Methods and standards for testing of composite materials

Karel Doubrava

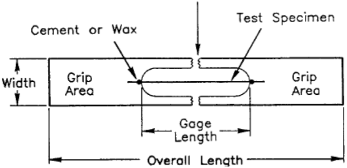
Faculty of Mechanical Engineering, CTU in Prague

January 11, 2016

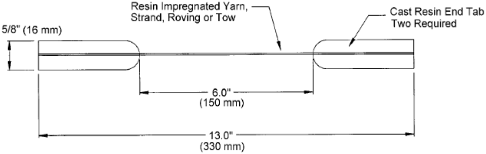
Contents

Mechanical testing of fiber

- ASTM D 3379



- ASTM D 4018

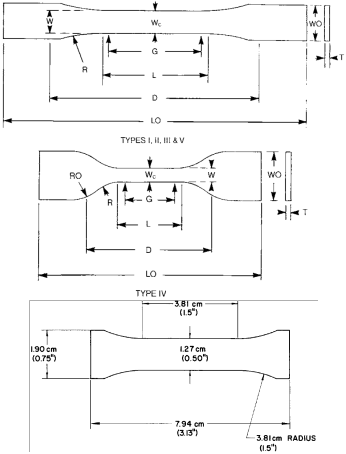


- Fiber properties from test of UD laminate

$$\text{Property } (100\%) = \frac{\text{Property} \times 100}{V_f}$$

Mechanical properties test of matrix

- Tension ASTM D 638
  F_m^{tu}, F_m^{ty}, E_m^{t}, ν_m^{t}, ε_m^{tu}
- Compression
  ASTM D 695
  F_m^{cu}, F_m^{cy}, E_m^{c}, ν_m^{c}, ε_m^{cu}
- Shear ASTM E 143,
  ASTM D 5379
  F_m^{su}, F_m^{sy}, G_m^{s}

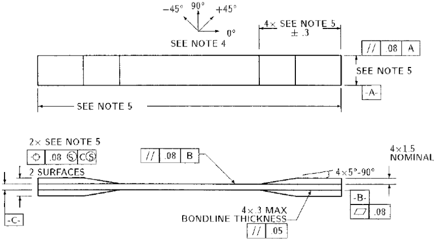


Mechanical testing of lamina and laminate

- Tension ASTM D 3039
- Compression ASTM D 3410, ASTM D 695
- Shear ASTM D 3518, ASTM D 5379, . . .
- Interlaminar shear ASTM D 2344

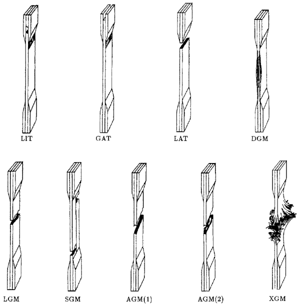
Tension properties ASTM D 3039

- Tensile strength
  $F^{\mathrm{tu}} = P^{\max}/A$
- Tensile chord modulus of elasticity
  $E_1 = \frac{\sigma_1^b - \sigma_1^a}{\varepsilon_1^b - \varepsilon_1^a}$,
  a. . . 0.1%, b. . . 0.3%
- Poisson ratio $\nu = -\frac{\Delta\varepsilon_2}{\Delta\varepsilon_1}$



Tensile Test Failure Code/ Typical Mode ASTM D 3039

Type	Code	Area	Code	Location	Code
Angled	A	Inside grip	I	Bottom	B
edge Delam.	D	At grip	A	Top	T
Grip/tab	G	< 1W from grip	W	Left	L
Lateral	L	Gage	G	Right	R
Multi–mode	M	Multiple areas	M	Middle	M
long.–Splitting	S	Various	V	Various	V
eXplosive	X	Unknown	U	Unknown	U
Other	O				

