

Normy pro zjišťování mechanických vlastností kompozitových materiálů

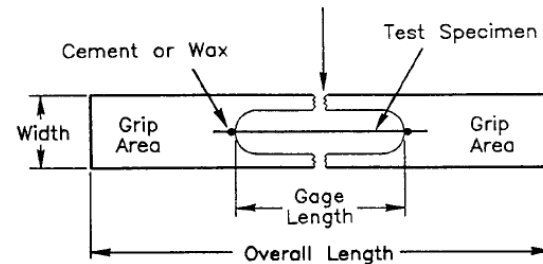
Karel Doubrava

ČVUT v Praze, Fakulta strojní

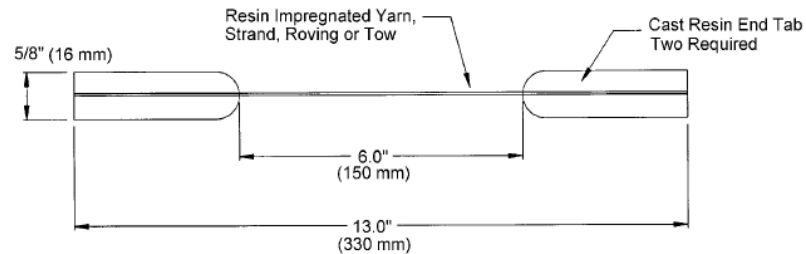
- Zkoušení laminátů
 - Vlákna, Matrice, Laminy, Lamináty
- Zkoušení sendvičů
- Odporová tenzometrie na kompozitních konstrukcích

Vlákná

- ASTM D 3379



- [ASTM D 4018](#)



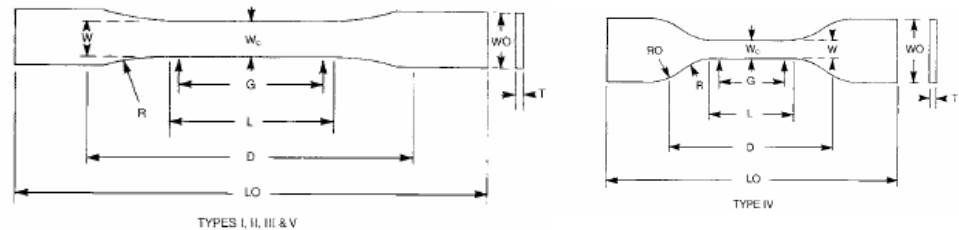
- Zkouška jednosměr. laminátu [ASTM D 3039](#)

$$Vlastnost_f [\%] = \frac{Vlastnost_{0^\circ} \cdot 100}{V_f}$$

Matrice

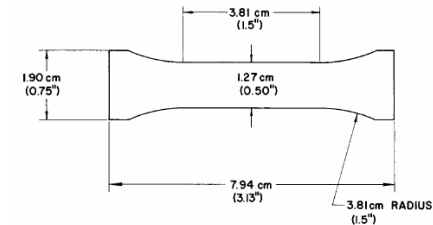
- Tah [ASTM D 638](#)

$$F_m^{tu}, F_m^{ty}, E_m^t, V_m^t, \varepsilon_m^{tu}$$



- Tlak [D 695](#) $F_m^{cu}, F_m^{cy}, E_m^c, V_m^c, \varepsilon_m^{cu}$

(prizma, válce, tenké vzorky)



- Smyk ASTM E 143, [ASTM D 5379](#)

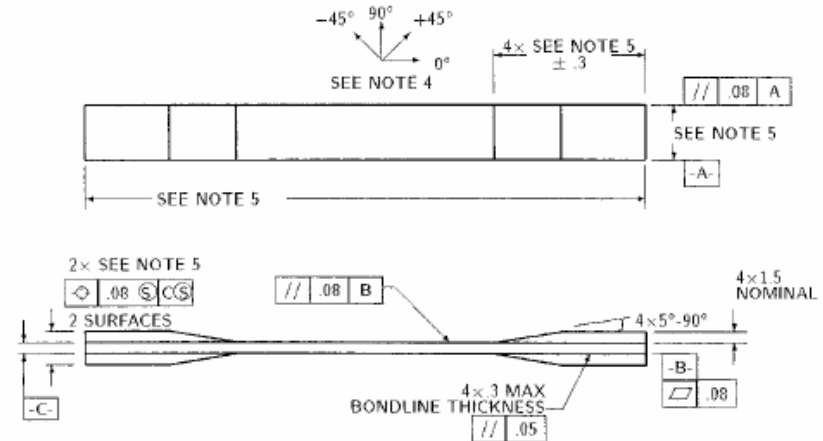
$$F_m^{su}, F_m^{sy}, G_m^s$$

Druhy zkoušek – laminy, lamináty

- Tah ([ASTM D 3039](#))
- Tlak ([ASTM D 3410](#), [ASTM D 695](#))
- Smyk ([ASTM D 3518](#), [D 5379](#), ...)
- Interlaminární smyk ([ASTM D 2344](#))

