Measurements of in-plane shear properties of GEV206 at ambient room conditions using 30-off axes test specimen

21st November 2003

Confidential

OB_TG3_R010[1]

TG3[2]

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[1] Document number: 10147
[2]

Issue/revision	date	pages	Summary of change
0	Nov. 14, 2003	Na	Na
	Nov. 21, 2003	5	the references to the VUB 30-off data are corrected

1. Introduction

The in-plane shear properties, shear modulus G_{12} and it's degradation as a function of applied strain, the ultimate shear strength (shear strain and shear stress to failure) for GEV206 system are measured at ambient room conditions (OPTIMAT reference conditions). The 30^0-off speciemns are used [3, 2]. This work is a part of the work package 8, OPTIMAT TG3, and is carried out according to DPA of TG3. The test that are carried out at Risø are presented in this report at this moment. The additional test results will be added as they will be provided by other partners.

The main focus of the report is on the results of in-plane shear properties obtained by using 30^0-off speciemns. However, there is a short reference made to the results obtained by using the alternative methods, such as the tensile test with V-notched beam [1] specimens. The detailed analysis of the two alternative methods will be a subject of an other report.

The materials and specimens as well as experimental procedures and measurements are discussed shortly in corresponding section of the report. The results are presented and discussed in section “Results and discussions”, and all the additional information (illustrations) are given in Appendix.

2. Specimens and material

The material tested is GEV206, OPTIMAT reference material. The test specimens are manufactured and prepared according to the selected test method, see for details [3, 2]. The fiber orientation, however, is used 30^0instead. Specimens are cut to the final dimensions out of plate by a diamond cutting tool and V-notch is cut by using programmable milling tool. The geometry of the specimens is illustrated in Figure 1.

The strain gauge rosette with one gauge placed in 90^0, and another in $+45^0$ with respect to specimen geometry and loading direction. The strain gauges that are used are: A59AF595-131513-15163. The whole setup of the test specimen is shematically shown in Figure 1.

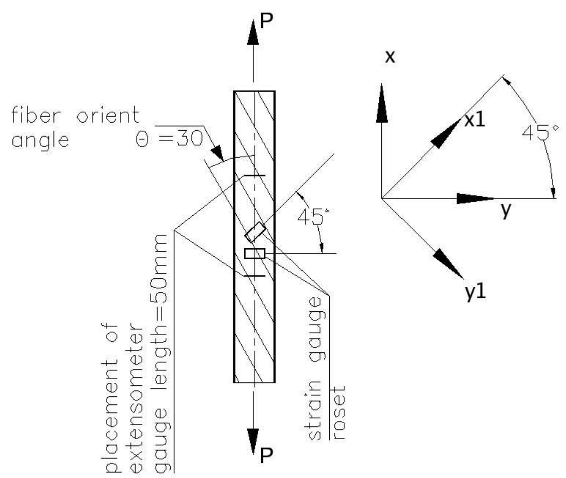


Figure 1: The geometry and set-up of the V-notched specimen.

The list of specimens that are manufactured and prepared for the test are listed in 1. Totally seven (7) specimens are planned to test, where three of them to be tested using standard [3, 2] loading ramp (called, static), and four specimens to be tested using loading - unloading ramp with increasing applied strain level for each loading step. The loading - unloading ramp is used in order to measure the degradation of shear modulus as a function of applied strain.

Table 1: List of specimens, GEV2006-I04-0(90)

Specimen ID	Dimensions		Gauge		Fiber	Loading	
	W mm	Th mm	R Ω	G-fact	orientation degree	Speed mm/min	Ramp
GEV206-I01-30-1	24.89	3.724	350	2.1	30	2	static
GEV206-I01-30-2	25.04	3.70	350	2.1	30	2	static
GEV206-I01-30-3	25.07	3.74	350	2.1	30	2	static
GEV206-I01-30-4	24.93	3.72	350	2.1	30	2	load-unload
GEV206-I01-30-5	25.08	3.74	350	2.1	30	2	load-unload
GEV206-I01-30-6	25.90	3.75	350	2.1	30	2	load-unload
GEV206-I01-30-7	25.04	3.78	350	2.1	30	2	load-unload
GEV206-I01-30-8			350	2.1	30	2	-
GEV206-I01-30-9			350	2.1	30	2	-

3. Test procedures and measurements

Tests are carried out according to the ASTM standard D3518/D3518M-94 [2, 1] in general. The specimen gripping, and cross head speed of $2.0(mm/min)$ according to the [1] is used. The load is measured using a standard load cell $\pm 50(kN)$ mounted on standard hydraulic INSTRON test machine. Strain is measured by mounted $90^0$and 45^o strain gauge rosette and extensometer, see Figure 1. The data sampling of $5(Hz)$ is used for all the data (load, displacement, strain).