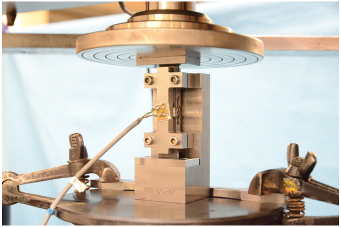


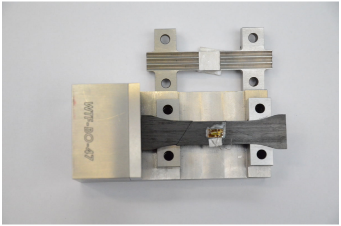
Compression in–plane tests

- ASTM D 695 (SACMA SRM-1)
- ASTM D 3410 (Celanese, IITRI)
- ASTM D 5467

Compression properties ASTM D 695

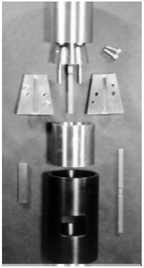
- Compressive strength
  $F^{\mathrm{cu}} = P^{\max}/A$
- Compressive modulus of elasticity
  $E_1 = \frac{\Delta\sigma}{\Delta\varepsilon}$





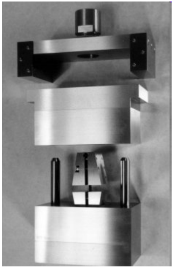
Compression ASTM D 3410

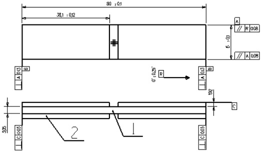
Procedure A – Celanese

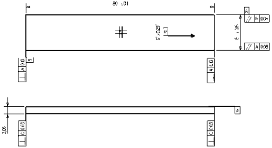


http://www.wyomingtestfixtures.com

Procedure B – IITRI

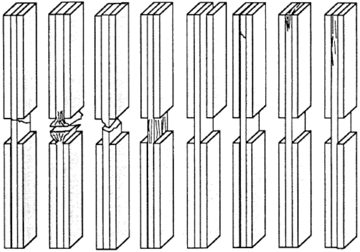






Failure Code ASTM D 3410

Type	Code	Area	Code	Location	Code
Angled	A	Inside grip	I	Bottom	B
Brooming	B	At grip	A	Top	T
end–Crushing	C	Gage	G	Left	L
Delamination	D	Multiple areas	M	Right	R
Euler bucling	E	Tab adhesive	T	Middle	M
tHrough–thickness	H	Various	V	Various	V
Kink bands	K	Unknown	U	Unknown	U
Lateral	L				
Multi–mode	M				
long.–Splitting	S				
Transverse shear	T				
eXplosive	X				
Other	O				

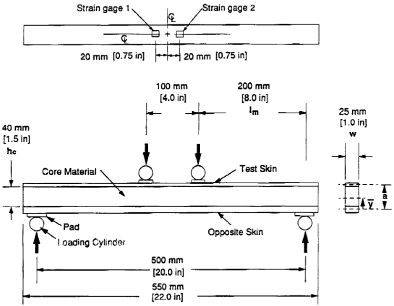


TAT BGM HAT SGV
Acceptable Failure Modes and Areas

DTT HIT CIT DIT
Unaceptable Failure Modes and Areas

Compression ASTM D 5467

- 4PB of sandwich beam



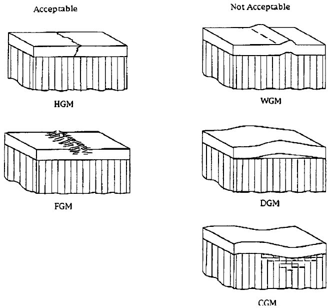
$$F^{\mathrm{cu}} = \frac{P^{\max} l_m \left(a - \bar{y} + \frac{h_f}{2}\right)}{2w\left[h_f(a-\bar{y})^2 + \frac{E_o}{E_f} h_o \bar{y}^2\right]}$$

$$E_1 = \frac{\sigma_1^b - \sigma_1^a}{\varepsilon_1^b - \varepsilon_1^a},$$

a. . . 0.1%, b. . . 0.3

Failure Code ASTM D 5467

Type	Code	Area	Code	Location	Code
Skin to core Delamination	D	At load cylinder	A	Left	L
Filament fracture	F	Gage	G	Right	R
tHrough–thickness	H	Multiple areas	M	Middle	M
Layer instability	L	Outside gage	U	Various	V
local Wrinkling	W	Various	V	Unknown	U
Multi–mode	M L	Unknown	U		
core Crushing	C				
long.–Splitting	S				
Transverse shear	T				
eXplosive	X				
Other	O				



