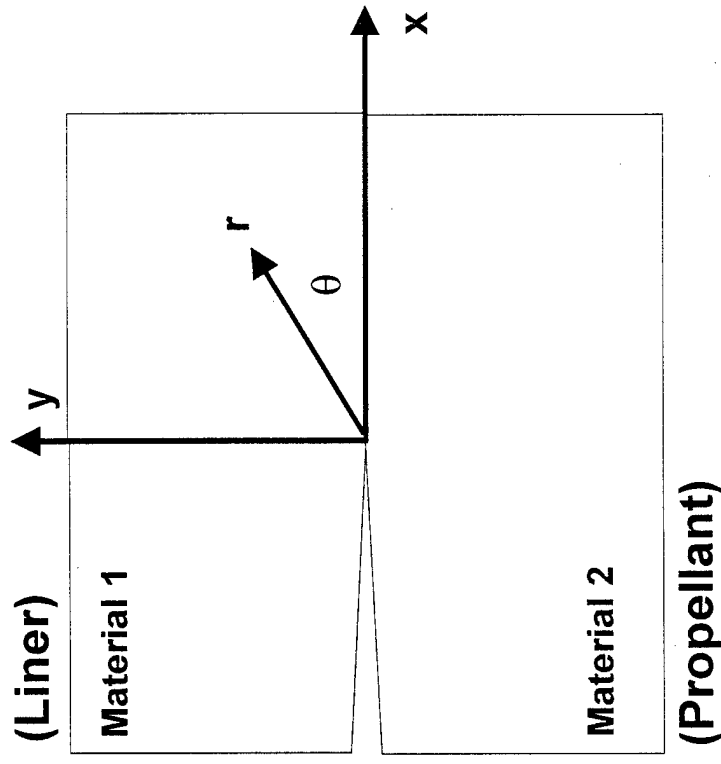
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Introduction

Liner - Propellant Failures

1. Materials are Incompressible
2. Plane Strain Conditions Exist
3. E_2/E_1 Varies with Materials Used

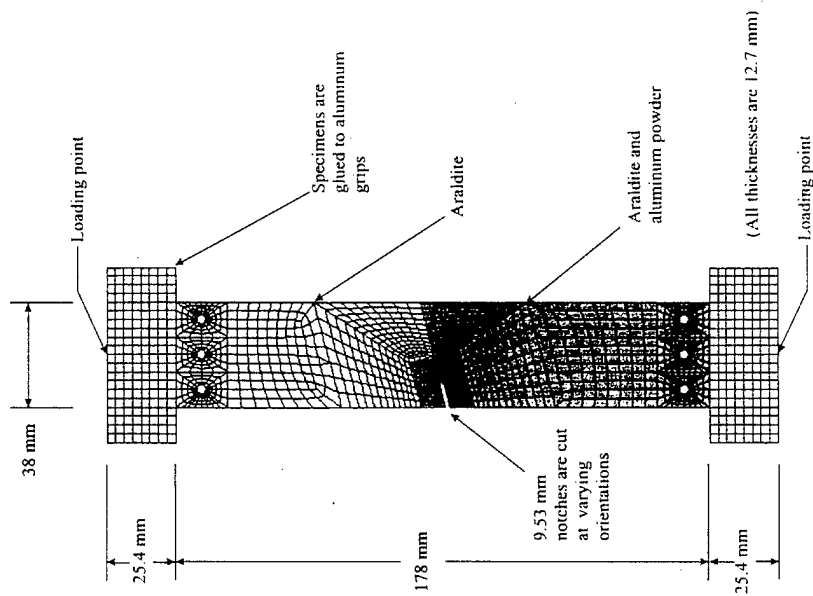
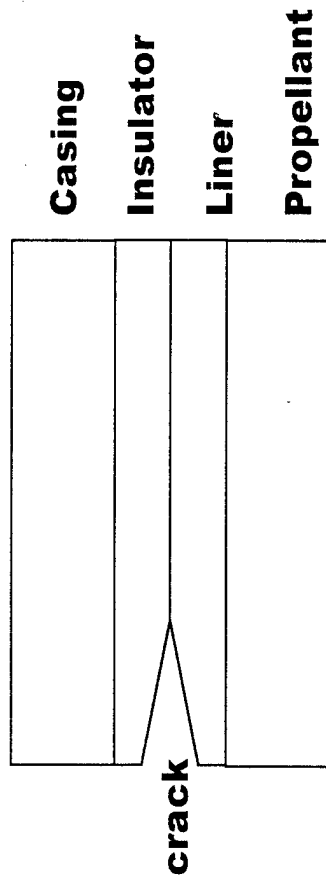




