Cours MSE 340 Composites Polymères 2024, Exo B avec ESACOMP : résistances, critères de rupture Exemples de déterminations de la rupture du premier pli et de l'optimisation des facteurs de réserve pour éviter les ruptures.

La même approche est utilisée pour valider vos choix de matériaux et de structure du stratifié pour votre bouteille sous pression et votre snowboard.

pierre-etienne.bourban@epfl.ch

Strength, First Ply Failure and reserve factor RF

Laminate FPF analysis

Laminate : C 04590S
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

Ply		t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12	G_31 GPa	G_23 GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t MPa	X_c MPa	Y_t MPa	Y_c MPa	S MPa	R MPa	Q MPa	X_eps,t %	X_eps,c %	Y_eps,t %	Y_eps,c %	S_e
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN sur 10 cm
Modified : Sun Nov 11 18:15:35 2012
Type : Forces and moments (Var.;E)

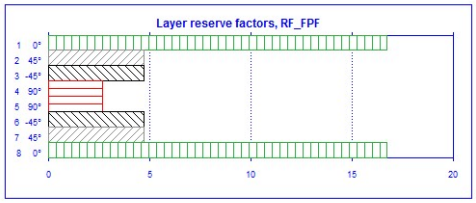
N_x = 50000 N/m M_x = 0 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Puck 2D; Max strain; Von Mises; Out-of-plane shear; Out-of-plane sl
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhes
Failure crit. param. : p_TII+/TII-/TT-/s/M(carbon)=0.35/0.3/0.275/0.5/0.5;(other)=0.3/0.25/(
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	2.70	iff(A)	2.70	iff(A)	(90°)	-	-



Layer reserve factors - FPF

	Ply	theta °			RF	
1	a	0	t	3.	16.74	fft
			b		16.74	
2	a	45	t	2.	4.72	iff(A)
			b		4.72	
3	a	-45	t	2.	4.72	iff(A)
			b		4.72	
4	a	90	t	1.	2.70	iff(A)
			b		2.70	
5	a	90	t	1.	2.70	iff(A)
			b		2.70	
6	a	-45	t	2.	4.72	iff(A)
			b		4.72	
7	a	45	t	2.	4.72	iff(A)
			b		4.72	
8	a	0	t	3.	16.74	fft
			b		16.74	

Laminate FPF analysis

Laminate : C 04590S
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

Ply		t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12	G_31 GPa	G_23 GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t MPa	X_c MPa	Y_t MPa	Y_c MPa	S MPa	R MPa	Q MPa	X_eps,t %	X_eps,c %	Y_eps,t %	Y_eps,c %	S_e
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN sur 10 cm
Modified : Sun Nov 11 18:15:35 2012
Type : Forces and moments (Var.;E)

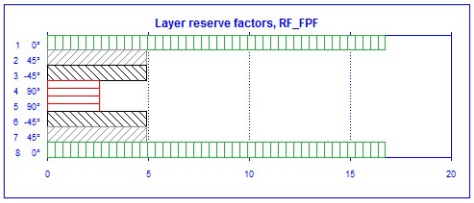
N_x = 50000 N/m M_x = 0 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane sl
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhes
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	2.60	2t	2.60	2t	(90°)	-	-



Layer reserve factors - FPF

	Ply	theta °			RF	
1	a	0	t	3.	16.74	1t
			b		16.74	
2	a	45	t	2.	4.95	2t
			b		4.95	
3	a	-45	t	2.	4.95	2t
			b		4.95	
4	a	90	t	1.	2.60	2t
			b		2.60	
5	a	90	t	1.	2.60	2t
			b		2.60	
6	a	-45	t	2.	4.95	2t
			b		4.95	
7	a	45	t	2.	4.95	2t
			b		4.95	
8	a	0	t	3.	16.74	1t
			b		16.74	

Laminate FPF analysis

Laminate : **C 04590S**
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

Ply		t	E_1	E_2	G_12	nu_12	G_31	G_23
		mm	GPa	GPa	GPa		GPa	GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t	X_c	Y_t	Y_c	S	R	Q	X_eps,t	X_eps,c	Y_eps,t	Y_eps,c	S_
	MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.94

Load : **5kN sur 10 cm et Mx500Nm sur 25 cm**
Modified : Sun Nov 11 19:20:02 2012
Type : Forces and moments (Var.;E)