Shear in–plane tests

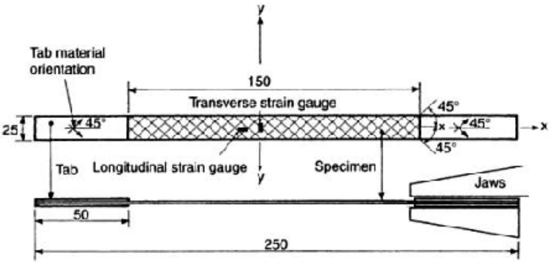
- $\pm 45^\circ$ tensile shear test
- Rail Shear Method
- V–Notched Beam Method
- Tube torsion test

$\pm 45^\circ$ tensile shear test

- BS EN ISO 14,129, ASTM D 3518
- Ply < 0.125 mm, 16 plies

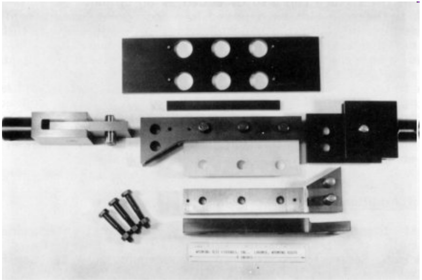
$$\sigma_{11} = \frac{\sigma_{xx}}{2} + \tau_{xy},\ \sigma_{22} = \frac{\sigma_{xx}}{2} - \tau_{xy},\ \tau_{12} = \pm\tau_{xy},$$

$$\varepsilon_{11} = \varepsilon_{22} = \frac{\varepsilon_{xx}+\varepsilon_{yy}}{2},\ \gamma_{12} = \varepsilon_{xx} - \varepsilon_{yy}$$

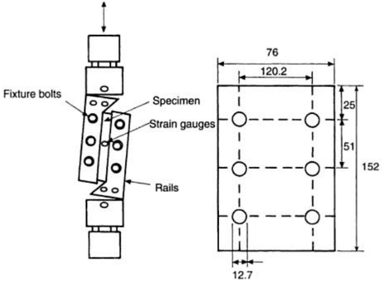


$$G_{12} = \frac{\sigma_{xx}}{2(\varepsilon_{xx}-\varepsilon_{yy})} = \frac{\tau_{12}^b-\tau_{12}^a}{\gamma_{12}^b-\gamma_{12}^a},\ S_{12} = \frac{P_{\max}}{2bh}$$

Two-rail shear test ASTM D 4255



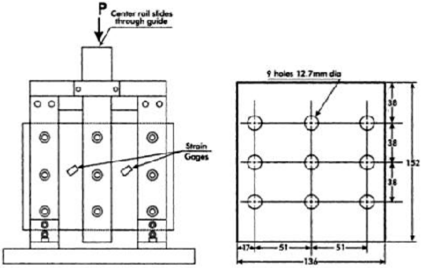
http://www.wyomingtestfixtures.com



$$S_{xy} = \frac{P^{\max}}{Lh}, \; G_{12} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{2Lh\Delta\varepsilon_{45}}$$