The static loading ramp is straight forward as it is described in standard [2, 3] to measure in-plane shear modulus and shear strength of the material, exept the data reduction methodology. The data reduction methodology is slightly different due to the 30^0 fibero orientation. It is given in Appendix A.2.

The loading - unloading ramp is designed so that there are five (5) steps possible until specimen breaks. The initial shear modulus, G_{12}, is measured in the first step within range of applied shear strain $0.05(\%) \leq \gamma_{12} \leq 0.35(\%)$. The fellowing steps of loading ramp are used to measure the degradation of the shear modulus as a function of applied shear strain.

All the tests are carried out at ambient room conditions.

4. Results

The tests carried out at Risø are presented and discussed at this moment. More data, obtained by other partners of TG3, will be added. There are seven specimens tested totally, where three of them are tested using, so called, static ramp, and four specimens are tested using, so called loading-unloading ramp. The stattic test of one specimen, GEV206-I01-30-2, failed, and it is not included in the data. The initial shear modulus G_{12} (initial- property of the material without damage) is measured within limits of applied shear strain, $0.05(\%) \leq \gamma_{12} \leq 0.25(\%)$. The measured values and calculated average are given in Table 2. The strain - stress curves of the static and loading-unloading tests are given in 2 and 3 respectively. The strain and stress to failure are measured for all specimens, and values are given in Table 2.

Table 2: Experimental results of the in-plane shear properties of GEV206 using 30^0-off speciemn. OPTIMAT reference material at reference environmental conditions.

Specimen ID	Width (mm)	Thickness (mm)	G_{12} (GPa)	σ_{12} (MPa)	γ_{12} (%)
GEV206-I01-30-2	25.04	3.70	7.19	47.87	0.954
GEV206-I01-30-3	25.07	3.74	8.57	49.22	1.157
GEV206-I01-30-4	24.93	3.72	8.51	49.50	1.128
GEV206-I01-30-5	25.08	3.74	8.52	50.67	1.308
GEV206-I01-30-6	25.90	3.75	9.17	50.67	1.888
GEV206-I01-30-7	25.04	3.78	9.72	50.76	1.362
Average	25.18	3.74	8.62	49.78	1.30
STDEV	0.36	0.03	0.85	1.15	0.32

The shear modulus is calculated by using least squares method to fit a linear function to the experimental data of the strain - stress curves, see Appendix Figure 4.

The obtained vales of the shear modulus, in average, $G_{12} = 8.6\,[GPa]$ are consistent with values obtained using the V-notched beam specimen. However, the stress and strain to failure obtained by V-notched beam are higher as compared with 30-off axis specimens obtained by both, RISOE and VUB ([4]), see Table 3.

Table 3: In - plane shear properties of GEV206 using different test methods.

Test method/Lab	G_{12} $[GPa]$	σ_{12} $[MPa]$	γ_{12} [%]
V-notch, (Risø)	7.3	81	7.88
30-off, (Risø)	8.6	50	1.30
30-off, (VUB)	7.5	53	2.29

The obtained values for strain and stress to failure using two methods, are considerably different. It is supposed that te V-notched beam specime gives over estimated strain and stress to failure. It is due to the complex fracture mechanisms that takes place and controles the final failure of the V-notched beam specimen. On the other hand, the 30^0- off axes tensile specimens fails in almost pure shear. The strain - stress curve of the 30^0- off axes tensile specimens and V-notched beam specimens tested ar Risø are compared in Figure 6. The all the curves are close to each other antil the failure point. It conformes the consitency of the measured in-plane shear modulus, and shows the considerable difference for maximum stress and strain to failure.