Specimen Geometry and Related Application

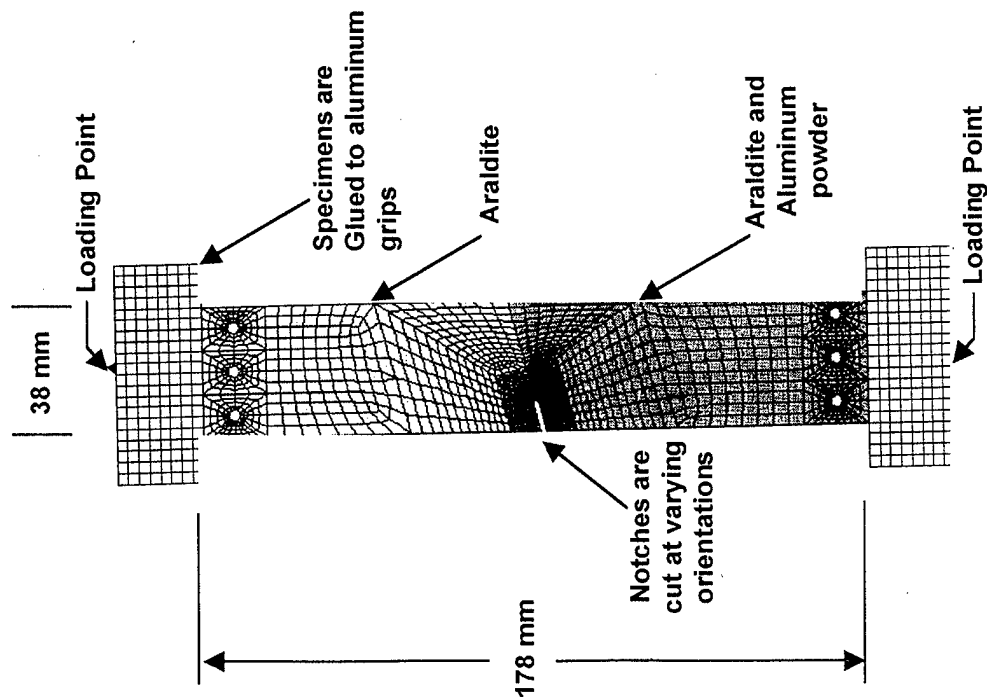
Applications to Composite Structures

Related Photoelastic Stress Freezing Experiments

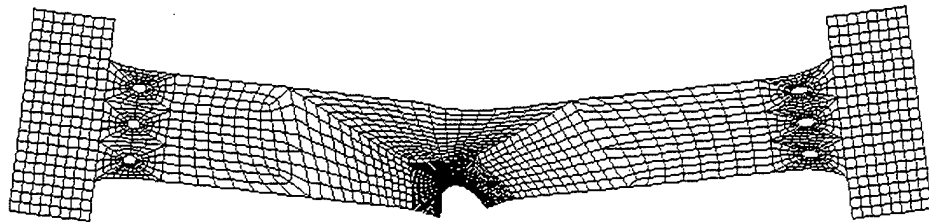




Modeling of Incompressible Bimaterials Under Plane Strain Conditions



- Both homogeneous and bimaterial specimens are considered
- Mode mixity is varied by changing crack angle (0, 15, 30, 45 degrees).



Typical Finite Element Model -
Crack Orientation = 15 Degrees

Loaded Specimen in
Deformed Configuration



Incompressible Bimaterial Pans Under Plane Strain Conditions

General Interfacial Fracture

Plane Strain/Incompressible
Materials

$$\epsilon \neq 0 \quad \beta \neq 0$$

$$\epsilon = 0 \quad \beta = 0$$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}} \{ \operatorname{Re}(K r^{i\epsilon}) \Sigma'_{pq}(\theta) + \operatorname{Im}(K r^{i\epsilon}) \Sigma''_{pq}(\theta) \}$$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}} \{ \operatorname{Re}(K) \Sigma'_{pq}(\theta) + \operatorname{Im}(K) \Sigma''_{pq}(\theta) \}$$

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{K r^{i\epsilon}}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}} [\cos(\epsilon Lnr) + i \sin(\epsilon Lnr)]$$

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{K}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}}$$

$$J = G = \frac{\Lambda_1 + \Lambda_2}{16 \cosh^2(\pi\epsilon)} |K|^2$$

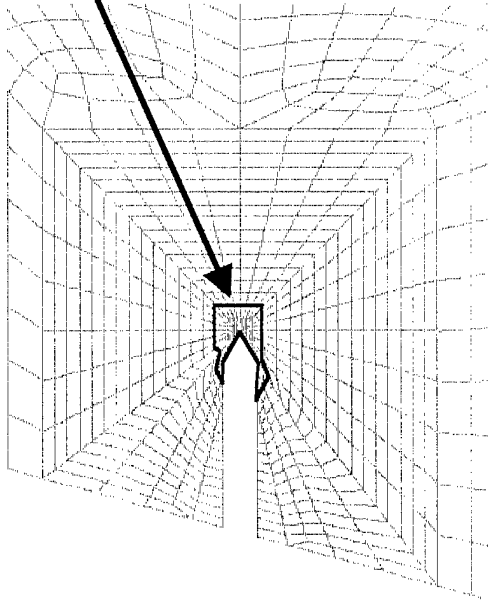
$$J = G = \frac{K^2}{E^*}, \quad \frac{1}{E^*} = \frac{1}{2} \left[\frac{1}{E_1} + \frac{1}{E_2} \right],$$

$$\overline{E}_1 = \frac{E_1}{1 - \nu_1^2}, \quad \overline{E}_2 = \frac{E_2}{1 - \nu_2^2}$$

