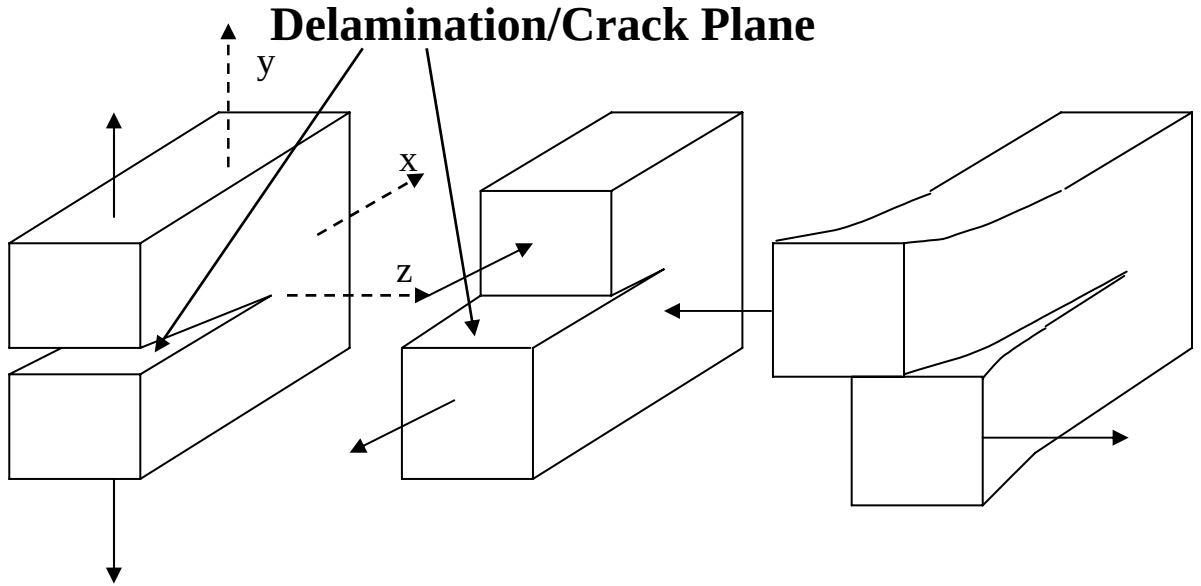
Chapter 9 Interlaminar Fracture



1. Opening or Peeling mode
DCB test

$$\sigma_y \ \alpha \ \frac{1}{\sqrt{x}}$$

2. Sliding or In plane searing
End Notched Flexure Test

$$\tau_{xy} \ \alpha \ \frac{1}{\sqrt{x}}$$

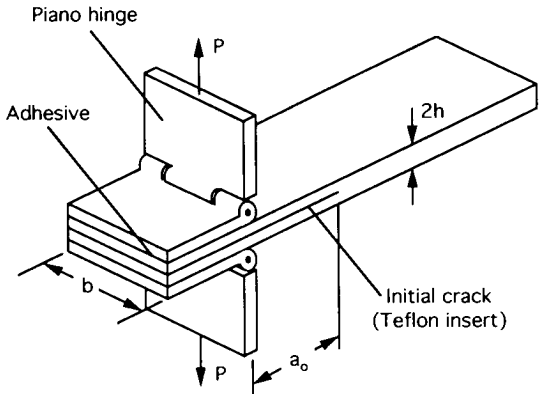
3. Tearing Mode
Split DCB

$$\tau_{xz} \ \alpha \ \frac{1}{\sqrt{x}}$$

Stress intensity factor, K $K = \lambda\sigma\sqrt{a}$

Strain energy release rate G $G = \frac{K^2}{E}$

Mode I Interlaminar Fracture Test



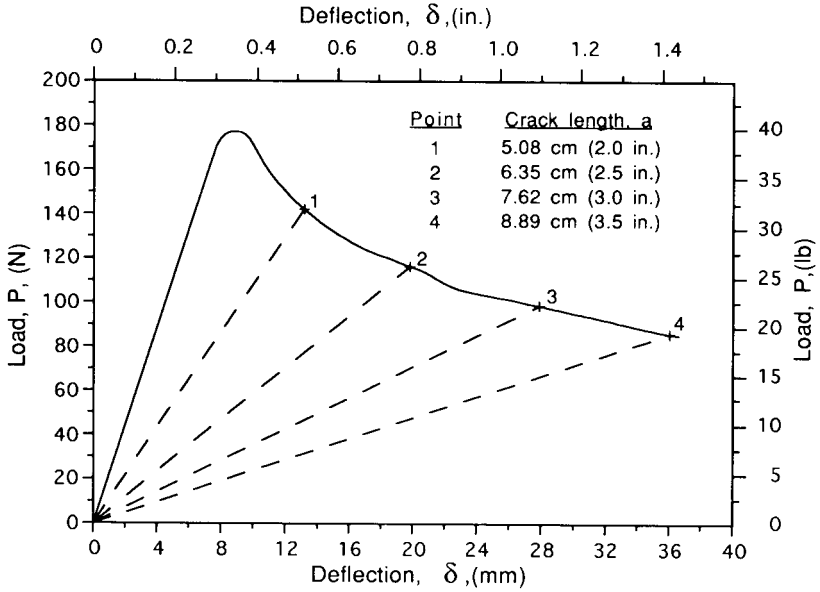
$$G_{I_c} = \frac{12P^2K^2}{E_1h^3}\left[1+\frac{1}{10}\frac{E_1}{G_{31}}\left(\frac{h}{a}\right)^2\right]$$