The loading-unloading tensile test is curried out in order to measure degradation of the in-plane shear modulus, G_{12} as a function of applied strain. To mention here that the stiffness degradation is considered as a measure of the damage evolution, and the obtained results can be further used in damage dependent lamination theory to describe the inelastic behavior of the material and to do damage based predictions of lifetime. The measured stiffness degradation as a function of applied strain, $G_{12}(i)/G_{12}(0)$ is measured and results are given in graphical way in Figure 5. Also the numerical values are given in Table 4.

Table 4: Experimental results of the in-plane shear properties of GEV206, OPTIMAT reference material at reference environmental conditions. Measurements of the stiffness degradation.

Specimen	γ_{12} $[mm/mm]$	G_{12} $[Pa]$	$\frac{G_{12}(i)}{G_{12}(0)}$
GEV206-I01-30-4	2.675E-03	8.11E+09	1.00E+00
	3.144E-03	7.59E+09	9.36E-01
	4.156E-03	7.95E+09	9.81E-01
	4.586E-03	7.33E+09	9.04E-01
	4.863E-03	6.42E+09	7.92E-01
	1.012E-02	5.69E+09	7.01E-01
GEV206-I01-30-5	2.828E-03	9.285E+09	1.000E+00
	3.181E-03	7.059E+09	7.603E-01
	8.321E-03	6.490E+09	6.990E-01
	1.045E-02	5.682E+09	6.120E-01
	1.128E-02	5.427E+09	5.845E-01
GEV206-I01-30-6	2.473E-03	9.78E+09	1.00E+00
	4.086E-03	8.40E+09	8.59E-01
	5.758E-03	7.50E+09	7.66E-01
	7.212E-03	6.62E+09	6.76E-01
	7.463E-03	6.44E+09	6.58E-01
GEV206-I01-30-7	2.473E-03	1.05E+10	1.00E+00
	3.745E-03	9.45E+09	9.04E-01
	5.950E-03	8.00E+09	7.65E-01
	8.459E-03	6.67E+09	6.38E-01
	1.123E-02	5.65E+09	5.41E-01

5. Concluding remarks

The in-plane shear properties of GEV206 at ambient room temperature are measured using 30^0- off axes tensile specimens. The obtained values are compared with data obtained using the alternative, V-notched beam method. The measured in-plane shear modulus is consitent with modulus obtained by using V-notched beam specimen. The obtained values of the strain and stress at to failure are generally lower as compared with one obtained by using V-notched beam specimen. It is supposed, that the 30^0- off axes tensile specimen gives more realistic values of the stress and strain to failure.

The data obtained at Risø are presented and analyzed at this moment. The additional data, that will be obtained by other partners of TG3 will be included in the nearest future, as there are more test planned to be carried out according to the DPA.

A. Appendix

A.1. Figures

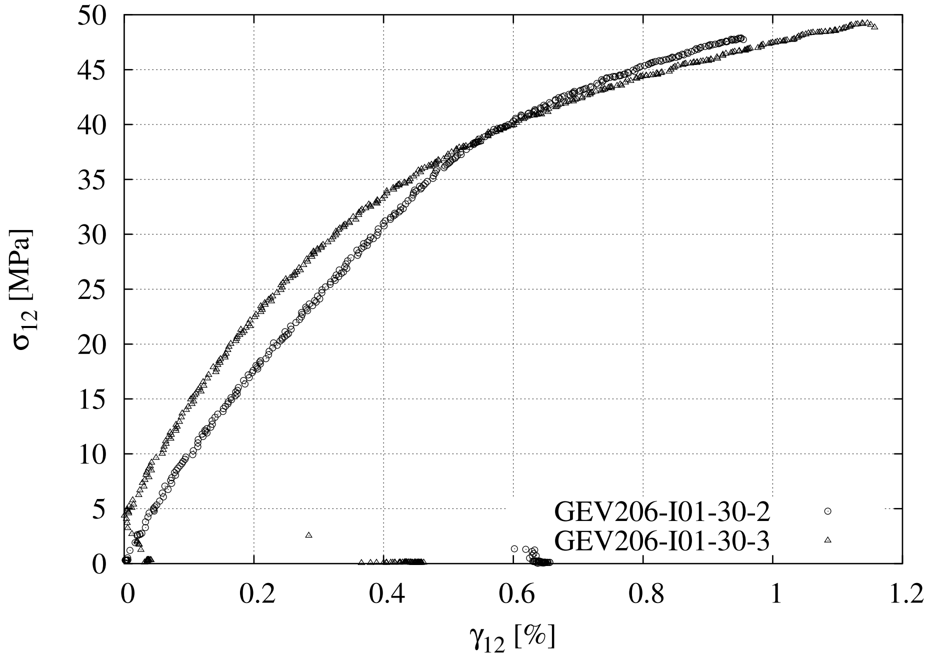


Figure 2: Static shear tests using 30^0-off specimen. Strain - stress curves.