Tahová zkouška ASTM D 3039

- Pevnost v tahu
- Modul pružnosti
- Poissonovo číslo

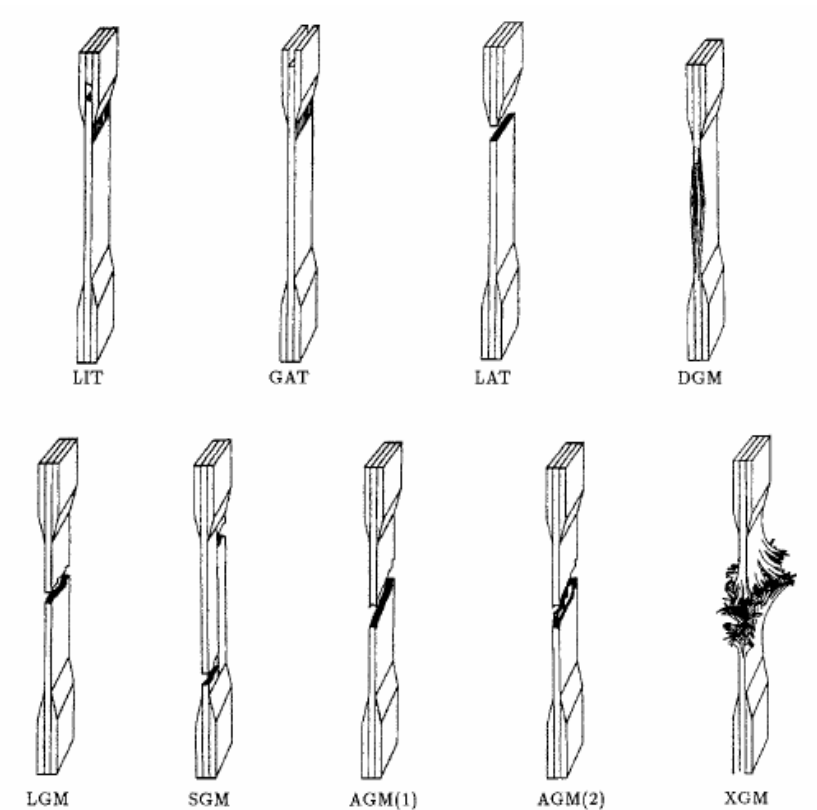


$$E_1 = \frac{\sigma_1^b - \sigma_1^a}{\epsilon_1^b - \epsilon_1^a}$$

$a \dots 0,1\%$, $b \dots 0,3\%$

ASTM D 3039 klasifikace poruch

1. znak	2. znak	3. znak	
Mód poruchy	Plocha poruchy	Místo poruchy	
Angled edge Delamination	A Inside grip/tab	I Bottom	B
	D At grip/tab	A Top	T
Grip/tab	G <1W from grip/tab	A Left	L
Lateral	L Gage	G Right	R
Multi—mode long.-Splitting	M Multiple areas	M Middle	M
	S Various	V Various	V
eXplosive	X Unknown	U Unknown	U
Other	O		



Tlakové zkoušky

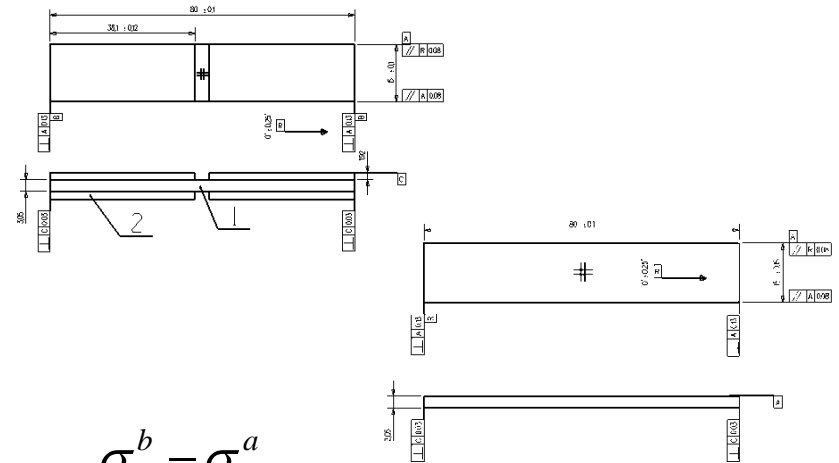
- [ASTM D-695](#) (SACMA SRM-1)
- [ASTM D 3410](#) (Celanese, IITRI)
- [ASTM D 5467](#)

Tlakové zkoušky ASTM D-695

- Pevnost v tlaku
- Modul pružnosti v tlaku



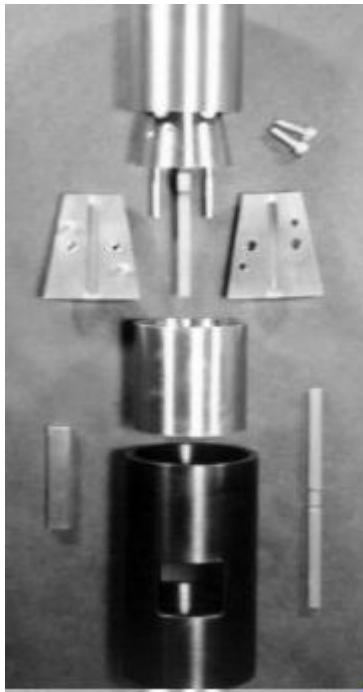
<http://www.wyomingtestfixtures.com/>



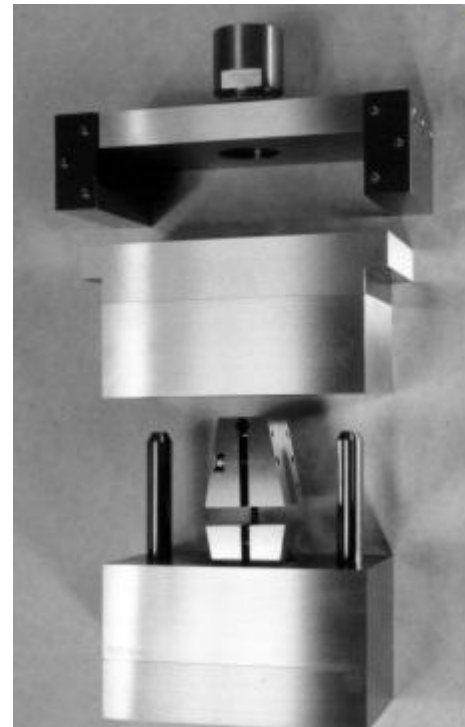
$$E_1 = \frac{\sigma_1^b - \sigma_1^a}{\epsilon_1^b - \epsilon_1^a}$$