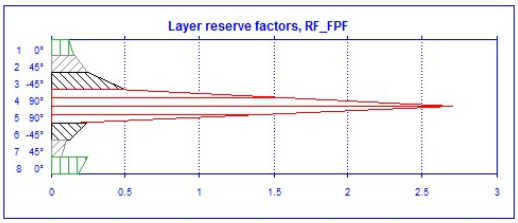
N_x	= 50000 N/m	M_x	= 2000 Nm/m
N_y	= 0 N/m	M_y	= 0 Nm/m
N_xy	= 0 N/m	M_xy	= 0 Nm/m

Q_x	= 0 N/m
Q_y	= 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Puck 2D; Max strain; Von Mises; Out-of-plane shear; Out-of-plane s
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhe
Failure crit. param. : p_TII+/TII-/TT-/s/M(carbon)=0.35/0.3/0.275/0.5/0.5;(other)=0.3/0.25/
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	0.07	iff(A)	0.07	iff(A)	7(45°)	-	-



Layer reserve factors - FPF

	Ply	theta °		RF	
1	a	0	t	2. 0.11	iff(A)
			b	0.15	
2	a	45	t	5. 0.16	iff(C)
			b	0.25	
3	a	-45	t	7. 0.25	iff(B)
			b	0.50	
4	a	90	t	8. 0.44	iff(A)
			b	2.70	
5	a	90	t	3. 2.70	iff(A)
			b	0.12	
6	a	-45	t	4. 0.24	iff(A)
			b	0.12	
7	a	45	t	1. 0.11	iff(A)
			b	0.07	
8	a	0	t	6. 0.25	fft
			b	0.19	

Laminate FPF analysis

Laminate : **C 04590S**
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

Ply		t	E_1	E_2	G_12	nu_12	G_31	G_23
		mm	GPa	GPa	GPa		GPa	GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t	X_c	Y_t	Y_c	S	R	Q	X_eps,t	X_eps,c	Y_eps,t	Y_eps,c	S_
	MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.94

Load : **5kN sur 10 cm et Mx500Nm sur 25 cm**
Modified : Sun Nov 11 19:20:02 2012
Type : Forces and moments (Var.;E)

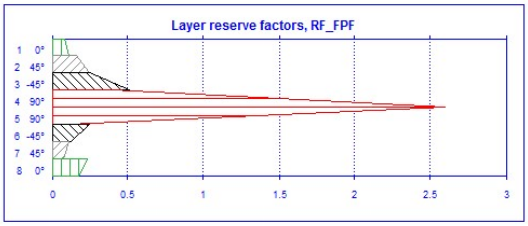
N_x	= 50000 N/m	M_x	= 2000 Nm/m
N_y	= 0 N/m	M_y	= 0 Nm/m
N_xy	= 0 N/m	M_xy	= 0 Nm/m

Q_x	= 0 N/m
Q_y	= 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane s
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhe
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

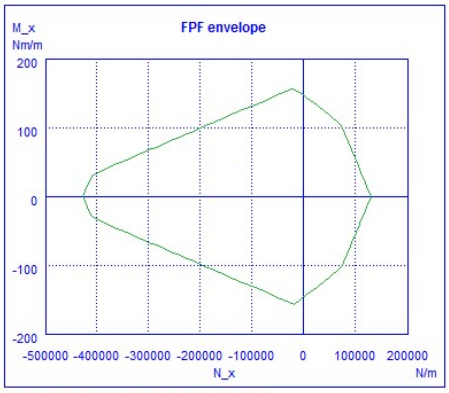
	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	0.07	2t	0.07	2t	7(45°)	-	-



Layer reserve factors - FPF

	Ply	theta °		RF	
1	a	0	t	2. 0.08	1c/2t
			b	0.11	
2	a	45	t	5. 0.16	s
			b	0.25	
3	a	-45	t	7. 0.25	s
			b	0.51	
4	a	90	t	8. 0.40	2c
			b	2.60	
5	a	90	t	3. 2.60	2t
			b	0.11	
6	a	-45	t	4. 0.25	2t/s
			b	0.13	
7	a	45	t	1. 0.11	2t
			b	0.07	
8	a	0	t	6. 0.23	1t
			b	0.17	

Sous charge combinée de Nx et Mx, plusieurs RF sont inférieurs à 1. Le plus petit est 0.07.
Donc le bas du pli 7 avec des fibres à 45 va se rompre à une charge de 7% de celle appliquée.
Le critère de Tsai Wu est plus conservateur que Puck



Plot x- and y-components not in the same scale.

Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane shear; None
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhesive)
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate : **C 04590S**
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

Ply
a E;Epoxy;UD-.230/299/50

Les Nx et Mx max sont ainsi déterminés pour le composite donné.

Laminate FPF analysis

Laminate : C 04590S
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

	Ply	t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12	G_31 GPa	G_23 GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t MPa	X_c MPa	Y_t MPa	Y_c MPa	S MPa	R MPa	Q MPa	X_eps,t %	X_eps,c %	Y_eps,t %	Y_eps,c %	S_
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.94

Load : 5kN10cm Mx125sur25cm
Modified : Sun Nov 11 21:02:20 2012
Type : Forces and moments (Var.;E)

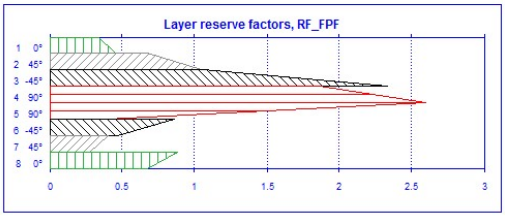
N_x = 50000 N/m M_x = 500 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane s
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhe
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	0.28	2t	0.28	2t	7(45°)	-	-



Layer reserve factors - FPF

	Ply	theta °			RF	
1	a	0	t	2.	0.34	1c/2t
			b		0.45	
2	a	45	t	6.	0.68	s
			b		1.05	
3	a	-45	t	7.	1.06	s
			b		2.33	
4	a	90	t	8.	1.86	2c
			b		2.60	
5	a	90	t	3.	2.60	2t
			b		0.40	
6	a	-45	t	4.	0.86	2t/s
			b		0.47	
7	a	45	t	1.	0.40	2t
			b		0.28	
8	a	0	t	5.	0.89	1t
			b		0.67	

Laminate FPF analysis

Laminate : C 04590S
Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/+45a/-45a/90a)SE h = 1.84 mm

	Ply	t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12	G_31 GPa	G_23 GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t MPa	X_c MPa	Y_t MPa	Y_c MPa	S MPa	R MPa	Q MPa	X_eps,t %	X_eps,c %	Y_eps,t %	Y_eps,c %	S_e
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN10cm Mx25sur25cm
Modified : Sun Nov 11 21:05:33 2012
Type : Forces and moments (Var.;E)

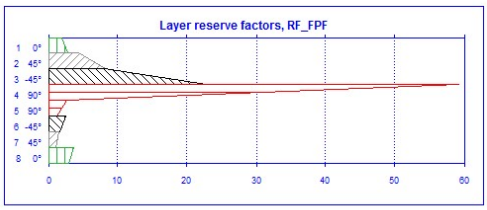
N_x = 50000 N/m M_x = 100 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane st
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhes
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	1.13	2t	1.13	2t	7(45°)	-	-



Layer reserve factors - FPF

	Ply	theta °			RF	
1	a	0	t	4.	1.93	1c/2t
			b		2.74	
2	a	45	t	7.	4.43	s
			b		8.22	
3	a	-45	t	8.	8.06	s
			b		22.77	
4	a	90	t	5.	59.19	2t
			b		2.60	
5	a	90	t	2.	2.60	2t
			b		1.23	
6	a	-45	t	3.	2.54	2t
			b		1.71	
7	a	45	t	1.	1.52	2t
			b		1.13	
8	a	0	t	6.	3.68	1t
			b		2.91	

Le composite ne se rompra pas sous le deuxième cas de charge Mx réduit, (tous les RF sont supérieurs à 1)

Ajouter des plis permet de supporter sans rupture le cas de charge initial:

Normalized laminate stiffness and compliance matrices

Laminate : **04590s 8mm**
Modified : Sun Nov 11 22:01:22 2012

Lay-up : ((0a)4/(+45a)4/(-45a)4/(90a)4)SE h = 7.36 mm

Ply
a E;Epoxy;UD-.230/299/50

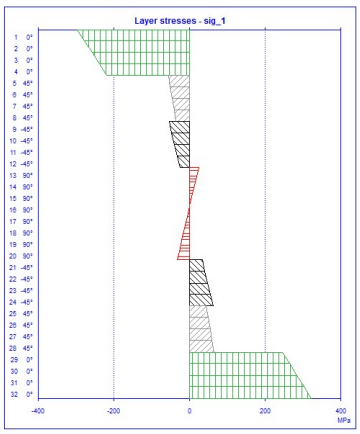
Normalized stiffness matrices (N/m²)

[A*]	2.04986e+010	6.27206e+009	0
	6.27206e+009	2.04986e+010	0
	0	0	7.11326e+009
[B*]	0	0	0
	0	0	0
	0	0	0
[D*]	2.94912e+010	5.61333e+009	1.38898e+009
	5.61333e+009	1.28234e+010	1.38898e+009
	1.38898e+009	1.38898e+009	6.45452e+009

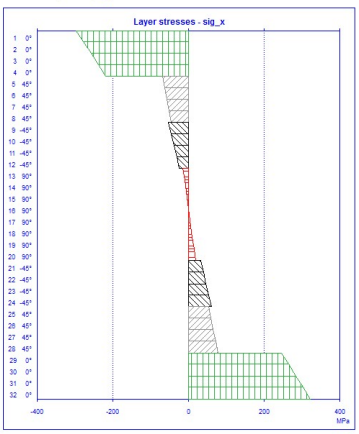
Normalized compliance matrices (m²/N)

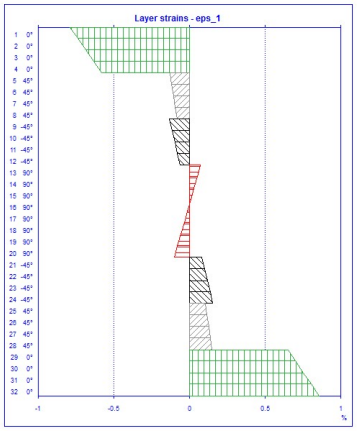
[a*]	5.38228e-011	-1.64685e-011	0
	-1.64685e-011	5.38228e-011	-0
	0	-0	1.40583e-010
[b*]	0	0	0
	-0	-0	-0
	0	0	0
[d*]	3.71233e-011	-1.57522e-011	-4.59895e-012
	-1.57522e-011	8.65274e-011	-1.52305e-011
	-4.59895e-012	-1.52305e-011	1.59197e-010

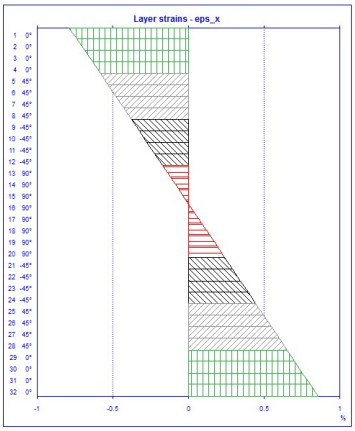
Actual stress, Actual (=Eq.) strain



Actual stress, Actual (=Eq.) strain







Laminate : **04590s 8mm**
Modified : Sun Nov 11 22:01:22 2012

Lay-up : ((0a)4/(+45a)4/(-45a)4/(90a)4)SE h = 7.36 mm

Ply	t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12
a E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3

Load : **5kN sur 10 cm et Mx500Nm sur 25 cm**
Modified : Sun Nov 11 22:02:53 2012
Type : Forces and moments (Var,E)

N_x = 50000 N/m M_x = 2000 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Laminate : **04590s 8mm**
Modified : Sun Nov 11 22:01:22 2012

Lay-up : ((0a)4/(+45a)4/(-45a)4/(90a)4)SE h = 7.36 mm

Ply	t mm	E_1 GPa	E_2 GPa	G_12 GPa	nu_12
a E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3

Load : **5kN sur 10 cm et Mx500Nm sur 25 cm**
Modified : Sun Nov 11 22:02:53 2012
Type : Forces and moments (Var,E)

N_x = 50000 N/m M_x = 2000 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Laminate FPF analysis

