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Fabrication, Testing, and Analysis of Anisotropic Carbon/Glass Hybrid Composites
Volume 2: Test Data

Thomas M. Hermann and James E. Locke
National Institute for Aviation Research, Wichita State University
and
Kyle K. Wetzel
Wetzel Engineering, Inc.

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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FABRICATION, TESTING AND ANALYSIS OF ANISOTROPIC, CARBON/GLASS HYBRID COMPOSITES

Thomas M. Hermann and James E. Locke
National Institute for Aviation Research
Wichita State University
Wichita, Kansas 67260

Kyle K. Wetzel
Wetzel Engineering, Inc.
Lawrence, Kansas 66046

Abstract

Anisotropic carbon/glass hybrid composite laminates have been fabricated, tested, and analyzed. The laminates have been fabricated using vacuum-assisted resin transfer molding (VARTM). Five fiber complexes and a two-part epoxy resin system have been used in the study to fabricate panels of twenty different laminate constructions. These panels have been subjected to physical testing to measure density, fiber volume fraction, and void fraction. Coupons machined from these panels have also been subjected to mechanical testing to measure elastic properties and strength of the laminates using tensile, compressive, transverse tensile, and in-plane shear tests. Interlaminar shear strength has also been measured. Out-of-plane displacement, axial strain, transverse strain, and in-plane shear strain have also been measured using photogrammetry data obtained during edgewise compression tests.

The test data have been reduced to characterize the elastic properties and strength of the laminates. Constraints imposed by test fixtures might be expected to affect measurements of the moduli of anisotropic materials; classical lamination theory has been used to assess the magnitude of such effects and correct the experimental data for the same. The tensile moduli generally correlate well with experiment without correction and indicate that factors other than end constraints dominate. The results suggest that shear moduli of the anisotropic materials are affected by end constraints.

Classical lamination theory has also been used to characterize the level of extension-shear coupling in the anisotropic laminates. Three factors affecting the coupling have been examined: the volume fraction of unbalanced off-axis layers, the angle of the off-axis layers, and the composition of the fibers (i.e., carbon or glass) used as the axial reinforcement. The results indicate that extension/shear coupling is maximized with the least loss in axial tensile stiffness by using carbon fibers oriented 15° from the long axis for approximately two-thirds of the laminate volume (discounting skin layers), with reinforcing carbon fibers oriented axially comprising the remaining one-third of the volume.

Finite element analysis of each laminate has been performed to examine first ply failure. Three failure criteria - maximum stress, maximum strain, and Tsai-Wu - have been compared. Failure predicted by all three criteria proves generally conservative, with the stress-based criteria the most conservative. For laminates that respond nonlinearly to loading, large error is observed in the prediction of failure using maximum strain as the criterion.

This report documents the methods and results in two volumes. Volume 1 contains descriptions of the laminates, their fabrication and testing, the methods of analysis, the results, and the conclusions and recommendations. Volume 2 contains a comprehensive summary of the individual test results for all laminates.

Acknowledgments

This work has been supported by a grant from the U.S. Department of Energy via Agreement number DE-FG02-03ER86174 by and between USDOE and Wetzel Engineering, Inc. Dr. Jack Cadogan is Project Officer.

Several people at the National Institute for Aviation Research have assisted with the fabrication and testing reported here, including Drs. Yeow Ng and Brijesh Kumar, as well as Lamia Salah, Sanjay Sharma, Wadii Benjaliny, Ian Goodman, and Waruna Seneviratne.

We would like to acknowledge Chris Kissinger and Saertex USA for the donation of some of the glass materials used in the present research and for his help in sourcing appropriate fiber complexes, and Jeff Bassman of JeffCo Products, for his assistance in developing an appropriate resin system for our hybrid laminates.

Finally, we would also like to acknowledge the advice and technical expertise that has been provided in connection with this project more informally by a number of our colleagues in the wind energy industry, including Drs. Paul Veers, Tom Ashwill, and Daniel Laird of Sandia National Laboratories, Emil Moroz of Garrad Hassan America, Eric Jacobsen of GE Wind Energy, and Dr. Wendy Lin of GE Global Research.

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A. Test Data

The summary tables and detailed plots from the tension, compression, in-plane shear, interlaminar shear and edgewise compression tests are presented in this appendix.

A.1 Physical Test Results

Table A.1: D792-00 Specific Gravity (Relative Density).

				Water		Specific		
		W_1	W_2	Temperature	Density	Gravity	Specimen Density	
Laminate	Panel	(g)	(g)	$°C$	(g/cc)	(—)	(g/cc)	(lbm/in^3)
1	A	5.00	2.32	17.8	0.99864	1.863	1.861	0.067
1	B	4.76	2.22	15.6	0.99902	1.876	1.874	0.068
2	A	3.14	1.13	17.8	0.99864	1.558	1.555	0.056
2	B	2.62	0.90	25.0	0.99705	1.526	1.521	0.055
3	A	4.94	2.29	16.7	0.99884	1.863	1.861	0.067
3	B	5.35	2.43	25.0	0.99705	1.832	1.827	0.066
4	A	3.58	1.34	16.7	0.99884	1.600	1.599	0.058
4	B	3.63	1.34	15.6	0.99902	1.589	1.588	0.057
5	A	3.39	1.26	16.7	0.99884	1.594	1.592	0.058
5	B	3.53	1.30	15.6	0.99902	1.584	1.582	0.057
6	A	4.15	1.80	16.7	0.99884	1.763	1.761	0.064
6	B	4.53	1.93	15.6	0.99902	1.744	1.742	0.063
7	A	3.13	1.15	16.7	0.99884	1.579	1.577	0.057
7	B	3.57	1.31	16.7	0.99884	1.579	1.578	0.057
8	A	3.55	1.32	22.2	0.99773	1.591	1.588	0.057
8	B	3.54	1.31	15.6	0.99902	1.587	1.585	0.057
9	A	3.76	1.35	22.2	0.99773	1.559	1.555	0.056
9	A*(r)*	3.92	1.46	16.7	0.99884	1.592	1.591	0.057
9	B	3.86	1.47	22.2	0.99773	1.617	1.613	0.058
10	A	3.48	1.30	16.7	0.99884	1.596	1.594	0.058
10	B	3.64	1.36	15.6	0.99902	1.595	1.594	0.058
11	A	3.62	1.33	22.2	0.99773	1.582	1.578	0.057
12	A	3.60	1.33	22.2	0.99773	1.589	1.585	0.057
13	A	4.09	1.38	22.2	0.99773	1.508	1.505	0.054
13	A*(r)*	4.20	1.45	16.7	0.99884	1.530	1.528	0.055
14	A	3.84	1.44	16.7	0.99884	1.597	1.595	0.058
15	A	4.67	1.62	16.7	0.99884	1.530	1.529	0.055
16	A	4.55	1.55	27.2	0.99646	1.519	1.513	0.055
18	A	4.76	2.17	15.6	0.99902	1.839	1.837	0.066
20	A	4.48	2.19	16.7	0.99884	1.953	1.951	0.070
21	A	3.77	1.32	16.7	0.99884	1.539	1.537	0.056

Panels marked with an 'r' are repeated tests.

Table A.2: D2584-02 Ignition Loss of Cured Composites.

Laminate	Panel	Crucible Weight (g)	Crucible + Specimen Weight (g)	Crucible + Fiber Weight (g)	Fiber Weight (%)	Resin Weight (%)	Fiber Density (g/cc)
1	A	23.97	28.96	27.34	67.5	32.5	2.600
1	B	27.56	32.32	30.82	68.5	31.5	2.600
2	A	24.54	27.69	26.73	69.6	30.4	1.800
2	B	24.55	27.17	26.32	67.4	32.6	1.800
3	A	24.54	29.48	27.90	67.9	32.1	2.600
3	B	24.88	30.23	28.42	66.1	33.9	2.600
4	A	23.97	27.55	26.35	66.5	33.5	1.937
4	B	28.16	31.79	30.65	68.6	31.4	1.937
5	A	27.56	30.96	29.80	65.9	34.1	1.937
5	B	25.12	28.65	27.58	69.6	30.4	1.937
6	A	29.24	33.40	31.96	65.2	34.8	2.377
6	B	26.03	30.56	29.01	65.9	34.1	2.377
7	A	25.12	28.25	27.13	64.2	35.8	1.937
7	B	28.33	31.89	30.56	62.7	37.3	1.937
8	A	26.92	30.46	29.24	65.4	34.6	1.937
8	B	23.97	27.51	26.41	68.9	31.1	1.937
9	A	24.54	28.30	26.81	60.4	39.6	2.030
9	A*(r)*	25.16	29.07	27.48	59.3	40.7	2.030
9	B	29.24	33.11	31.70	63.7	36.3	2.030
10	A	26.92	30.40	29.17	64.6	35.4	1.937
10	B	24.49	28.13	26.99	68.6	31.4	1.937
11	A	23.97	27.59	26.30	64.4	35.6	1.937
12	A	28.33	31.93	30.72	66.5	33.5	1.937
13	A	25.12	29.20	27.43	56.5	43.5	1.958
13	A*(r)*	24.00	28.20	26.35	56.0	44.0	1.958
14	A	24.54	28.39	27.06	65.4	34.6	1.937
15	A	22.89	27.56	25.56	57.2	42.8	1.958
16	A	29.25	33.80	31.78	55.6	44.4	1.956
18	A	26.92	31.68	30.12	67.3	32.7	2.600
20	A	26.92	31.40	30.20	73.3	26.7	2.600
21	A	28.33	32.10	30.81	65.6	34.4	1.800

Panels marked with an 'r' are repeated tests.

Table A.3: D2734-94 Void Content.

Laminate	Panel	Fiber Volume (%)	Resin Density (g/cc)	Void Content Volume (%)
1	A	48.3	1.154	-0.74
1	B	49.4	1.154	-0.46
2	A	60.2	1.154	-1.09
2	B	56.9	1.154	0.07
3	A	48.6	1.154	-0.36
3	B	46.4	1.154	-0.10
4	A	54.9	1.154	-1.29
4	B	56.2	1.154	0.56
5	A	54.2	1.154	-1.19
5	B	56.9	1.154	1.45
6	A	48.3	1.154	-1.40
6	B	48.3	1.154	0.21
7	A	52.3	1.154	-1.20
7	B	51.1	1.154	-2.06
8	A	53.6	1.154	-1.23
8	B	56.4	1.154	0.88
9	A	46.3	1.154	0.34
9	A*(r)*	46.5	1.154	-2.56
9	B	50.6	1.154	-1.37
10	A	53.2	1.154	-2.06
10	B	56.4	1.154	0.18
11	A	52.5	1.154	-1.17
12	A	54.4	1.154	-0.44
13	A	43.4	1.154	-0.17
13	A*(r)*	43.7	1.154	-1.98
14	A	53.9	1.154	-1.68
15	A	44.7	1.154	-1.32
16	A	43.0	1.154	-1.25
18	A	47.5	1.154	0.39
20	A	55.0	1.154	-0.19
21	A	56.1	1.154	-1.84

Panels marked with an 'r' are repeated tests.

A.2 Laminate 1 - SC/GUD16 - $[(0_G)_8]$

A.2.1 Tension 0

Table A.4: Laminate 1 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.8	3.7	25.3	25.3	25.3	24.4	47	SGM AIB AIT
2	3.8	3.7	3.7	25.3	25.3	25.3	24.4	47	LIB SGM
3	3.7	3.8	3.7	25.3	25.3	25.3	24.4	47	LIB SGM

Table A.5: Laminate 1 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.0672	0.018	25.3	0.0000	0.000	93.9
2	3.7	0.0672	0.018	25.3	0.0000	0.000	94.0
3	3.7	0.0529	0.014	25.3	0.0000	0.000	93.8

Table A.6: Laminate 1 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	36.7	0.999999	0.00011	0.255	0.999949	0.00085
2	35.4	0.999997	0.00020	0.262	0.999984	0.00049
3	37.3	0.999996	0.00024	0.254	0.999967	0.00069

Table A.7: Laminate 1 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	93.9	68,727	732	20,651
2	94.0	63,166	672	19,512
3	93.8	66,384	708	19,703
Average	93.9	66,092	704	19,955
STDEV	0.1	2,792	30.1	610
CV	0.0011	0.042	0.043	0.031

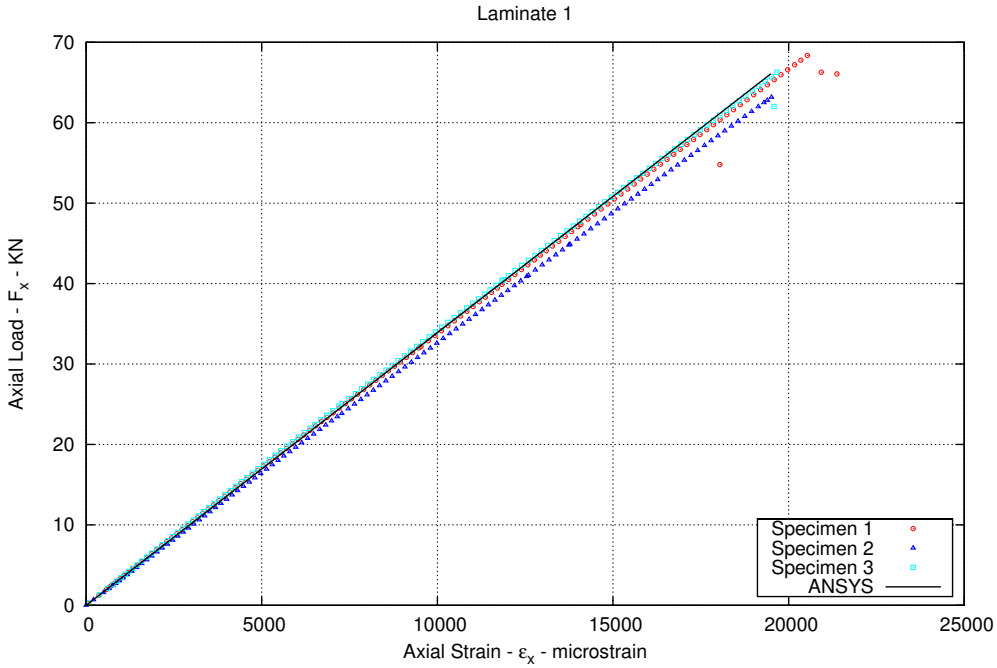


Figure A.1: Laminate 1 axial strain induced with an axial tensile load.

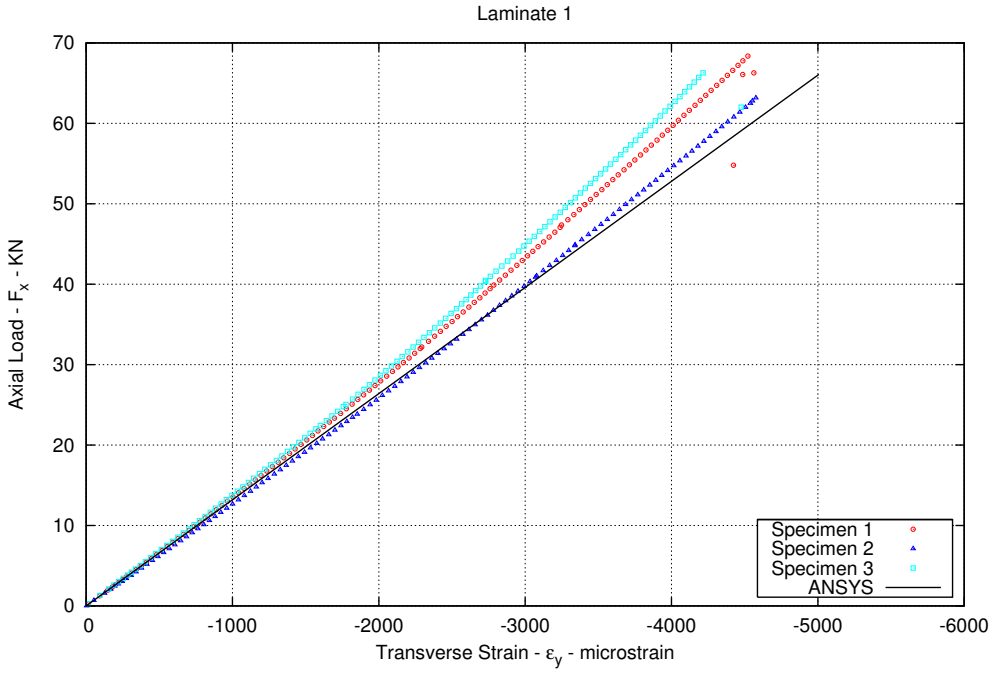


Figure A.2: Laminate 1 transverse strain induced with an axial tensile load.

A.2.2 Tenion 90

Table A.8: Laminate 1 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.8	3.6	3.6	25.4	25.4	25.4	24.4	45	LWT
2	3.8	3.8	3.6	25.3	25.3	25.3	24.4	45	LAT
3	3.7	3.8	3.7	25.3	25.3	25.3	24.4	45	LGM

Table A.9: Laminate 1 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.0916	0.025	25.4	0.0000	0.000	92.8
2	3.7	0.0880	0.024	25.3	0.0000	0.000	93.9
3	3.7	0.0639	0.017	25.3	0.0000	0.000	94.2

Table A.10: Laminate 1 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	13.3	0.999039	0.00247	0.097	0.998991	0.00253
2	12.2	0.999554	0.00177	0.091	0.999437	0.00198
3	12.3	0.999372	0.00210	0.091	0.999258	0.00229

Table A.11: Laminate 1 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	92.8	5,461	58.8	5,001
2	93.9	5,493	58.5	5,004
3	94.2	5,425	57.6	5,007
Average	93.6	5,459	58.3	5,004
STDEV	0.7	34	0.65	3
CV	0.0079	0.006	0.011	0.001

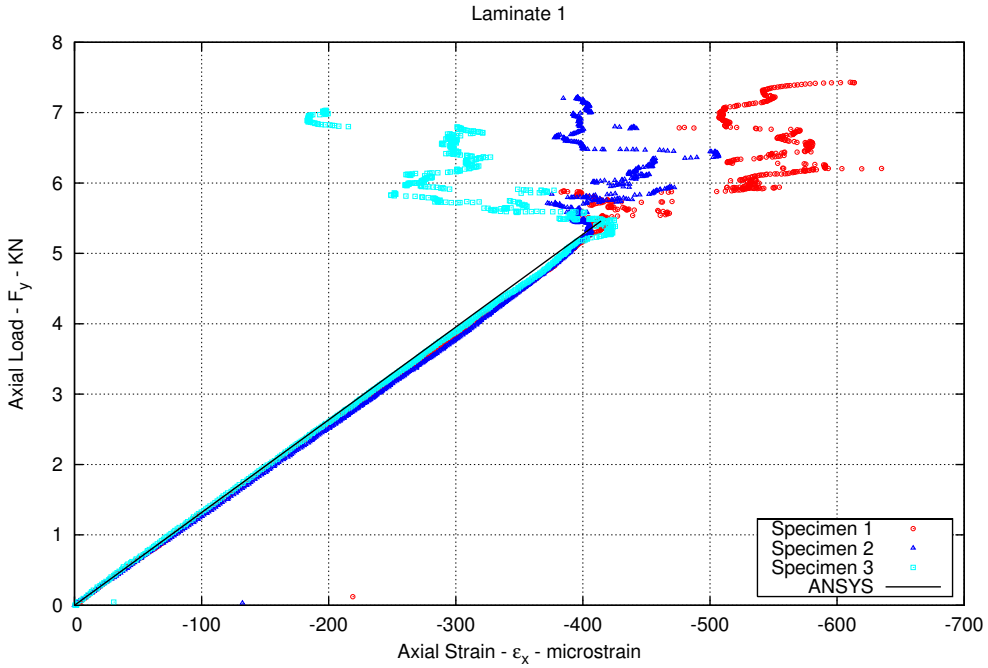


Figure A.3: Laminate 1 axial strain induced with a transverse tensile load.

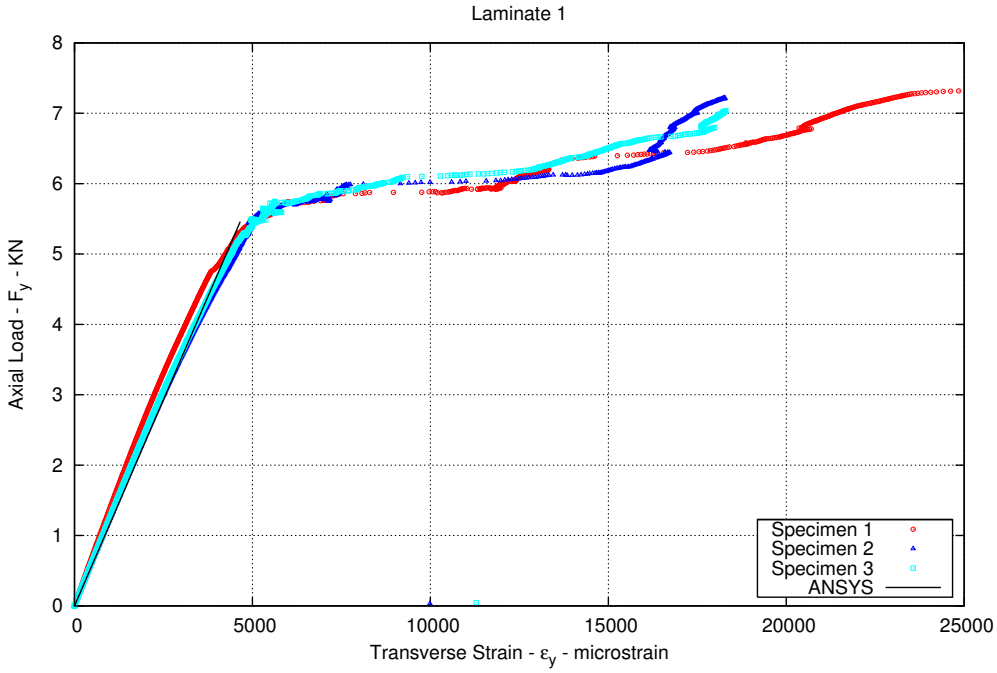


Figure A.4: Laminate 1 transverse strain induced with a transverse tensile load.

A.2.3 Compression

Table A.12: Laminate 1 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
2	3.8	3.8	12.7	12.7	23.9
3	3.7	3.7	12.6	12.6	23.9
4	3.7	3.7	12.7	12.7	23.9

Table A.13: Laminate 1 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	3.8	0.0000	0.000	12.7	0.0180	0.001	48.0
3	3.7	0.0359	0.010	12.6	0.0180	0.001	46.8
4	3.7	0.0539	0.015	12.7	0.0000	0.000	46.9

Table A.14: Laminate 1 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
2	37.4	0.999872	0.00115
3	38.4	0.999883	0.00108
4	37.8	0.999893	0.00104

Table A.15: Laminate 1 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.5	3.6	12.6	12.6	25.6	24	BGM
2	3.7	3.7	12.7	12.7	25.6	24	BGM
4	3.6	3.6	12.7	12.7	25.6	24	BGM

Table A.16: Laminate 1 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.6	0.0799	0.022	12.6	0.0000	0.000	45.1
2	3.7	0.0242	0.007	12.7	0.0000	0.000	46.6
4	3.6	0.0287	0.008	12.7	0.0000	0.000	45.9

Table A.17: Laminate 1 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
2	48.0	35,977	749	19,784
3	46.8	36,191	774	20,433
4	46.9	39,909	850	22,451
Average	47.2	37,359	791	20,889
STDEV	0.7	2,211	52.7	1,391
CV	0.0144	0.059	0.067	0.067

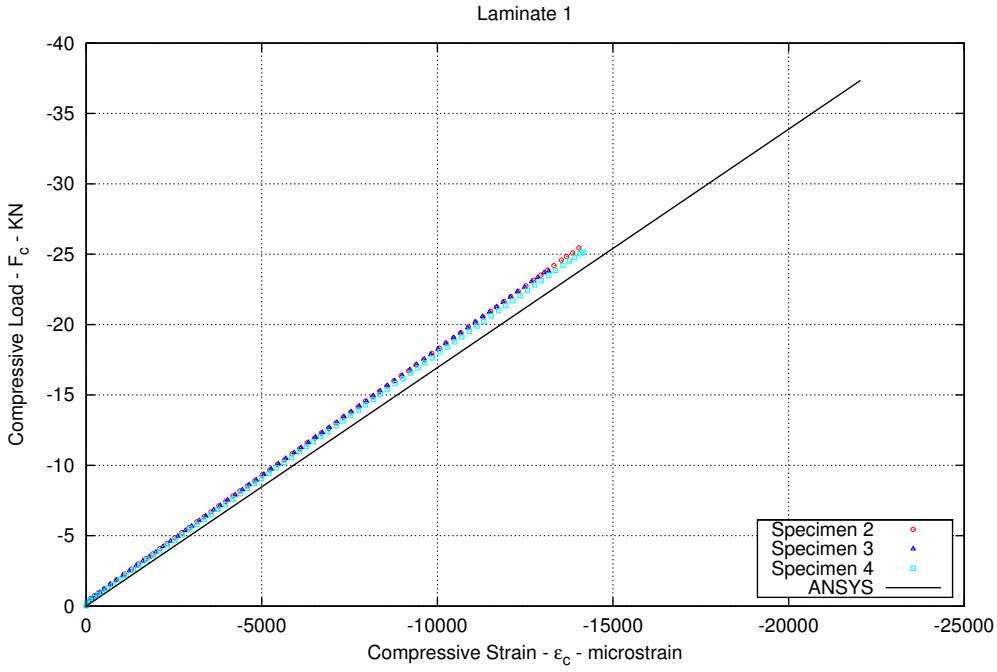


Figure A.5: Laminate 1 axial strain induced with an axial compressive load.