Tlakové zkoušky ASTM D 3410

Celanese



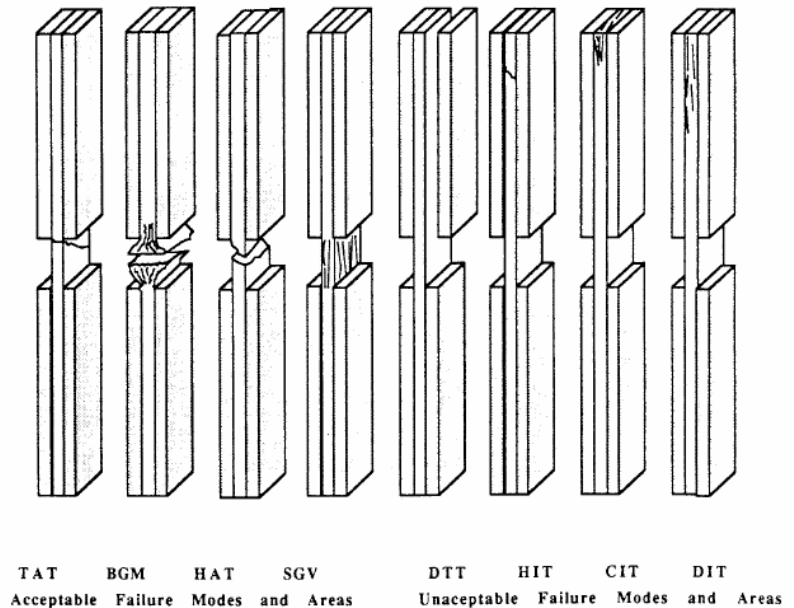
IITRI



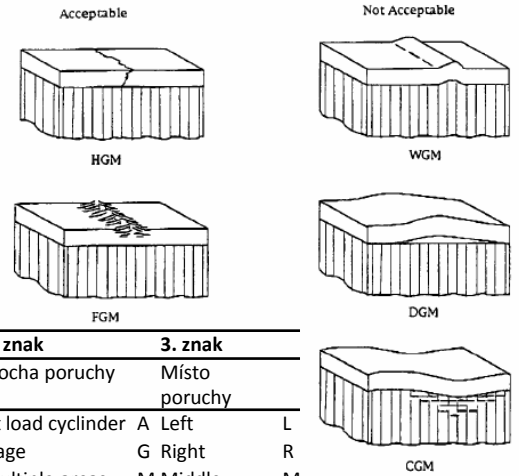
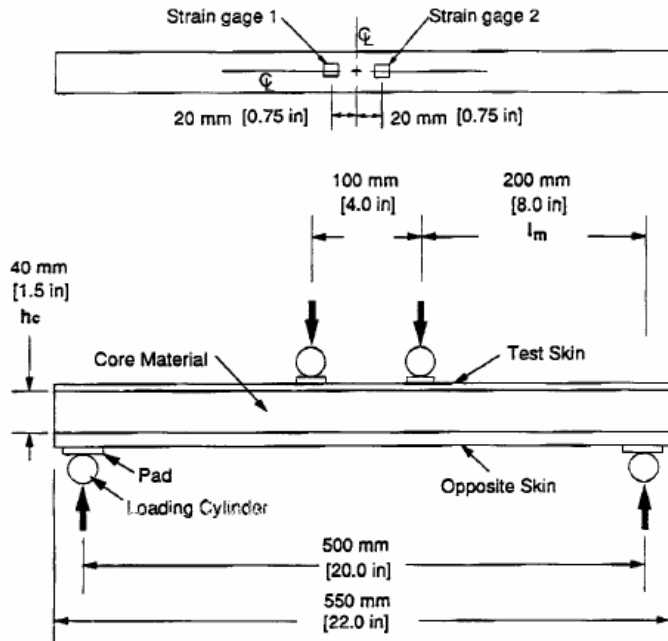
<http://www.wyomingtestfixtures.com/>

ASTM D 3410 klasifikace poruch

1. znak	2. znak	3. znak
Mód poruchy	Plocha poruchy	Místo poruchy
Angled	A Inside grip/tab	I Bottom B
Brooming	B At grip/tab	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	



ASTM D 5467



1. znak	2. znak	3. znak
Mód poruchy	Plocha poruchy	Místo poruchy
skin to core Delamination	D	At load cyclinder
Filament fracture	F	Gage
tHrough-tickness	H	Multiple areas
Layer instability	L	Outside gage
local Wrinkling	W	Various
Multi-mode	M	Unknown
core Crushing	C	
long.-Splitting	S	
Transverse shear	T	
eXplosive	X	
Other	O	

$$F^{cu} = \frac{P^{\max} l_m \left(a - \bar{y} + \frac{h_f}{2} \right)}{2w \left[h_f (a - \bar{y})^2 + \frac{E_0}{E_f} h_a \bar{y}^2 \right]}$$

$$\sigma^c = \frac{P l_m \left(a - \bar{y} + \frac{h_f}{2} \right)}{2w \left[h_f (a - \bar{y})^2 + \frac{E_0}{E_f} h_a \bar{y}^2 \right]}$$

$$E = \frac{\sigma^b - \sigma^a}{\varepsilon^b - \varepsilon^a}$$

a ... 0,1%, b ... 0,3%

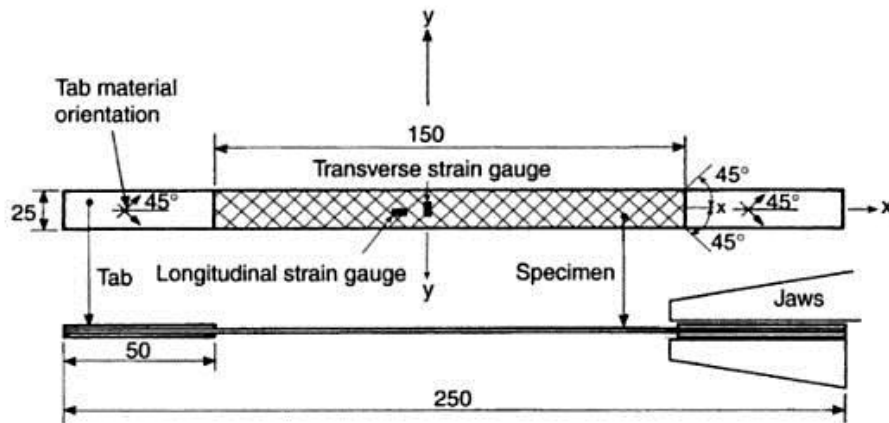
Smykové zkoušky

- Jednoosý tah $\pm 45^\circ$ laminátu
- Smykové testy s dvojitým a trojitým vedením
- Smykový vzorek s V vrubem (Iosipescu, s vedením)
- Krut tenkostěnné trubky

Smyk - Jednoosý tah $\pm 45^\circ$ laminátu

- BS EN ISO 14,129, [ASTM D 3518](#)
- Vzorek vrstva $>0,125$ mm, 16 vrstev

$$\sigma_{11} = \frac{\sigma_{xx}}{2} + \tau_{xy}; \quad \sigma_{22} = \frac{\sigma_{xx}}{2} - \tau_{xy}; \quad \tau_{12} = \pm \tau_{xy} \quad \varepsilon_{11} = \varepsilon_{22} = \frac{\varepsilon_{xx} + \varepsilon_{yy}}{2}; \quad \gamma_{12} = \varepsilon_{xx} - \varepsilon_{yy}$$