or

$$G_{I_c} = \left[\frac{P_I^2}{b\,E_1 I}\right]\left[a^2+\frac{2a}{\lambda}+\frac{1}{\lambda^2}+\frac{h^2E_1}{10G_{13}}\right]$$

$$\lambda = \frac{1}{h}\left[\frac{6E_2}{E_1}\right]^{\frac{1}{4}}$$

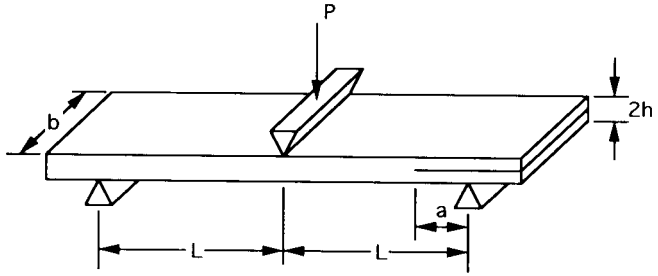
$$I = \frac{b\,h^3}{12}$$



Typical load-deflection response

P = Maximum applied load at crack extension.
b = Specimen width
h = Cantilever beam thickness
E_1 = Longitudinal modulus
G_{13} = Transverse shear modulus = G_{12}
a = Crack (delamination) length

Mode II Interlaminar Fracture Test

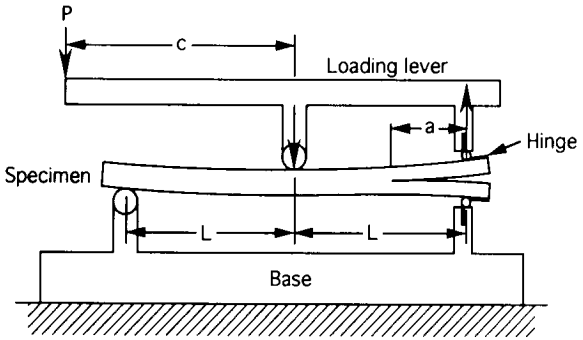


$$G_{IIc} = \frac{9P^2a^2}{16E_1b^2h^3}\left[1 + \frac{1}{5}\frac{E_1}{G_{31}}\left(\frac{h}{a}\right)^2\right]$$

End-notched flexure (ENF) specimen.

P = Maximum applied load at crack extension.
b = Specimen width
h = Beam half-thickness
E_1 = Longitudinal modulus
G_{13} = Transverse shear modulus = G_{12}
a = Crack (delamination) length

Mixed-Mode Interlaminar Fracture Test

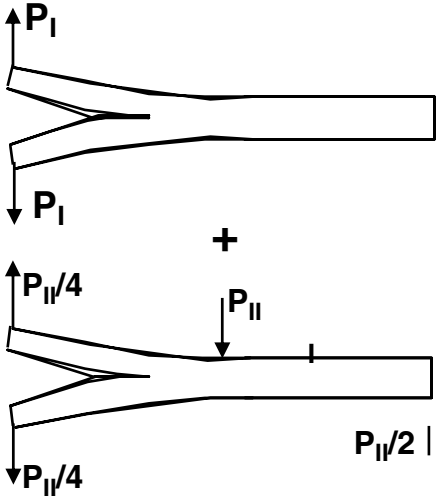


Mode I Load

$$P_I = \left(\frac{3C-L}{4L}\right)P + \left(\frac{3C_g-L}{4L}\right)P_g$$

Mode II Load

$$P_{II} = \left(\frac{C+L}{L}\right)P + \left(\frac{C_g+L}{L}\right)P_g$$



Mode I & II components:

$$G_{Ic}^{m} = \left(\frac{P_I^2}{BE_{11}I}\right)\left\{a^2 + \frac{2a}{\lambda} + \frac{1}{\lambda^2} + \frac{2h^2E_{11}}{10G_{12}}\right\}$$

$$G_{IIc}^{m} = \left(\frac{3P_{II}^2}{64BE_{11}I}\right)\left\{a^2 + \frac{2h^2E_{11}}{10G_{12}}\right\}$$

where $\lambda = \frac{1}{h}\sqrt[4]{6E_{22}/E_{11}}$

Where:

P = Total applied load @ c.