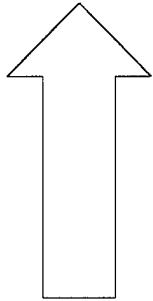


Method for Characterizing Complex Stress Intensity Factor in Bimaterial Problems

Magnitude Assessment

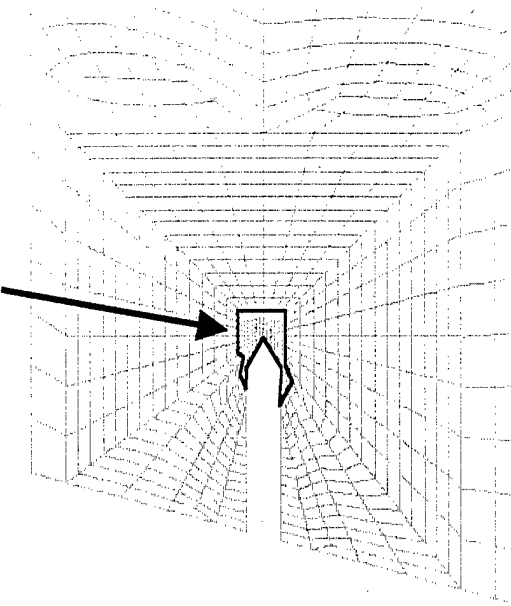


Contour Path



Gauss Divergence Theorem

Area of Integration

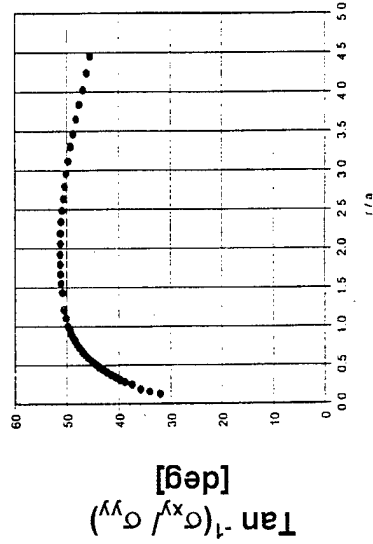


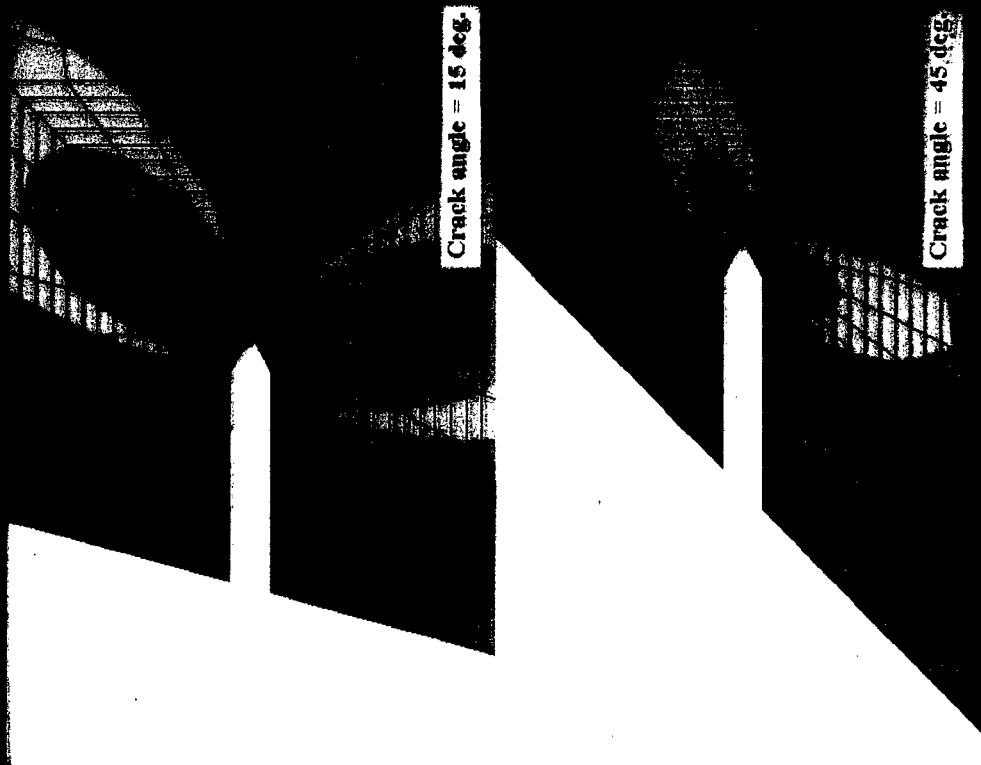
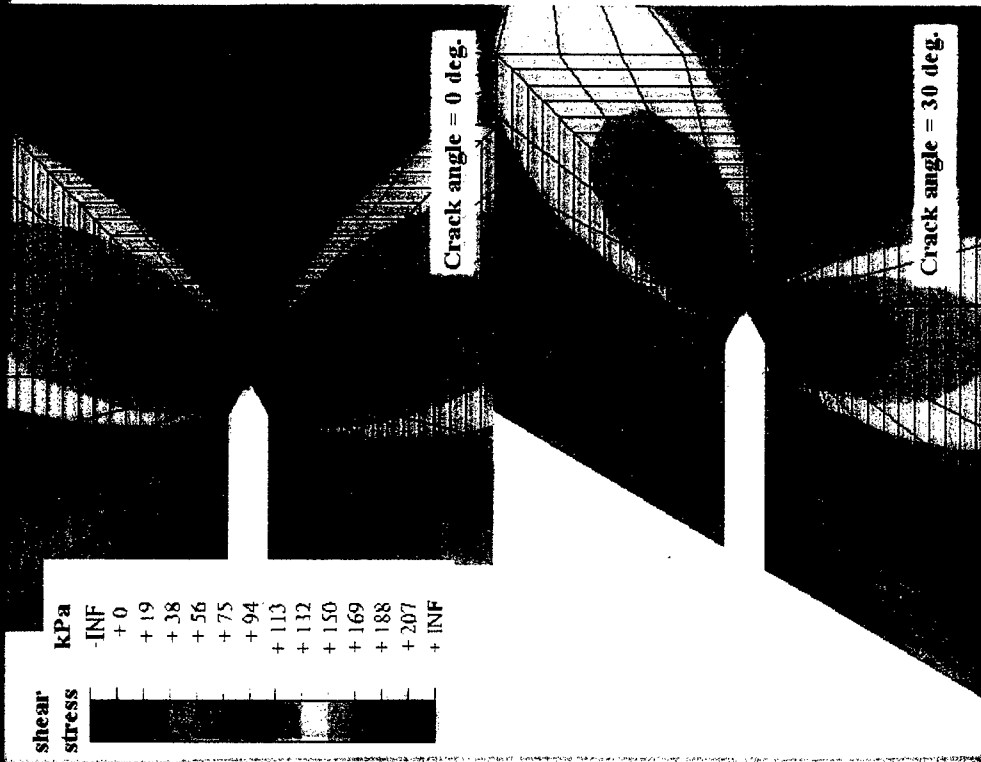
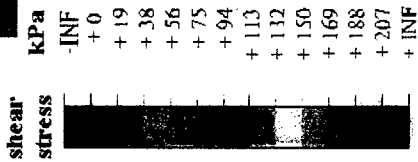
J as Contour Integral

$$J = \int_A [\sigma_{ij} u_{j,1} - w d_{1,i}] q_{1,i} dA, |K| = \sqrt{J E^*}, E^* = \text{Effective plane strain modulus}, \frac{1}{E^*} = \frac{1}{2} \left(\frac{1}{E_1} + \frac{1}{E_2} \right)$$

- T_{xy} and T_{yy} Averaged at Nodes Along $y = 0$
- $\psi(r/a)$ is Cubic Fit of $\tan^{-1}[(T_{xy}/T_{yy})_{\theta=0}]$ vs. r/a
- $\Psi \equiv \tan^{-1} \left(\frac{K_{II}}{K_{III}} \right) = \lim_{r/a \rightarrow 0} \psi(r/a)$

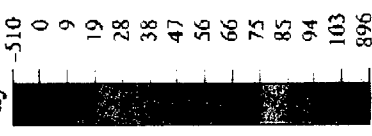
J as Equivalent Area Integral







σ_{xy} [kPa]



Crack angle = 0 deg

Crack angle = 30 deg

Crack angle = 15 deg

Crack angle = 45 deg



σ_{yy} [kPa]