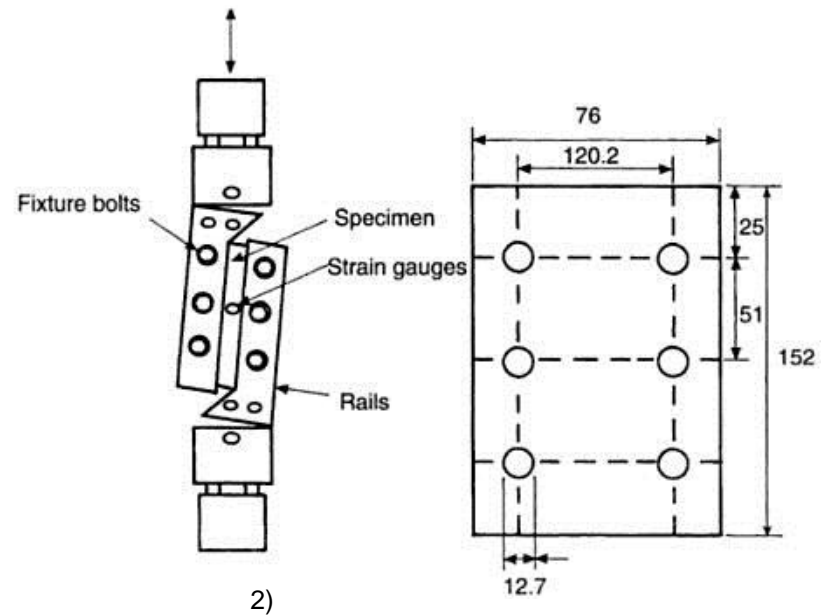
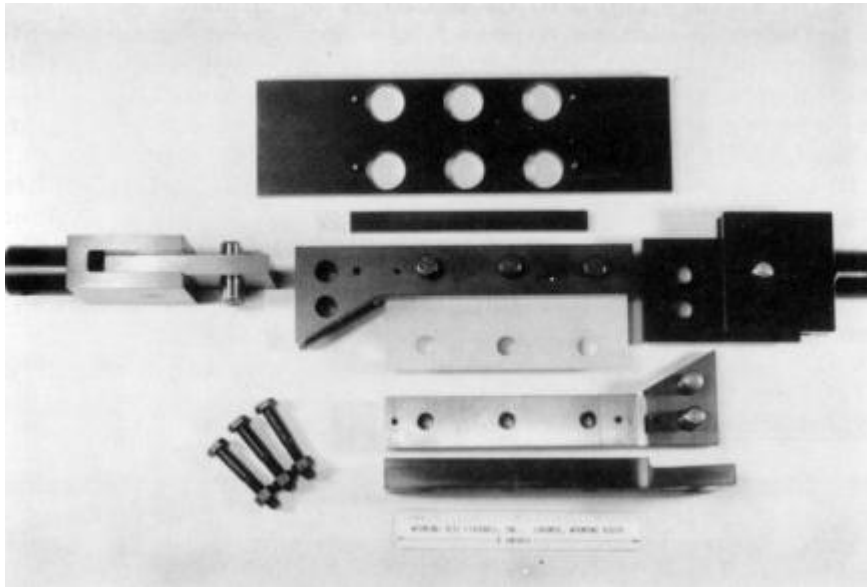


$$G_{12} = \frac{\sigma_{xx}}{2(\varepsilon_{xx} - \varepsilon_{yy})} = \frac{\tau_{12}^b - \tau_{12}^a}{\gamma_{12}^b - \gamma_{12}^a}$$

$$S_{12} = \frac{P_{\max}}{2bh}$$

Smykové testy s dvojitým vedením

ASTM D 4255



<http://www.wyomingtestfixtures.com/>

$$S_{xy} = \frac{P_{\max}}{Lh}$$

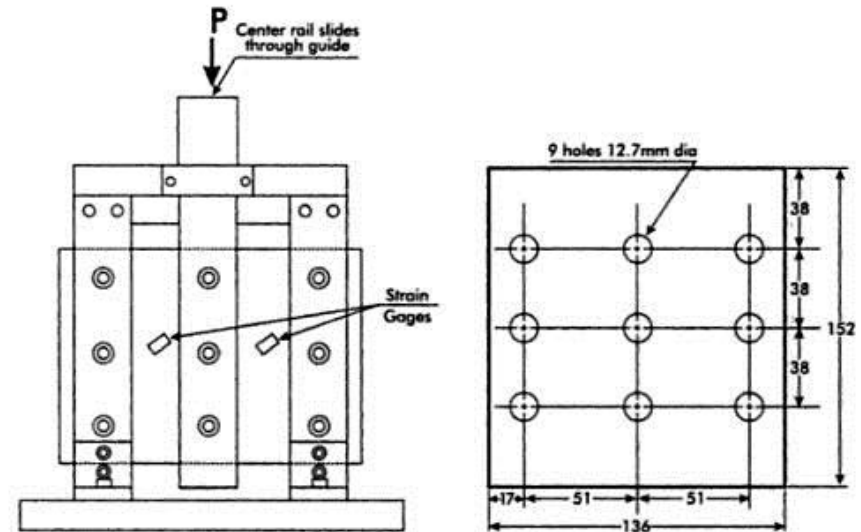
$$G_{12} = \frac{\Delta\tau_{xy}}{\Delta\gamma_{xy}} = \frac{\Delta P}{2Lh\Delta\varepsilon_{45}}$$

Smykové testy s trojitým vedením

ASTM D 4255



<http://www.wyomingtestfixtures.com/>

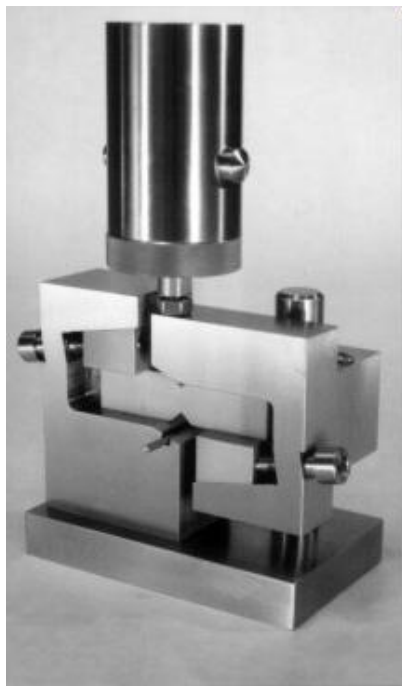


3)

