Effects of extreme conditions on properties of the reference material

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TG 3

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Change record

Issue/revision	date	pages	Summary of changes
draft	12-Feb-04	Na	na
Rev001	28/10/2004		More static data are added on SW1 and SW2
Rev002	09/09/2005		More data and revision of data and data evaluation

Introduction

The effects of the extreme conditions, as they are defined according to DPA, on the mechanical properties of the reference material are analyzed and reported in this report. The extreme environmental conditions according to DPA are considered. The mechanical properties according to DPA are considered in this study.

The data that are analyzed and presented within this report are available in the OptiDat database. Therefore no tables but only the plots are given in this report.

Materials, specimens and experimental procedures

The unidirectional laminate GEV206 (UD) and multidirectional laminate GEV207 (MD) are analyzed in this study. Both are considered to be the Optimat reference material.

Various geometries of the specimens have been used for different tests in order to render the most reliable data from particular mechanical characteristic of concern. The detailed analyses of particular tests are reported for each test, and are available in the data archive of the OPTIMAT project.

All the tests that are used for this analysis are carried out according to DPAs.

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Results and discussion

Static tests

According to DPA, the mechanical properties of the reference material (GEV206, GEV207) are tested at different extreme environmental conditions. The ambient room conditions (RT) are selected as reference conditions, and selected mechanical properties of the reference material are compared at different conditions.

The results are summarized in Table 1.

Table 1 Elastic properties of UD composite, GEV206.

Properties	GEV206				
	RT (STDEV)	T60 (STDEV)	T40 (STDEV)	SW1 (STDEV)	SW2 (STDEV)
Young's modulus, $E_1^{(+)}(GPa)$	38.8 (2.5)			37.8 (1.6)	38.1 (1.2)
Young's modulus, $E_1^{(-)}(GPa)$	39.6 (0.9)			36.4 (1.2)	39.0 (0.8)
Young's modulus, $E_2^{(+)}(GPa)$	13.8 (1.0)			12.2 (0.7)	12.5 (0.3)
Young's modulus, $E_2^{(-)}(GPa)$	14.2 (0.6)			12.8 (0.7)	14.5 (0.5)
Shear modulus, $G_{12}(GPa)$,30°	4.4 (0.39)	3.26(0.46)		4.18 (0.46)	3.7 (0.16)
Shear modulus, G_{12} *(GPa)*, Iosipescu	5.30(0.26)	2.20(0.46)	5.9(0.89)	4.66(0.28)	
Shear modulus, G_{21} *(GPa)*, Iosipescu	4.59(0.26)				
Shear modulus, G_{12} *(GPa)*, ±45°					
Poisson's ratio, $\nu_{12}^{(+)}$	0.38 (0.07)			0.30 (0.07)	0.27 (0.01)

NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for nom. 6 month
SW2- conditioned in salt water for nom. 12 month

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Table 2 Strength properties of UD composite, GEV206.

Properties	GEV206				
	RT (STDEV)	T60 (STDEV)	T40 (STDEV)	SW1 (STDEV)	SW2 (STDEV)
Tensile strength, $\sigma_1^{(+)}(MPa)$	808 (19.2)	760(68.5)*		655 (16.1)	714 (14.9)
Tensile strength, $\sigma_2^{(+)}(MPa)$	55 (2.6)	55 (5.2)*		53 (1.8)	56 (1.9)
Compression strength, $\sigma_1^{(-)}(MPa)$	-694 (74.0)	394(48.0)*		-452 (9.0)	-540 (90.2)
Compression strength, $\sigma_2^{(-)}(MPa)$	-168 (9.9)	-93(3.2)*		-150 (7.2)	-155 (3.3)
Shear stress to failure, $\sigma_{12}(MPa)$,30°	48.9 (0.90)	27.4(3.07)		27.4(1.96)	26.7 (0.19)
Shear stress to failure, $\sigma_{12}(MPa)$,Iosip.	76 (6)	43 (2)	123 (5)	74 (2)	
Tensile strain to failure, $\varepsilon_1^{(+)}(\%)$	2.31 (0.08)			1.92 (0.07)	1.99 (0.13)
Tensile strain to failure, $\varepsilon_2^{(+)}(\%)$	0.49 (0.04)			0.56 (0.04)	0.57 (0.04)
Compression strain to failure, $\varepsilon_1^{(-)}(\%)$	-1.86 (0.34)			-1.18 (0.13)	-1.36(0.19)
Compression strain to failure, $\varepsilon_2^{(-)}(\%)$	-1.77 (0.21)			-2.63 (0.89)	-2.25 0.89)
Shear strain to failure, $\gamma_{12}(\%)$,30°	2.41 (0.24)	1.7(0.59)		0.84 (0.18)	1.06 (0.13)
Shear strain to failure, $\gamma_{12}(\%)$,Iosip.	6.7(0.6)	5.8	5.9 (0.9)	6.8(1.1)	

NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for nom. 6 month
SW2- conditioned in salt water for nom. 12 month
* Optimat test specimens R03. Not valid in compression

Table 3 Elastic properties of MD laminate, GEV207.

Properties	GEV207				
	RT (STDEV)	T60 (STDEV)	T40 (STDEV)	SW1 (STDEV)	SW2 (STDEV)
Young's modulus, $E_1^{(+)}(GPa)$	28.5 (0.9)			25.9 (0.8)	-
Young's modulus, $E_1^{(-)}(GPa)$	27.0 (1.7)			26.8 (0.7)	26.4 (1.1)
Young's modulus, $E_2^{(+)}(GPa)$	14.8 (0.7)			13.8 (1.2)	14.0 (0.5)
Poisson's ratio, $\nu_{12}^{(+)}$	0.55 (0.11)			0.36 (0.18)	-
Poisson's ratio, $\nu_{21}^{(+)}$	0.31 (0.05)			0.35 (0.21)	0.35 (0.15)

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NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for nom. 6 month
SW2- conditioned in salt water for nom. 12 month

Table 4 Strength properties of GEV207

Properties	GEV207				
	RT (STDEV)	T60 (STDEV)	T40 (STDEV)	SW1 (STDEV)	SW2 (STDEV)
Tensile strength, $\sigma_1^{(+)}(MPa)$	548 (16.3)	497(45.5)*		463 (12.0)	-
Tensile strength, $\sigma_2^{(+)}(MPa)$	145 (3.9)			136 (0.32)	135 (0.44)
Compression strength, $\sigma_1^{(-)}(MPa)$	-504 (5.9)			-452 (9.6)	-456 (16.0)
Compression strength, $\sigma_2^{(-)}(MPa)$	-201 (8.4)			-197 (1.0)	-186 (1.6)
Tensile strain to failure, $\varepsilon_1^{(+)}(\%)$	2.40 (0.12)			2.18 (0.14)	-
Tensile strain to failure, $\varepsilon_2^{(+)}(\%)$	2.94 (0.21)			2.92 (0.17)	2.75 (0.15)
Compression strain to failure, $\varepsilon_1^{(-)}(\%)$	-2.28 (0.01)			-1.85 (0.11)	-1.92 (0.12)
Compression strain to failure, $\varepsilon_2^{(-)}(\%)$	-2.32 (0.51)			-3.58 (0.38)	-2.55 (0.16)

NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for nom. 6 month
SW2- conditioned in salt water for nom. 12 month
* Optimat test specimens R03

Fatigue

The fatigue life of the UD (GEV206) at room temperature (RT) is compared with fatigue life at temperature $T = 60^0 C$ (T60) and fatigue life if material has been exposed to salt water for nom. 6 month before testing. The tensile-tensile ($R = 0.1$) fatigue conditions do not show obvious difference in fatigue life at considered conditions. All the data of fatigue life for extreme conditions are within confidence limits of the reference data set. However, the data of fatigue life at T=60C are consistently bellow the regression line of the reference conditions. The more detailed statistical analysis will be performed in order to find out whether the difference is significant or not. The 95%95% confidence limit was selected. It is rather conservative, and gives broader confidence band as compared to 50%95% confidence limit.