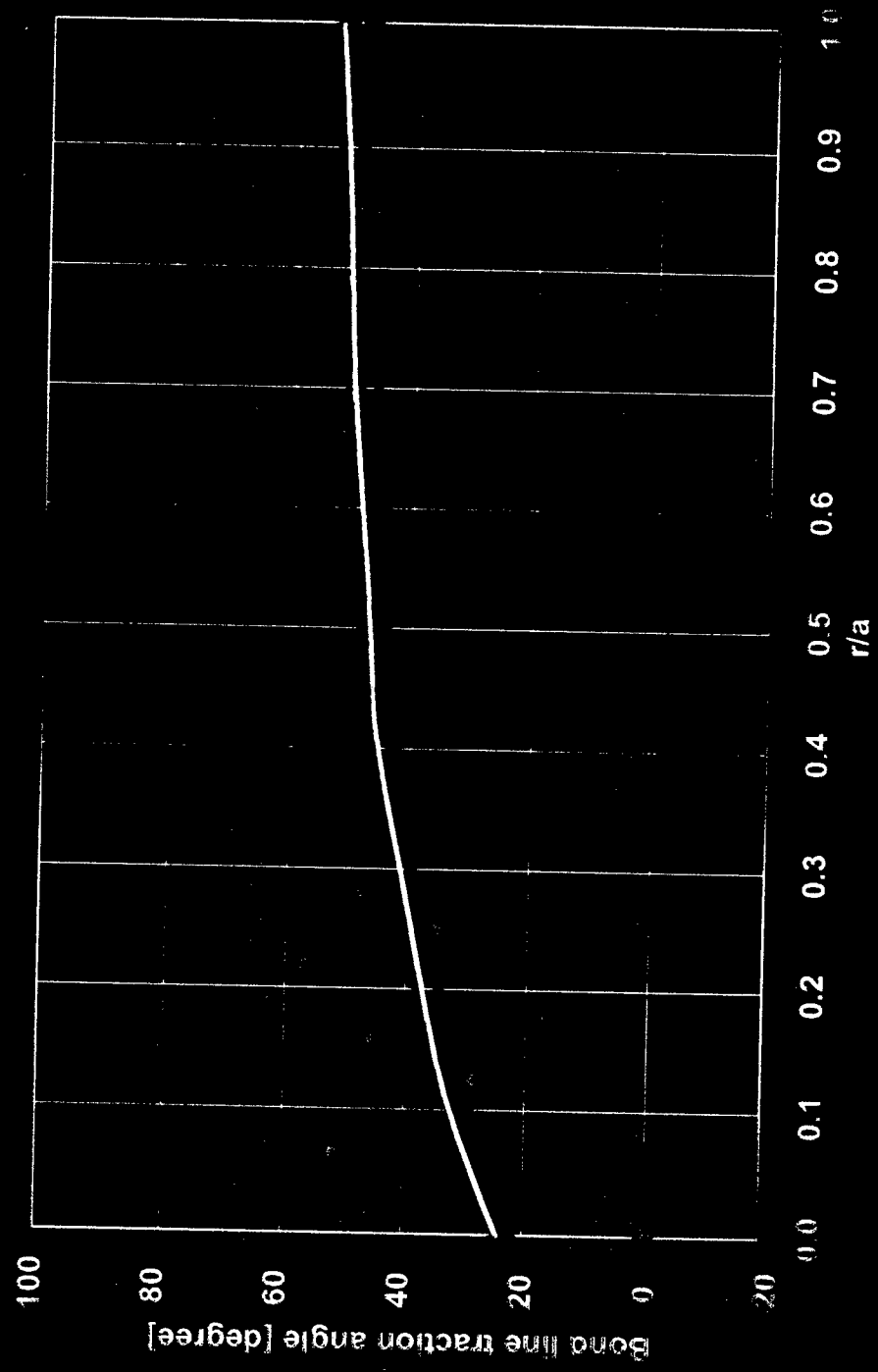
-182
0
25
50
75
100
125
150
175
200
225
250
275
300

Crack angle = 0 deg.

Crack angle = 30 deg.

Crack angle = 15 deg.

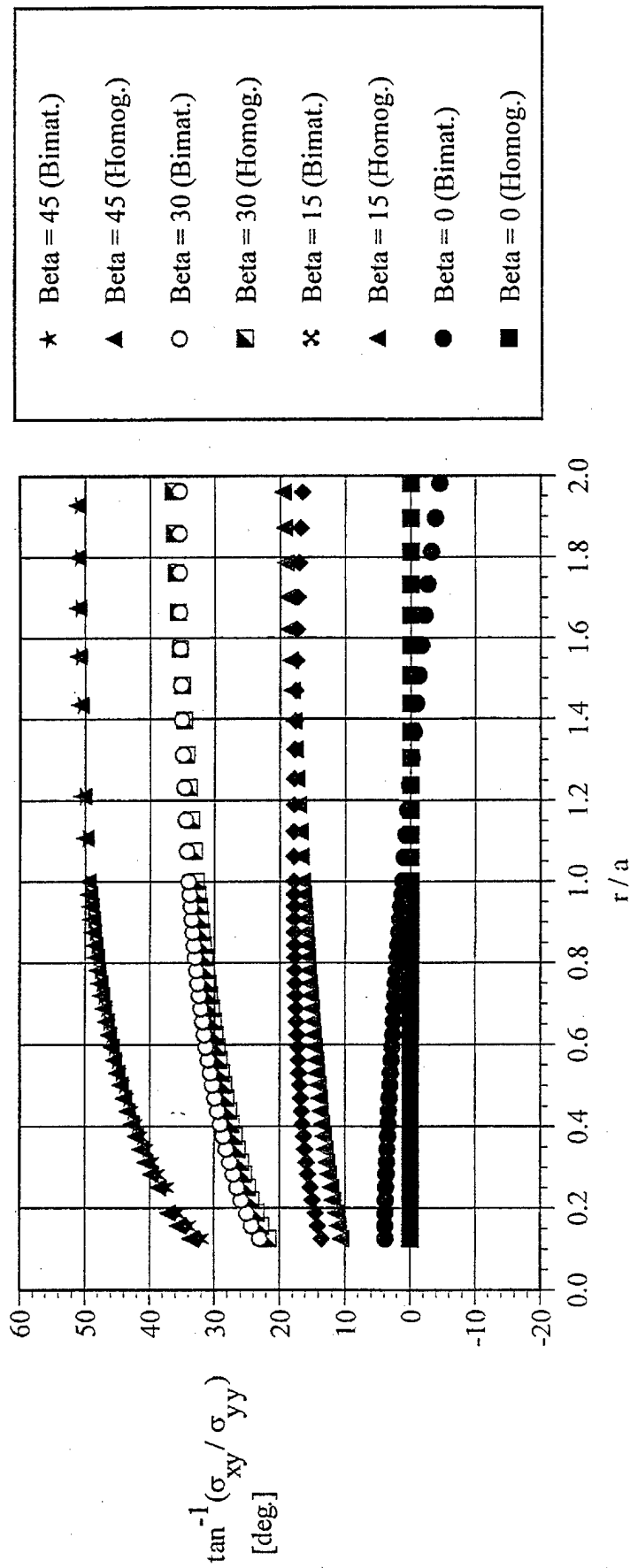
Crack angle = 45 deg.