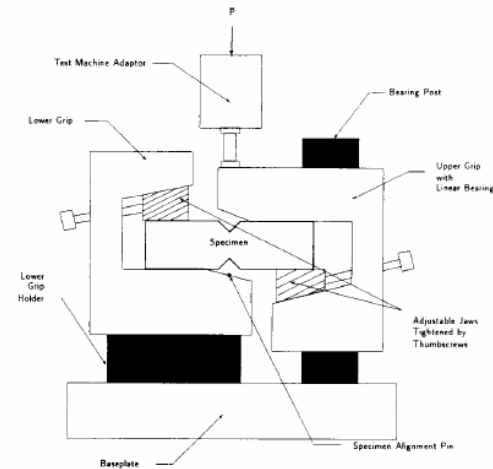
$$S_{xy} = \frac{P_{\max}}{2Lh}$$

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

Smyk -- Smykový vzorek s V vrubem (Iosipescu) ASTM D 5379



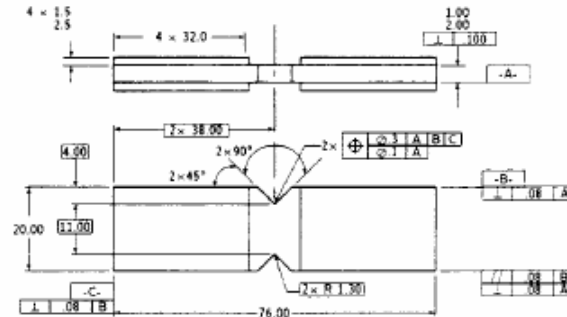
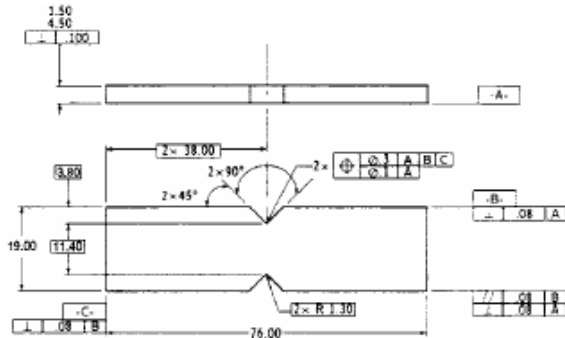
<http://www.wyomingtestfixtures.com/>



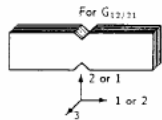
$$F^u = \frac{P^u}{w \cdot h}, \tau_i = \frac{P_i}{w \cdot h}$$

$$\gamma = \left| \varepsilon_{45^\circ} \right| + \left| \varepsilon_{-45^\circ} \right| \quad G = \frac{\Delta \tau}{\Delta \gamma}$$

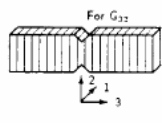
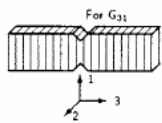
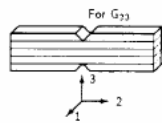
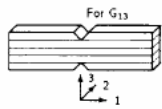
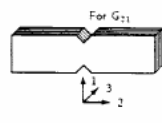
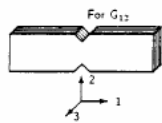
ASTM D 5379



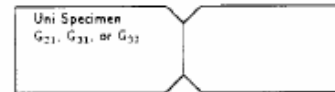
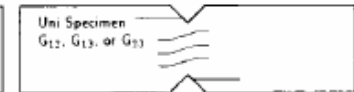
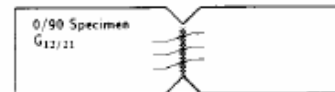
[0/90]_ns or [90/0]_ns Laminates



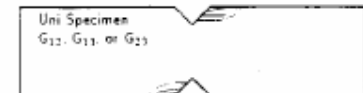
Unidirectional Laminates



Typical Acceptable Failure Modes

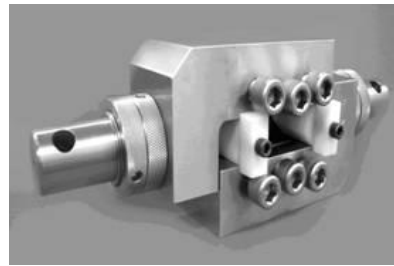
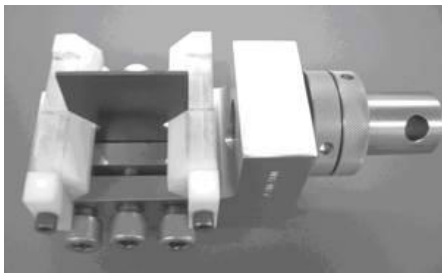
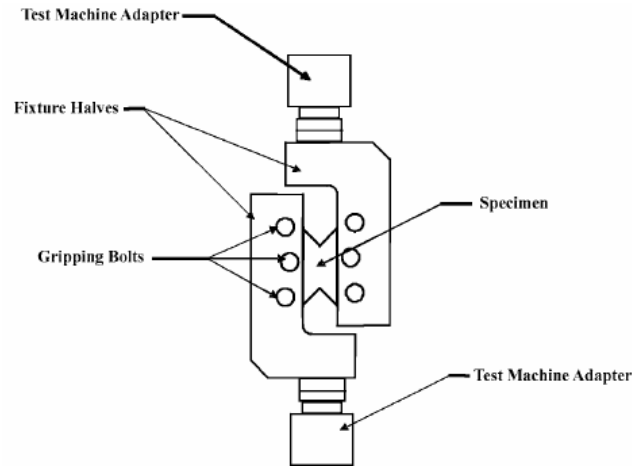
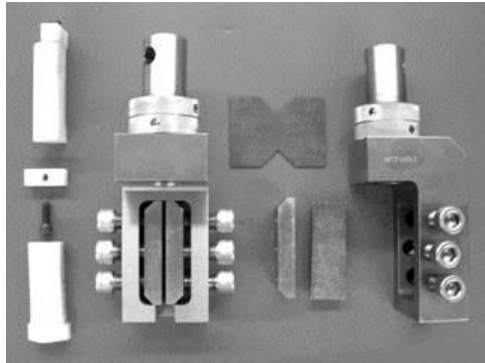