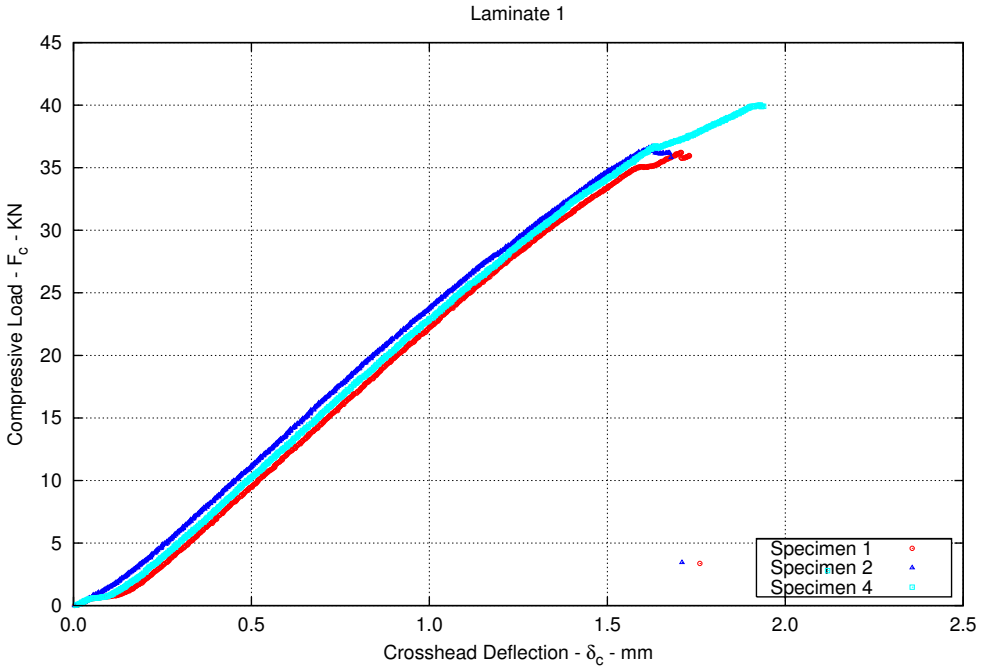


Figure A.6: Response of Laminate 1 to compressive loading.

A.2.4 In-Plane Shear

Table A.18: Laminate 1 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
2	3.7	3.7	11.4	11.4	24.4	49	null
3	3.7	3.7	11.4	11.4	24.4	49	null
4	3.6	3.6	11.4	11.4	24.4	49	null

Table A.19: Laminate 1 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	3.7	0.0359	0.010	11.4	0.0359	0.003	41.9
3	3.7	0.0000	0.000	11.4	0.0359	0.003	42.3
4	3.6	0.0180	0.005	11.4	0.0000	0.000	41.0

Table A.20: Laminate 1 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
2	3.9	0.9942	0.0133
3	3.7	0.9977	0.0088
4	4.2	0.9959	0.0114

Table A.21: Laminate 1 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
2	41.9	2,611	62.3	50,000
3	42.3	2,571	60.8	50,000
4	41.0	2,638	64.4	50,000
Average	41.7	2,607	62.5	50,000
STDEV	0.7	34	1.8	0.0
CV	0.016	0.013	0.029	0.0

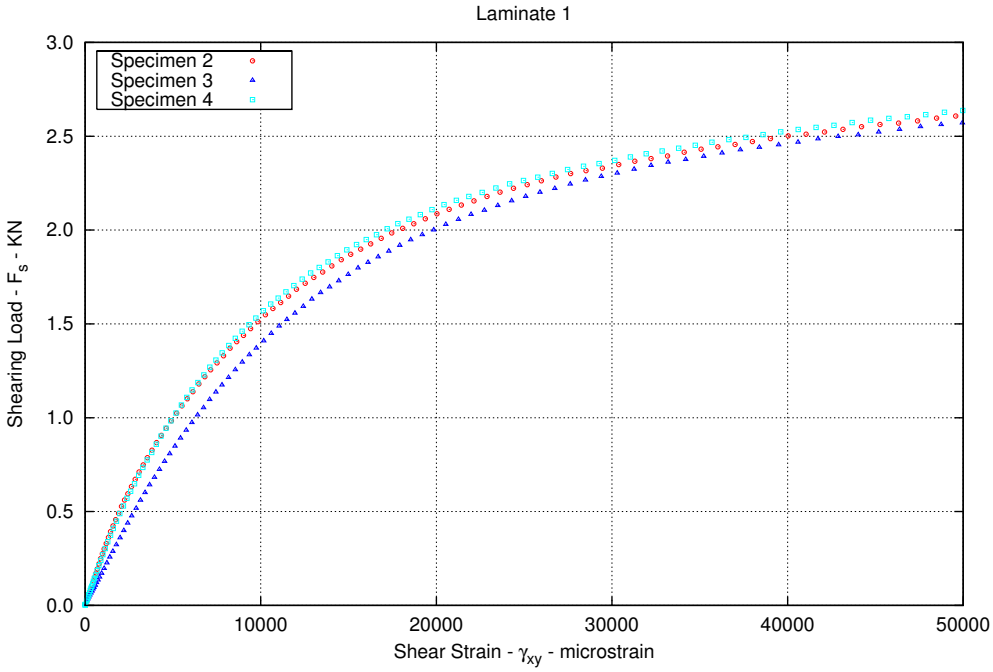


Figure A.7: Laminate 1 shear strain induced with an in-plane shear load.

A.2.5 Interlaminar Shear

Table A.22: Laminate 1 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.8	6.4	6.4	25.6	24	GOOD FAIL
2	3.7	3.8	6.4	6.3	25.6	24	GOOD FAIL
3	3.7	3.7	6.4	6.4	25.6	24	GOOD FAIL

Table A.23: Laminate 1 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.1356	0.037	6.4	0.0000	0.000	23.6
2	3.7	0.0287	0.008	6.3	0.0539	0.009	23.7
3	3.7	0.0314	0.009	6.4	0.0180	0.003	23.5

Table A.24: Laminate 1 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	23.6	1741.0	56.0
2	23.7	1796.1	57.6
3	23.5	1691.1	54.7

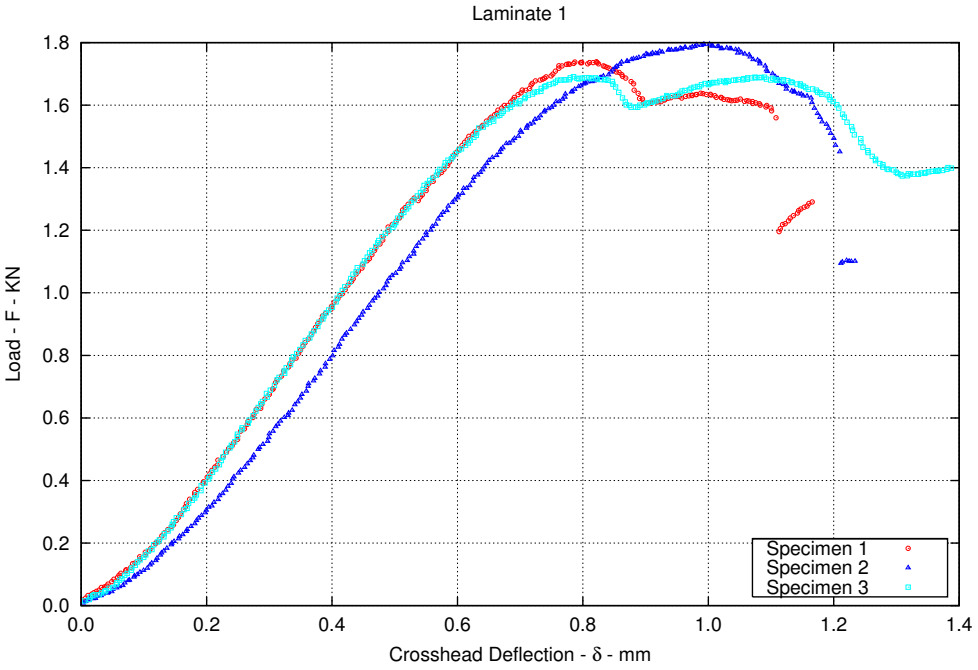


Figure A.8: Laminate 1 interlaminar shear response.

A.3 Laminate 2 - SC/CUD - $[(0_C)_6]$

A.3.1 Tension 0

Table A.25: Laminate 2 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	2.9	3.0	2.9	25.4	25.4	25.4	24.4	40	SGM LIT
2	2.7	2.8	2.8	25.4	25.4	25.4	24.4	40	AIT SGM AIB
3	2.8	2.7	2.8	25.4	25.4	25.4	24.4	40	AIT SGM AIB

Table A.26: Laminate 2 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	2.9	0.0388	0.013	25.4	0.0000	0.000	74.7
2	2.8	0.0388	0.014	25.4	0.0000	0.000	70.5
3	2.8	0.0529	0.019	25.4	0.0000	0.000	71.1

Table A.27: Laminate 2 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	125.1	0.999960	0.00051	0.318	0.999986	0.00030
2	130.2	0.999968	0.00049	0.259	0.999985	0.00033
3	126.5	0.999955	0.00058	0.408	0.999976	0.00042

Table A.28: Laminate 2 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	74.7	119,831	1,604	11,938
2	70.5	112,843	1,600	12,225
3	71.1	110,353	1,552	12,047
Average	72.1	114,342	1,585	12,070
STDEV	2.3	4,914	29.0	145
CV	0.0313	0.043	0.018	0.012

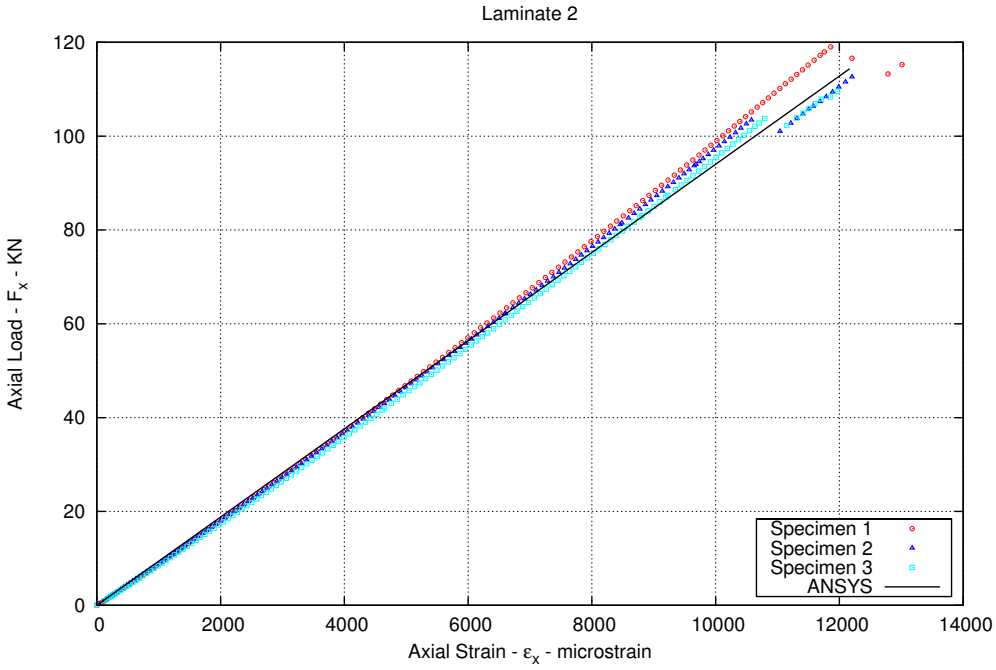


Figure A.9: Laminate 2 axial strain induced with an axial tensile load.

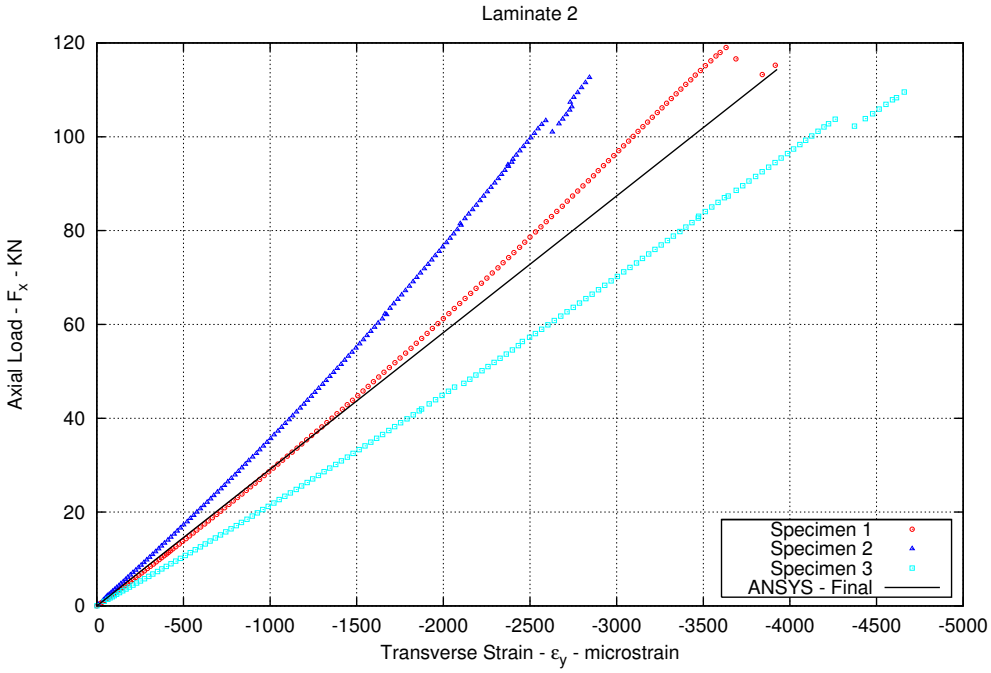


Figure A.10: Laminate 2 transverse strain induced with an axial tensile load.

A.3.2 Tenion 90

Table A.29: Laminate 2 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	2.8	3.0	2.9	25.4	25.4	25.4	24.4	45	LAB
2	2.8	3.0	2.7	25.4	25.4	25.4	24.4	45	LAT
3	2.7	2.7	3.0	25.4	25.4	25.4	24.4	45	LAB

Table A.30: Laminate 2 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	2.9	0.0776	0.027	25.4	0.0000	0.000	73.3
2	2.9	0.1278	0.045	25.4	0.0147	0.001	72.7
3	2.8	0.1399	0.050	25.4	0.0000	0.000	71.4

Table A.31: Laminate 2 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	8.3	0.999958	0.00049	0.020	0.999003	0.00238
2	8.9	0.999966	0.00040	0.025	0.999336	0.00175
3	9.1	0.999973	0.00037	0.024	0.999296	0.00192

Table A.32: Laminate 2 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	73.3	2,395	32.7	3,923
2	72.7	3,037	41.8	4,726
3	71.4	2,010	28.1	3,076
Average	72.5	2,481	34.2	3,908
STDEV	1.0	519	7.0	825
CV	0.0136	0.209	0.203	0.211

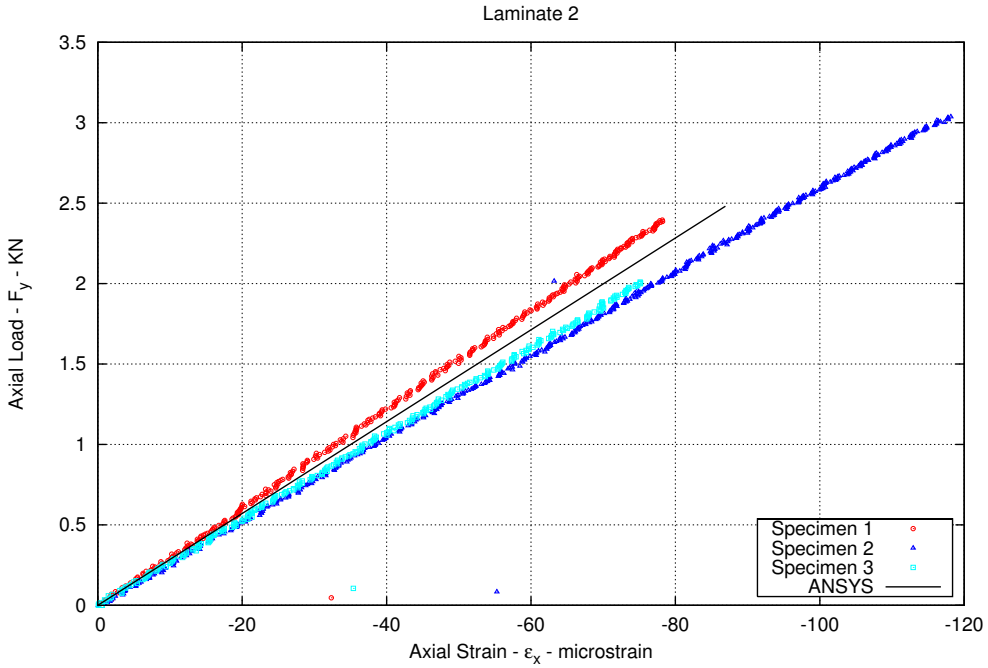


Figure A.11: Laminate 2 axial strain induced with a transverse tensile load.

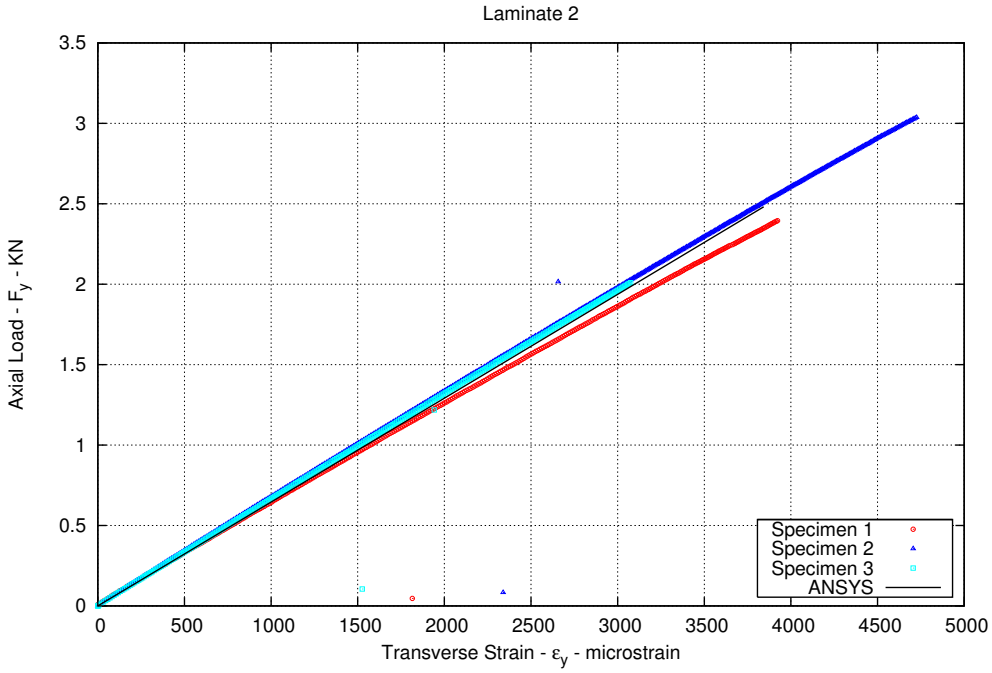


Figure A.12: Laminate 2 transverse strain induced with a transverse tensile load.

A.3.3 Compression

Table A.33: Laminate 2 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	2.8	2.8	12.7	12.7	23.9
2	2.9	2.9	12.7	12.7	23.9
3	2.9	2.8	12.7	12.7	23.9

Table A.34: Laminate 2 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	2.8	0.0539	0.019	12.7	0.0180	0.001	35.7
2	2.9	0.0180	0.006	12.7	0.0180	0.001	36.6
3	2.8	0.0359	0.013	12.7	0.0180	0.001	36.2

Table A.35: Laminate 2 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	122.0	0.999933	0.00075
2	121.2	0.999948	0.00065
3	125.3	0.999960	0.00056

Table A.36: Laminate 2 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	2.8	2.8	12.7	12.7	25.6	24	BGM
2	3.0	2.8	12.6	12.6	25.6	24	BGM
3	2.9	2.8	12.6	12.6	25.6	24	BGM

Table A.37: Laminate 2 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	2.8	0.0413	0.015	12.7	0.0000	0.000	35.4
2	2.9	0.1293	0.045	12.6	0.0000	0.000	36.8
3	2.9	0.0727	0.025	12.6	0.0090	0.001	36.1

Table A.38: Laminate 2 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	35.4	34,898	985	8,021
2	36.8	34,660	942	7,668
3	36.3	34,127	940	7,658
Average	36.2	34,562	956	7,782
STDEV	0.7	395	25.4	206
CV	0.0192	0.011	0.027	0.027

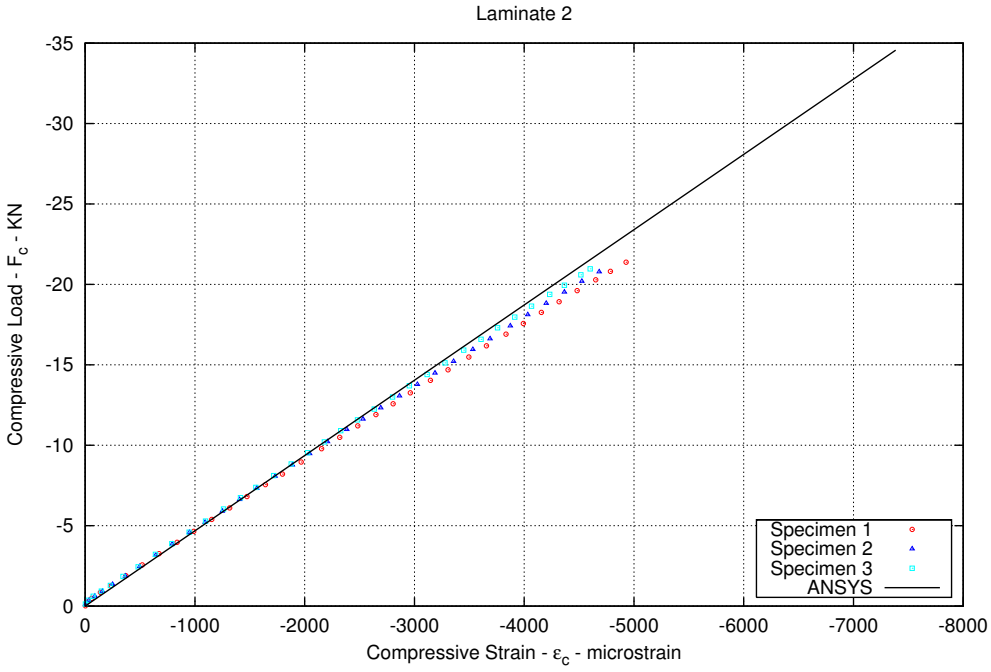


Figure A.13: Laminate 2 axial strain induced with an axial compressive load.