Phase Angle Extrapolation

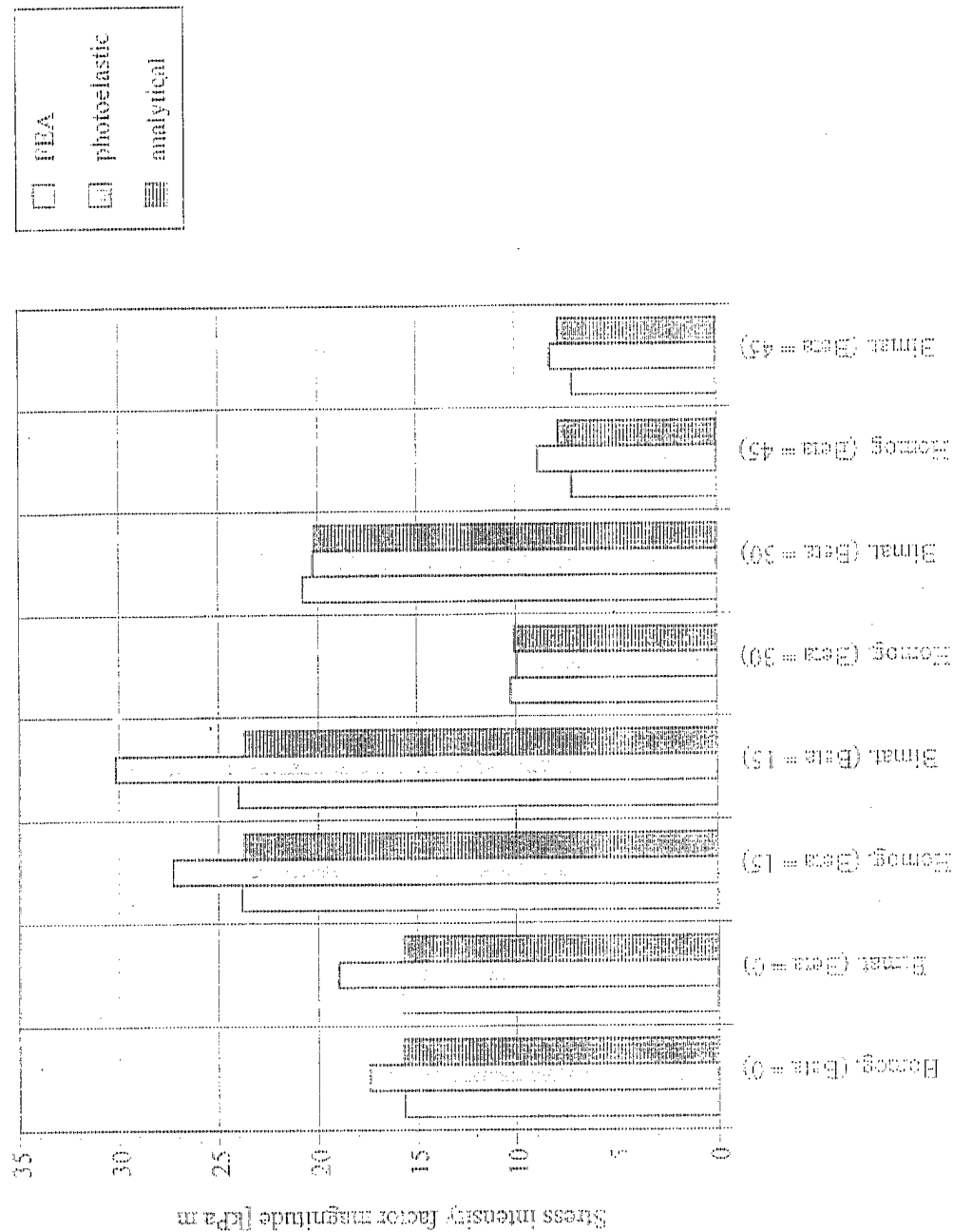
Phase Angle is Evaluated from Bond Line Traction Near Crack Tip