Common Unacceptable Failure Modes
(Typically Initiated At Loading Points)



Smykový vzorek s V vrubem

ASTM D 7078



$$F^u = \frac{P^u}{w \cdot h}, \tau_i = \frac{P_i}{w \cdot h}$$

$$\gamma = \left| \varepsilon_{45^\circ} \right| + \left| \varepsilon_{-45^\circ} \right| \quad G = \frac{\Delta \tau}{\Delta \gamma}$$

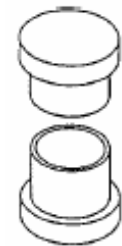
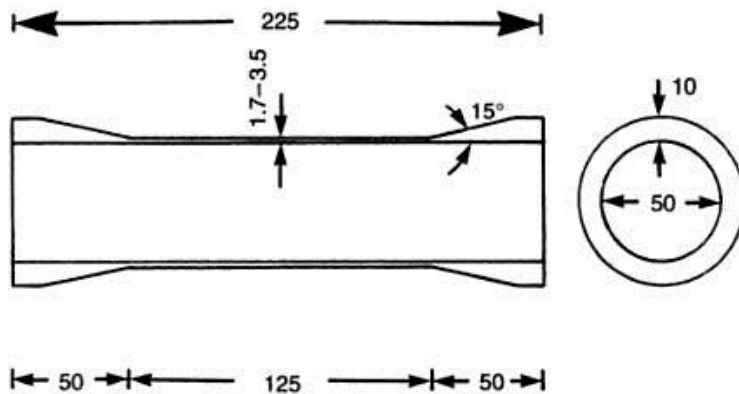
<http://www.wyomingtestfixtures.com/>

Krut tenkostěnné trubky

ASTM D 5448

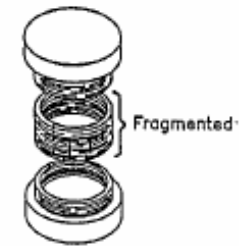
$$\tau_{xy} = \frac{2TR_o}{\pi(R_o^4 - R_i^4)}$$

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



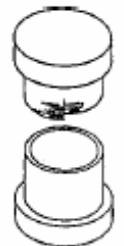
CLASSICAL

(CL)



CATASTROPHIC

(CA)



LOCAL
INSTABILITY

(LI)



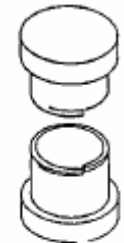
PARTIAL

(PA)



BAND
SPIRAL

(BS)



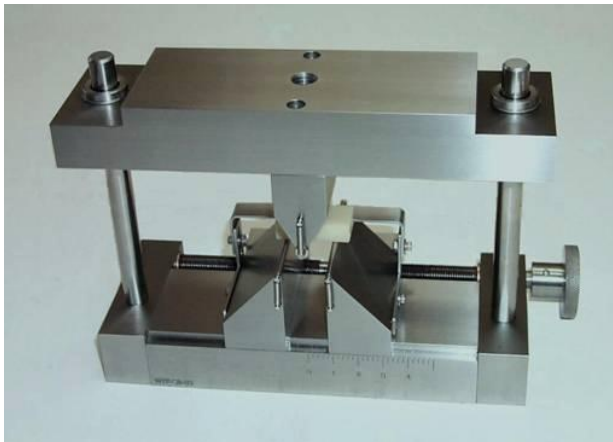
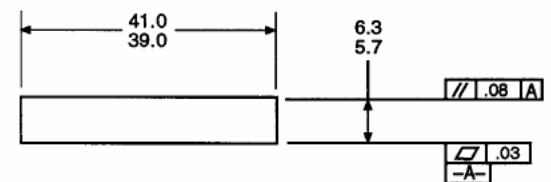
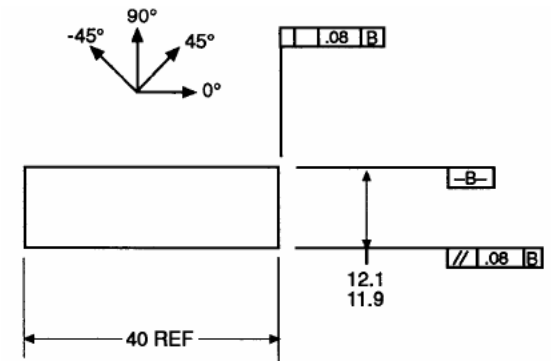
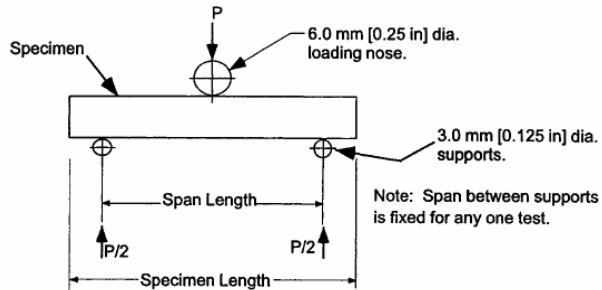
BAND
DETACHMENT

(BD)

2)