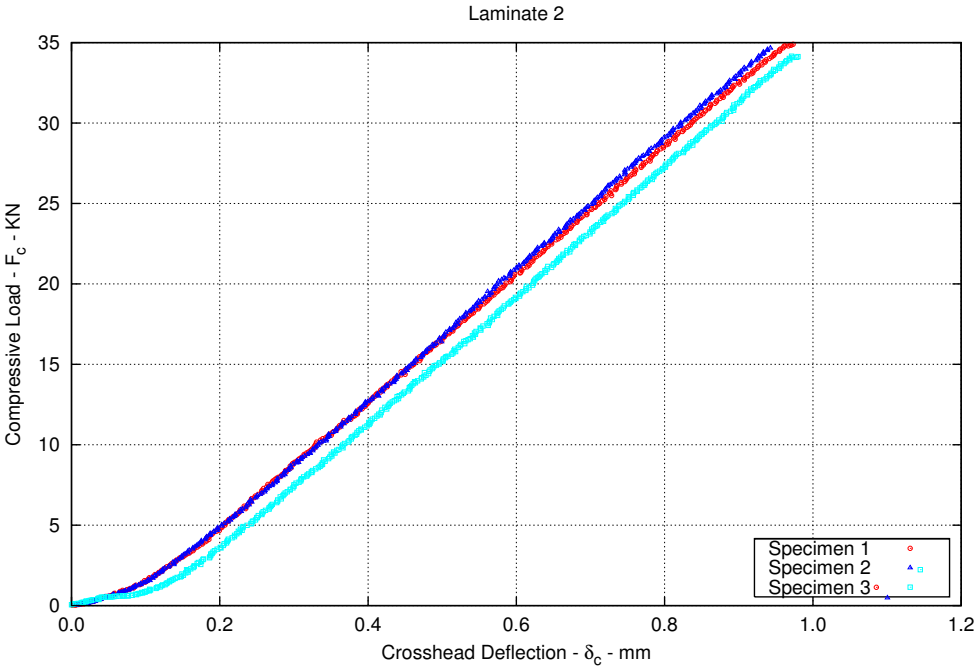


Figure A.14: Response of Laminate 2 to compressive loading.

A.3.4 In-Plane Shear

Table A.39: Laminate 2 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	2.8	2.9	11.5	11.5	22.2	52	null
2	2.6	2.7	11.4	11.4	22.2	52	null
3	2.9	2.9	11.4	11.5	22.2	52	null

Table A.40: Laminate 2 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	2.8	0.0359	0.013	11.5	0.0000	0.000	32.6
2	2.7	0.0359	0.013	11.4	0.0539	0.005	30.4
3	2.9	0.0180	0.006	11.4	0.0539	0.005	33.3

Table A.41: Laminate 2 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	5.3	0.9976	0.0082
2	5.1	0.9976	0.0085
3	4.8	0.9982	0.0074

Table A.42: Laminate 2 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	32.6	2,469	75.8	50,000
2	30.4	2,220	73.0	50,000
3	33.3	2,398	72.0	50,000
Average	32.1	2,362	73.6	50,000
STDEV	1.5	128	1.9	0.0
CV	0.0472	0.054	0.026	0.0

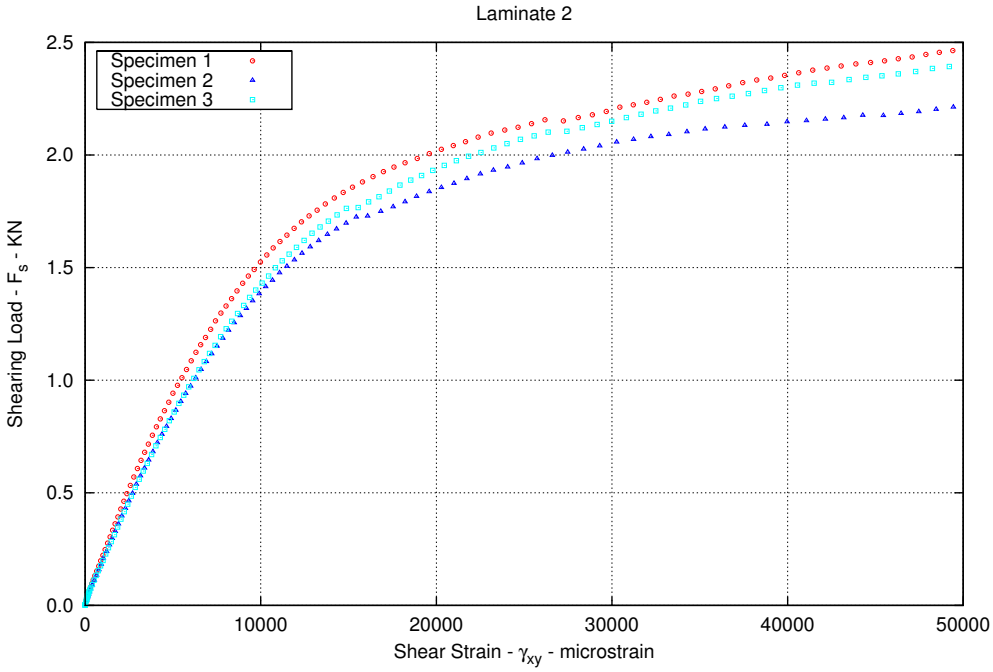


Figure A.15: Laminate 2 shear strain induced with an in-plane shear load.

A.3.5 Interlaminar Shear

Table A.43: Laminate 2 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	2.9	2.9	6.4	6.4	23.9	26	GOOD FAIL
2	3.0	3.0	6.4	6.4	23.9	26	GOOD FAIL
3	3.0	3.0	6.3	6.3	23.9	26	GOOD FAIL

Table A.44: Laminate 2 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	2.9	0.0341	0.012	6.4	0.0000	0.000	18.6
2	3.0	0.0036	0.001	6.4	0.0090	0.001	19.0
3	3.0	0.0018	0.001	6.3	0.0000	0.000	19.1

Table A.45: Laminate 2 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	18.6	1608.0	65.9
2	19.0	1644.5	65.9
3	19.1	1771.9	70.7

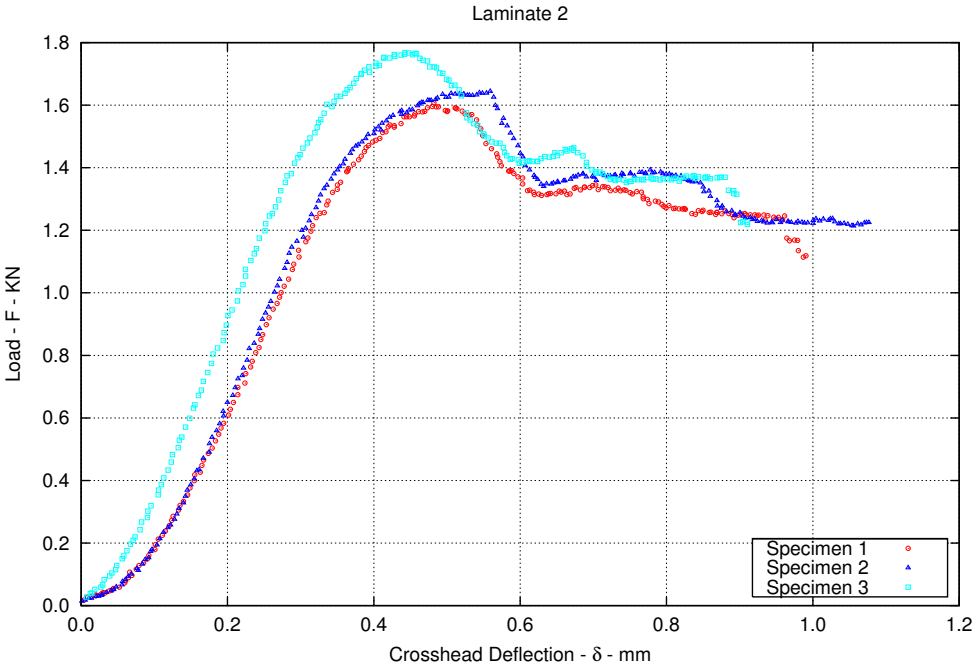


Figure A.16: Laminate 2 interlaminar shear response.

A.4 Laminate 3 - 85GUD/15GDB - $[\pm 45_{DB}/(0_G)_4]_s$

A.4.1 Tension 0

Table A.46: Laminate 3 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.4	4.3	4.3	25.3	25.3	25.3	24.4	55	AIT
2	4.4	4.2	4.4	25.4	25.3	25.3	24.4	55	DGM AIB
3	4.3	4.2	4.3	25.4	25.4	25.4	24.4	55	LIB

Table A.47: Laminate 3 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.4	0.0147	0.003	25.3	0.0000	0.000	110.3
2	4.3	0.0880	0.020	25.4	0.0147	0.001	110.1
3	4.3	0.0293	0.007	25.4	0.0000	0.000	108.6

Table A.48: Laminate 3 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	33.2	0.999986	0.00044	0.315	0.999968	0.00066
2	32.6	0.999993	0.00031	0.301	0.999976	0.00058
3	33.0	0.999999	0.00014	0.314	0.999986	0.00044

Table A.49: Laminate 3 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	110	75,128	681	21,774
2	110	73,092	664	21,604
3	109	73,402	676	21,452
Average	110	73,874	674	21,610
STDEV	0.9	1,097	8.9	161
CV	0.0086	0.015	0.013	0.007

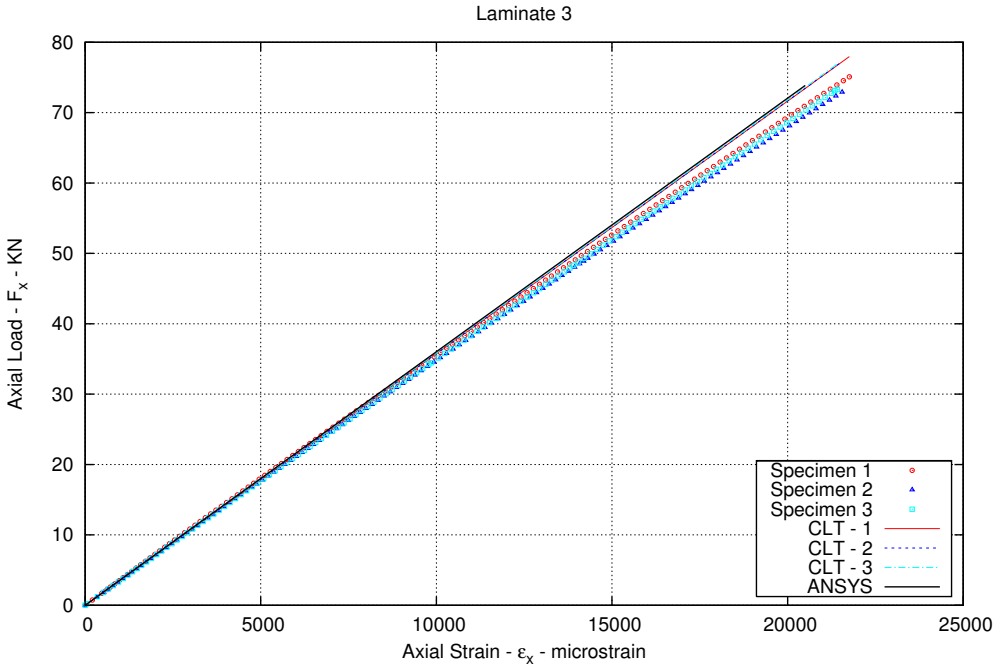


Figure A.17: Laminate 3 axial strain induced with an axial tensile load.

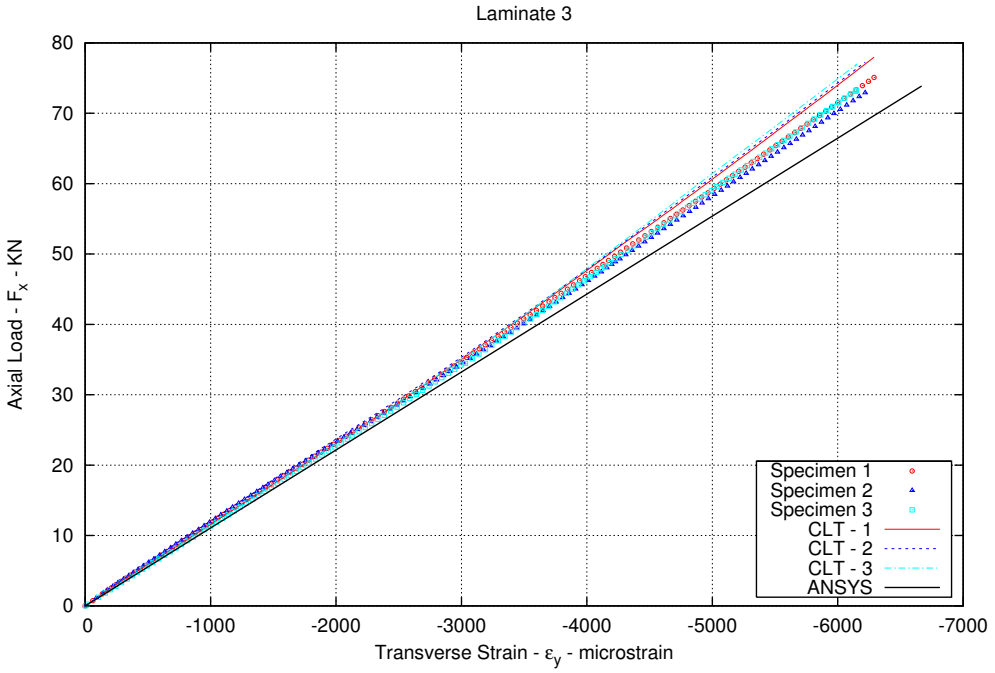


Figure A.18: Laminate 3 transverse strain induced with an axial tensile load.

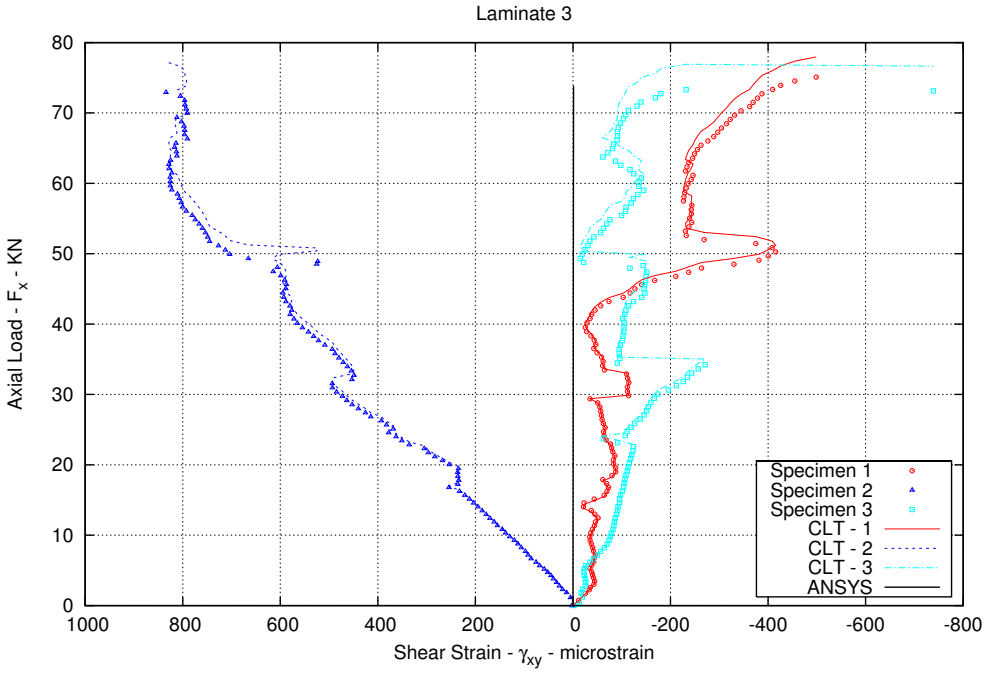


Figure A.19: Laminate 3 shear strain induced with an axial tensile load.

A.4.2 Tenion 90

Table A.50: Laminate 3 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.4	4.4	4.3	25.4	25.4	25.4	24.4	45	LWT
2	4.5	4.5	4.3	25.4	25.4	25.4	24.4	45	LWT
3	4.5	4.4	4.3	25.4	25.4	25.4	24.4	45	LWT

Table A.51: Laminate 3 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.4	0.0388	0.009	25.4	0.0147	0.001	111.3
2	4.5	0.1466	0.033	25.4	0.0000	0.000	113.2
3	4.4	0.0892	0.020	25.4	0.0000	0.000	112.6

Table A.52: Laminate 3 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	13.7	0.999323	0.00254	0.136	0.999747	0.00155
2	13.2	0.999648	0.00196	0.124	0.999706	0.00179
3	12.9	0.999583	0.00241	0.125	0.999845	0.00147

Table A.53: Laminate 3 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	111	12,135	109	20,990
2	113	11,673	103	18,775
3	113	12,308	109	20,530
Average	112	12,039	107	20,098
STDEV	1.0	329	3.5	1,169
CV	0.0086	0.027	0.033	0.058

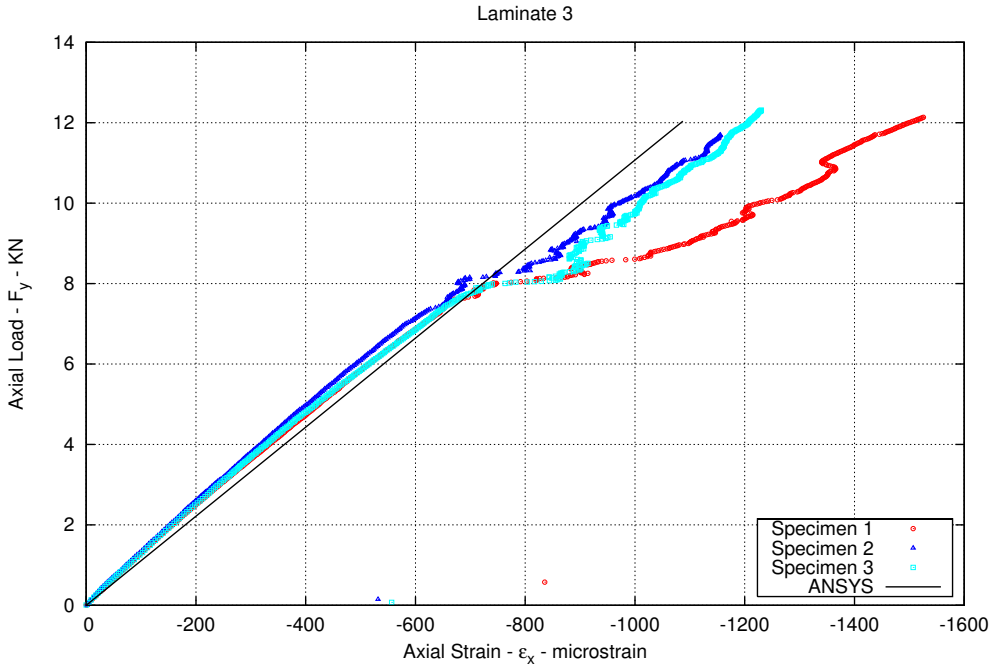


Figure A.20: Laminate 3 axial strain induced with a transverse tensile load.

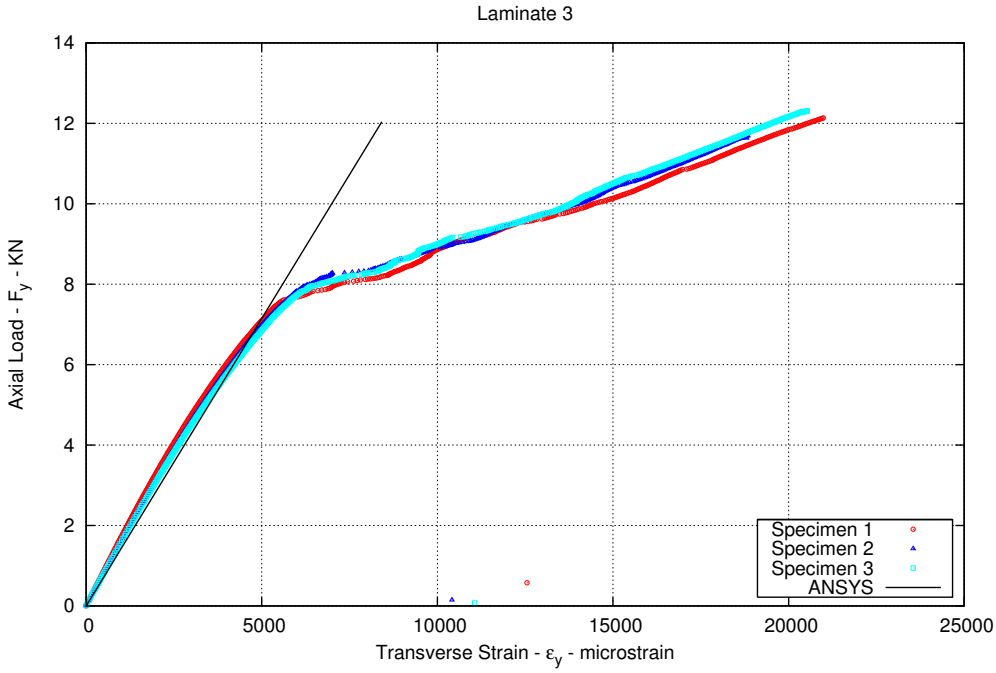


Figure A.21: Laminate 3 transverse strain induced with a transverse tensile load.

A.4.3 Compression

Table A.54: Laminate 3 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	4.4	4.4	12.7	12.7	23.9
2	4.4	4.3	12.7	12.7	23.9
3	4.4	4.4	12.7	12.7	23.9

Table A.55: Laminate 3 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.4	0.0000	0.000	12.7	0.0000	0.000	56.6
2	4.3	0.0539	0.012	12.7	0.0000	0.000	55.1
3	4.4	0.0359	0.008	12.7	0.0000	0.000	55.9

Table A.56: Laminate 3 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	35.6	0.999929	0.00083
2	32.7	0.999859	0.00120
3	33.4	0.999845	0.00126

Table A.57: Laminate 3 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
2	4.3	4.3	12.7	12.7	24.4	0	BGM
3	4.3	4.3	12.7	12.7	24.4	0	TAT
4	4.3	4.3	12.7	12.7	24.4	0	BGM
5	4.4	4.4	12.7	12.7	24.4	0	BGM

Table A.58: Laminate 3 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
2	4.3	0.0153	0.004	12.7	0.0000	0.000	55.1
3	4.3	0.0036	0.001	12.7	0.0000	0.000	54.9
4	4.3	0.0018	0.000	12.7	0.0000	0.000	55.0
5	4.4	0.0081	0.002	12.7	0.0000	0.000	55.4

Table A.59: Laminate 3 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
2	55.1	38,892	706	20,830
3	54.9	37,228	678	19,998
4	55.0	38,951	708	20,901
5	55.4	35,854	648	19,108
Average	55.1	37,731	685	20,209
STDEV	0.2	1,485	28.5	841
CV	0.0035	0.039	0.042	0.042

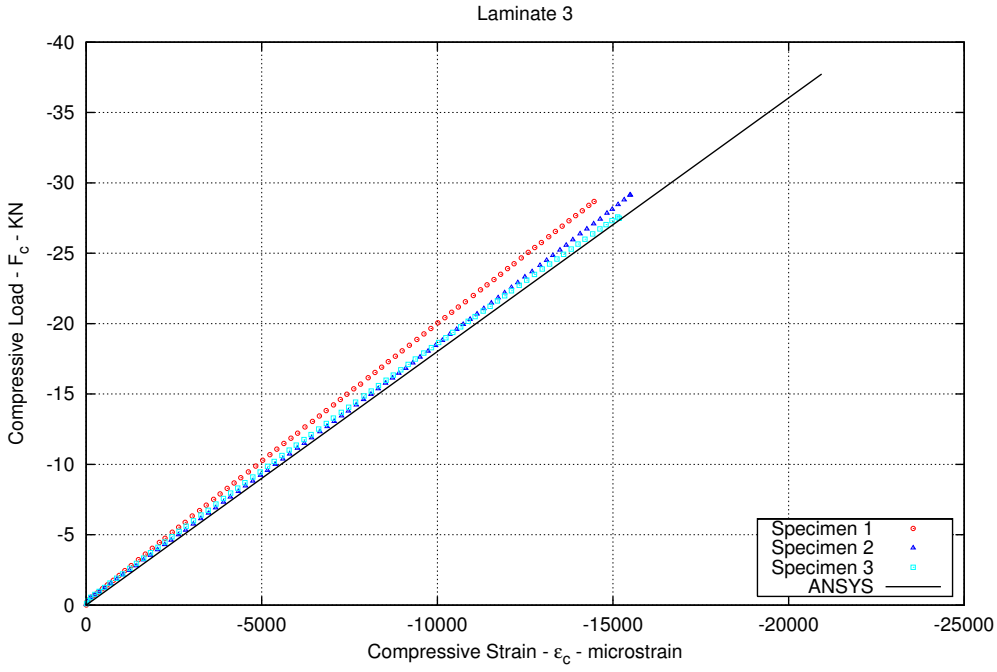


Figure A.22: Laminate 3 axial strain induced with an axial compressive load.