Stress Intensity Factor Magnitude Comparisons

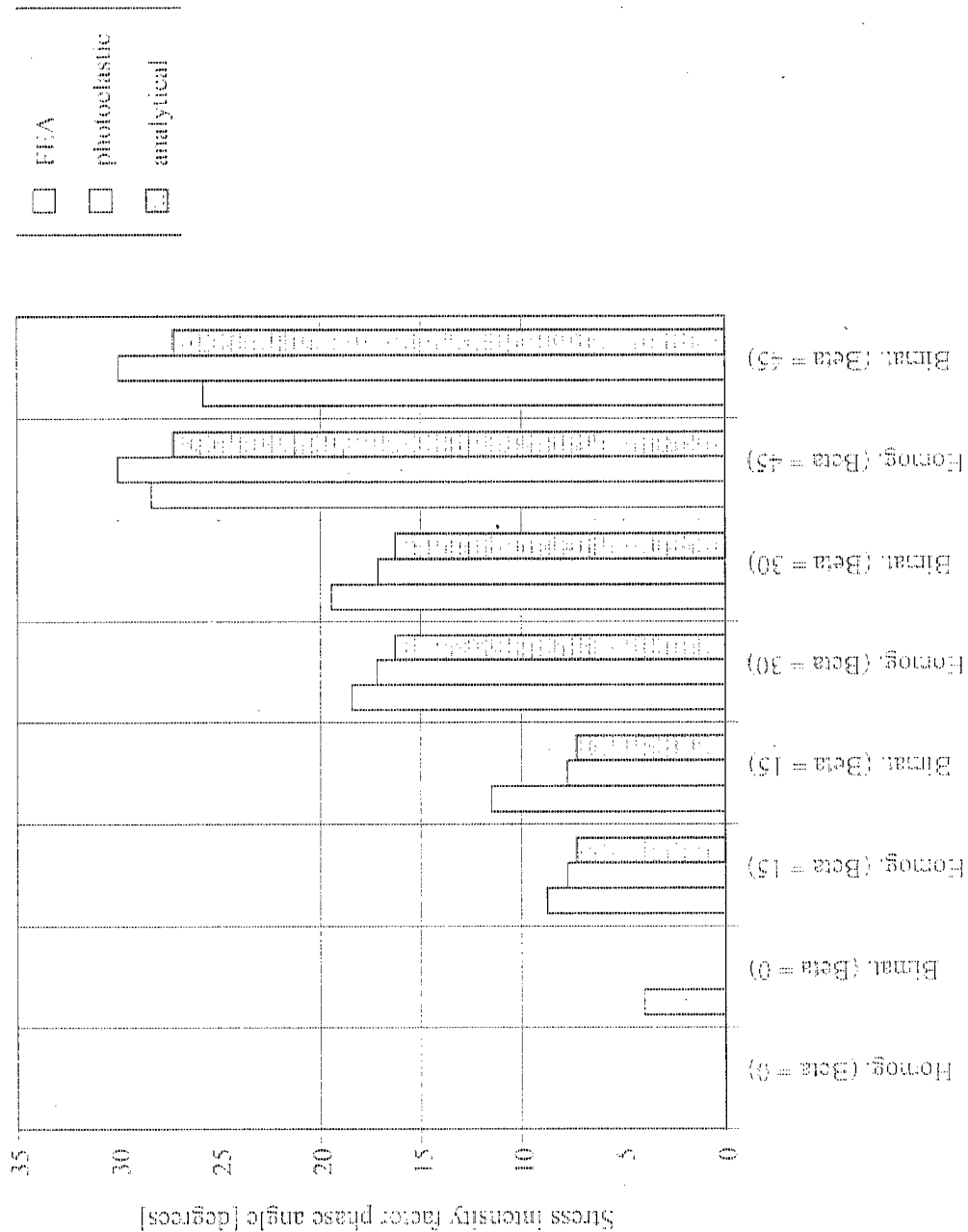
(Comparison of Numerical and Photoelastic Results)