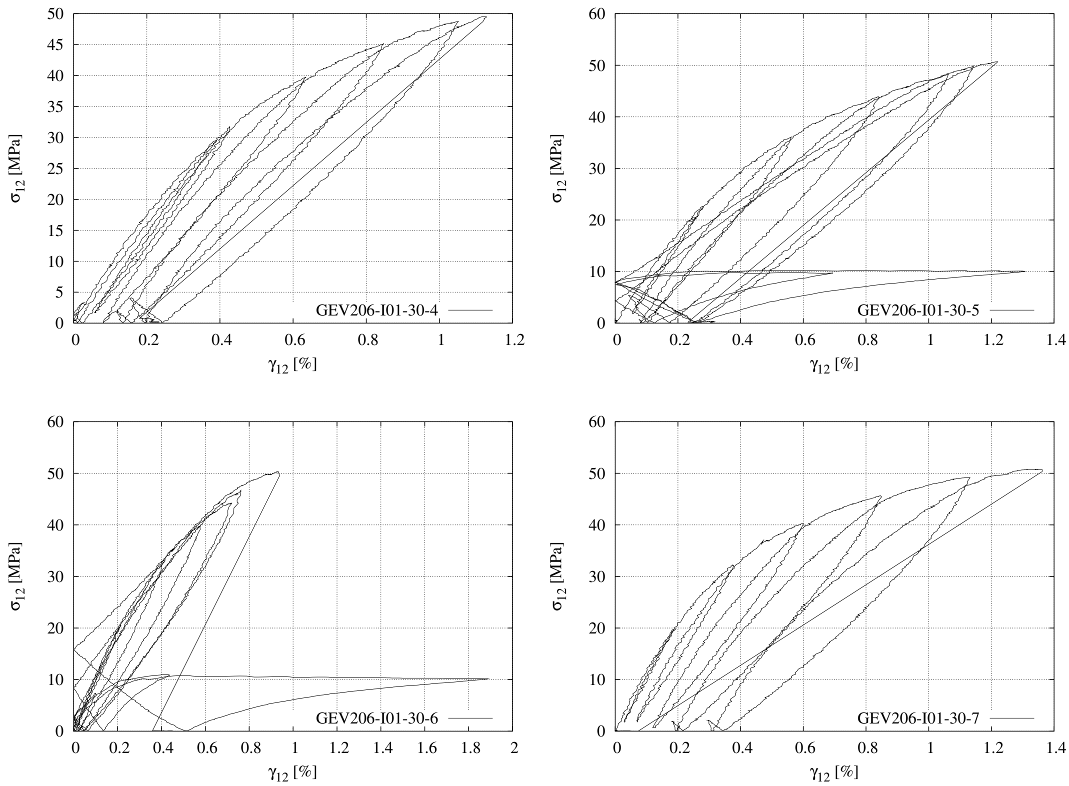
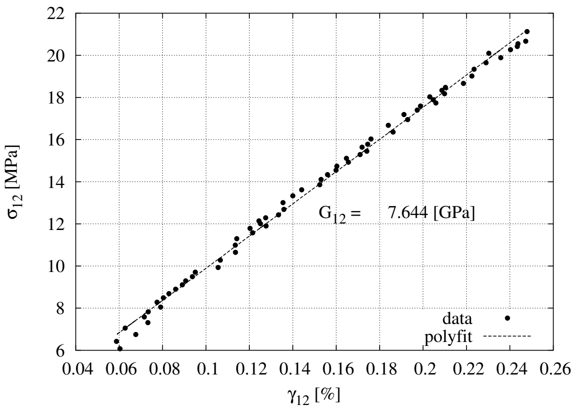
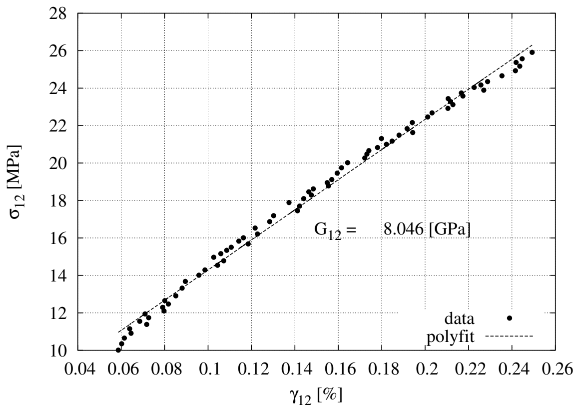