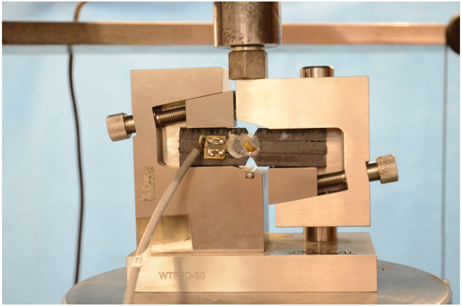
Three-rail shear test ASTM D 4255

http://www.wyomingtestfixtures.com



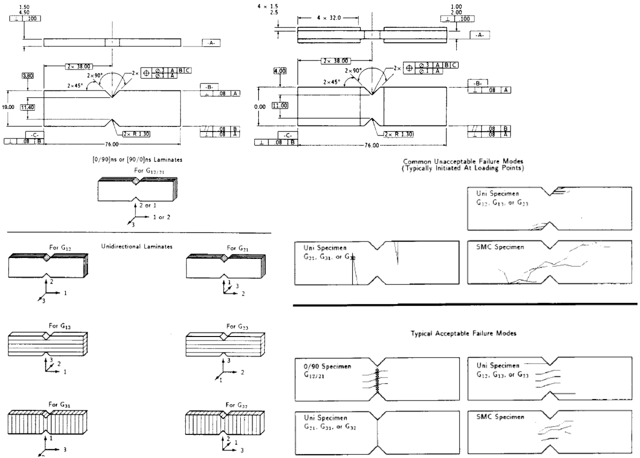
$$S_{xy} = \frac{P^{\max}}{Lh},\ G_{12} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{4Lh\Delta\varepsilon_{45}}$$

Shear V-Not. Beam ASTM D 5379

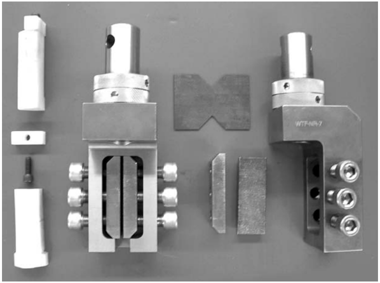


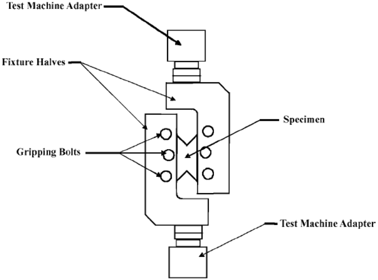
$$F^u = \frac{P_{\max}}{wh},$$
$$\tau_i = \frac{P_i}{wh},$$
$$\gamma = |\varepsilon_{45^\circ}| + |\varepsilon_{-45^\circ}|$$
$$G = \frac{\Delta\tau}{\Delta\gamma},$$

Shear V-Not. Beam ASTM D 5379



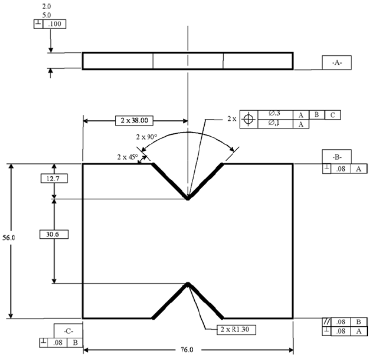
Shear V-Not. Rail ASTM D 7078

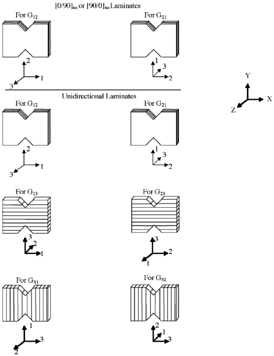




$$F^u = \frac{P_{\max}}{wh},\ \tau_i = \frac{P_i}{wh},\ \gamma = |\varepsilon_{45^\circ}| + |\varepsilon_{-45^\circ}|\ G = \frac{\Delta\tau}{\Delta\gamma}$$

Shear V-Not. Rail ASTM D 7078

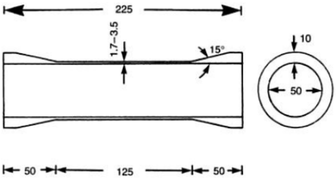


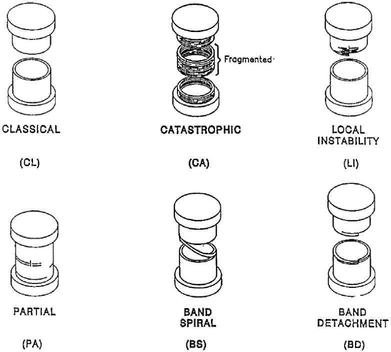


Tube torsion test ASTM D 5448

$$\tau_{xy} = \frac{2TR_o}{\pi(R_o^4 - R_i^4)})$$

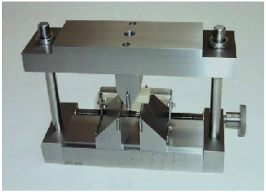
$$G_{12} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta\tau_{xy}}{\Delta(\varepsilon_{45^\circ} - \varepsilon_{-45^\circ})}$$

