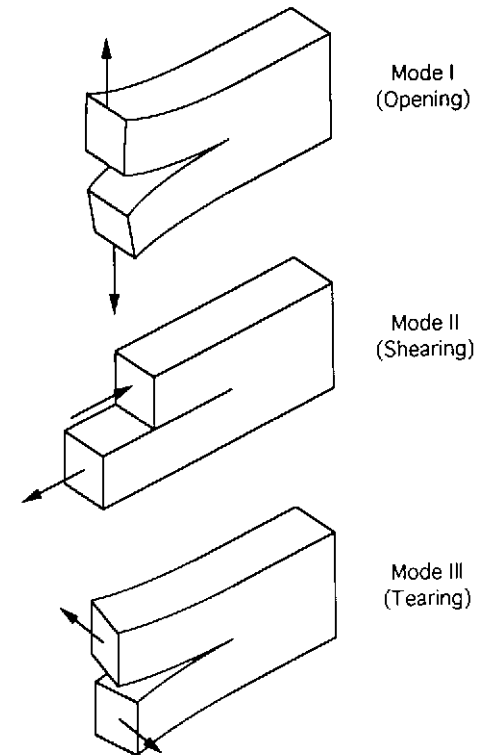


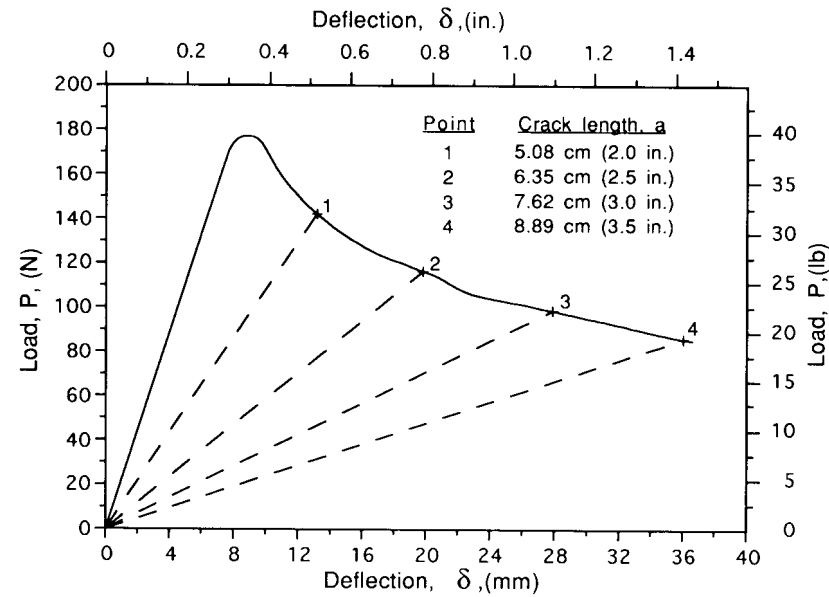
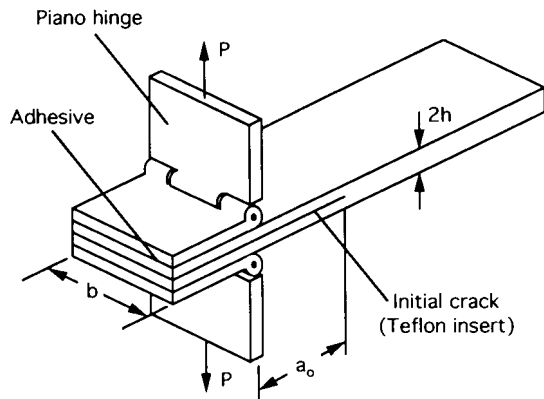
10. Determination of Interlaminar Fracture Toughness

10.1 Interlaminar failure (Cracking or delamination) can occur in three basic modes:

1. Opening or Peeling Mode (Mode-I)
-Double Cantilever Beam Test
2. Sliding or Inplane Shearing Mode (Mode-II)
-End Notched Flexure Test
3. Tearing Mode (Mode-III)
-Split DCB Test



10.2 Mode-I Fracture Test (DCB Specimen)



Critical strain energy release rate, from beam analysis, G_{Ic} ,

$$G_{Ic} = \frac{12P^2a^2}{E_1b^2h^3} \left\{ 1 + \frac{E_1h^2}{10G_{31}a^2} \right\}$$

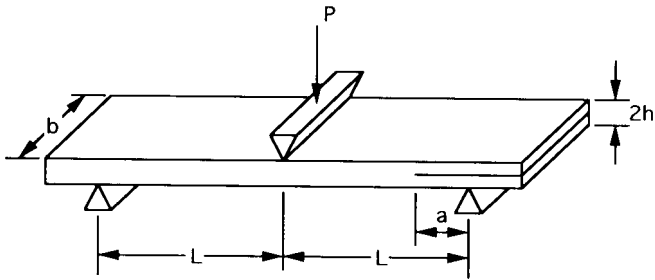
Where:

- P = Maximum applied load at crack extension
- b = Specimen width
- h = Cantilever beam thickness
- E_1 = Longitudinal modulus
- $G_{31} = G_{12}$ = Transverse shear modulus
- a = Crack/delamination length

Area method:

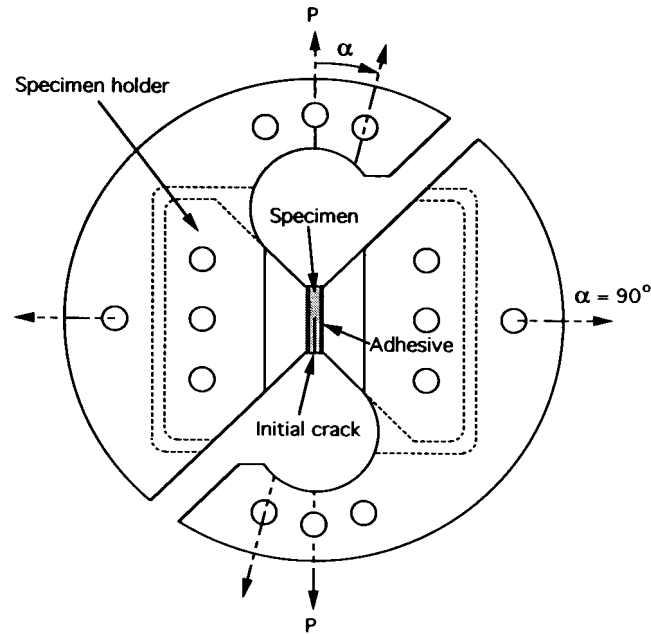
$$G_{Ic} = \frac{L}{2b\Delta a} (P_1\delta_2 - P_2\delta_1)$$

10.3 Mode-II Fracture Test (ENF Specimen)



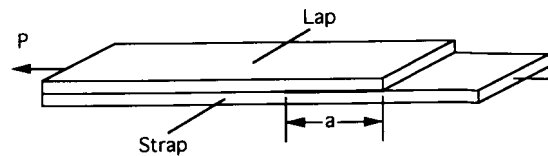
Critical strain energy release rate, from beam analysis, G_{IIc} ,

$$G_{IIc} = \frac{9P^2 a^2}{16E_1 b^2 h^3} \left\{ 1 + \frac{E_1 h^2}{5G_{31} a^2} \right\}$$

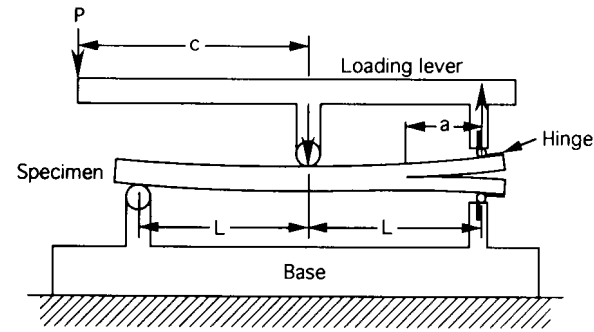


10.4 Mixed Mode Testing

A number of test methods, such as, cracked-lap shear (CLS), mixed-mode bending (MMB), edge delamination tension, and the Arcan specimen were used to measure the mixed mode fracture toughness of laminated composites. Of these, MMB and edge delamination specimens are very commonly used.



Cracked-lap shear specimen



Mixed mode bending apparatus

(a) Mixed mode bending test

Expressions for critical fracture toughness under the mixed mode stress state:

$$G_{Ic}^m = \frac{3P^2 a^2}{4E_1 L^2 b^2 h^3} \left\{ 1 + \frac{E_1 h^2}{10G_3 a^2} \right\} (3c - L)^2$$

$$G_{IIc}^m = \frac{9P^2 a^2}{16E_1 L^2 b^2 h^3} \left\{ 1 + \frac{E_1 h^2}{5G_3 a^2} \right\} (c + L)^2$$

Note that, neglecting shear deformation, we can show that $c \geq L/3$ for a valid mixed mode test.

(b) Edge delamination test

Specimen: $[(\pm\theta)_2/90/90]_s$ or $[(\pm\theta)_2/0/90]_s$

Loading: Tension and measure strain at delamination initiation

$$G_C = \frac{\varepsilon_c^2 h}{2} (\bar{E}_x - \bar{E}_x^*)$$

ε_c = Tensile Strain at delamination onset

h = Specimen thickness

\bar{E}_x = Laminate modulus before delamination

\bar{E}_x^* = Laminate modulus after delamination along one or more interfaces

10.5 Mode III Test

Mode III fracture toughness: $G_{IIIc} = \frac{3P^2 e^2}{E_1 b h^4}$