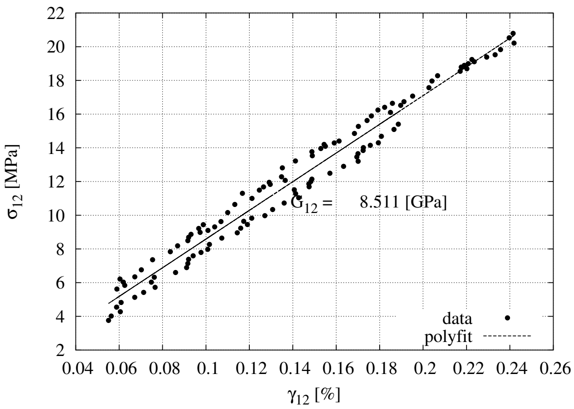
Figure 3: Stain - stress curves of the loading unloading test, GEV206-I01-30.



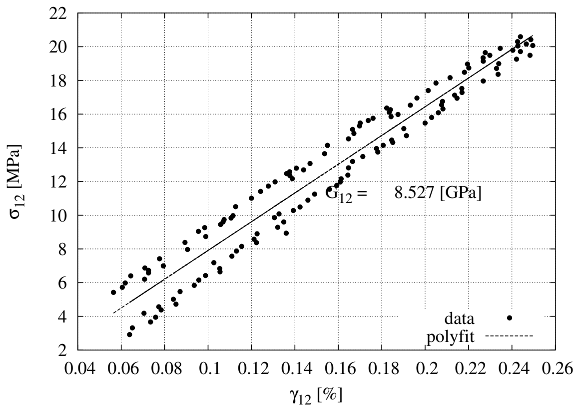
(a) GEV206-I01-30-2



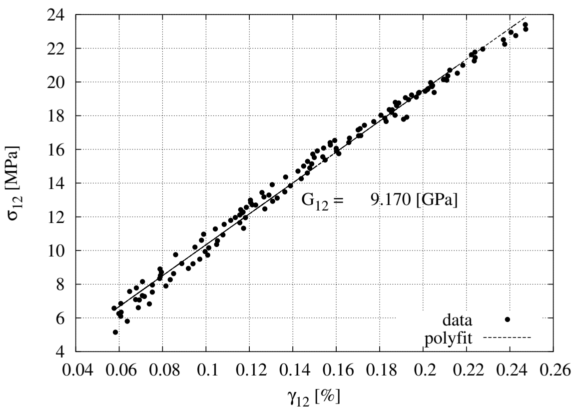
(b) GEV206-I01-30-3



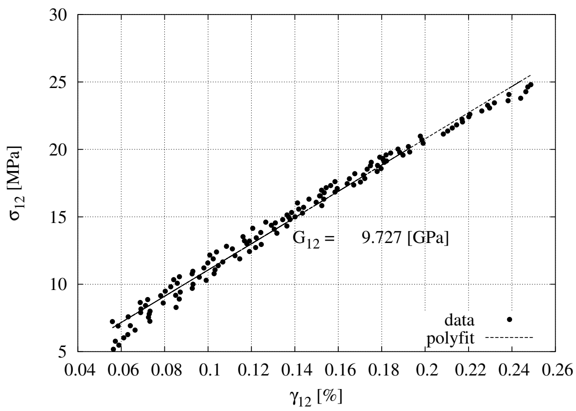
(c) GEV206-I01-30-4



(d) GEV206-I01-30-5



(e) GEV206-I01-30-6



(f) GEV206-I01-30-7

Figure 4: The results of static shear test. Calculated shear modulus for GEV206-I01-30.