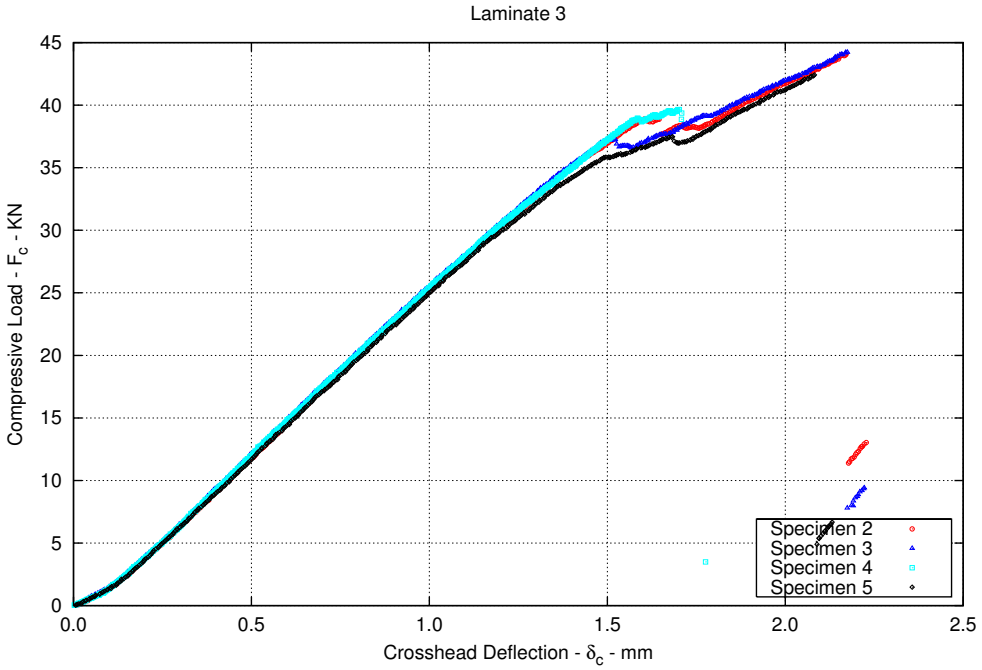


Figure A.23: Response of Laminate 3 to compressive loading.

A.4.4 In-Plane Shear

Table A.60: Laminate 3 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.4	4.5	11.3	11.3	23.3	31	null
2	4.3	4.3	11.4	11.4	23.3	31	null
3	4.3	4.4	11.3	11.3	23.3	31	null

Table A.61: Laminate 3 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.4	0.0359	0.008	11.3	0.0180	0.002	50.3
2	4.3	0.0180	0.004	11.4	0.0180	0.002	48.9
3	4.4	0.0180	0.004	11.3	0.0180	0.002	49.1

Table A.62: Laminate 3 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	6.1	0.9951	0.0074
2	5.4	0.9987	0.0042
3	5.5	0.9979	0.0053

Table A.63: Laminate 3 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	50.3	5,544	110	40,044
2	48.9	5,150	105	40,007
3	49.1	5,368	109	40,095
Average	49.4	5,354	108	40,049
STDEV	0.8	197	2.7	44
CV	0.015	0.037	0.025	0.001

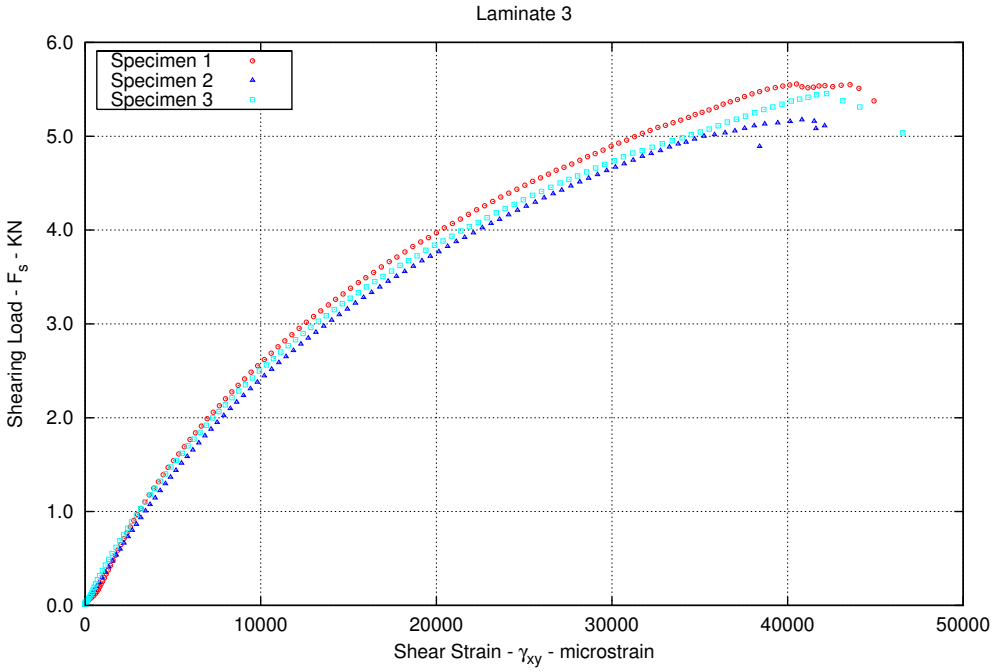


Figure A.24: Laminate 3 shear strain induced with an in-plane shear load.

A.4.5 Interlaminar Shear

Table A.64: Laminate 3 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.3	4.3	6.4	6.4	23.9	40	Interlaminar Shear
2	4.3	4.2	6.4	6.4	23.9	40	Interlaminar Shear
4	4.3	4.3	6.3	6.3	23.9	40	Interlaminar Shear

Table A.65: Laminate 3 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.3	0.0063	0.001	6.4	0.0000	0.000	27.1
2	4.3	0.0620	0.015	6.4	0.0000	0.000	27.1
4	4.3	0.0000	0.000	6.3	0.0000	0.000	27.4

Table A.66: Laminate 3 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	27.1	1902.4	53.3
2	27.1	1847.6	51.8
4	27.4	1871.6	51.9

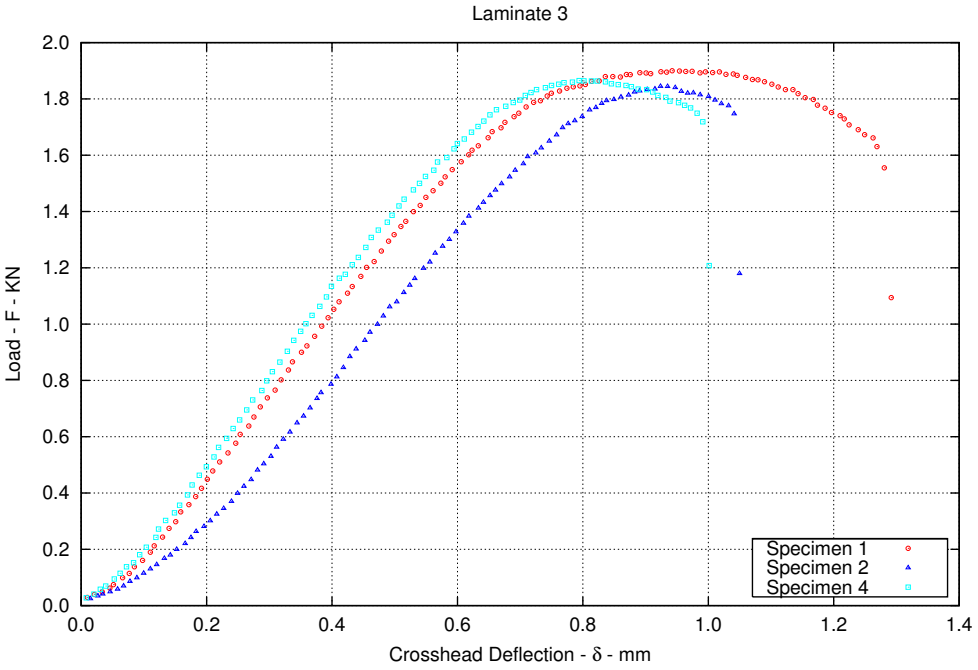


Figure A.25: Laminate 3 interlaminar shear response.

A.5 Laminate 4 - 85CUD/15GDB - $[\pm 45_{DB}/(0_C)_3]_s$

A.5.1 Tension 0

Table A.67: Laminate 4 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.9	3.9	3.9	25.4	25.4	25.4	25	56	SGM AIB AIT
2	3.5	3.5	3.5	25.4	25.4	25.4	25	56	AIT AIB
3	3.5	3.6	3.6	25.4	25.4	25.4	25	56	SIB
4	3.6	3.6	3.5	25.4	25.4	25.4	25	56	LIB

Table A.68: Laminate 4 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.9	0.0254	0.007	25.4	0.0000	0.000	98.7
2	3.5	0.0293	0.008	25.4	0.0000	0.000	89.2
3	3.6	0.0388	0.011	25.4	0.0000	0.000	90.4
4	3.6	0.0816	0.023	25.4	0.0000	0.000	90.8

Table A.69: Laminate 4 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	111.7	0.999940	0.00063	0.362	0.999976	0.00040
2	107.7	0.999916	0.00079	0.264	0.999936	0.00069
3	110.6	0.999993	0.00021	0.344	0.999963	0.00050
4	103.9	0.999974	0.00044	0.411	0.999989	0.00029

Table A.70: Laminate 4 axial tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	98.7	131,026	1,327	11,160
2	89.2	131,281	1,471	12,682
3	90.4	97,647	1,080	9,371
4	90.8	115,603	1,274	11,515
Average	92.3	118,889	1,288	11,182
STDEV	4.3	15,947	162	1,371
CV	0.047	0.134	0.126	0.123

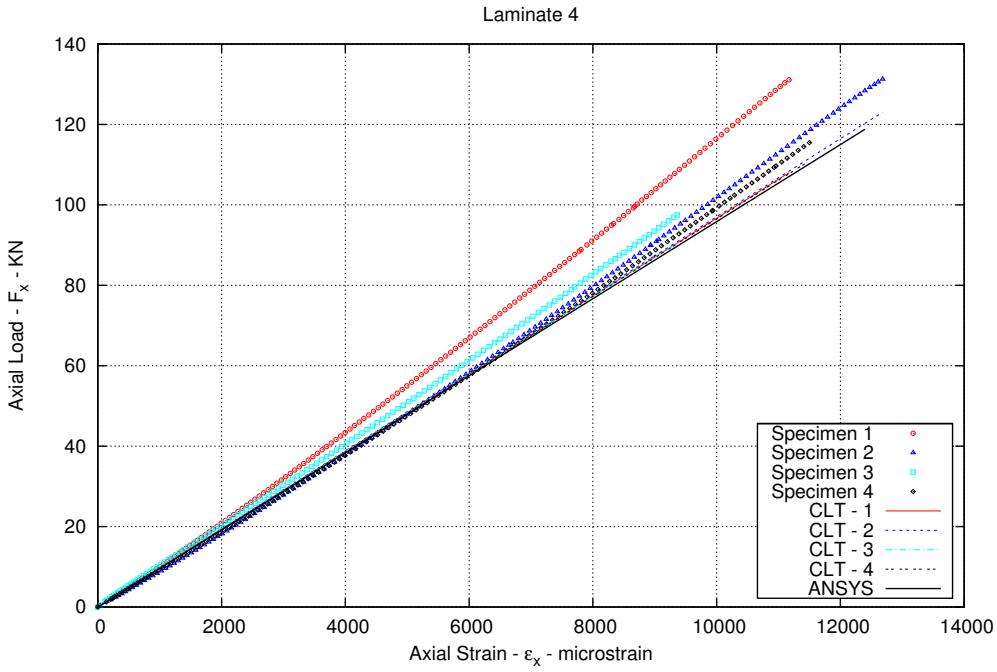


Figure A.26: Laminate 4 axial strain induced with an axial tensile load.

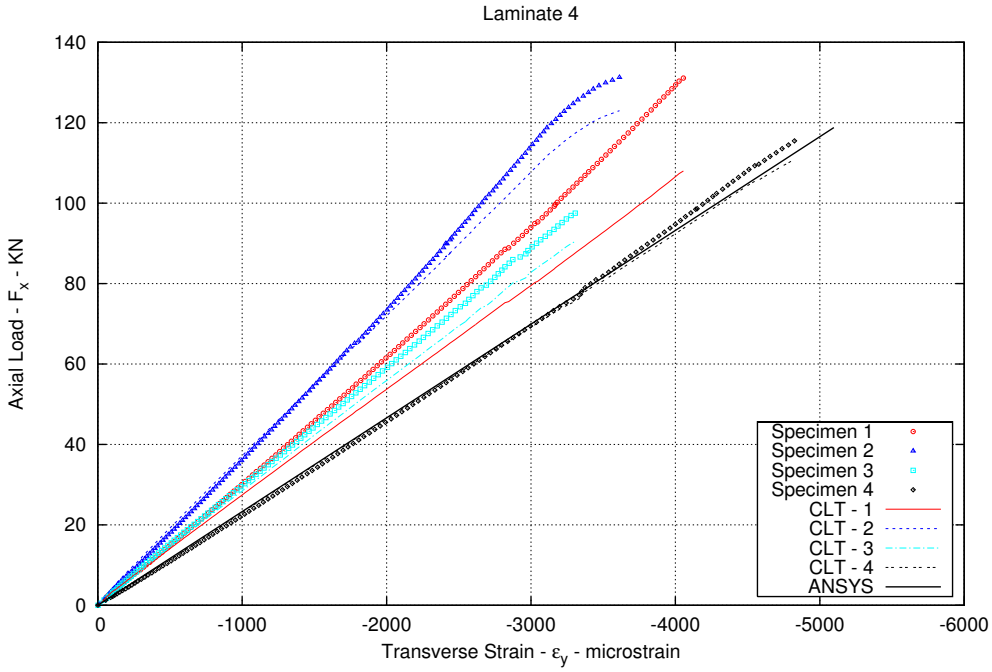


Figure A.27: Laminate 4 transverse strain induced with an axial tensile load.

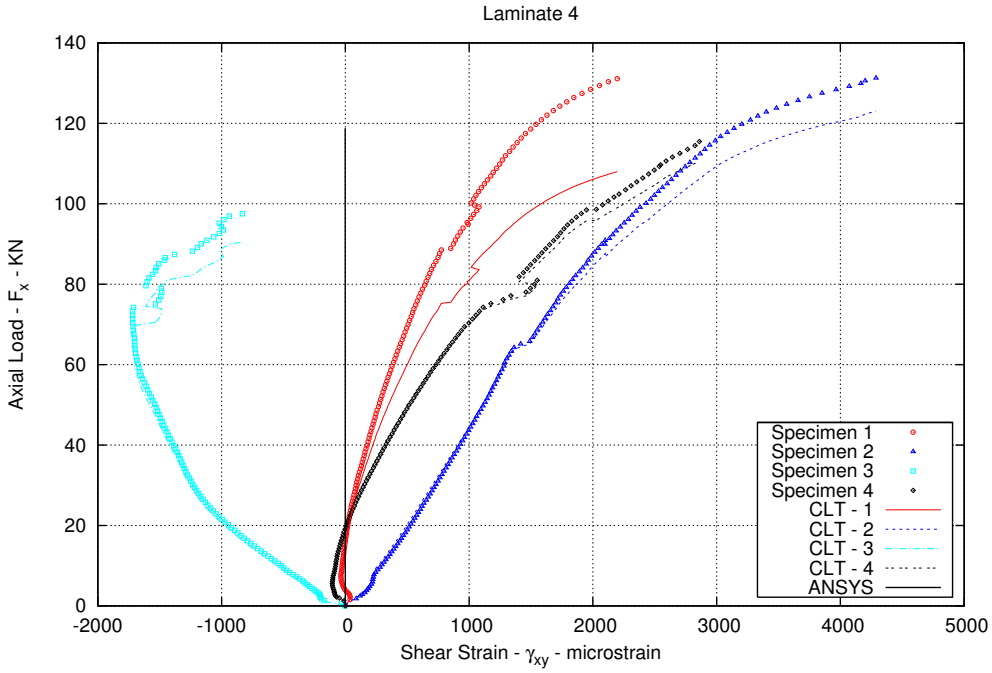


Figure A.28: Laminate 4 shear strain induced with an axial tensile load.

A.5.2 Tenion 90

Table A.71: Laminate 4 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
3	3.3	3.5	3.7	25.4	25.4	25.4	25.6	40	LAB
4	3.4	3.3	3.6	25.4	25.4	25.4	25.6	40	LWB
5	3.3	3.3	3.4	25.4	25.4	25.4	25.6	40	LGM

Table A.72: Laminate 4 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
3	3.5	0.1653	0.047	25.4	0.0000	0.000	88.6
4	3.5	0.1586	0.046	25.4	0.0000	0.000	87.7
5	3.3	0.0440	0.013	25.4	0.0000	0.000	84.5

Table A.73: Laminate 4 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
3	10.5	0.999918	0.00080	0.038	0.999510	0.00195
4	10.5	0.999897	0.00085	0.039	0.999465	0.00193
5	11.0	0.999844	0.00111	0.035	0.998936	0.00291

Table A.74: Laminate 4 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
3	88.6	4,982	56.2	5,847
4	87.7	5,162	58.8	6,673
5	84.5	4,741	56.1	5,336
Average	87.0	4,962	57.1	5,952
STDEV	2.2	211	1.5	675
CV	0.025	0.043	0.027	0.113

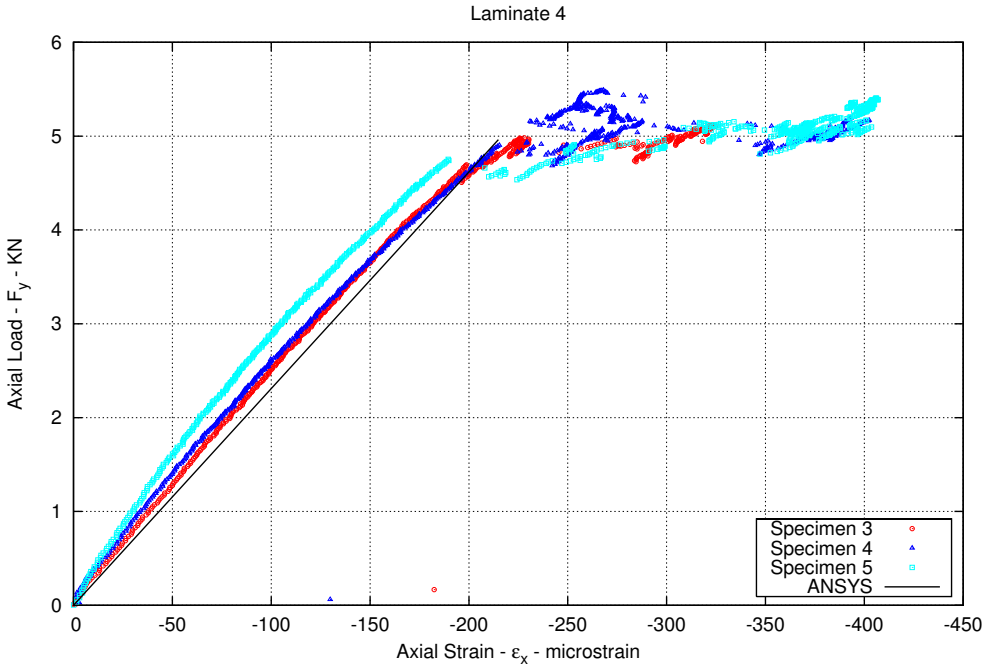


Figure A.29: Laminate 4 axial strain induced with a transverse tensile load.

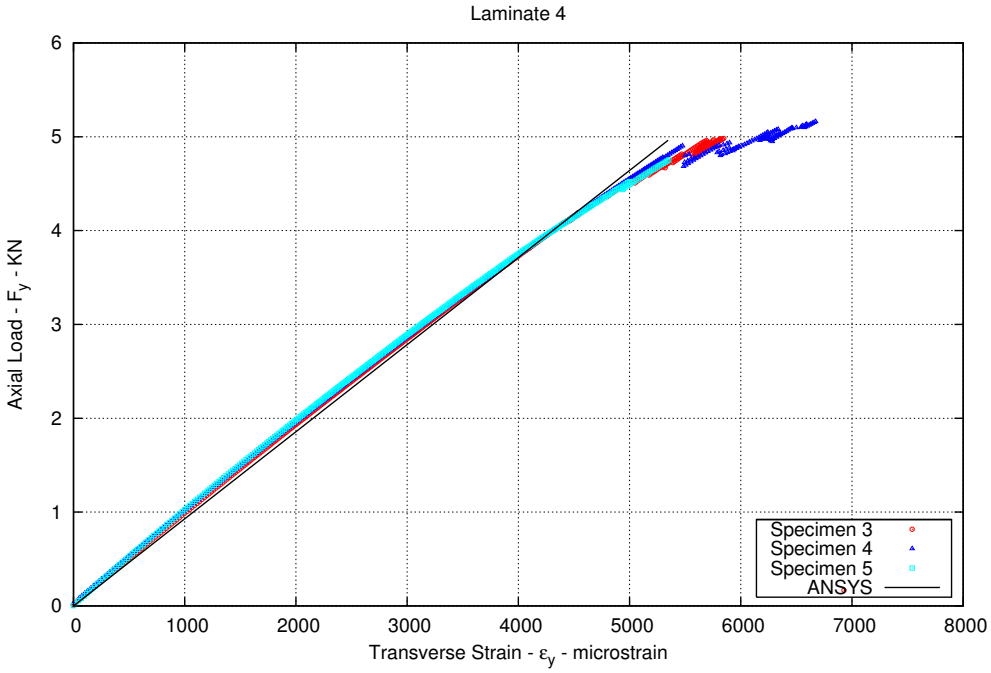


Figure A.30: Laminate 4 transverse strain induced with a transverse tensile load.