It is worth mentioning at this point, that there is no apparent constancy between static and fatigue conditions. Meaning, that the salt water conditioning has affected largely the mechanical properties such as strain and stress to failure, little less obvious decrease of Young's modulus, but has a no affect on the fatigue life. On the other hand, the high temperature (T60) had little affect on

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Young's modulus and strength, but did reduce the fatigue life. This phenomenon will be addressed in more detailed analysis in order to find out the controlling mechanisms.

Data of the tensile-tensile fatigue life are plotted in Figure 20-Figure 22, given in Appendix: Figures.

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References

1. Detailed plan of action, DPA of TG3, OB_TG3_O001.
2. Fatigue tests of the MD reference material (GEV207-D02-00) using Ris geometry for the test coupons, OB_TG3_R013
3. Fatigue tests of the UD reference material (GEV206-D02-00) using Ris geometry for the test coupons, CA fatigue at reference conditions, R=0.1, OB_TG3_R012
4. Static testing TG3: static tension tests on UD–OPTIMAT specimens with fibres at 0°, 30° and 90°, Loading-unloading-reloading tests, OB_TG3_R011
5. Measurements of in-plane shear properties of GEV206 at ambient room conditions using 30-off axes test specimen, Test report, OB_TG3_R010
6. Measurements of in-plane shear properties of GEV206 at ambient room conditions using V-notched beam test specimen, Test report, OB_TG3_R009
7. Static tests of UD and MD specimens using ISO geometries, Test report TG3, OB_TG3_R007
8. Static testing TG3: static tension tests on UD–OPTIMAT specimens with fibres at 0°, 30° and 90°, Loading-unloading-reloading tests, OB_TG3_R011
9. OptiDat.