Smyk krátkého nosníku

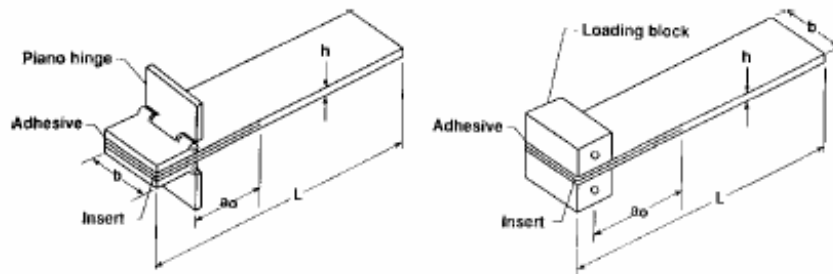
ASTM D 2344



<http://www.wyomingtestfixtures.com/>

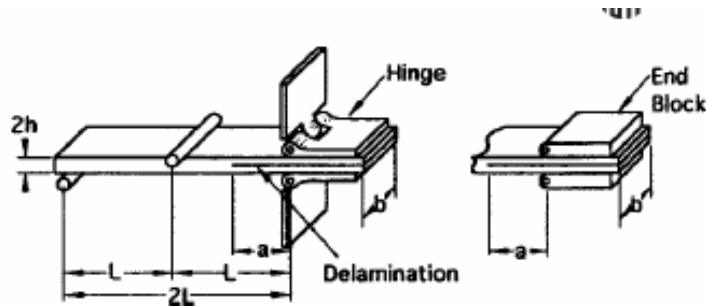
Interlaminární pevnost

Mód I [ASTM D 5528](#)



$$G_I = \frac{3P\delta}{2ba}$$

Mód I+mód II [ASTM D 6671](#)

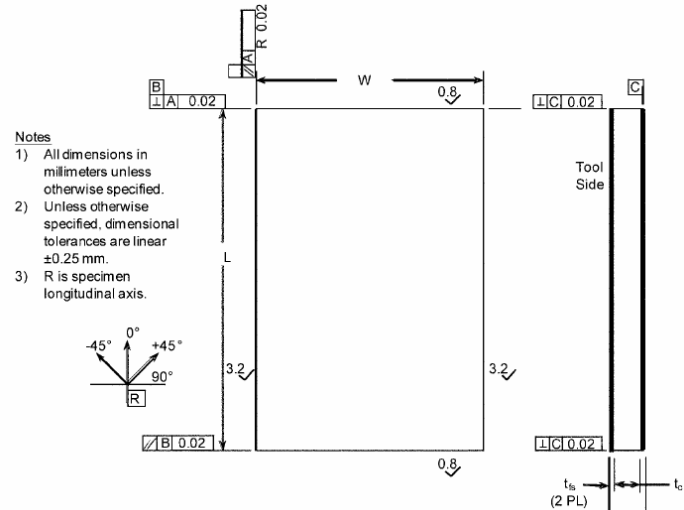
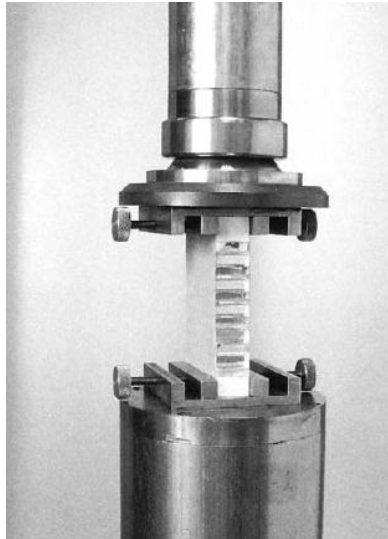


Sendviče

- Tah [ASTM C 297](#)
- Tlak [ASTM C 364](#), [C 365](#), [D7336](#)
- Smyk [ASTM C 273](#), [C393](#)
- Ohyb [ASTM D 7249](#), [D 5467](#)

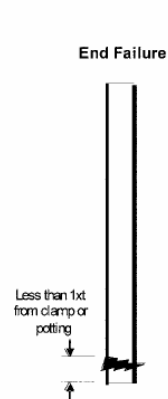
Příčný tlak ASTM C 364

$$\sigma = \frac{P_{\max}}{w(2t_{fs})}$$



1. znak	2. znak	3. znak	
Mód poruchy	Plocha poruchy	Místo poruchy	
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		
Overall Panel buckling	P		
eXplosive	X		
Other	O		

Unacceptable



Facesheet Buckling Failure



Facesheet Compression Failure

Acceptable Failure Modes

Facesheet Dimpling Failure (honeycomb only)