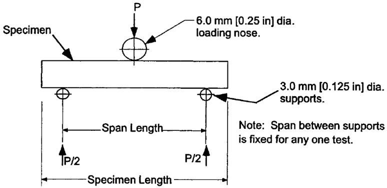


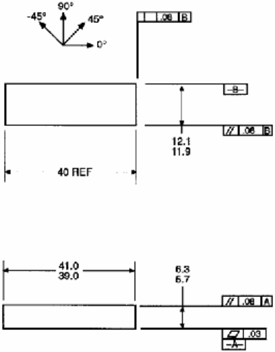


Shear of Short-Beam ASTM D 2344

$$F^{sbs} = 0.75 \times \frac{P_{\max}}{b \times h}$$



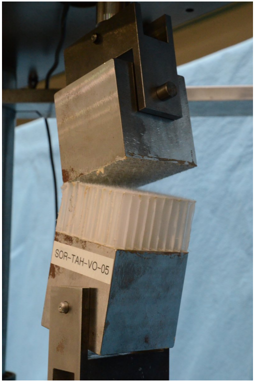




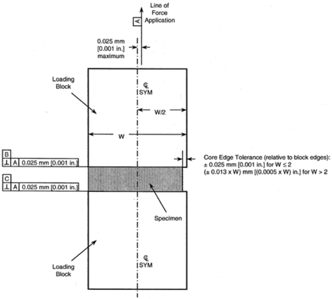
Sandwich Construction

- Tensile properties ASTM C 297
- Compression ASTM C 364, ASTM C 365, ASTM D 7336
- Shear ASTM C 273, ASTM C 393
- Bending ASTM D 7249, ASTM D 6457

Tensile properties ASTM C 297

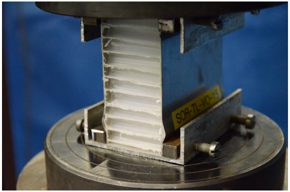


$$F_z^{ftu} = \frac{P_{\max}}{A}$$

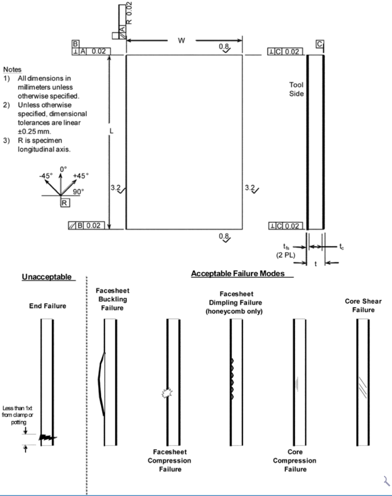


Min. Cell Size (mm)	Max. Cell Size (mm)	Min Facing Area (mm^2)
-	3	625
3	6	2500
6	9	5625

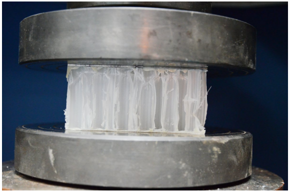
Compr. Edgewise ASTM C 364



Failure Type	Code	Area	Code	Location	Code
Facesheet compression	F	At end	A	Top	T
facesheet delam. Buckling	B	Gage	G	Bottom	B
honeycomb facesheet Dimpling	D	Various	V	Middle	M
core Compression	C	Unknown	U	Various	V
core Shear	S			Unknown	U
Multi mode	M				
overal Panel buckling	P				
eXplosive	X				



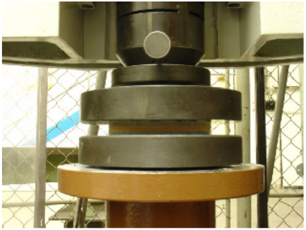
Flatwise Compr. ASTM C 365



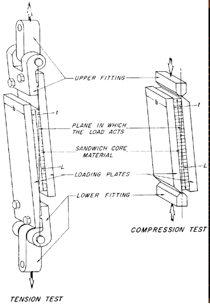
Min. Cell Size (mm)	Max. Cell Size (mm)	Min Facing Area (mm^2)
-	3	625
3	6	2500
6	9	5625

$$F_z^{fcu} = \frac{P_{\max}}{A}$$

$$E_z^{fc} = \frac{(P_{0.003} - P_{0.001}) \cdot t}{(\delta_{0.003} - \delta_{0.001}) \cdot A}$$