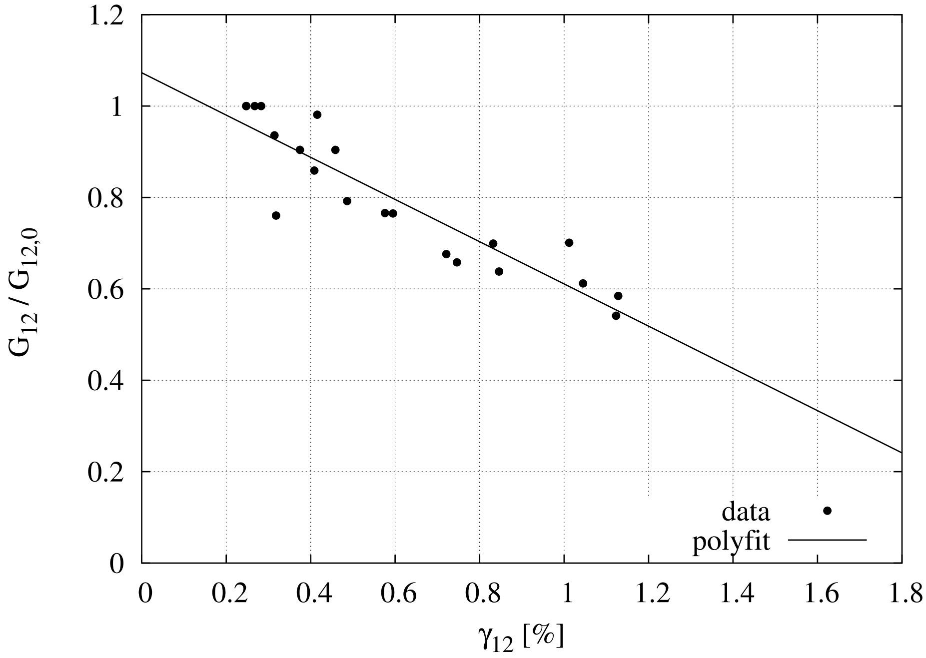


Figure 5: GEV206-I04-00, Normalized shear modulus versus applied shear strain. The linear fit $y = ax + b$. The constants are calculated, $a = -46.1977$, $b = 1.0727$.

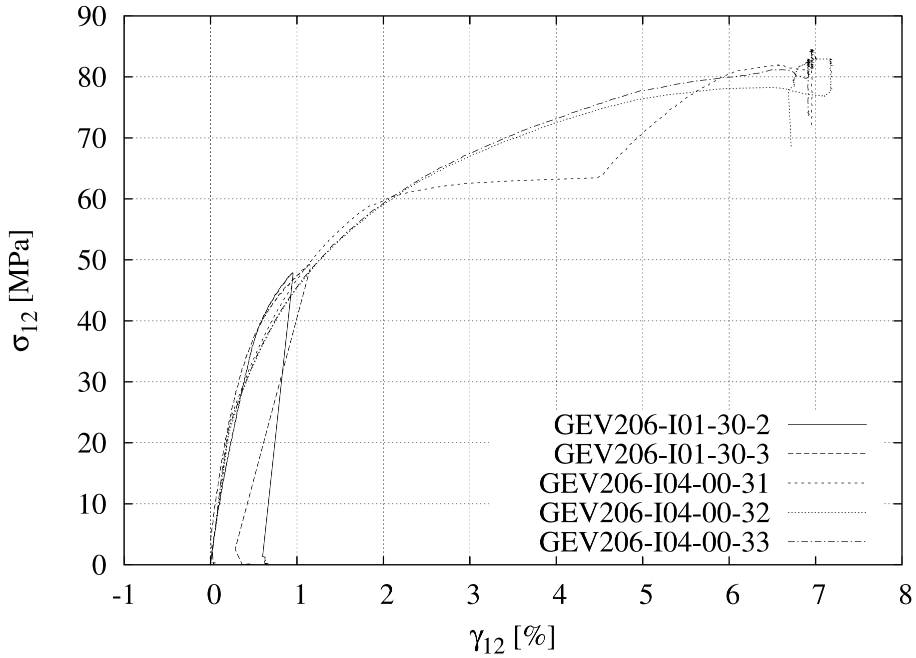


Figure 6: The strain - stress curves of the GEV206-00 using the V-notched beam and 30^0-off axis specimens.