A.5.3 Compression

Table A.75: Laminate 4 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.4	3.4	12.8	12.8	23.9
2	3.5	3.5	12.8	12.8	23.9
3	3.5	3.4	12.8	12.8	23.9

Table A.76: Laminate 4 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0359	0.011	12.8	0.0000	0.000	43.1
2	3.5	0.0180	0.005	12.8	0.0000	0.000	44.9
3	3.4	0.0539	0.016	12.8	0.0000	0.000	43.6

Table A.77: Laminate 4 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	99.2	0.999674	0.00166
2	93.2	0.999628	0.00181
3	100.2	0.999910	0.00088

Table A.78: Laminate 4 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.4	3.4	12.6	12.7	24.4	24	TAT
2	3.6	3.6	12.6	12.6	24.4	24	TAT
3	3.4	3.4	12.6	12.6	24.4	24	TAT

Table A.79: Laminate 4 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.4	0.0009	0.000	12.7	0.0090	0.001	43.4
2	3.6	0.0198	0.006	12.6	0.0000	0.000	45.4
3	3.4	0.0054	0.002	12.6	0.0000	0.000	43.1

Table A.80: Laminate 4 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	43.4	44,951	1,037	10,630
2	45.4	42,747	942	9,660
4	43.1	42,157	979	10,034
Average	43.9	43,285	986	10,108
STDEV	1.2	1,473	47.7	489
CV	0.028	0.034	0.048	0.048

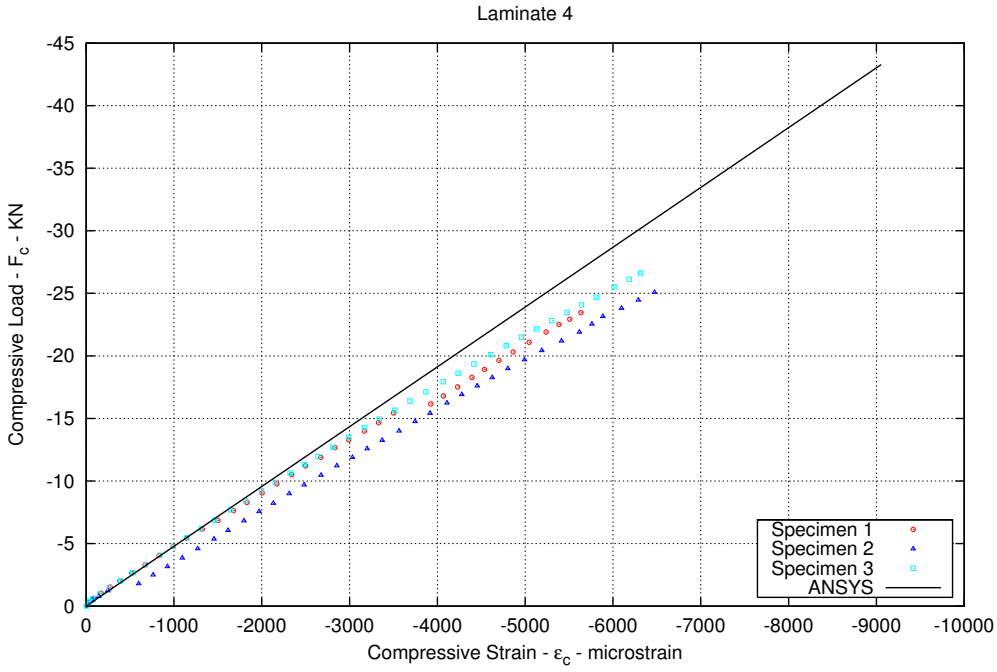


Figure A.31: Laminate 4 axial strain induced with an axial compressive load.

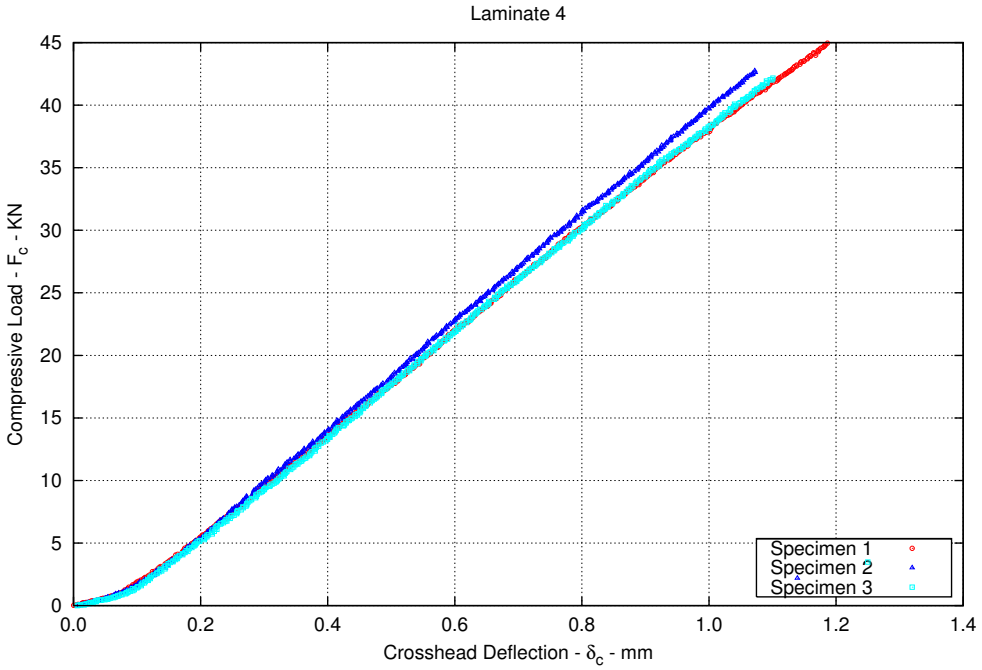


Figure A.32: Response of Laminate 4 to compressive loading.

A.5.4 In-Plane Shear

Table A.81: Laminate 4 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.4	11.5	11.5	24.4	31	null
2	3.5	3.4	11.3	11.3	24.4	31	null
3	3.6	3.5	11.3	11.3	24.4	31	null

Table A.82: Laminate 4 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0180	0.005	11.5	0.0000	0.000	39.5
2	3.4	0.0359	0.010	11.3	0.0000	0.000	38.6
3	3.5	0.0180	0.005	11.3	0.0000	0.000	40.1

Table A.83: Laminate 4 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	6.5	0.9994	0.0027
2	6.6	0.9989	0.0037
3	6.4	0.9990	0.0036

Table A.84: Laminate 4 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	39.5	4,638	117	40,009
2	38.6	4,760	123	43,090
3	40.1	4,762	119	40,530
Average	39.4	4,720	120	41,210
STDEV	0.8	71	3.2	1,649
CV	0.020	0.015	0.026	0.040

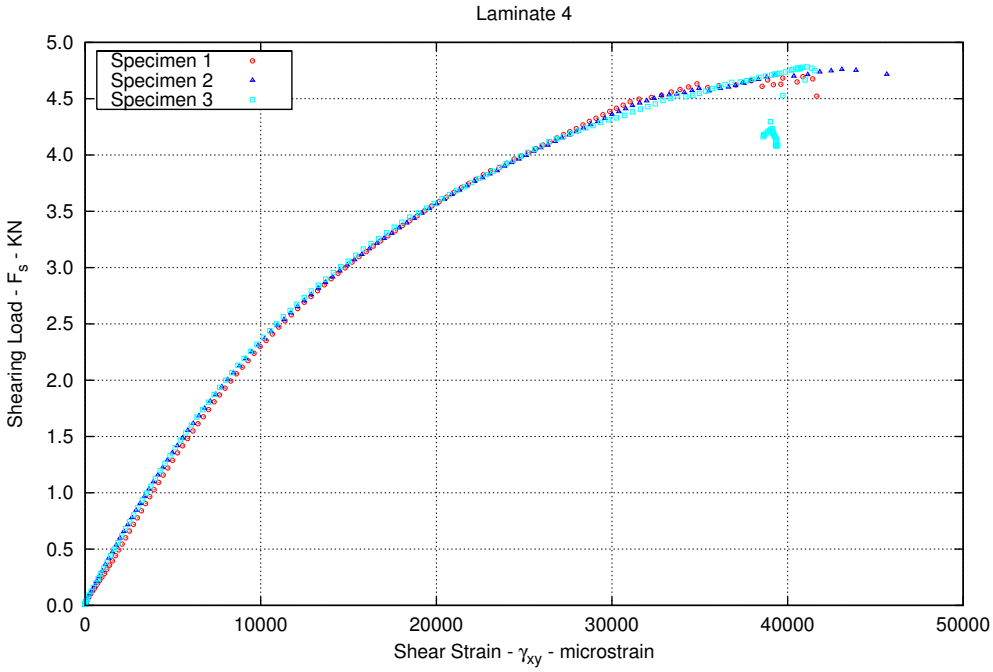


Figure A.33: Laminate 4 shear strain induced with an in-plane shear load.

A.5.5 Interlaminar Shear

Table A.85: Laminate 4 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.4	6.4	6.4	25	40	Interlaminar Shear
2	3.5	3.5	6.4	6.4	25	40	Interlaminar Shear
3	3.5	3.5	6.4	6.4	25	40	Interlaminar Shear

Table A.86: Laminate 4 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.1006	0.029	6.4	0.0000	0.000	22.4
2	3.5	0.0054	0.002	6.4	0.0000	0.000	22.4
3	3.5	0.0216	0.006	6.4	0.0000	0.000	22.3

Table A.87: Laminate 4 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.4	1708.5	58.0
2	22.4	1679.0	56.9
3	22.3	1657.3	56.5

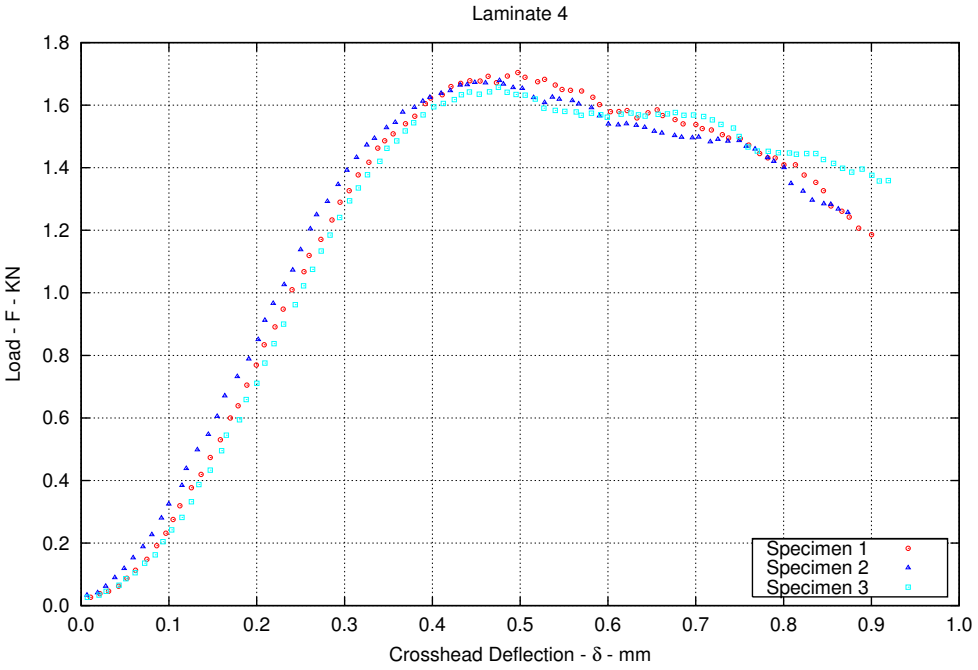


Figure A.34: Laminate 4 interlaminar shear response.

A.6 Laminate 5 - 55CUD/30C20/15GDB - $[\pm 45_{DB}/20_C/(0_C)_2]_s$

A.6.1 Tension 0

Table A.88: Laminate 5 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.6	3.6	3.5	25.5	25.5	25.5	25	57	LIB AAT
2	3.5	3.5	3.6	25.5	25.4	25.4	25	57	AWB DGM
3	3.6	3.4	3.6	25.5	25.5	25.5	25	57	LIT DGT

Table A.89: Laminate 5 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0587	0.017	25.5	0.0000	0.000	89.6
2	3.5	0.0639	0.018	25.4	0.0147	0.001	90.0
3	3.5	0.1200	0.034	25.5	0.0147	0.001	89.5

Table A.90: Laminate 5 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	89.1	0.999975	0.00045	0.634	0.999955	0.00061
2	82.2	0.999951	0.00066	0.588	0.999970	0.00051
3	85.7	0.999951	0.00066	0.540	0.999990	0.00030

Table A.91: Laminate 5 axial tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	89.6	110,480	1,233	13,280
2	90.0	111,860	1,243	14,673
3	89.5	103,906	1,161	12,710
Average	89.7	108,749	1,212	13,555
STDEV	0.3	4,251	44.4	1,010
CV	0.0030	0.039	0.037	0.074

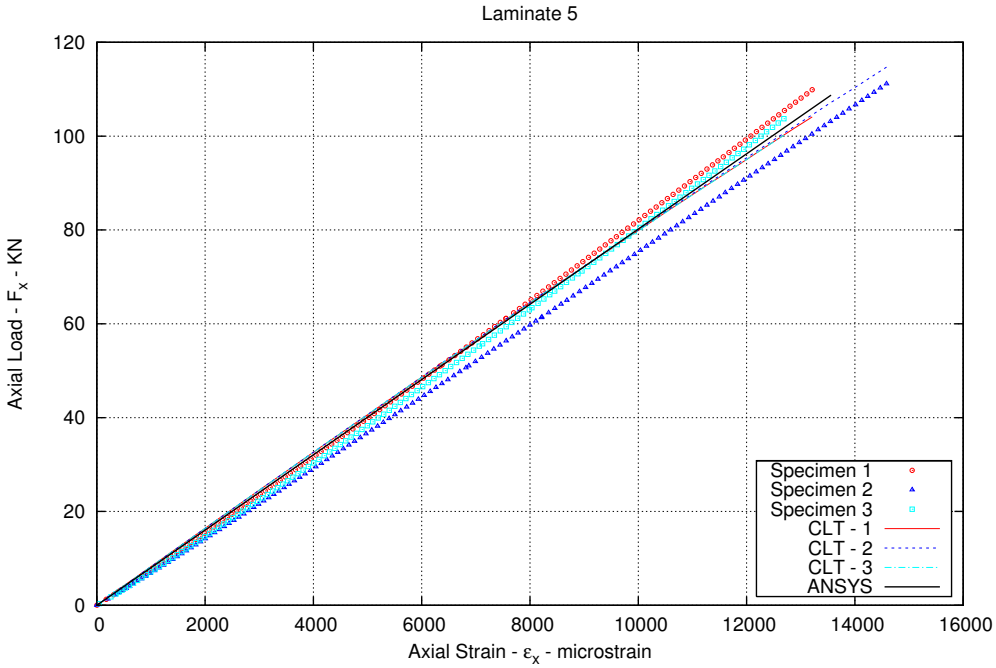


Figure A.35: Laminate 5 axial strain induced with an axial tensile load.

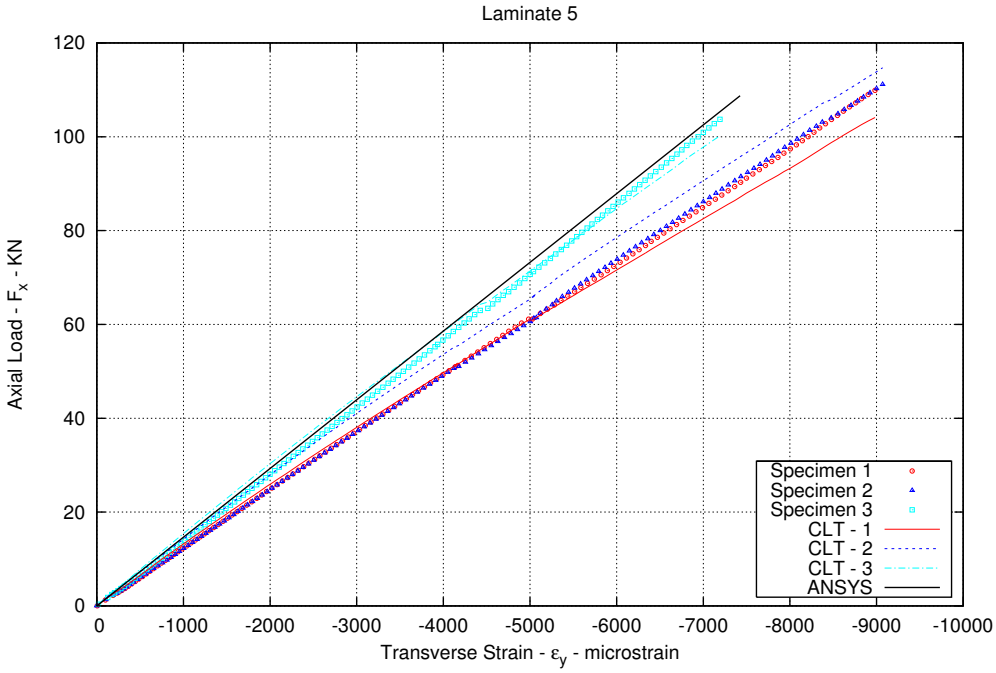


Figure A.36: Laminate 5 transverse strain induced with an axial tensile load.

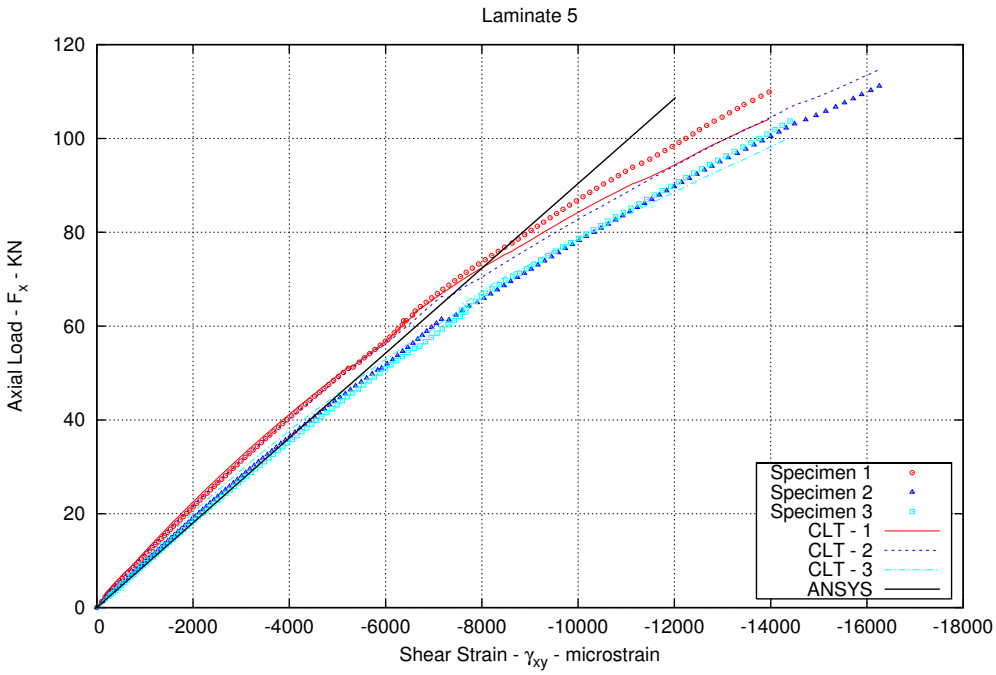


Figure A.37: Laminate 5 shear strain induced with an axial tensile load.

A.6.2 Tenion 90

Table A.92: Laminate 5 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	3.4	25.3	25.3	25.3	22.8	27	LWB
2	3.4	3.5	3.5	25.3	25.3	25.3	22.8	27	LGT
3	3.4	3.5	3.4	25.3	25.3	25.3	22.8	27	LGB

Table A.93: Laminate 5 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0962	0.027	25.3	0.0147	0.001	88.9
2	3.5	0.0254	0.007	25.3	0.0000	0.000	87.3
3	3.4	0.0440	0.013	25.3	0.0000	0.000	86.8

Table A.94: Laminate 5 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	10.7	0.999903	0.00118	0.060	0.992847	0.01014
2	11.4	0.999842	0.00147	0.032	0.980299	0.01659
3	11.0	0.999889	0.00126	0.042	0.987542	0.01342

Table A.95: Laminate 5 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	88.9	4,835	54.4	5,824
2	87.3	4,270	48.9	4,390
3	86.8	4,599	53.0	5,071
Average	87.7	4,568	52.1	5,095
STDEV	1.1	284	2.8	717
CV	0.0121	0.062	0.055	0.141

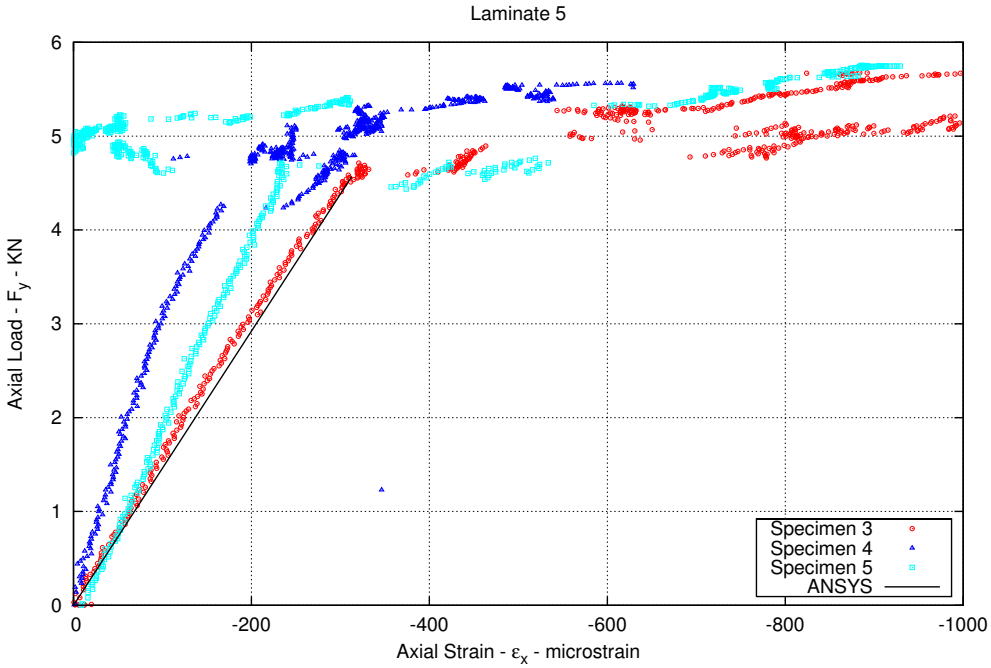


Figure A.38: Laminate 5 axial strain induced with a transverse tensile load.

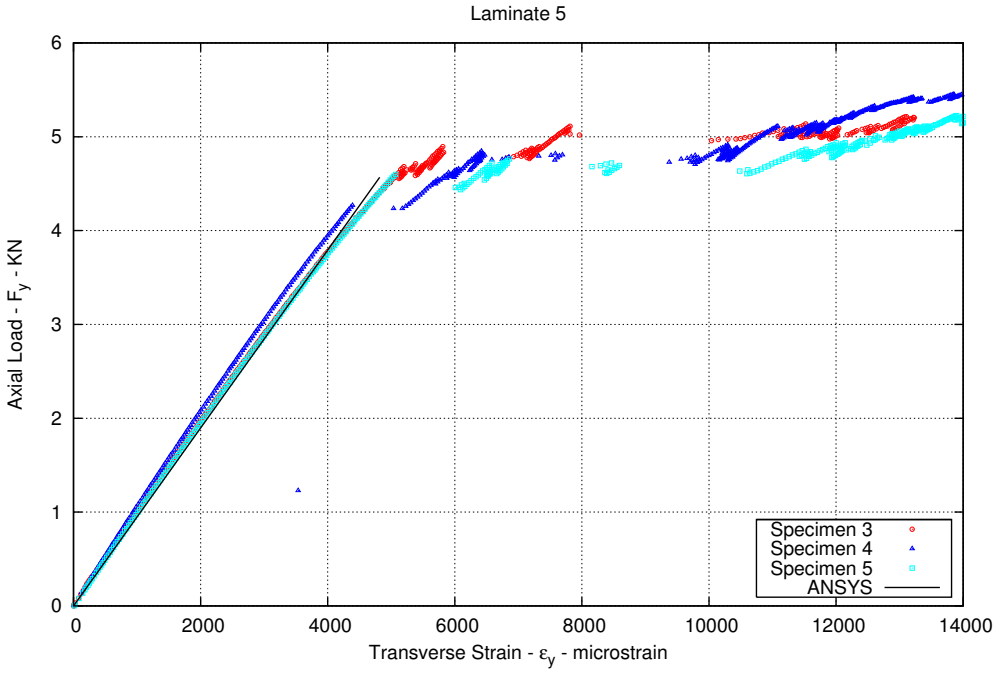


Figure A.39: Laminate 5 transverse strain induced with a transverse tensile load.