Laminate : **04590s 8mm**
Modified : Sun Nov 11 22:01:22 2012

Lay-up : ((0a)4/(+45a)4/(-45a)4/(90a)4)SE h = 7.36 mm

Ply		t	E_1	E_2	G_12	nu_12	G_31	G_23
		mm	GPa	GPa	GPa		GPa	GPa
a	E;Epoxy;UD-.230/299/50	0.23	38	9	3.6	0.3	3.6	3.46154

	X_t	X_c	Y_t	Y_c	S	R	Q	X_eps,t	X_eps,c	Y_eps,t	Y_eps,c	S_ep
	MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	
a	930	570	33	110	70	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : **5kN sur 10 cm et Mx500Nm sur 25 cm**
Modified : Sun Nov 11 22:02:53 2012
Type : Forces and moments (Var.;E)

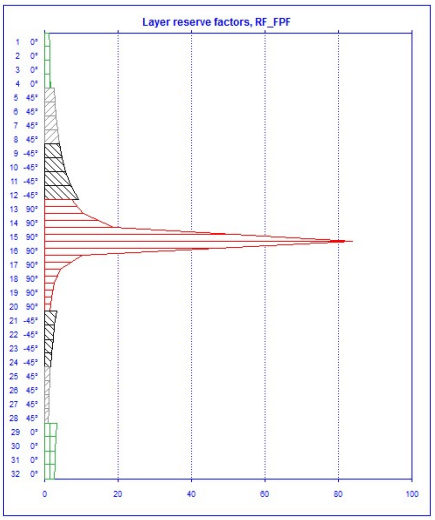
N_x = 50000 N/m M_x = 2000 Nm/m
N_y = 0 N/m M_y = 0 Nm/m
N_xy = 0 N/m M_xy = 0 Nm/m

Q_x = 0 N/m
Q_y = 0 N/m

Factor of safety : FoS^v = 1
Failure criterion : Tsai-Wu; Max strain; Von Mises; Out-of-plane shear; Out-of-plane sh
(UD; non-UD; homogeneous; honeyc. core; foam/other core; adhesi
Failure crit. param. : Tsai-Wu F_12*=-0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

	FPF	Mode	FPF-only	Mode	Crit. layers	ILS	Crit. interf.
RF =	1.11	2t	1.11	2t	28(45°)	-	-



Layer reserve factors - FPF

	Ply	theta			RF	
		°				
1	a	0	t	4.	1.35	1c/2t
			b		1.44	
2	a	0	t	5.	1.44	1c/2t
			b		1.54	
3	a	0	t	7.	1.54	1c/2t
			b		1.67	
4	a	0	t	9.	1.67	1c/2t
			b		1.81	
5	a	45	t	15.	2.71	s
			b		2.97	
6	a	45	t	19.	2.97	s
			b		3.29	
7	a	45	t	22.	3.29	s
			b		3.69	
8	a	45	t	23.	3.69	s
			b		4.19	
9	a	-45	t	24.	4.25	s
			b		4.92	
10	a	-45	t	26.	4.92	s
			b		5.84	
11	a	-45	t	27.	5.84	s
			b		7.18	
12	a	-45	t	28.	7.18	s
			b		9.32	
13	a	90	t	29.	7.43	2c
			b		10.68	
14	a	90	t	31.	10.68	2c
			b		18.97	
15	a	90	t	32.	18.97	2c
			b		83.82	
16	a	90	t	30.	83.82	2t
			b		10.38	
17	a	90	t	25.	10.38	2t
			b		4.36	
18	a	90	t	16.	4.36	2t
			b		2.76	
19	a	90	t	11.	2.76	2t
			b		2.02	
20	a	90	t	8.	2.02	2t
			b		1.59	
21	a	-45	t	17.	3.44	2t/s
			b		2.85	
22	a	-45	t	13.	2.85	2t/s
			b		2.43	
23	a	-45	t	12.	2.43	2t/s
			b		2.12	
24	a	-45	t	10.	2.12	2t/s
			b		1.88	
25	a	45	t	6.	1.62	2t
			b		1.45	
26	a	45	t	3.	1.45	2t
			b		1.31	
27	a	45	t	2.	1.31	2t
			b		1.20	
28	a	45	t	1.	1.20	2t
			b		1.11	
29	a	0	t	21.	3.54	1t
			b		3.28	
30	a	0	t	20.	3.28	1t
			b		3.06	
31	a	0	t	18.	3.06	1t
			b		2.86	
32	a	0	t	14.	2.86	1t
			b		2.69	