A.2. Data reduction

The constitutive relationships of the laminate is defined as

$$\{\sigma\} = \boxed{Q} \{\varepsilon^0\} \tag{1}$$

where $\left[\overline{Q}\right]$ is a stiffness matrix of the laminate in global coordinate system, $\{\sigma\}$ and $\{\varepsilon^0\}$ are stress and mid-plane strain vectors respectively.

The transformation of the strain and stress from global to $(x-y)$ coordinate system to local $(1-2)$ system is defined as

$$\left\{\begin{array}{c}\sigma_1\\ \sigma_2\\ \sigma_{12}\end{array}\right\}=\left[\begin{array}{ccc}m^2 & n^2 & 2mn\\ n^2 & m^2 & -2mn\\ -mn & mn & m^2-n^2\end{array}\right]\left\{\begin{array}{c}\sigma_x\\ \sigma_y\\ \sigma_{xy}\end{array}\right\} \tag{2}$$

$$\left\{\begin{array}{c}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{array}\right\}=\left[\begin{array}{ccc}m^2 & n^2 & mn\\ n^2 & m^2 & -mn\\ -2mn & 2mn & m^2-n^2\end{array}\right]\left\{\begin{array}{c}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{array}\right\} \tag{3}$$

where $n=\sin(\theta)$, $m=\cos(\theta)$, and θ is fiber orientation angle with respect to global coordinate system, see Figure 1.

The constitutive equations in material symmetery axis (local coordinate system) are defined

$$\{\sigma\}_\theta=[Q]\,\{\varepsilon\}_\theta \tag{4}$$

In case of uniaxial loading ($\{\sigma\}=\{\sigma_x,\,0,\,0\}^T$), the expressions for engineering constants E_x, G_{xy} can be found.

$$\begin{aligned}\frac{1}{E_x}&=\frac{\cos^4(\theta)}{E_1}+\frac{\sin^4(\theta)}{E_2}+\frac{1}{4}\left(\frac{1}{G_{12}}-\frac{2\nu_{12}}{E_1}\right)\sin^2(2\theta)\\ \frac{\nu_{xy}}{E_x}&=\frac{\nu_{12}}{E_2}-\frac{1}{4}\left(\frac{1}{E_1}+\frac{2\nu_{12}}{E_1}+\frac{1}{E_2}-\frac{1}{G_{12}}\right)\sin^2(2\theta)\\ \frac{1}{G_{xy}}&=\frac{1}{E_1}+\frac{2\nu_{12}}{E_1}+\frac{1}{E_2}-\left(\frac{1}{E_1}+\frac{2\nu_{12}}{E_1}+\frac{1}{E_2}-\frac{1}{G_{12}}\right)\cos^2(2\theta)\end{aligned} \tag{5}$$

The in-plane shear modulus, G_{12}, can be calculated using (5) if the E_x is measured experimentally, and the E_1, E_2, and $\nu_{12}$are known from independent tests, or solving system of equations (1) and (2) of (5). Solving the system of equations gives G_{12} and E_T.

The alternative methodology to calculate in-plane shear modulus is to use σ_{12} vs. γ_{12} plot, and calculate it by linear curve fit to the experimental data of σ_{12} and γ_{12}. The σ_{12} and γ_{12} are calulated according to (2,3). For considered loading conditions, $\{\sigma\}=\{\sigma_x,\,0,\,0\}^T$, the stress is calculated

$$\sigma_{12}=-mn\sigma_x, \tag{6}$$

and shear strain in material symmetry axis, γ_{12} using (3), where the shear strain, γ_{xy} is calculated as

$$\gamma_{xy}=2\varepsilon_{45}-\varepsilon_x-\varepsilon_y, \tag{7}$$

where ε_{45} is strain measured in strain gauge placed in 45^0 to loading direction, ε_x is measured by extensometer, and ε_y is measured by strain gauge placed in transverse to loading direction.

References

[1] ASTM D5379/D 5379M-98, Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method.

[2] ASTM D3518/D3518M-94 (Reapproved 2001), Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a $\pm 45^0$ Laminate.

[3] ASTM D3039/D3039M-00, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.

[4] OB_TG3_R008-rev.000, Static testing TG3: static tension tests on UD-material with fibers at 0^0, 90^0 and 30^0. Loading-unloading-reloading tests. Arwen Smith, Danny Van Hemelrijck, VUB.