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Appendix: Figures

Figure 1, static tensile tests, GEV206-I0200 (RT), GEV206-I1100 (SW),GEV206-R0300 (60°)
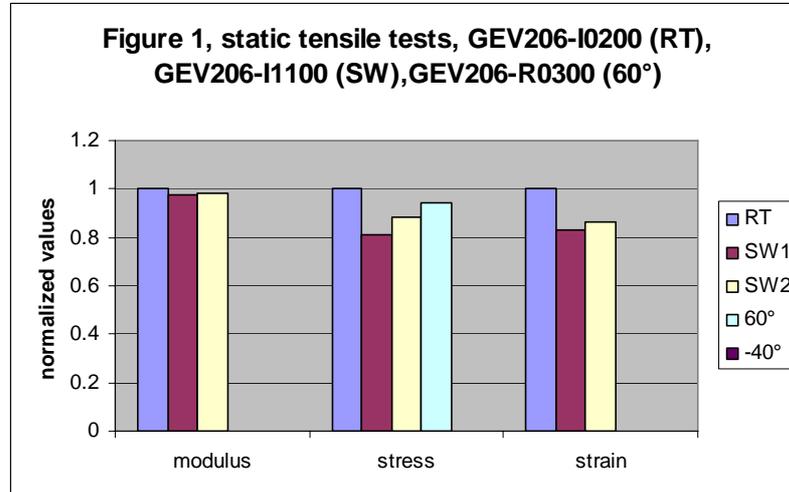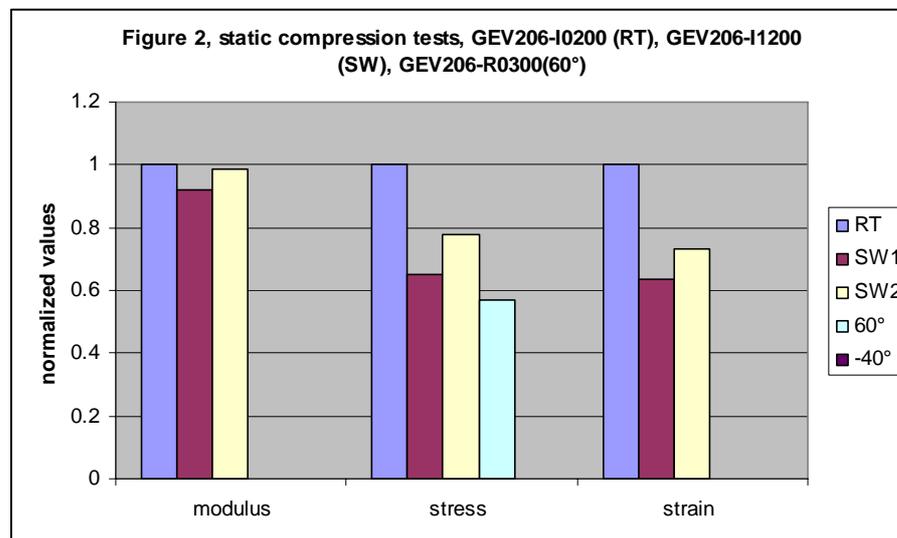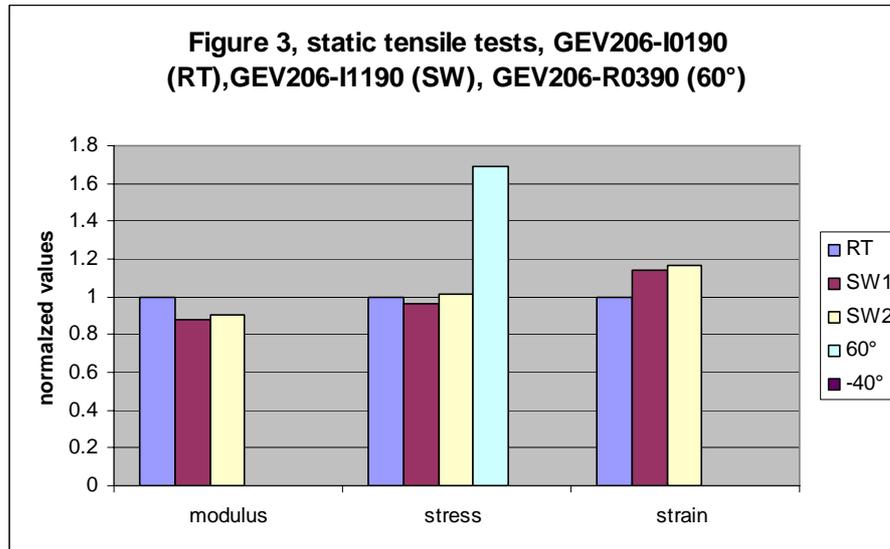
Figure 1. Results of static _tensile_ tests at extreme conditions of UD laminate, _GEV206-00_. The normalized values of the modulus $E_1^{(+)} / E_{1(RT)}^{(+)}$, stress to failure, $\sigma_1^{(+)} / \sigma_{1(RT)}^{(+)}$ and strain to failure, $\varepsilon_1^{(+)} / \varepsilon_{1(RT)}^{(+)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
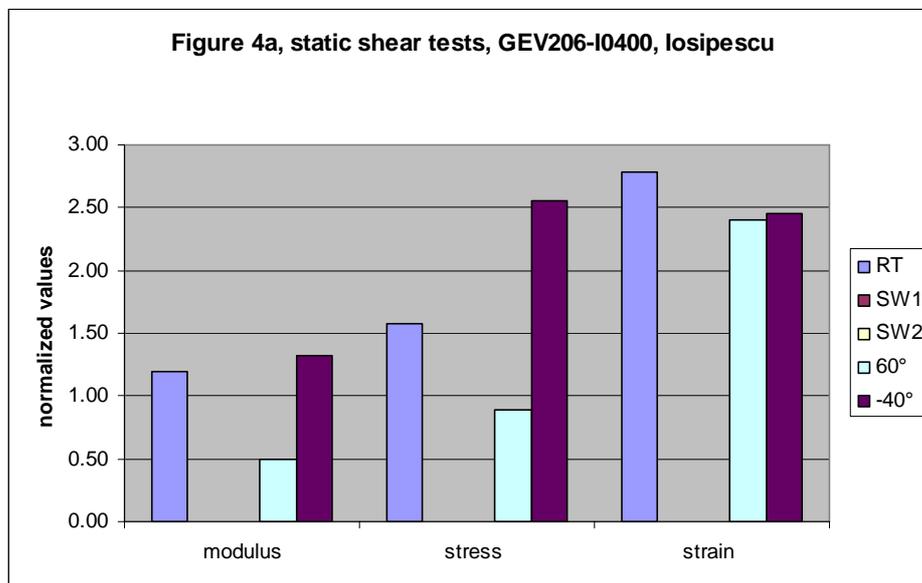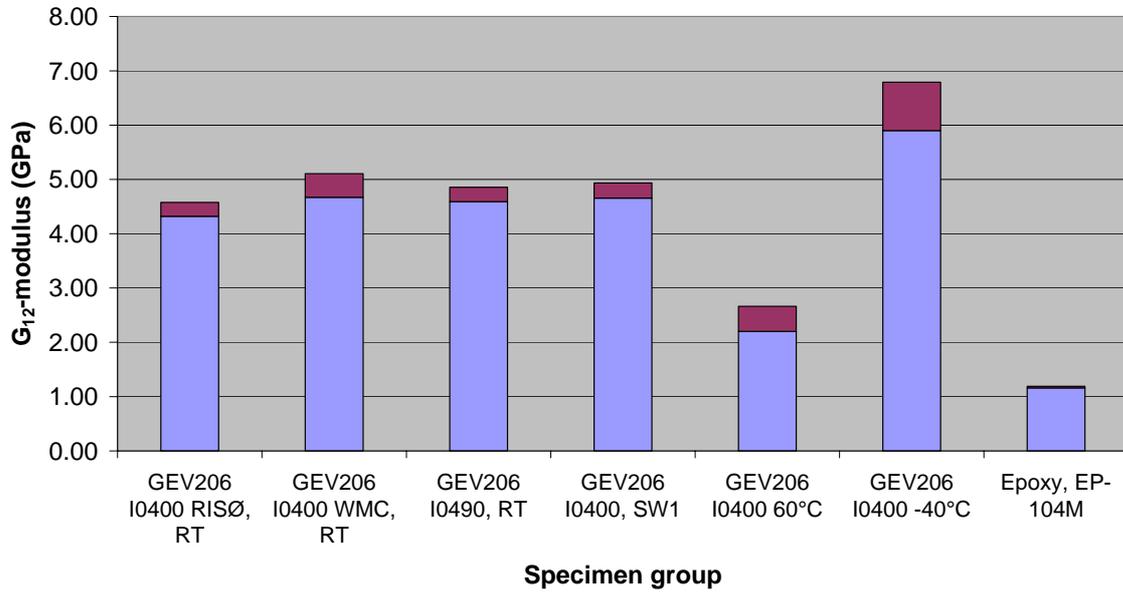

Figure 2, static compression tests, GEV206-I0200 (RT), GEV206-I1200 (SW), GEV206-R0300(60°)

Figure 2. Results of static _compression_ tests at extreme conditions of UD laminate, _GEV206-00_. The normalized values of the modulus $E_1^{(-)} / E_{1(RT)}^{(-)}$, stress to failure, $\sigma_1^{(-)} / \sigma_{1(RT)}^{(-)}$ and strain to failure, $\varepsilon_1^{(-)} / \varepsilon_{1(RT)}^{(-)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.