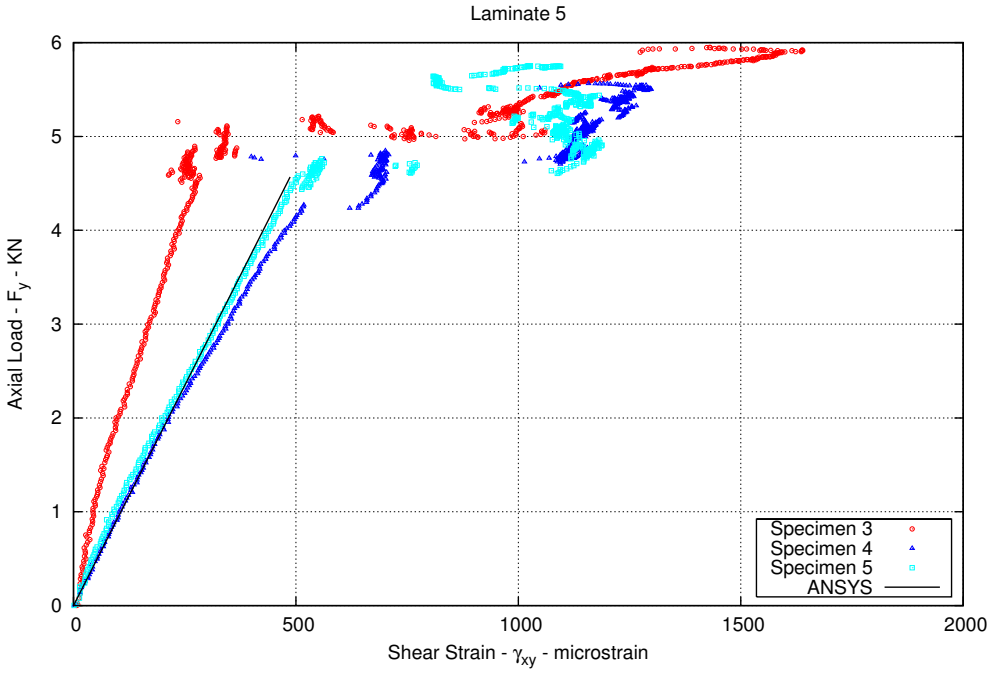


Figure A.40: Laminate 5 shear strain induced with a transverse tensile load.

A.6.3 Compression

Table A.96: Laminate 5 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.6	3.4	12.8	12.8	23.9
2	3.6	3.5	12.7	12.7	23.9
3	3.5	3.6	12.7	12.7	23.9

Table A.97: Laminate 5 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.1257	0.036	12.8	0.0000	0.000	44.2
2	3.6	0.1078	0.030	12.7	0.0000	0.000	45.3
3	3.5	0.0180	0.005	12.7	0.0000	0.000	45.1

Table A.98: Laminate 5 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	86.0	0.999950	0.00065
2	84.0	0.999890	0.00099
3	89.5	0.999912	0.00086

Table A.99: Laminate 5 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.2	3.5	12.4	12.4	24.4	0	BGM
2	3.5	3.5	12.7	12.7	24.4	0	BGM
3	3.3	3.4	12.7	12.7	24.4	0	BGM
4	3.5	3.4	12.6	12.6	24.4	0	BGM

Table A.100: Laminate 5 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.3	0.1877	0.056	12.4	0.0000	0.000	41.5
2	3.5	0.0027	0.001	12.7	0.0000	0.000	44.0
3	3.3	0.0099	0.003	12.7	0.0000	0.000	42.4
4	3.4	0.0431	0.013	12.6	0.0000	0.000	43.4

Table A.101: Laminate 5 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	41.5	36,379	876	10,124
2	44.0	36,001	817	9,446
3	42.4	33,173	782	9,039
4	43.4	36,156	833	9,630
Average	42.8	35,427	827	9,560
STDEV	1.1	1,511	38.9	450
CV	0.026	0.043	0.047	0.047

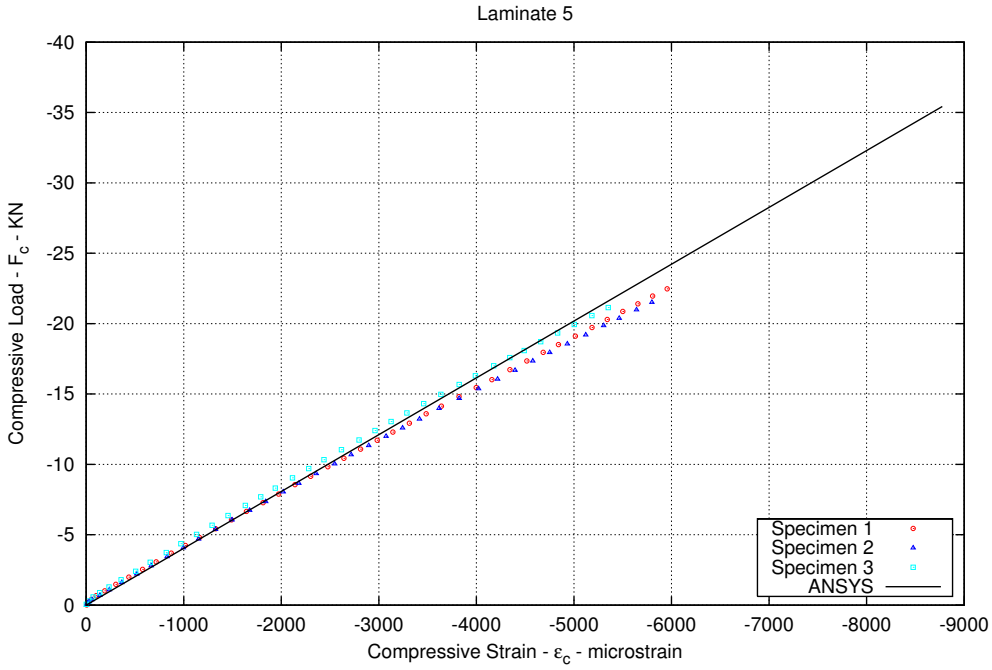


Figure A.41: Laminate 5 axial strain induced with an axial compressive load.

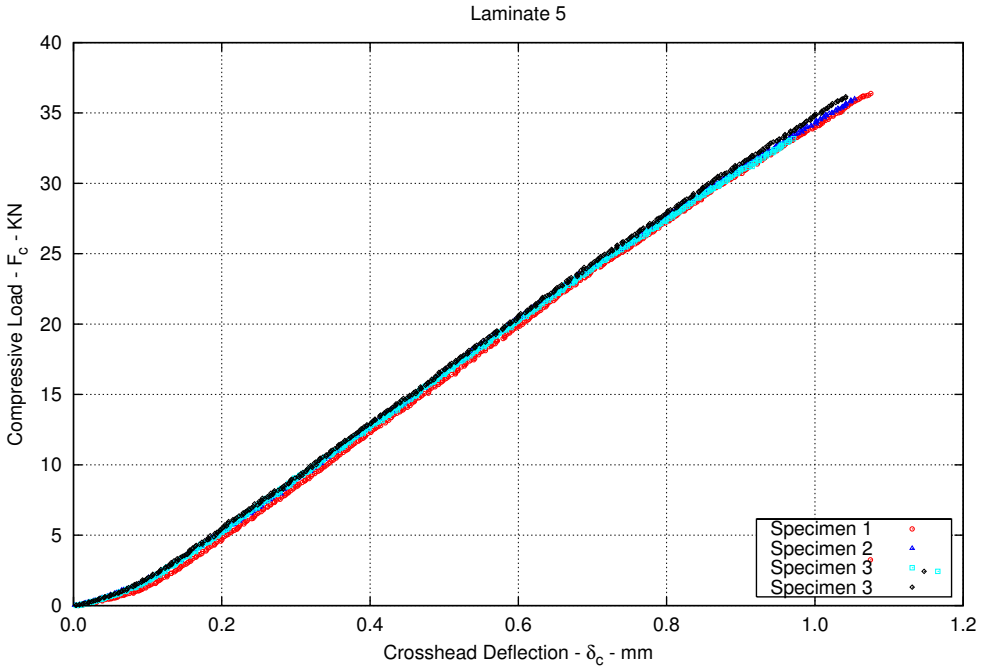


Figure A.42: Response of Laminate 5 to compressive loading.

A.6.4 In-Plane Shear

Table A.102: Laminate 5 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.4	3.6	11.4	11.4	22.8	45	null
2	3.5	3.5	11.5	11.5	22.8	45	null
3	3.9	3.7	11.4	11.4	22.8	45	null

Table A.103: Laminate 5 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.1257	0.036	11.4	0.0000	0.000	40.2
2	3.5	0.0359	0.010	11.5	0.0000	0.000	40.2
3	3.8	0.0898	0.024	11.4	0.0000	0.000	43.3

Table A.104: Laminate 5 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	8.1	0.9995	0.0023
2	9.2	0.9997	0.0018
3	8.4	0.9986	0.0039

Table A.105: Laminate 5 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.2	4,859	121	20,308
2	40.2	5,005	124	20,065
3	43.3	5,072	117	19,450
Average	41.3	4,979	121	19,941
STDEV	1.8	109	3.6	442
CV	0.043	0.022	0.030	0.022

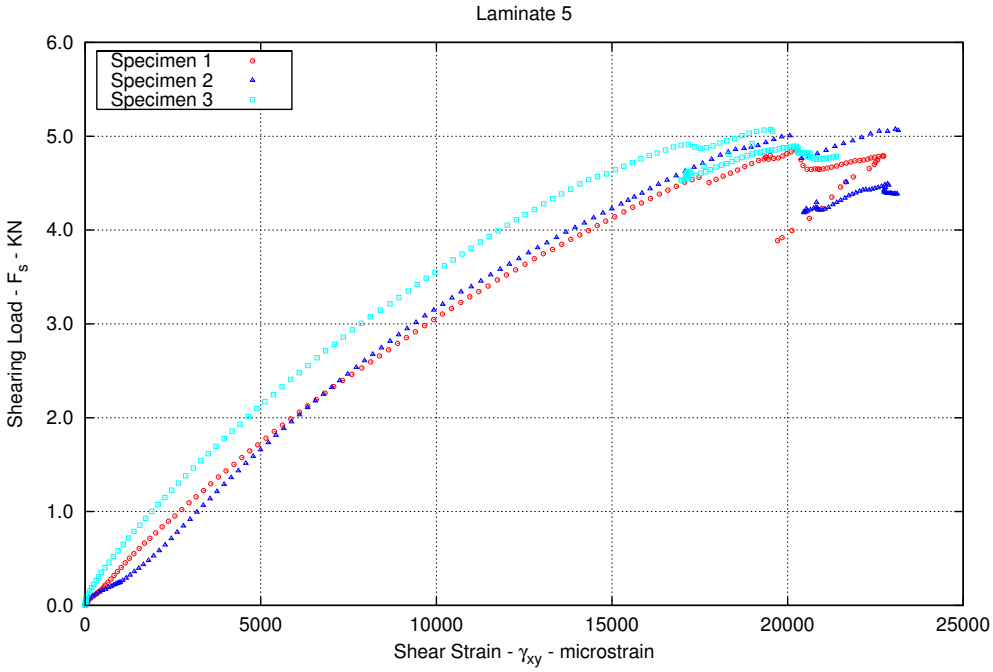
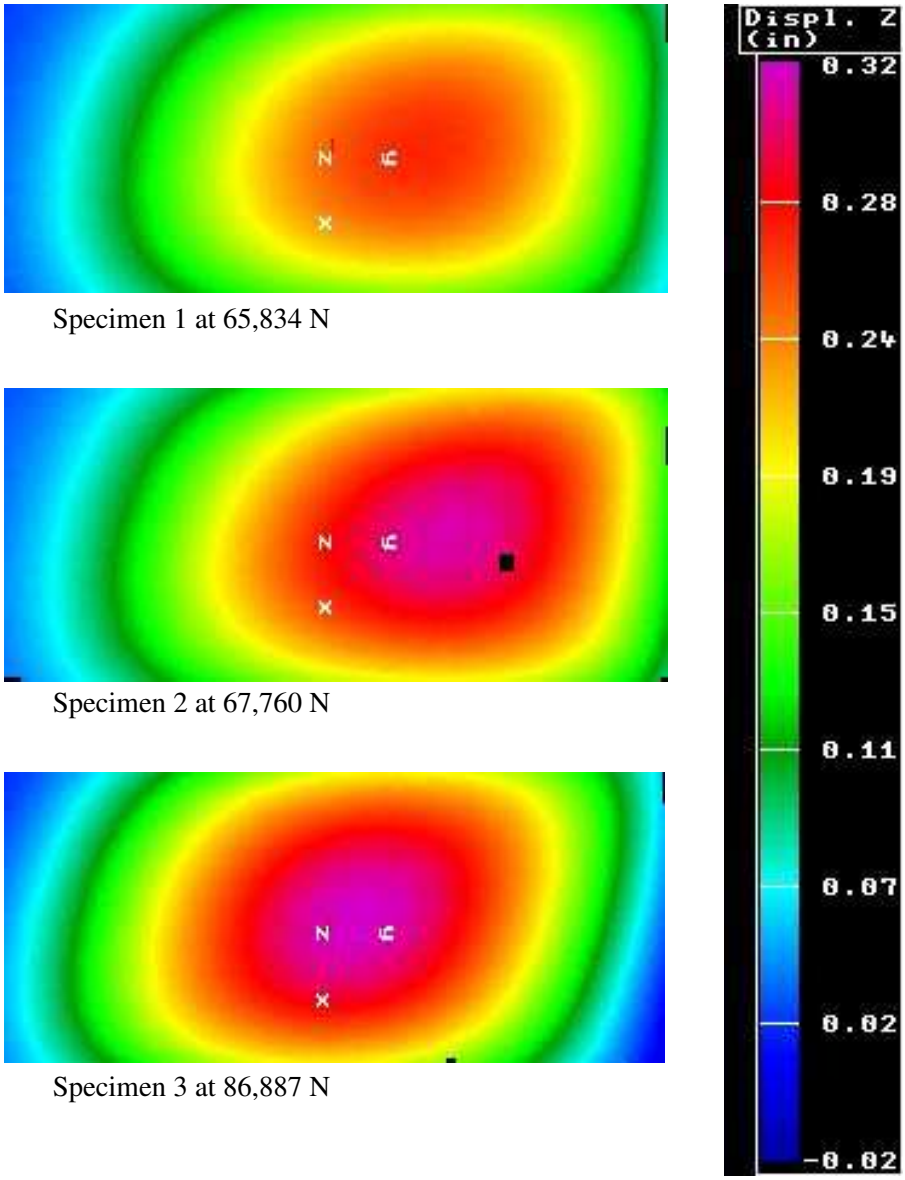


Figure A.43: Laminate 5 shear strain induced with an in-plane shear load.

A.6.5 Edgewise Compression

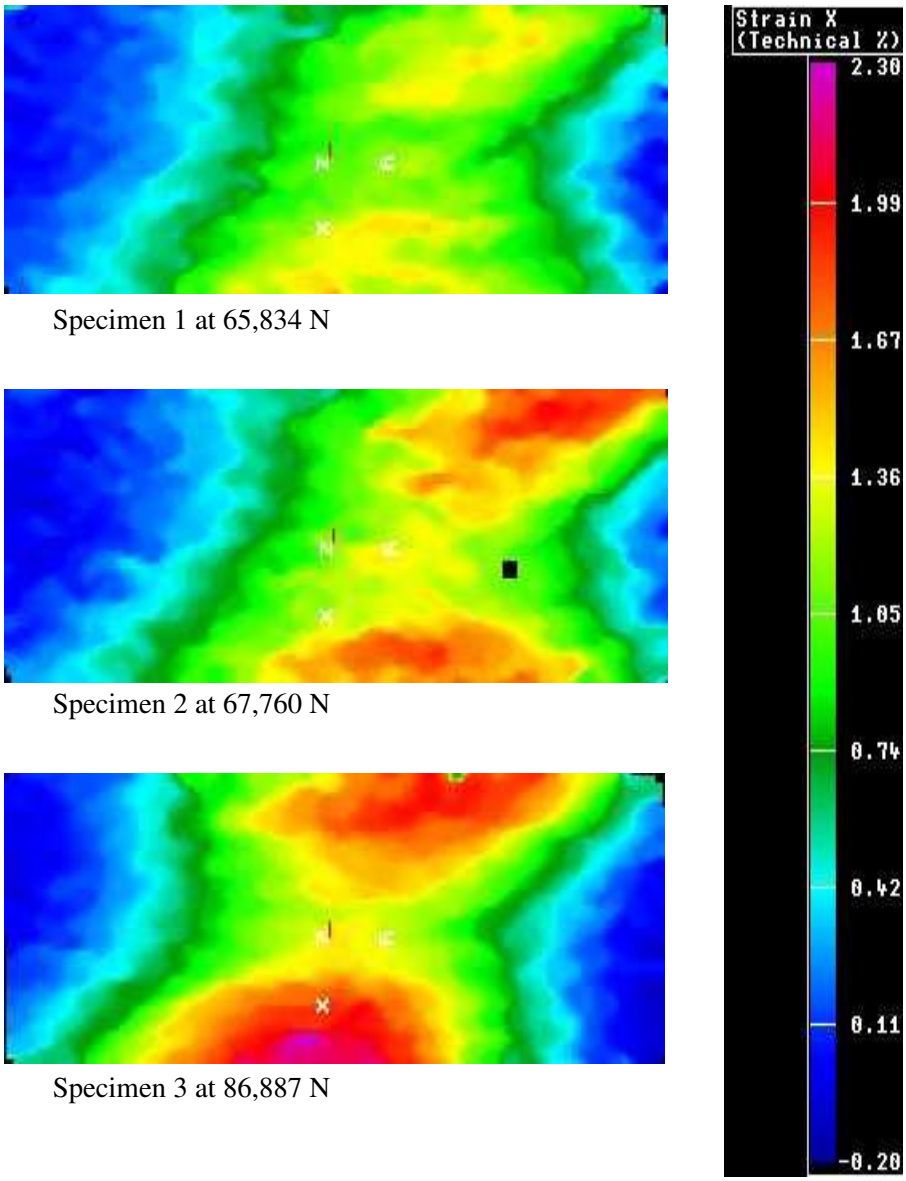


Specimen 1 at 65,834 N

Specimen 2 at 67,760 N

Specimen 3 at 86,887 N

Figure A.44: Laminate 5 out-of-plane displacement due to edgewise compression.

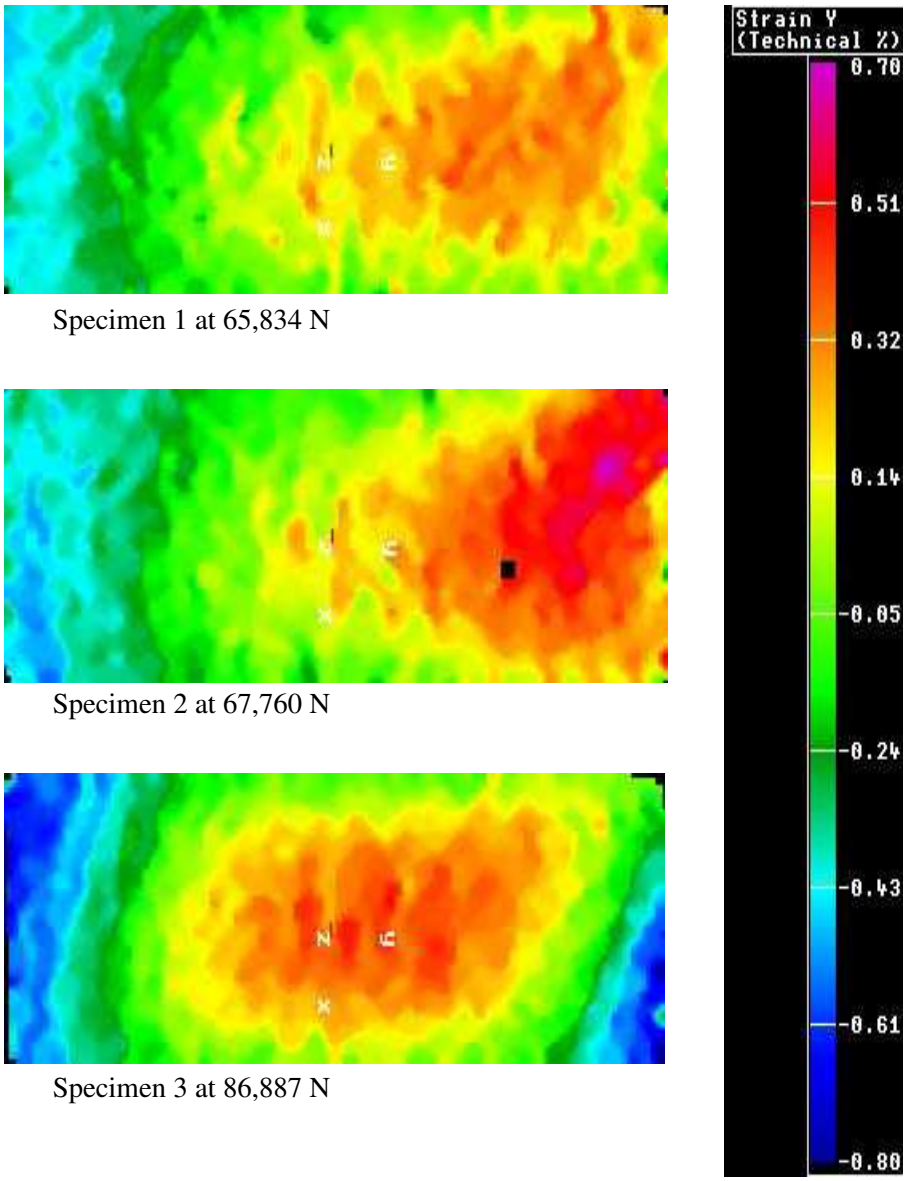


Specimen 1 at 65,834 N

Specimen 2 at 67,760 N

Specimen 3 at 86,887 N

Figure A.45: Laminate 5 axial strain displacement due to edgewise compression.