Shear of Core ASTM C 273



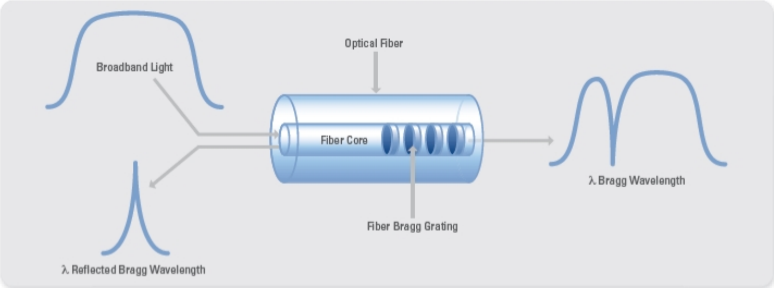
$$\tau = \frac{P}{Lb}, \gamma = \frac{u}{t},$$
$$G = \frac{(\Delta P/\Delta u)t}{Lb}$$

Failure Type	Code	Area	Code	Location	Code
core Shear	S	At end	A	Top	T
Interface failure	I	Gage	G	Bottom	B
eXplosive	X	one Corner	C	Middle	M
Other	O	Various	V	Entire length	E
		Unknown	U	Various	V
				Unknown	U

Resistance strain gauges

- Grid size
- Self-heating $P = U \cdot I = \frac{U^2}{R}$ $R = 350\Omega$
- Temperature compensation – half bridge
- Surface preparing
- 2 components adhesive

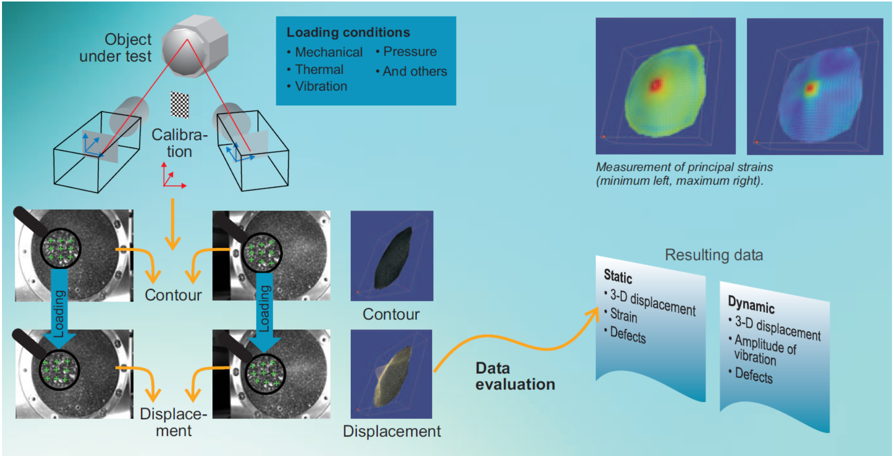
Fiber Bragg Grating (FBG) Sensors



$$\frac{\Delta\lambda}{\lambda_0} = (1 - p_e) \cdot \varepsilon(\alpha_{Lamda} + \alpha_n) \cdot \Delta T$$

http://www.ni.com

DIC



http://www.dantecdynamics.com/

References

- Mallick, P. K.: *Composites Engineering Handbook*, CRC Press, 1997, ISBN 0824793048
- Hodgkinson, J.M.:*Mechanical testing of advenced fibre composites*, Woodhead Publishing 2000, ISBN 1855733129
- Carlsson, L.A., Adams, D.F., Pipes, R.B.:*Experimental Characterization of Advanced Composite Materials*, Third Edition, CRC Press, 2002 , ISBN1587161001
- COMPOSITE MATERIALS HANDBOOK – VOLUME 1*Polymer Matrix Composites, Guidelines for Characterization of Structural Materials MIL-HDBK-17*, US Army Research Laboratory, 2002, Fort Belvoir