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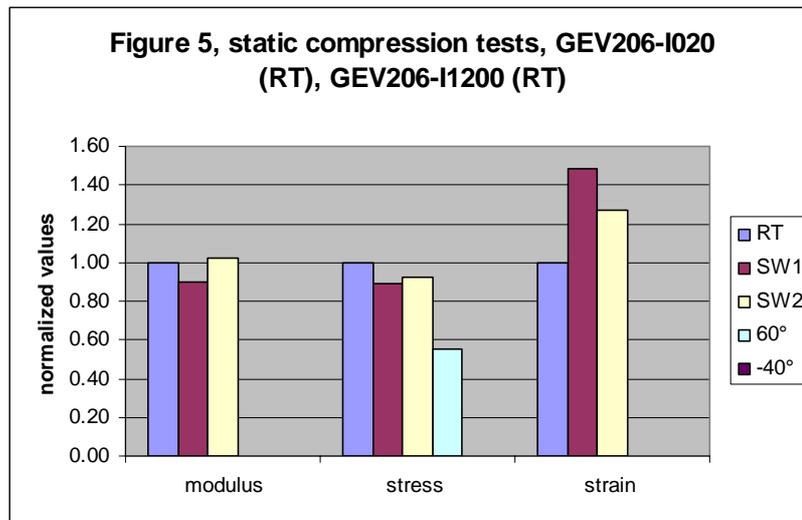Figure 3. Results of static <u>tensile</u> tests at extreme conditions of UD laminate, <u>GEV206-90</u>. The normalized values of the modulus $E_2^{(+)}\big/E_{2(RT)}^{(+)}$, stress to failure, $\sigma_2^{(+)}\big/\sigma_{2(RT)}^{(+)}$ and strain to failure, $\varepsilon_2^{(+)}\big/\varepsilon_{2(RT)}^{(+)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
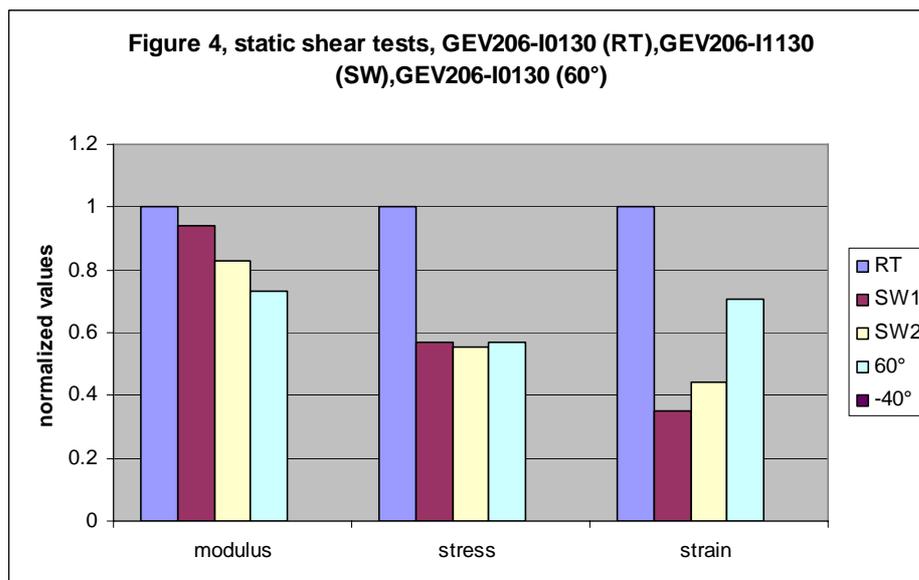
Figure 4. Results of static shear tests at extreme conditions of UD laminate, <u>GEV206-30</u>. The normalized values of the shear modulus $G_{12}^{(+)}\big/G_{12(RT)}^{(+)}$, stress to failure, $\sigma_{12}^{(+)}\big/\sigma_{12(RT)}^{(+)}$ and strain to failure, $\gamma_{12}^{(+)}\big/\gamma_{12(RT)}^{(+)}$

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are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
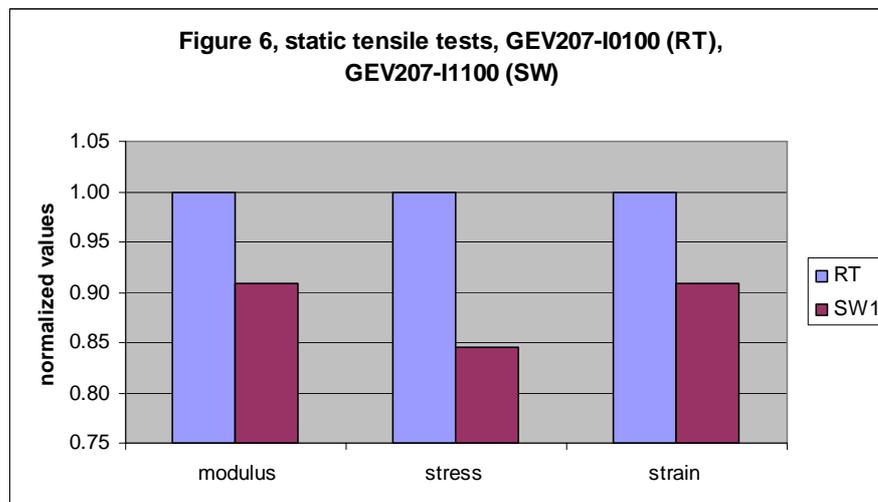
Figure 4a, static shear tests, GEV206-I0400, Iosipescu

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Shear Modulus, Iosipescu

Shear Strength, Iosipescu
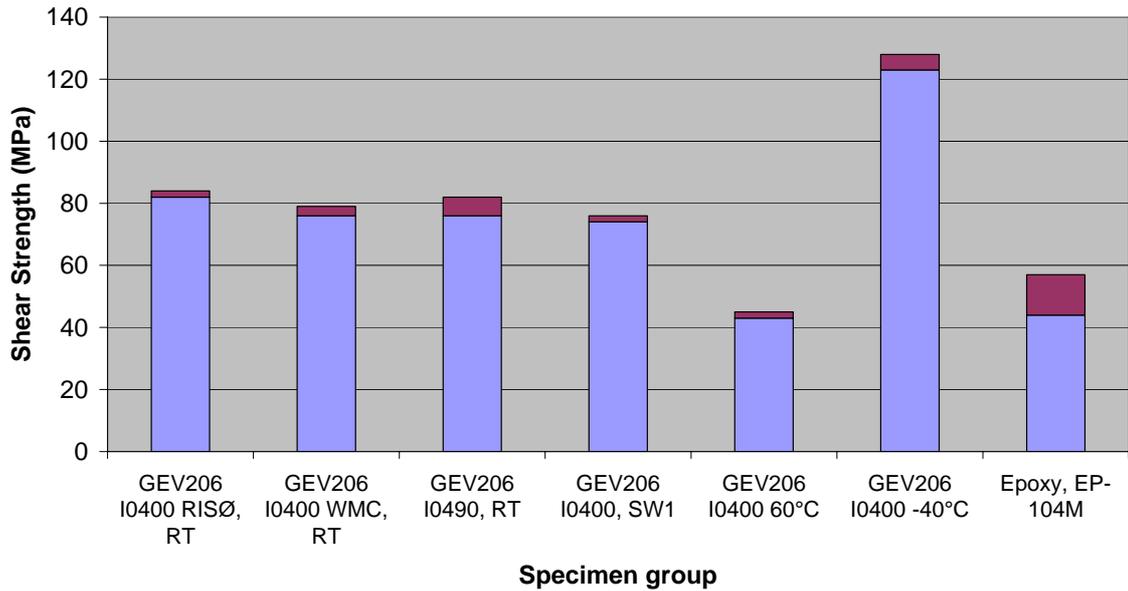
Figure 5. Results of static shear tests at extreme conditions of UD laminate, <u>GEV206,</u> measured using the Iosipescu specimens goemetry.

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Figure 5, static compression tests, GEV206-I020 (RT), GEV206-I1200 (RT)

Figure with bars for modulus, stress, strain; legend RT, SW1, SW2, 60°, -40°.