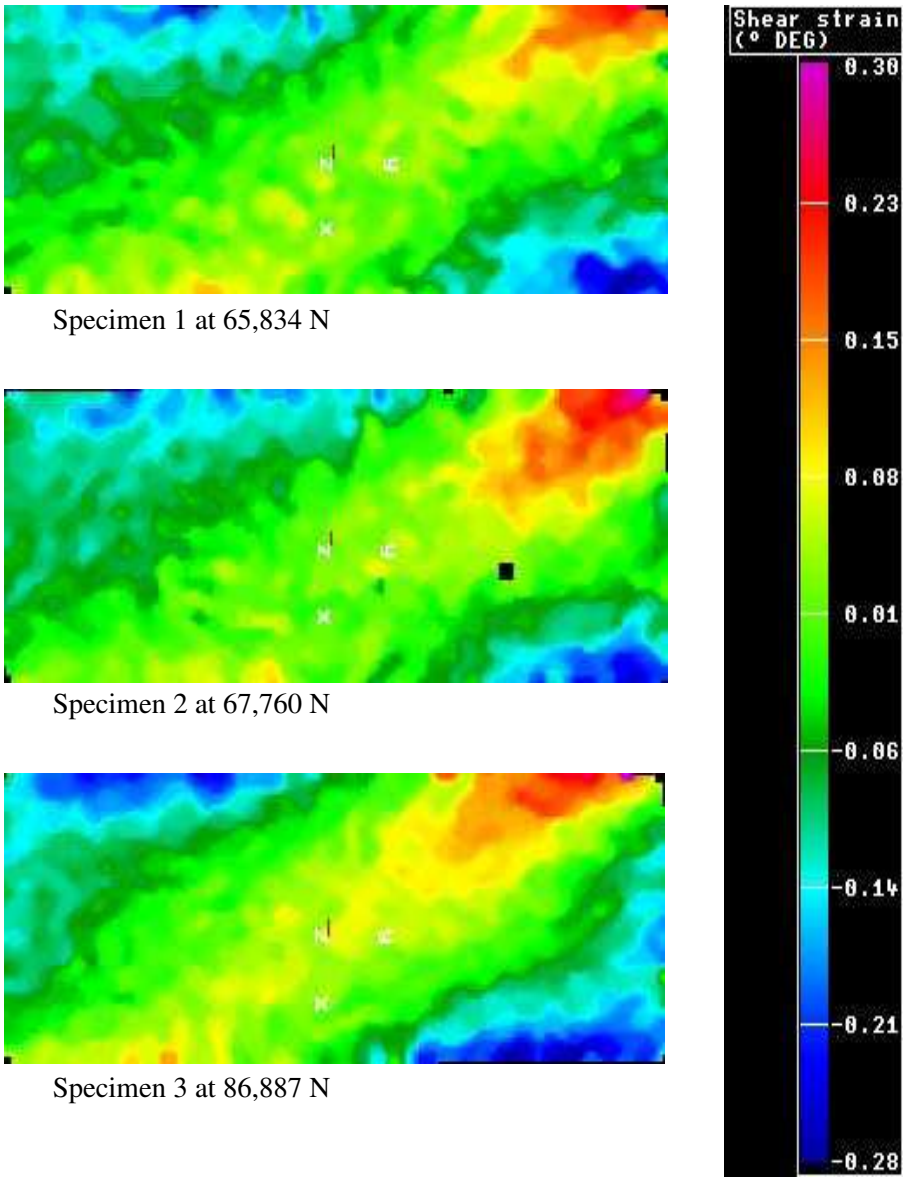


Specimen 1 at 65,834 N

Specimen 2 at 67,760 N

Specimen 3 at 86,887 N

Figure A.46: Laminate 5 transverse strain displacement due to edgewise compression.



Specimen 1 at 65,834 N

Specimen 2 at 67,760 N

Specimen 3 at 86,887 N

Figure A.47: Laminate 5 shear strain displacement due to edgewise compression.

A.6.6 Interlaminar Shear

Table A.106: Laminate 5 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.5	6.4	6.4	25	40	Interlaminar Shear
2	3.5	3.5	6.4	6.4	25	40	Interlaminar Shear
3	3.3	3.3	6.4	6.4	25	40	Interlaminar Shear

Table A.107: Laminate 5 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0386	0.011	6.4	0.0000	0.000	22.2
2	3.5	0.0395	0.011	6.4	0.0000	0.000	22.3
3	3.3	0.0018	0.001	6.4	0.0000	0.000	21.2

Table A.108: Laminate 5 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.2	1577.0	53.9
2	22.3	1702.9	58.1
3	21.2	1606.8	57.6

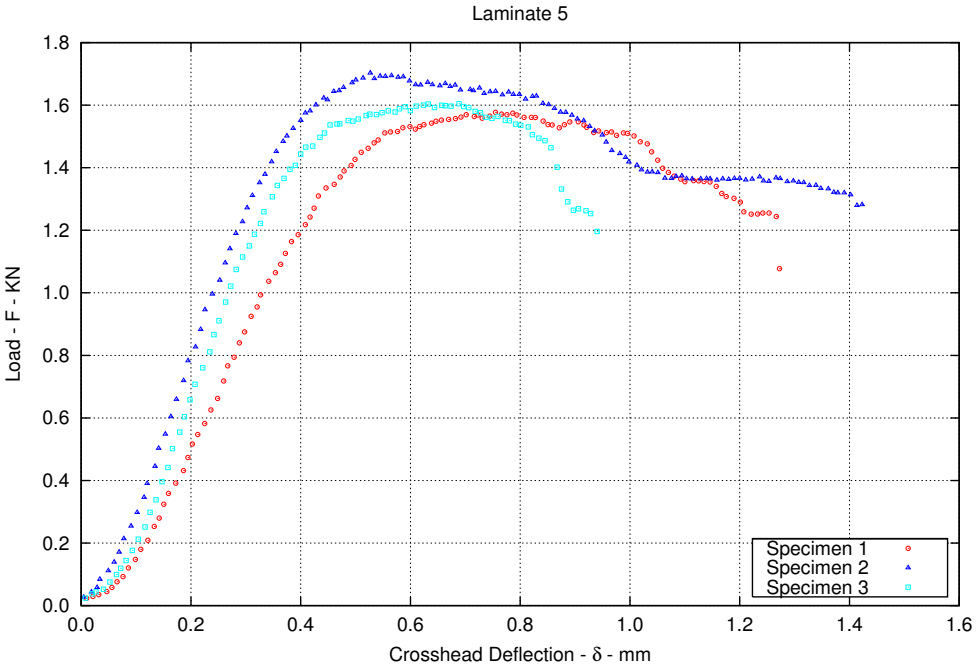


Figure A.48: Laminate 5 interlaminar shear response.

A.7 Laminate 6 - 55GUD/30C20/15GDB - $[\pm 45_{DB}/0_G/20_C/0_G/\overline{0}_G]_s$

A.7.1 Tension 0

Table A.109: Laminate 6 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.0	4.1	4.0	25.3	25.3	25.3	23.3	32	DWB
2	4.1	4.1	4.1	25.4	25.4	25.4	23.3	32	DGM SGT
3	4.0	4.0	4.0	25.3	25.3	25.3	23.3	32	DGB XGB

Table A.110: Laminate 6 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.0	0.0293	0.007	25.3	0.0147	0.001	102.1
2	4.1	0.0000	0.000	25.4	0.0000	0.000	103.9
3	4.0	0.0440	0.011	25.3	0.0000	0.000	101.6

Table A.111: Laminate 6 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	38.9	0.999984	0.00043	0.395	0.999524	0.00233
2	39.1	0.999982	0.00047	0.435	0.999897	0.00113
3	38.8	0.999985	0.00043	0.408	0.999869	0.00128

Table A.112: Laminate 6 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	102	59,700	585	17,348
2	104	60,397	581	17,562
3	102	61,143	602	18,077
Average	103	60,413	589	17,662
STDEV	1.2	722	10.8	375
CV	0.012	0.012	0.018	0.021

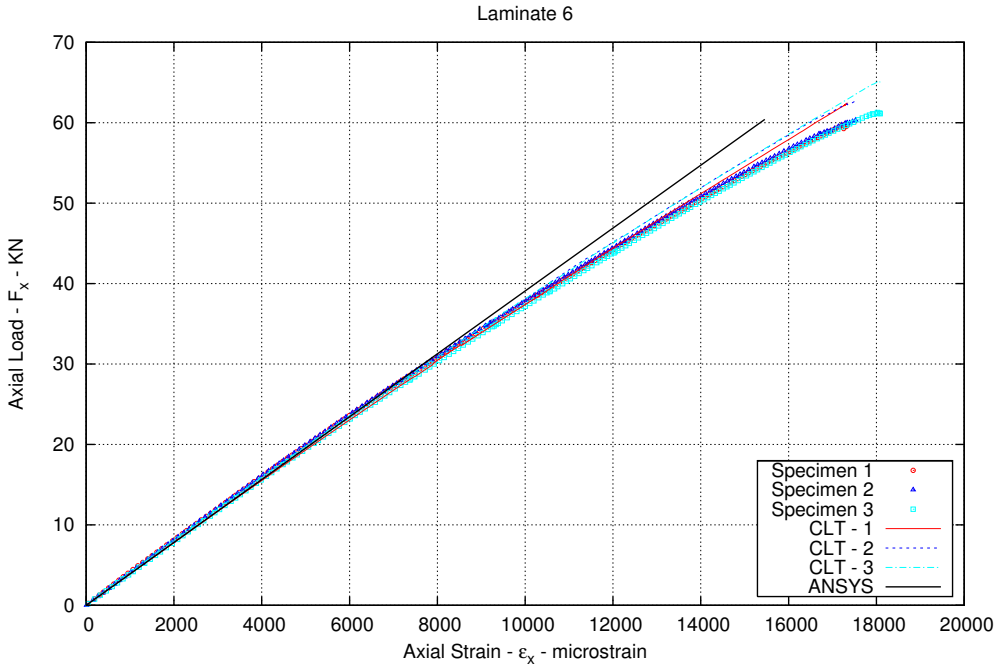


Figure A.49: Laminate 6 axial strain induced with an axial tensile load.

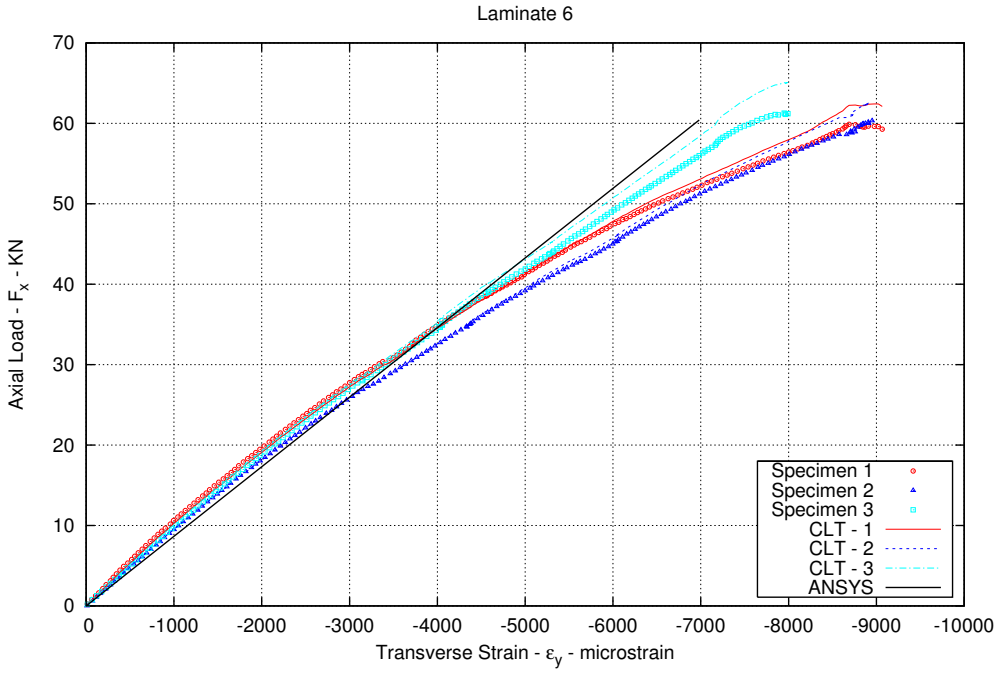


Figure A.50: Laminate 6 transverse strain induced with an axial tensile load.

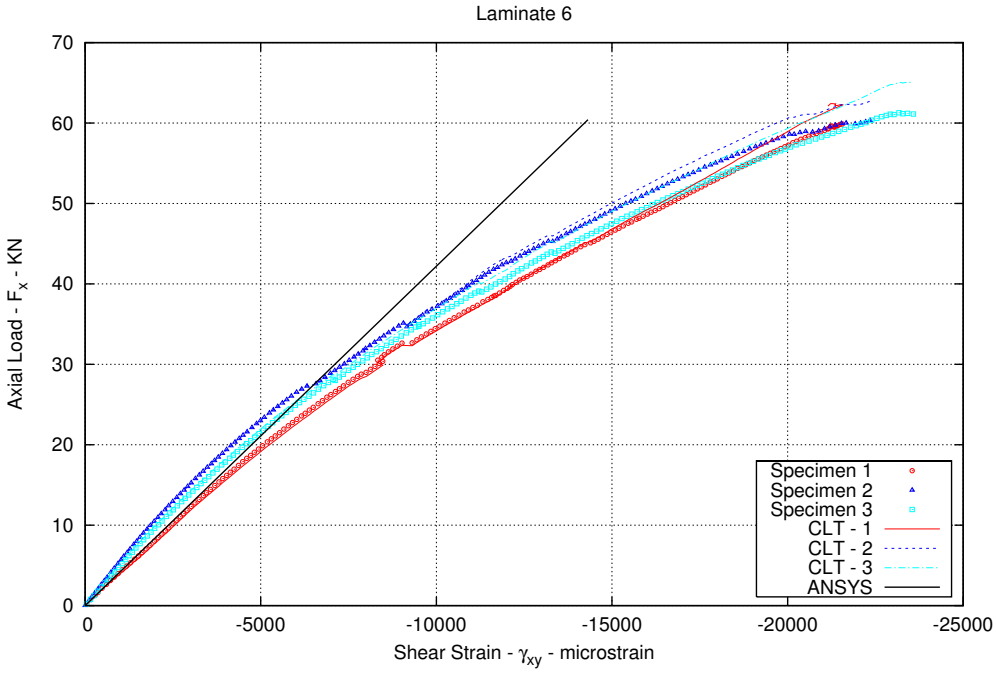


Figure A.51: Laminate 6 shear strain induced with an axial tensile load.

A.7.2 Tenion 90

Table A.113: Laminate 6 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.1	4.0	4.1	25.3	25.3	25.3	22.8	33	LGB
2	4.1	4.1	4.0	25.3	25.3	25.3	22.8	33	LGB
3	4.0	4.1	4.1	25.3	25.3	25.3	22.8	33	LAT

Table A.114: Laminate 6 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.1	0.0672	0.017	25.3	0.0000	0.000	102.8
2	4.0	0.0293	0.007	25.3	0.0000	0.000	102.4
3	4.1	0.0388	0.010	25.3	0.0000	0.000	103.0

Table A.115: Laminate 6 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	11.9	0.999709	0.00204	0.108	0.998504	0.00463
2	12.0	0.999795	0.00170	0.165	0.999379	0.00296
3	12.2	0.999785	0.00174	0.086	0.993715	0.00944

Table A.116: Laminate 6 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	103	10,420	101	23,496
2	102	9,872	96.4	20,523
3	103	10,503	102	21,321
Average	103	10,265	99.8	21,780
STDEV	0.3	343	3.0	1,539
CV	0.0032	0.033	0.030	0.071

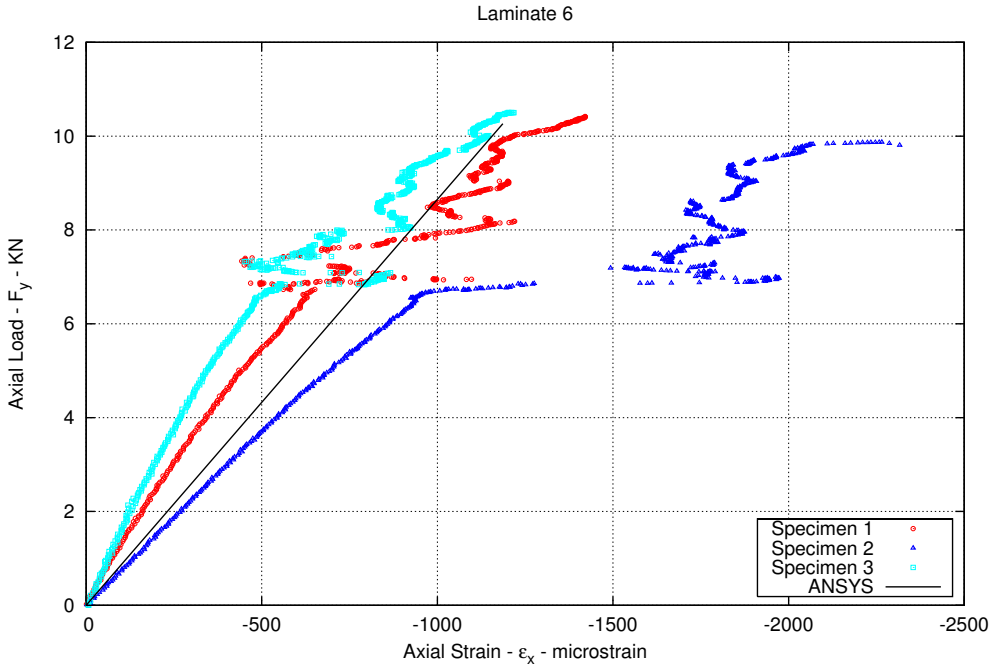


Figure A.52: Laminate 6 axial strain induced with a transverse tensile load.

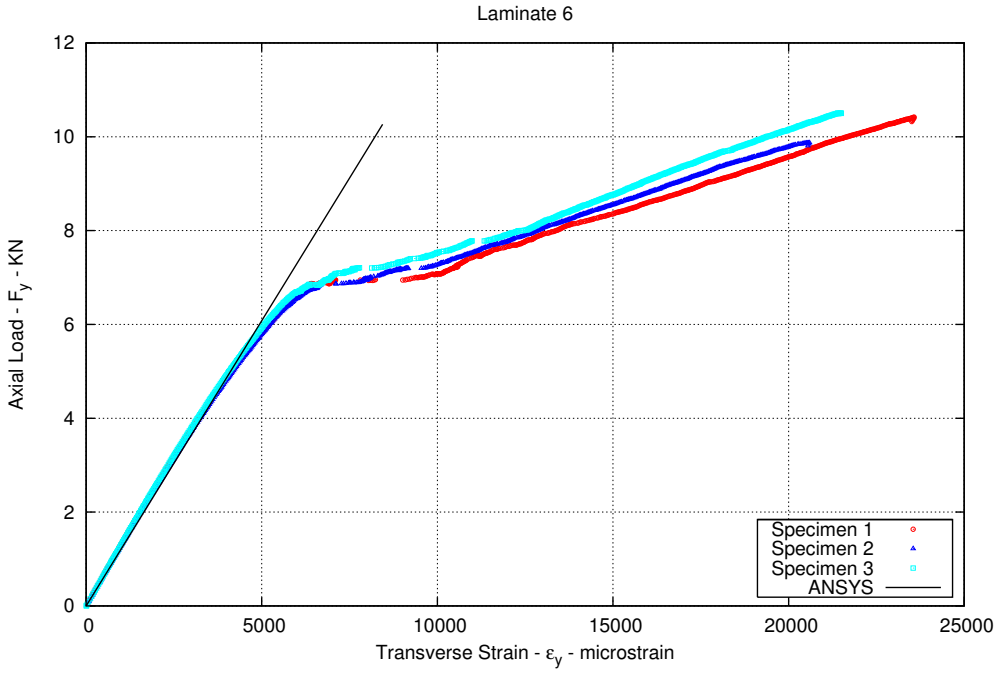


Figure A.53: Laminate 6 transverse strain induced with a transverse tensile load.

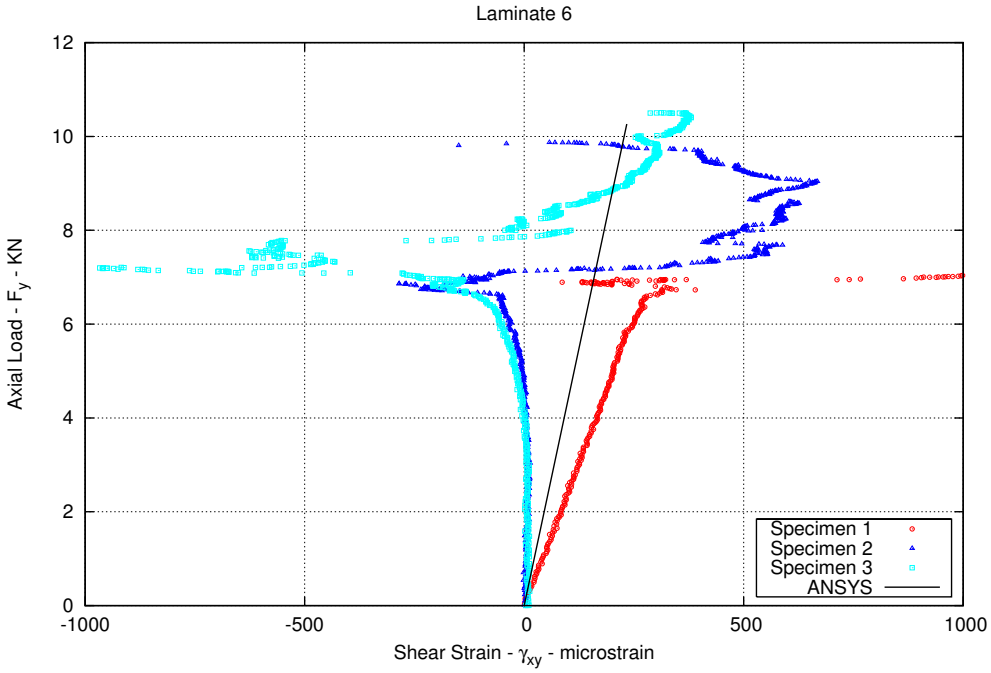


Figure A.54: Laminate 6 shear strain induced with a transverse tensile load.

A.7.3 Compression

Table A.117: Laminate 6 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	4.1	4.0	12.8	12.8	23.9
2	3.9	4.0	12.8	12.8	23.9
3	4.2	4.1	12.8	12.8	23.9

Table A.118: Laminate 6 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.1	0.0718	0.018	12.8	0.0000	0.000	51.9
2	4.0	0.0539	0.014	12.8	0.0000	0.000	50.9
3	4.1	0.0539	0.013	12.8	0.0000	0.000	52.8

Table A.119: Laminate 6 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	38.7	0.999842	0.00128
2	40.6	0.999858	0.00118
3	40.4	0.999883	0.00107

Table A.120: Laminate 6 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.0	4.0	12.7	12.7	24.4	0	BGM
2	4.0	4.0	12.7	12.7	24.4	0	BGM
3	3.9	3.9	12.7	12.7	24.4	0	BGM

Table A.121: Laminate 6 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	4.0	0.0018	0.000	12.7	0.0000	0.000	50.7
2	4.0	0.0314	0.008	12.7	0.0000	0.000	50.9
3	3.9	0.0009	0.000	12.7	0.0000	0.000	49.9

Table A.122: Laminate 6 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	50.7	27,247	538	13,481
2	50.9	29,062	570	14,304
3	49.9	27,142	544	13,645
Average	50.5	27,817	551	13,810
STDEV	0.6	1,079	17.4	435
CV	0.011	0.039	0.032	0.032

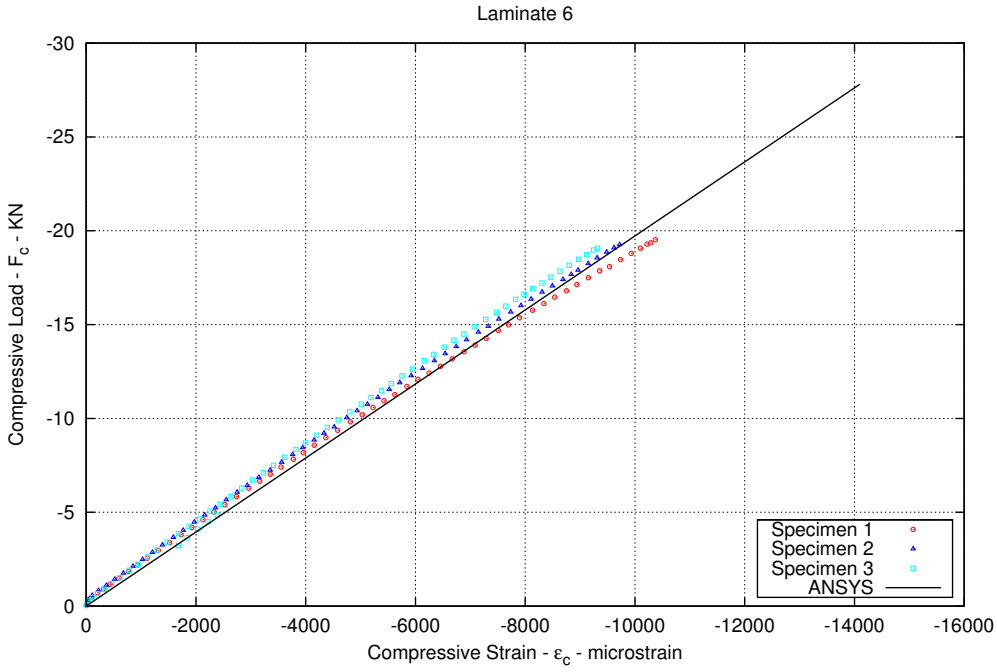


Figure A.55: Laminate 6 axial strain induced with an axial compressive load.