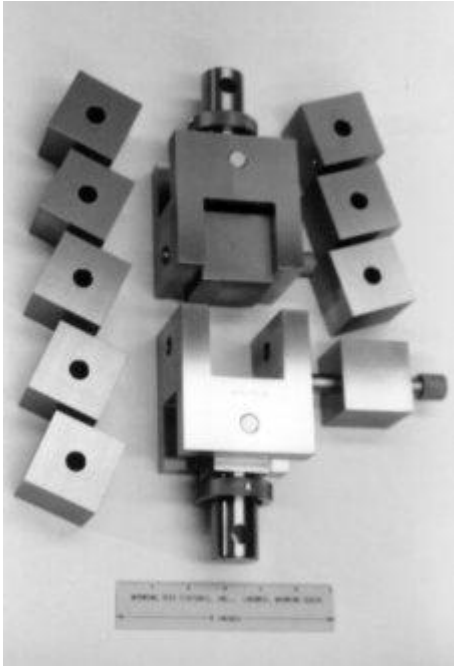


Core Compression Failure

Core Shear Failure

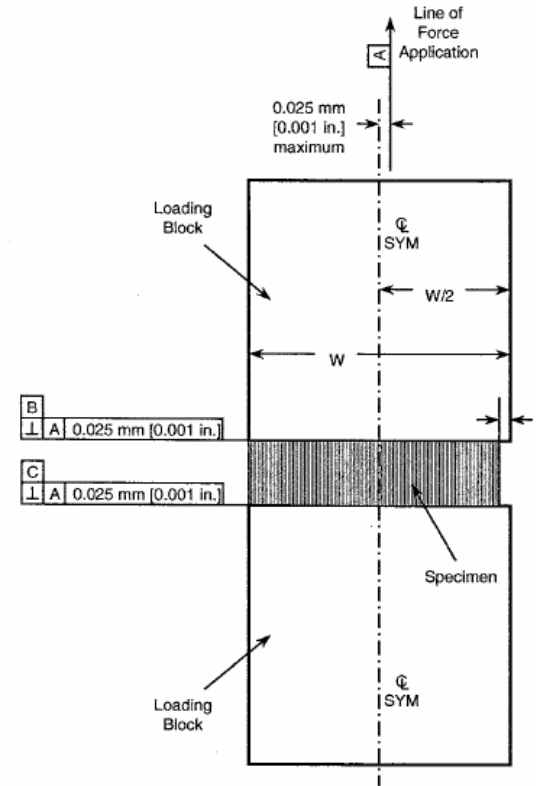


Tah ASTM C 297



<http://www.wyomingtestfixtures.com/>

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

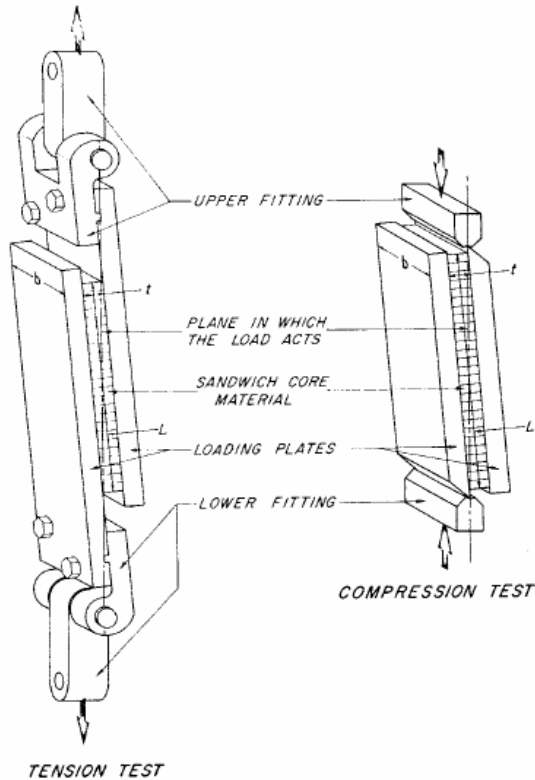


Tlak ASTM C 365



$$F_z^{fcu} = \frac{P_{\max}}{A}$$
$$E_z^{fc} = \frac{(P_{0,003} - P_{0,001}) \cdot t}{(\delta_{0,003} - \delta_{0,001}) \cdot A}$$

Smyk jádra ASTM C273

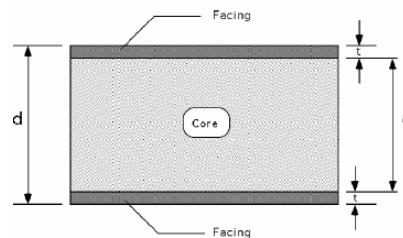
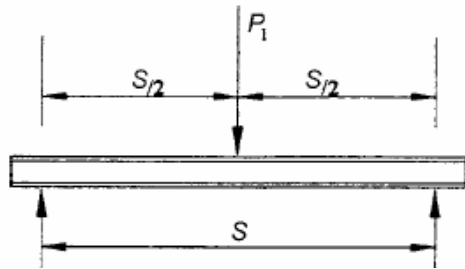


$$\tau = \frac{P}{Lb} \quad \gamma = \frac{u}{t}$$

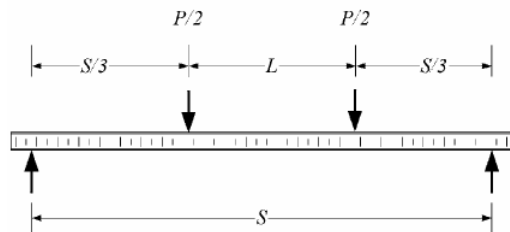
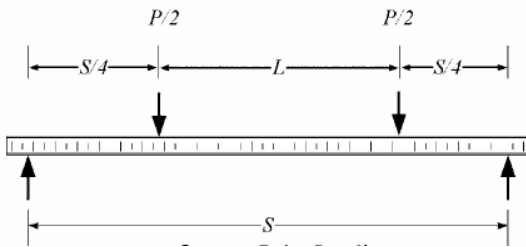
$$G = \frac{(\Delta P / \Delta u)t}{Lb}$$

1. znak	2. znak	3. znak	
Mód poruchy	Plocha poruchy	Místo poruchy	
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

Smykové vlastnosti jádra z ohybu sendviče ASTM C 393

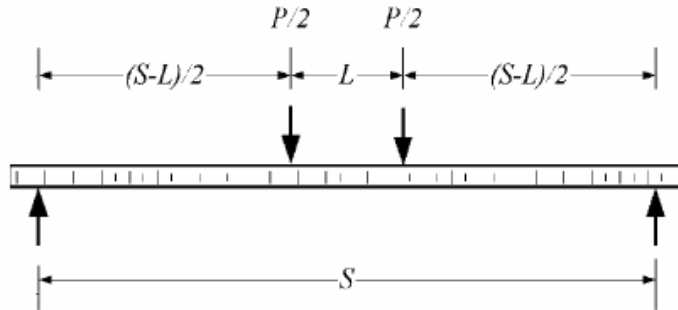


$$F_s^{ult} = \frac{P_{max}}{(d + c)b}$$



1. znak	2. znak	3. znak
Mód poruchy	Plocha poruchy	Místo poruchy
core Crushing	C At load bar	A Core
skin to core Delamination	D Gage	G Core-facing bond
Facing failure	F Multiple areas	M Bottom facing
Multi-mode	M One Corner	C Top facing
transverse Shear	S Various	V both Facing
eXplosive	X Unknown	U Various
Other	O	Unknown

Vlastnosti potahů z ohybu dlouhých nosníků ASTM D 7249



$$F^u = \frac{P_{\max} (S - L)}{2(d + c)bt}$$

konfigurace		Vzdálenost podpor	Vzdálenost sil
Standardní	4PB	560 mm	100 mm
Nestanadrní	3PB	S	0
	4PB čtvrtinová	S	S/2
	4PB třetinová	S	S/3

1. znak	2. znak	3. znak	
Mód poruchy	Plocha poruchy	Místo poruchy	
core Crushing	C At load bar	A Core	C
skin to core Delamination	D Gage	G Core-facing bond	A
Filament fracture	F Multiple areas	M Bottom facing	B
tThrough-thickness	H Outside gage	O Top facing	T
Layer instability	L Various	V both Facing	F
Multi-mode	M Unknown	U Various	V
longitudinal sPlitting	P	Unknown	U
teNsile	N		
local Wrinkling	W		
transverse Shear	S		
eXplosive	X		
Other	O		

Odporová tenzometrie na kompozitních konstrukcích

- Velikost (6mm)
- Odpor 350Ω , napájecí napětí \rightarrow tepelný výkon
- Teplotní kompenzace (půlmostové zapojení)
- Dvousložkové tmely
- Příprava povrchu
- Vlhkost

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