Figure 6. Results of static <u>compression</u> tests at extreme conditions of UD laminate, <u>GEV206-90</u>. The normalized values of the modulus $E_2^{(-)}/E_{2(RT)}^{(-)}$, stress to failure, $\sigma_2^{(-)}/\sigma_{2(RT)}^{(-)}$ and strain to failure, $\varepsilon_2^{(-)}/\varepsilon_{2(RT)}^{(-)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
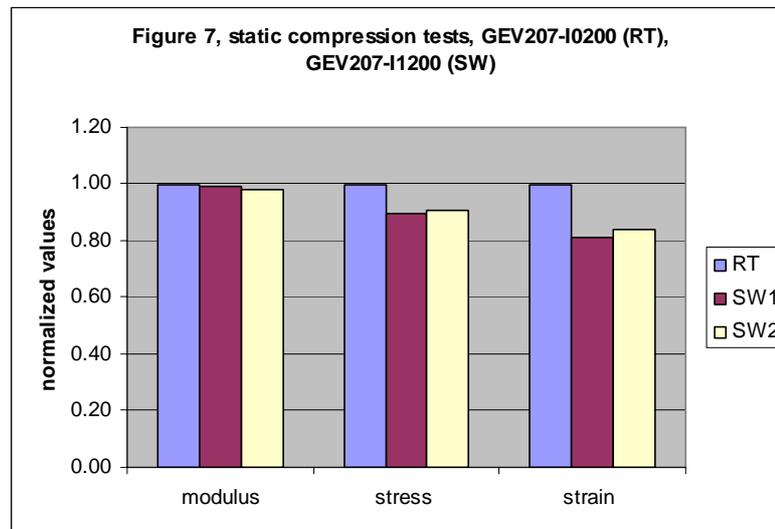
Figure 6, static tensile tests, GEV207-I0100 (RT), GEV207-I1100 (SW)

Figure with bars for modulus, stress, strain; legend RT, SW1.

Figure 7. Results of static <u>tensile</u> tests at extreme conditions of MD laminate, <u>GEV207-00</u>. The normalized values of the modulus $E_1^{(+)}/E_{1(RT)}^{(+)}$, stress to failure, $\sigma_1^{(+)}/\sigma_{1(RT)}^{(+)}$ and strain to failure, $\varepsilon_1^{(+)}/\varepsilon_{1(RT)}^{(+)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
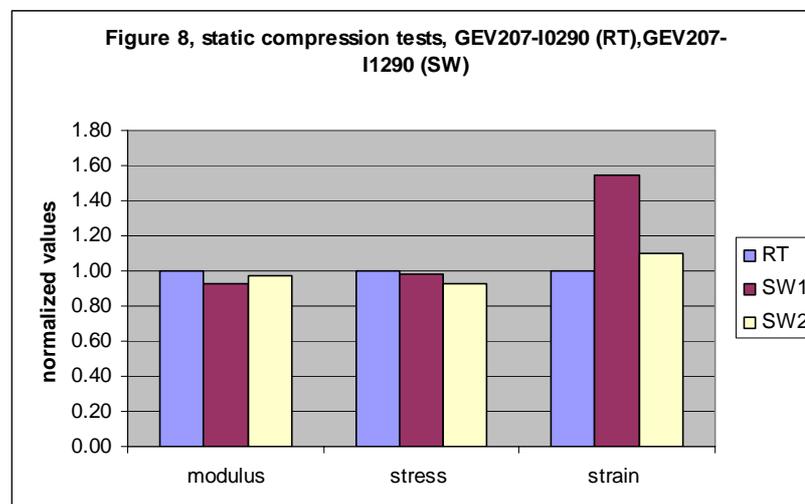
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Figure 7, static compression tests, GEV207-I0200 (RT), GEV207-I1200 (SW)

Figure 8. Results of static <u>compression</u> tests at extreme conditions of MD laminate, <u>GEV207-00</u>. The normalized values of the modulus $E_1^{(-)}/E_{1(RT)}^{(-)}$, stress to failure, $\sigma_1^{(-)}/\sigma_{1(RT)}^{(-)}$ and strain to failure, $\varepsilon_1^{(-)}/\varepsilon_{1(RT)}^{(-)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.


Figure 8, static compression tests, GEV207-I0290 (RT),GEV207-I1290 (SW)

Figure 9. Results of static <u>compression</u> tests at extreme conditions of MD laminate, <u>GEV207-90</u>. The normalized values of the modulus $E_2^{(-)}/E_{2(RT)}^{(-)}$, stress to failure, $\sigma_2^{(-)}/\sigma_{2(RT)}^{(-)}$ and strain to failure, $\varepsilon_2^{(-)}/\varepsilon_{2(RT)}^{(-)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.

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Figure 9, static tensile tests, GEV207-I0190 (RT),GEV207-I0190 (SW)
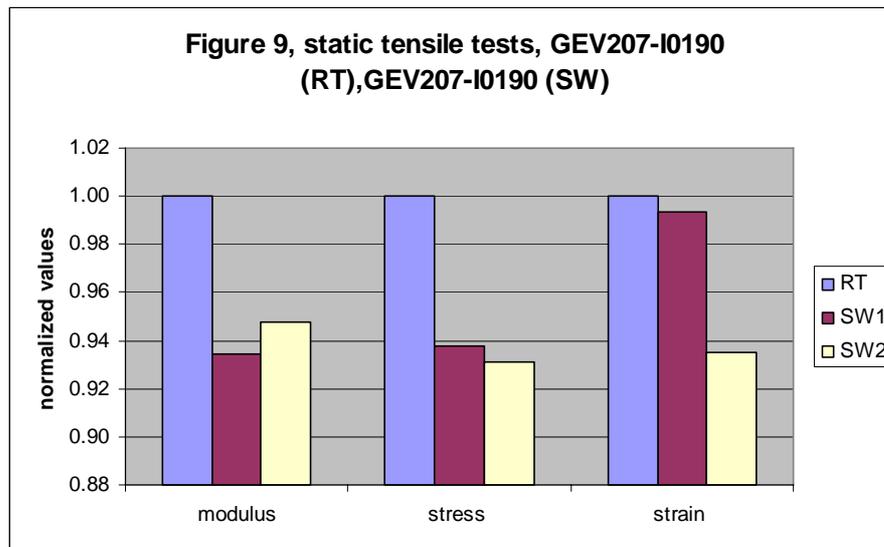
Figure 10. Results of static <u>tensile</u> tests at extreme conditions of MD laminate, <u>GEV207-90</u>. The normalized values of the modulus $E_2^{(+)}\big/E_{2(RT)}^{(+)}$, stress to failure, $\sigma_2^{(+)}\big/\sigma_{2(RT)}^{(+)}$ and strain to failure, $\varepsilon_2^{(+)}\big/\varepsilon_{2(RT)}^{(+)}$ are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
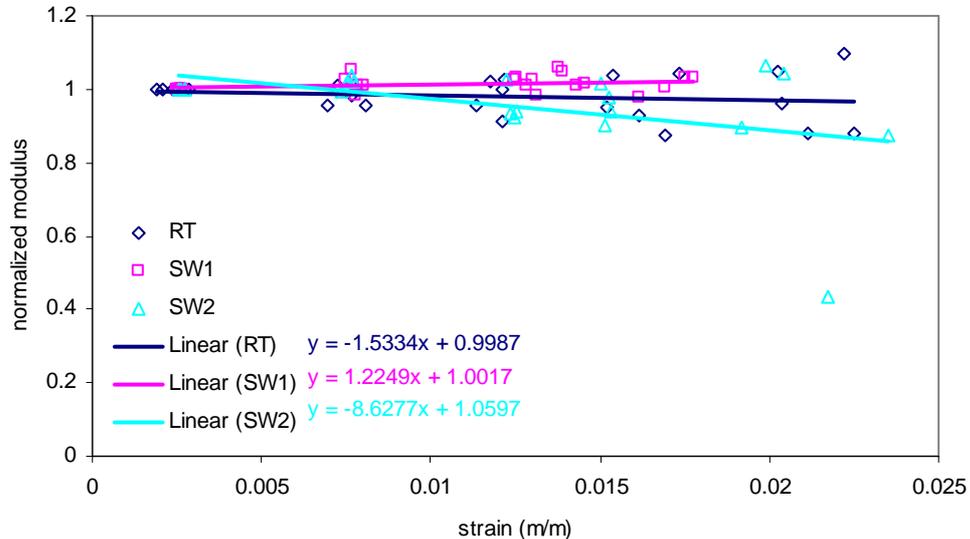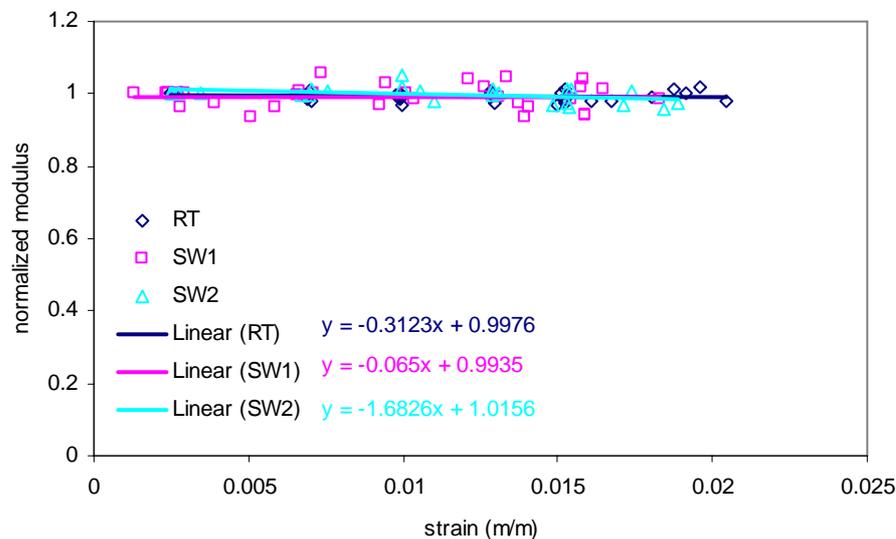