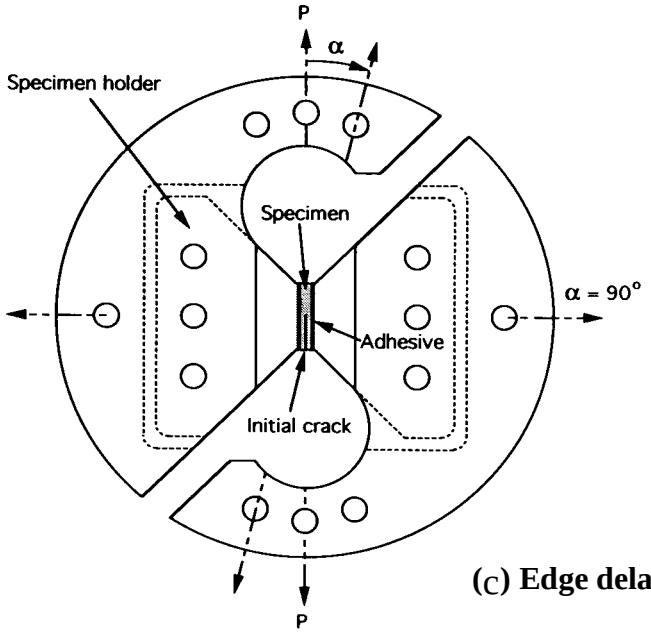
c = Distance between the load & the mid-span.

c_g = Distance between the lever C.G & the mid-span

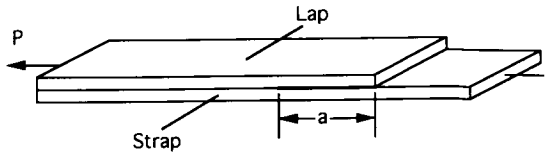
Pg = weight of the lever.

Other Mixed-Mode Fracture Specimens

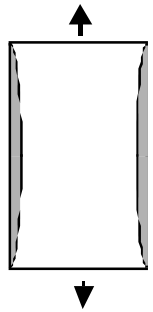
(a) Arcan fixture
Mixed-mode Interlaminar fracture test apparatus



(b) Crack-lap shear specimen
Mixed-mode interlaminar fracture



Edge Delaminated Specimen



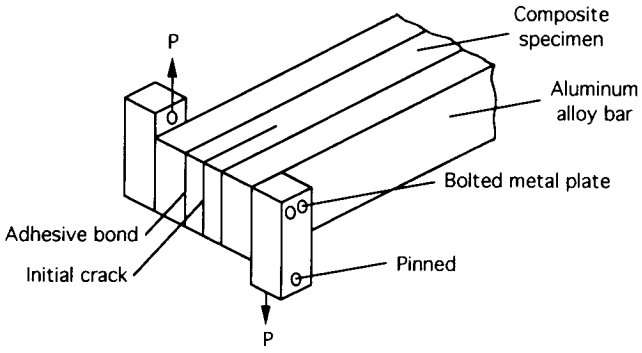
(c) Edge delamination test

Specimen: $[(\pm\theta)_2/90/90]_s$ or $[(\pm\theta)_2/\cancel{0}/90]_s$
Loading: Tension and measure strain at delamination initiation

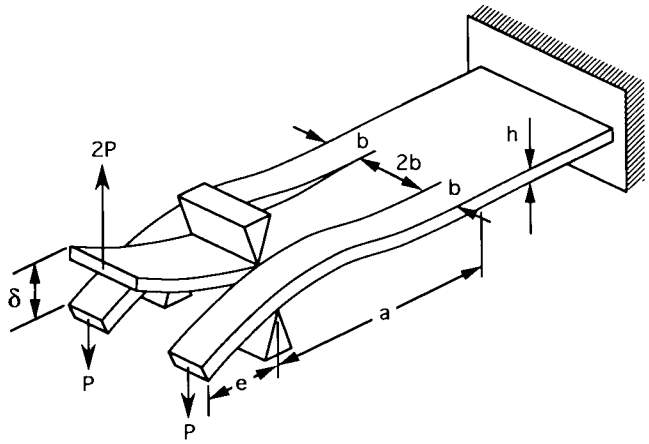
$$G_c = \frac{\varepsilon_c^2 h}{2}\left(\overline{E}_x - \overline{E}_x^*\right)$$

ε_c = Tensile Strain at delamination onset
h = Specimen thickness
$\overline{E}_x$ = Laminate modulus before delamination
$\overline{E}_x^*$ = Laminate modulus after delamination along one or more interfaces

Mode III Test



Split cantilever beam specimen



Doubly-Split double cantilever beam specimen

$$G_{IIIc} = \frac{3P^2e^2}{Ebh^4}$$

e = Distance between the end load and the support.
E = Modulus of laminate along the beam axis.
b = Width of outer split beams.
h = Laminate thickness.