Stress Intensity Factor Phase Angle Comparisons

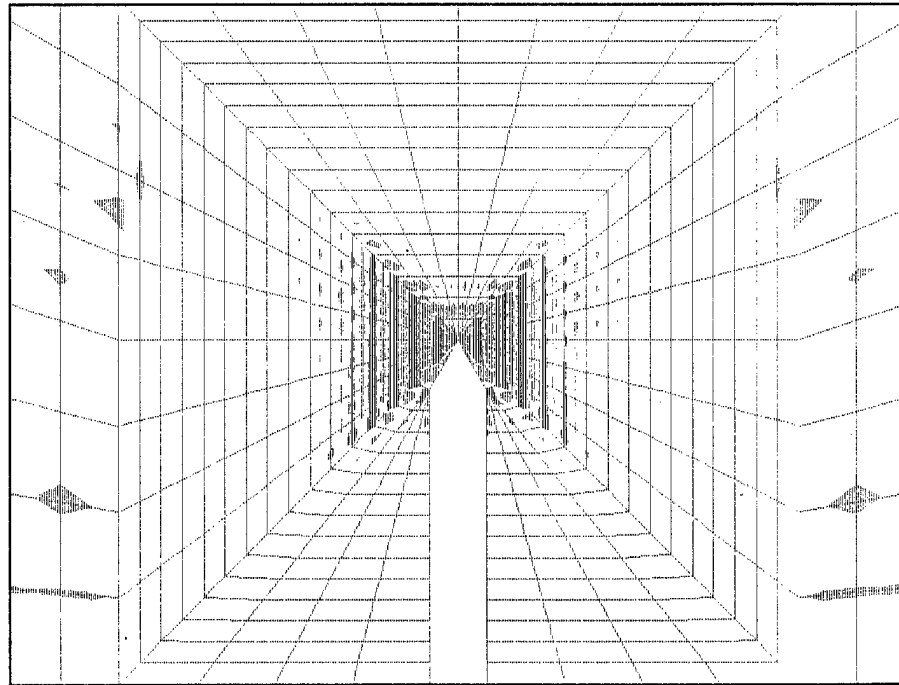
(Comparison of Numerical and Photoelastic Results)



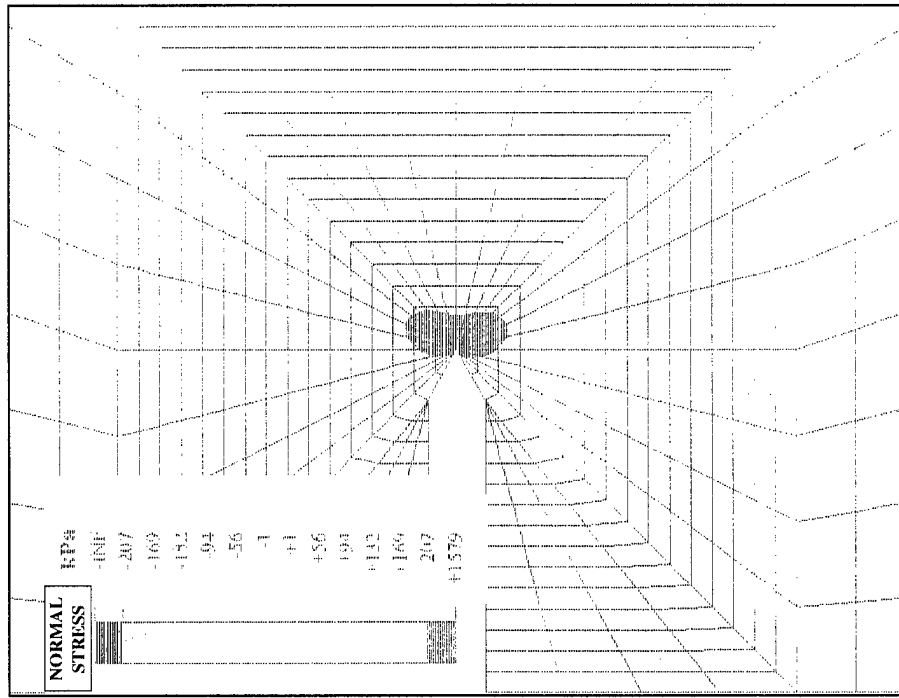


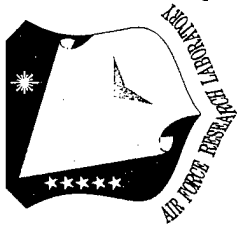
Hybrid Elements and Mixed Formulation Prevent Ill-Conditioning Problems

Conventional Formulation



Mixed Formulation





Conclusions

- Simplified field expressions can be used with incompressible bimaterials under plane strain conditions. The use of a mixed formulation and quarter point nodes are required for successful determination of the complex stress intensity factor $\vec{K} = K_I + i K_{II}$
- The Magnitude of the complex stress intensity factor can be determined by using area integration methods to determine the J integral and then converting J to K using effective plane strain modulus.
- The phase angle of the complex stress intensity factor can be determined by finding the limit as $r/a \rightarrow 0$ of a polynomial curve fit of $\tan^{-1}[(\tau_{xy}/\tau_{yy})_{\theta=0}]$ in a region near the crack tip.



- Experimental results and data - Dr. C.W. Smith,
Virginia Polytechnic Institute and State University
- Funding and Computational Facilities - Dr. C.T. Liu,
Air Force Research Laboratory, Edwards Air Force
Base, California