Figure 11. Results of static <u>tensile</u> tests at extreme conditions of UD composite, <u>GEV206-00</u>. The normalized values of the modulus, $E_1^{(+)}\big/E_{1(0)}^{(+)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of 6 nom. month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.

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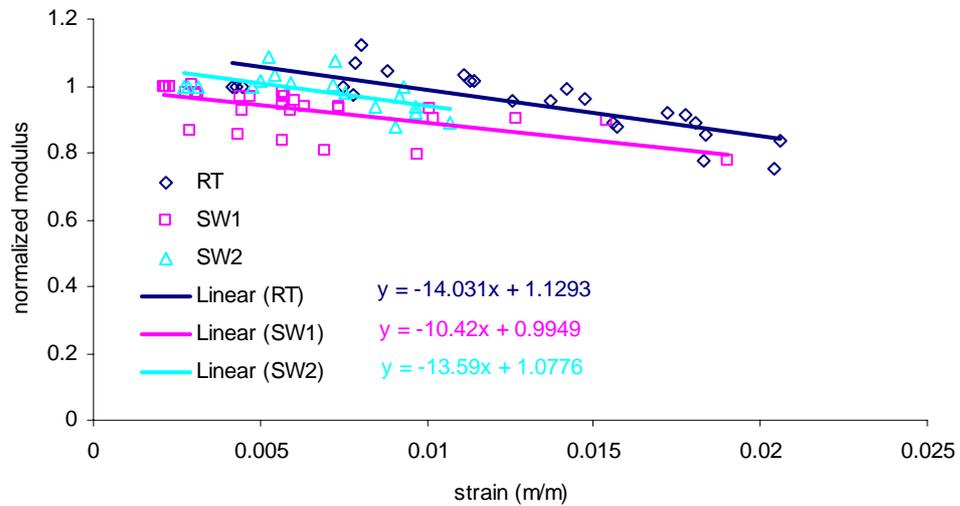
Figure 12. Results of static <u>tensile</u> tests at extreme conditions of UD composite, <u>GEV206-30</u>. The normalized values of the modulus, $G_{12}^{(+)}\big/G_{12(0)}^{(+)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of 6 nom. month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.

Figure 13. Results of static <u>compression</u> tests at extreme conditions of UD composite, <u>GEV206-00</u>. The normalized values of the modulus, $E_1\big/E_{1(0)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
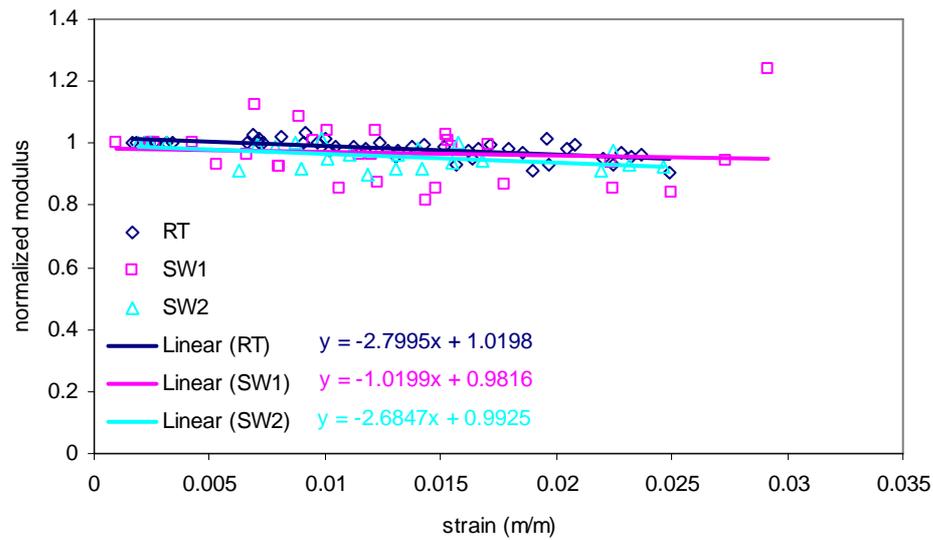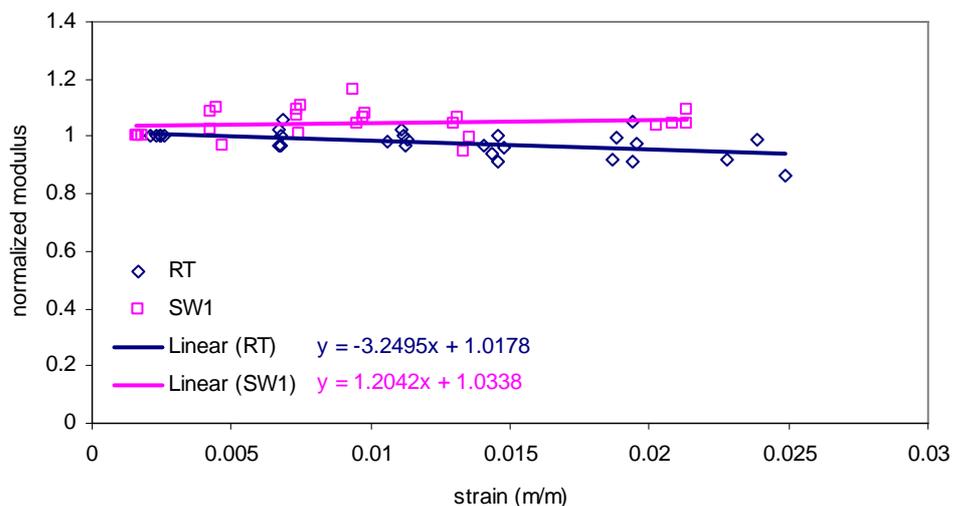
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Figure 14. Results of static <u>compression</u> tests at extreme conditions of UD composite, <u>GEV206-90</u>. The normalized values of the modulus, $E_2^{(-)}/E_{2(0)}^{(-)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
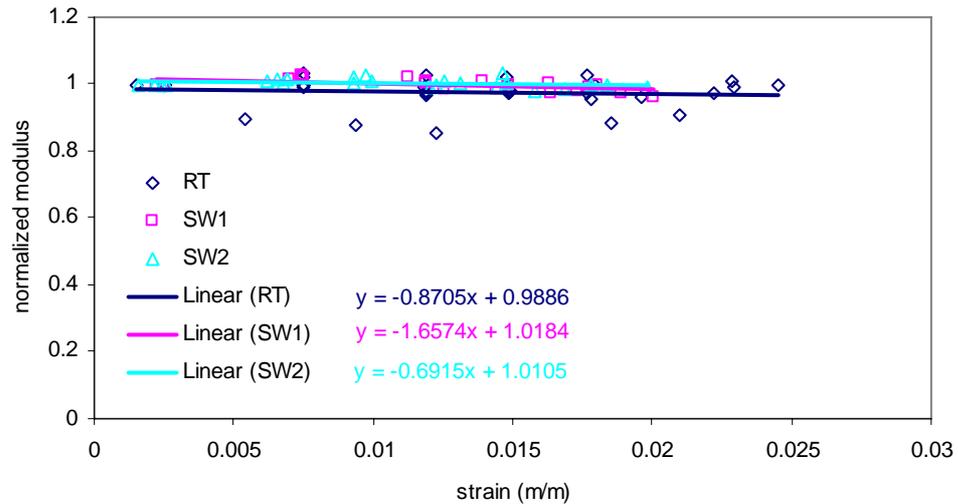

Figure 15. Results of static <u>tensile</u> tests at extreme conditions of MD laminate, <u>GEV207-00</u>. The normalized values of the modulus, $E_1^{(+)}/E_{1(0)}^{(+)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
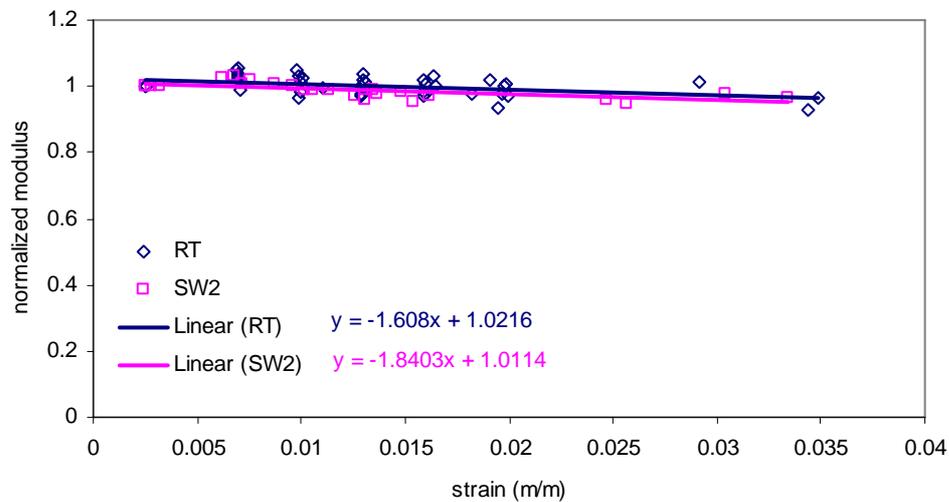
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Figure 16. Results of static <u>compression</u> tests at extreme conditions of MD laminate, <u>GEV207-00</u>. The normalized values of the modulus, $E_1^{(-)} / E_{1(0)}^{(-)}$, as function of applied strain are measured at extreme conditions. RT is considered as reference environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
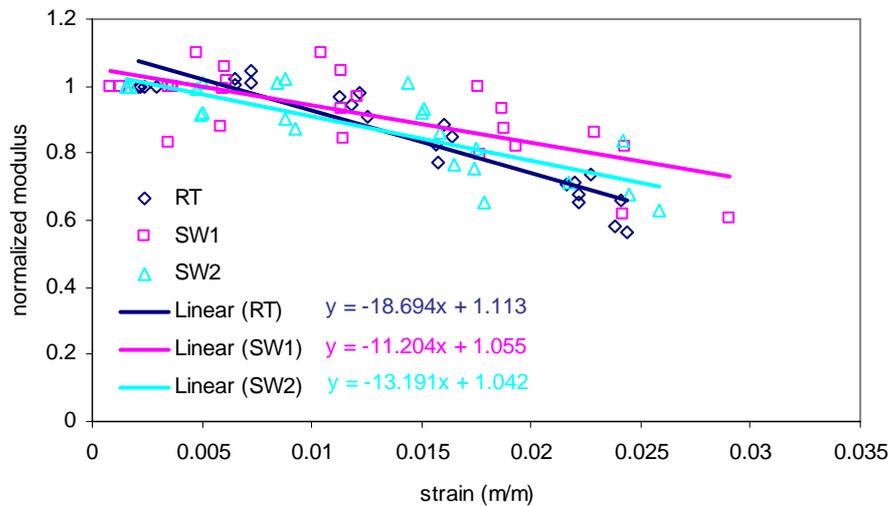

Figure 17. Results of static <u>compression</u> tests at extreme conditions of MD laminate, <u>GEV207-90</u>. The normalized values of the modulus, $E_2^{(-)} / E_{2(0)}^{(-)}$, as function of applied strain are measured at extreme conditions. RT is considered as <u>reference</u> environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
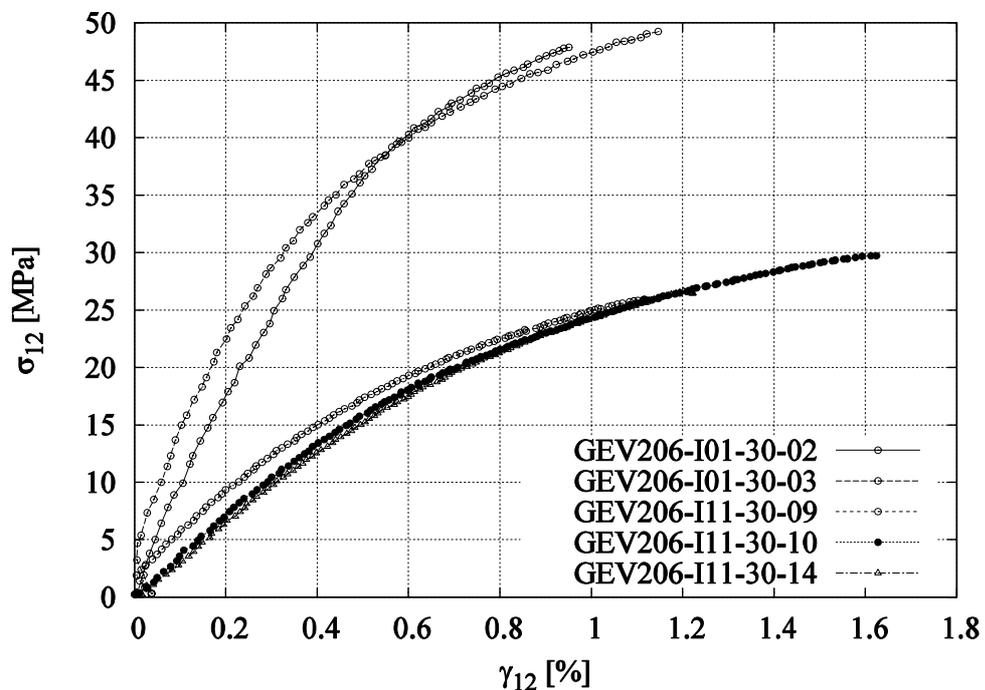
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Figure 18. Results of static <u>tensile</u> tests at extreme conditions of MD laminate, <u>GEV207-90</u>. The normalized values of the modulus, $E_2^{(+)}\big/E_{2(0)}^{(+)}$, as function of applied strain are measured at extreme conditions. RT is considered as <u>reference</u> environmental condition, ambiant room conditions. SW1 corresponds to specimens that have been preconditioned being submersed in salt watter for period of nom. 6 month. SW2 corresponds to preconditioning in salt watter for nom. 12 month.
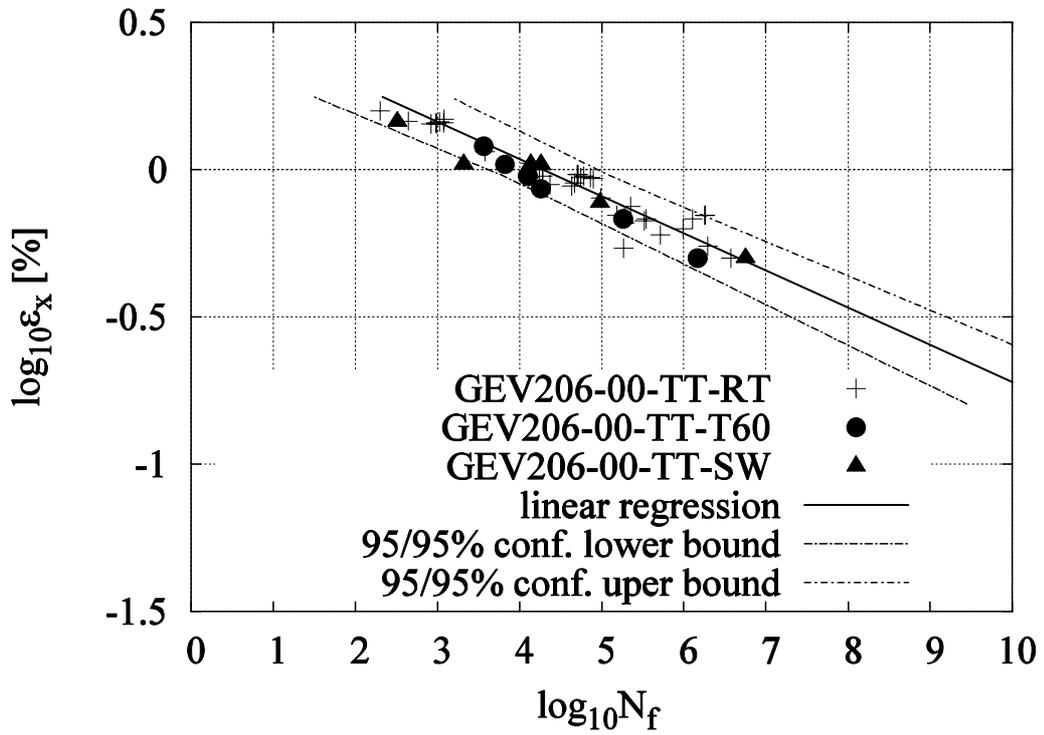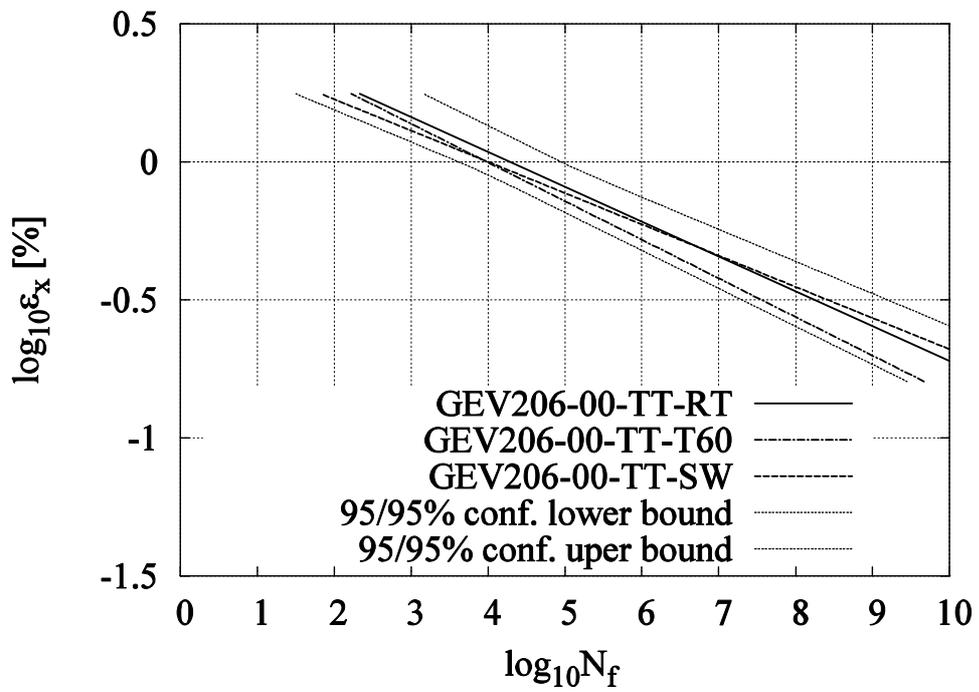

Figure 19

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Figure 20

Figure 21

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Figure 22