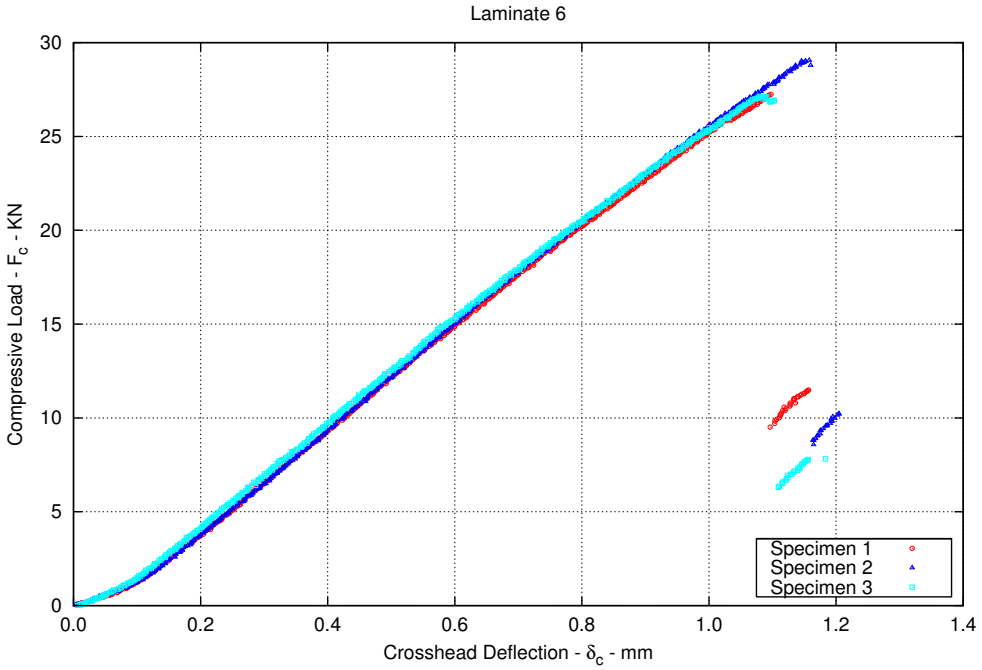


Figure A.56: Response of Laminate 6 to compressive loading.

A.7.4 In-Plane Shear

Table A.123: Laminate 6 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.1	4.1	11.4	11.4	22.2	50	null
2	4.0	4.0	11.5	11.5	22.2	50	null
3	4.2	4.2	11.5	11.5	22.2	50	null

Table A.124: Laminate 6 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.1	0.0180	0.004	11.4	0.0180	0.002	47.0
2	4.0	0.0359	0.009	11.5	0.0000	0.000	46.0
3	4.2	0.0000	0.000	11.5	0.0000	0.000	48.6

Table A.125: Laminate 6 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	7.1	0.9985	0.0042
2	7.2	0.9985	0.0042
3	6.6	0.9982	0.0044

Table A.126: Laminate 6 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	47.0	6,134	130	29,960
2	46.0	5,844	127	27,110
3	48.6	5,886	121	25,030
Average	47.2	5,955	126	27,367
STDEV	1.3	156	4.7	2,475
CV	0.028	0.026	0.037	0.090

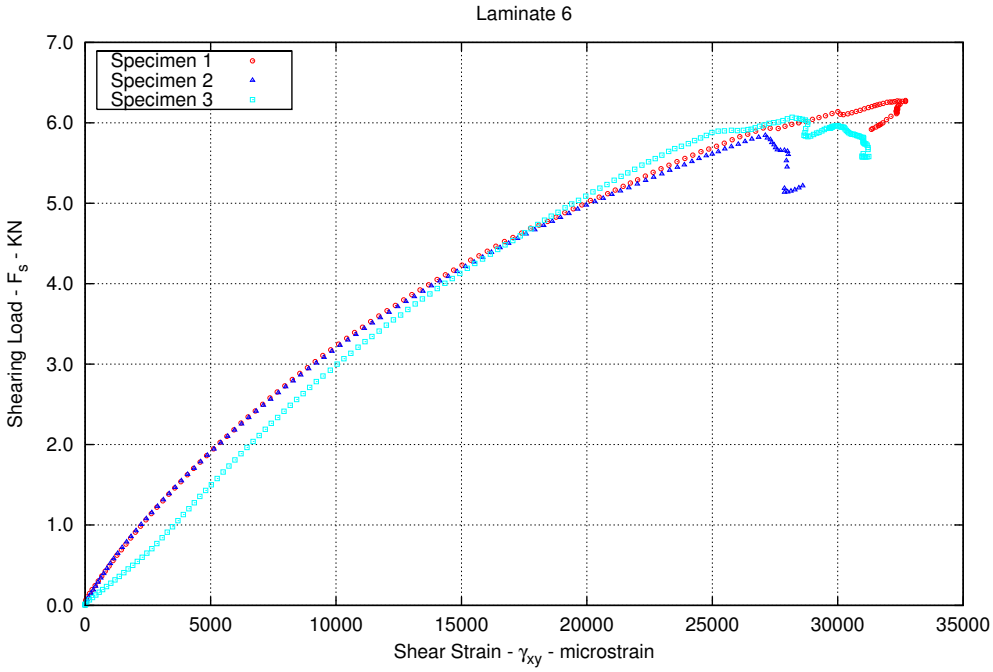


Figure A.57: Laminate 6 shear strain induced with an in-plane shear load.

A.7.5 Interlaminar Shear

Table A.127: Laminate 6 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
2	4.0	3.9	6.4	6.4	25	40	Interlaminar Shear
3	3.9	4.0	6.4	6.4	25	40	Interlaminar Shear
4	4.1	4.0	6.4	6.4	25	40	Interlaminar Shear

Table A.128: Laminate 6 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	4.0	0.0539	0.014	6.4	0.0000	0.000	25.3
3	4.0	0.0422	0.011	6.4	0.0000	0.000	25.3
4	4.1	0.0323	0.008	6.4	0.0000	0.000	25.9

Table A.129: Laminate 6 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
2	25.3	1805.2	54.2
3	25.3	1801.8	54.1
4	25.9	1854.0	54.4

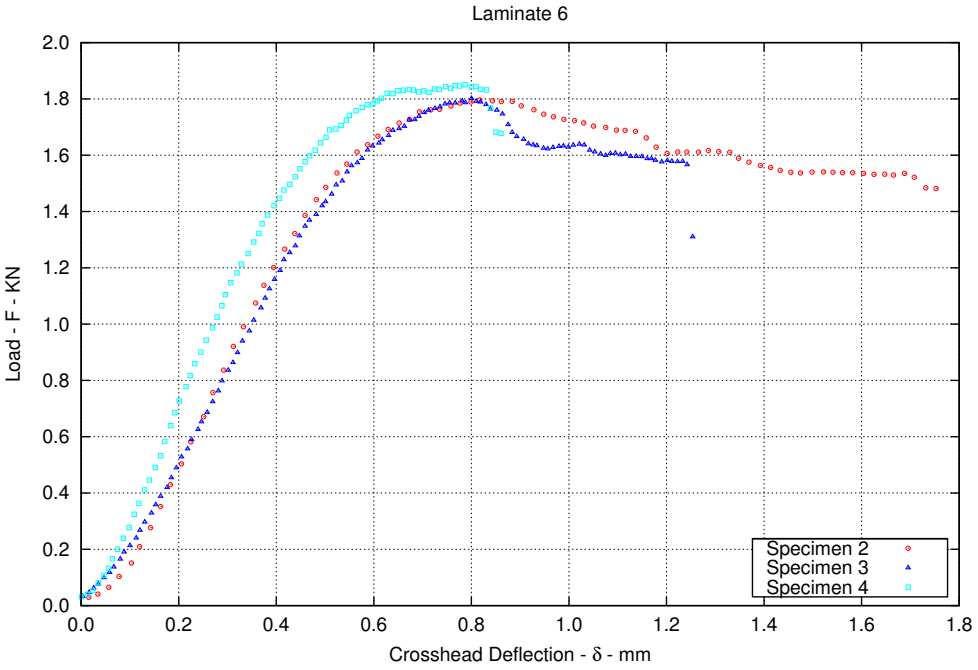
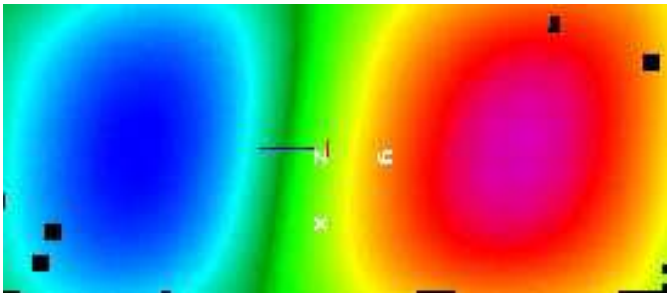
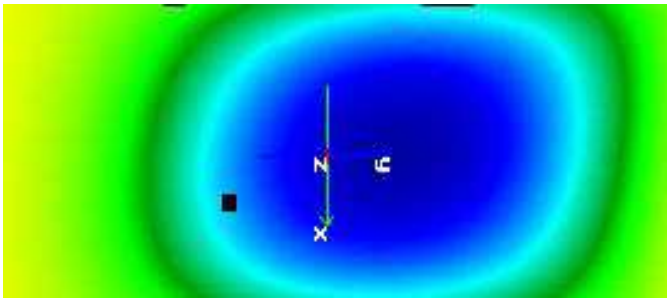


Figure A.58: Laminate 6 interlaminar shear response.

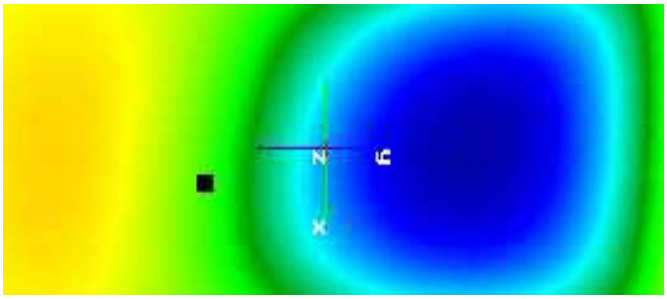
A.7.6 Edgewise Compression



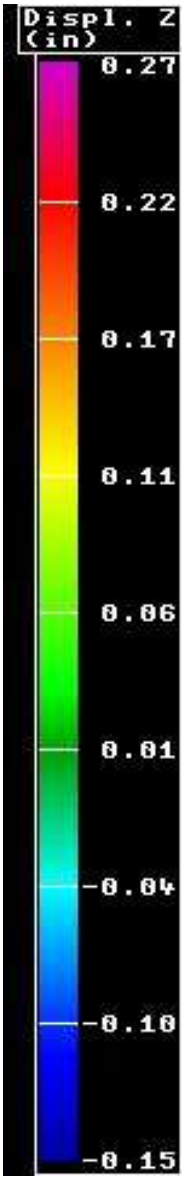
Specimen 1 at 76,830 N



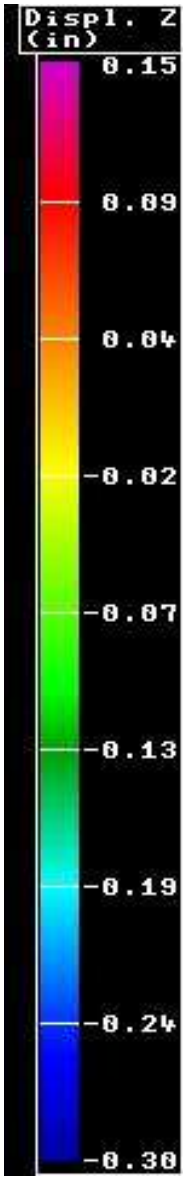
Specimen 2 at 76,114 N



Specimen 3 at 65,838 N

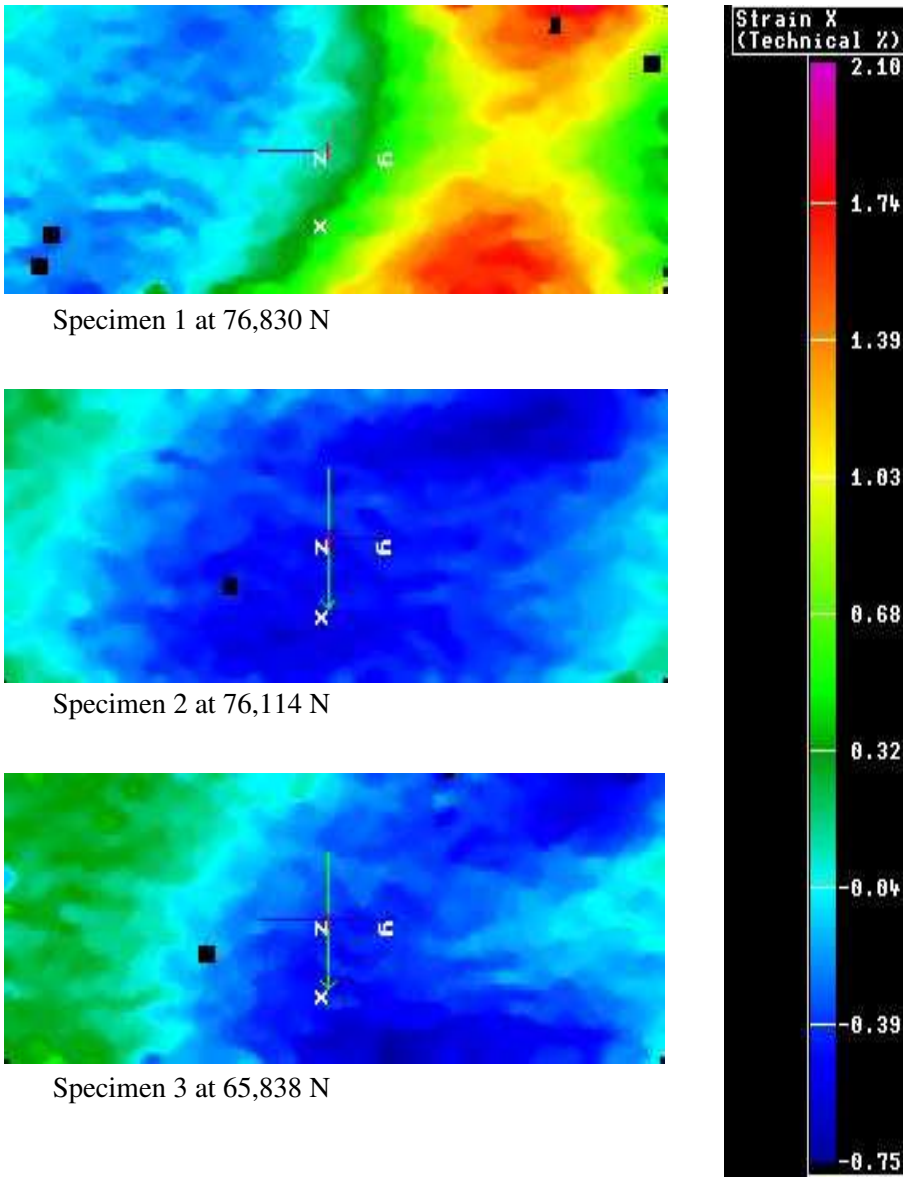


Specimen 1



Specimen 2
Specimen 3

Figure A.59: Laminate 6 out-of-plane displacement due to edgewise compression.

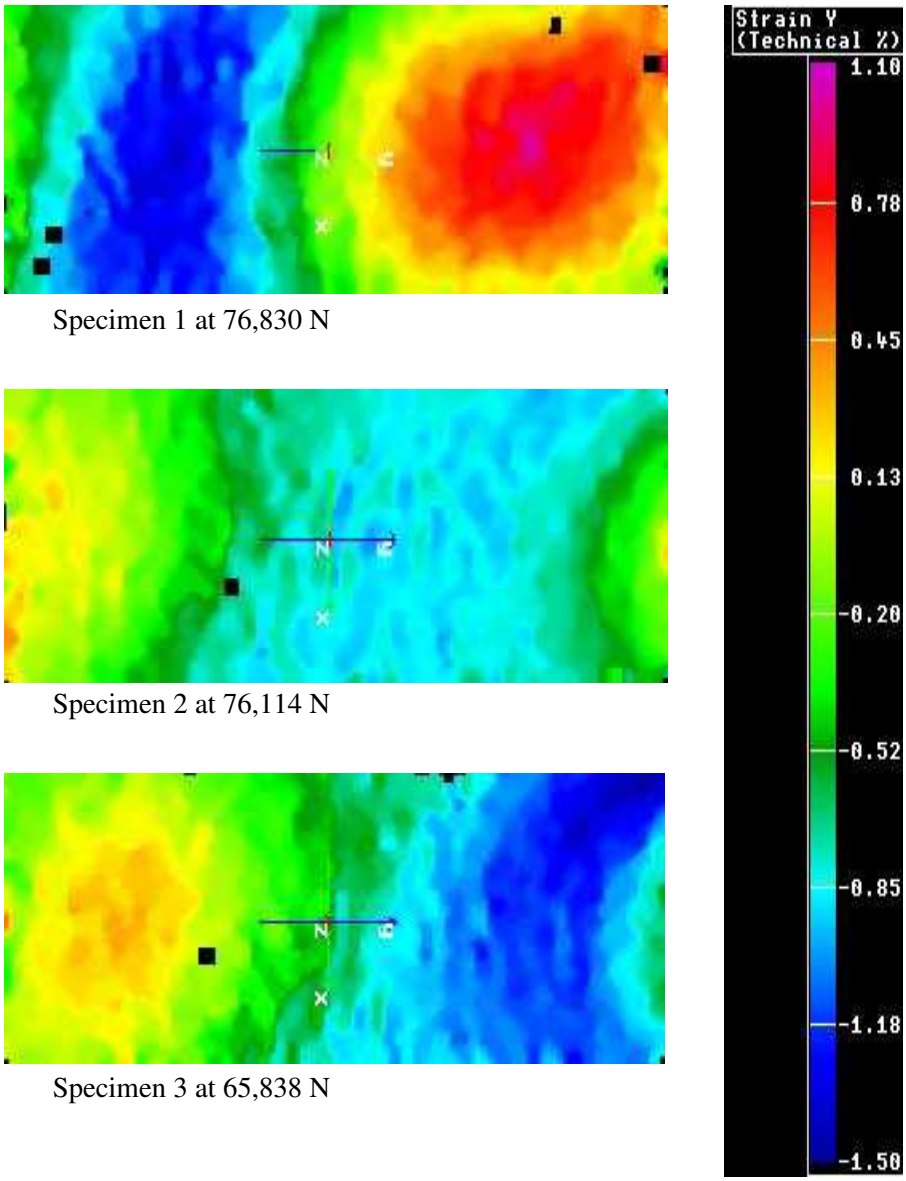


Specimen 1 at 76,830 N

Specimen 2 at 76,114 N

Specimen 3 at 65,838 N

Figure A.60: Laminate 6 axial strain displacement due to edgewise compression.

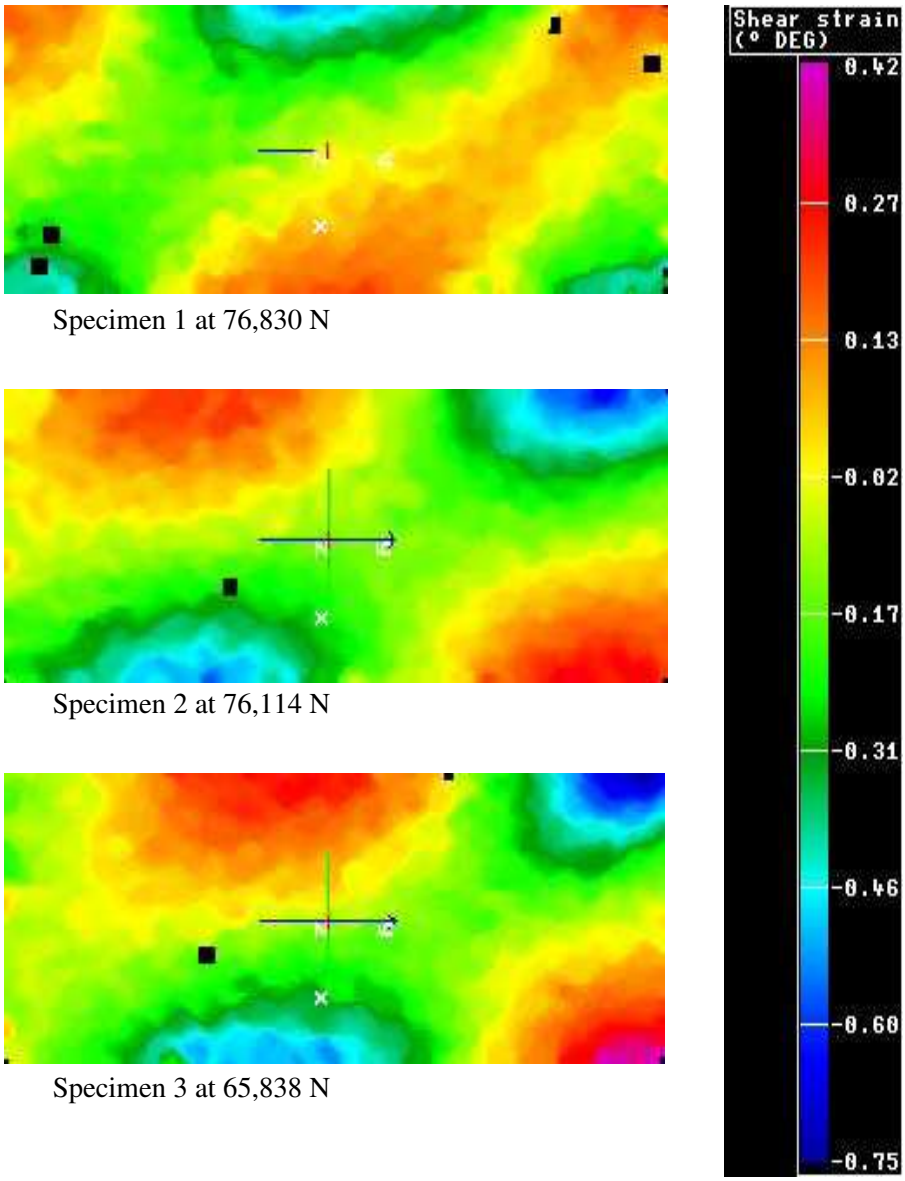


Specimen 1 at 76,830 N

Specimen 2 at 76,114 N

Specimen 3 at 65,838 N

Figure A.61: Laminate 6 transverse strain displacement due to edgewise compression.



Specimen 1 at 76,830 N

Specimen 2 at 76,114 N

Specimen 3 at 65,838 N

Figure A.62: Laminate 6 shear strain displacement due to edgewise compression.

A.8 Laminate 7 - 30CUD/55C20/15GDB - $[\pm 45_{DB}/(20_C)_2/0_C]_s$

A.8.1 Tension 0

Table A.130: Laminate 7 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.5	3.6	3.6	25.5	25.5	25.5	25	56	AIB AWB AGB
2	3.9	3.6	3.8	25.5	25.5	25.5	25	56	AIT AWT AGT
6	3.6	3.5	3.4	25.5	25.5	25.5	25	56	AIT AWT AGT

Table A.131: Laminate 7 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0733	0.021	25.5	0.0000	0.000	90.8
2	3.7	0.1278	0.034	25.5	0.0147	0.001	95.5
6	3.5	0.0776	0.022	25.5	0.0000	0.000	89.0

Table A.132: Laminate 7 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	67.6	0.999989	0.00024	0.572	0.999755	0.00112
2	62.4	0.999973	0.00037	0.613	0.999897	0.00073
6	65.5	0.999924	0.00063	0.647	0.999818	0.00097

Table A.133: Laminate 7 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	90.8	67,225	740	11,713
2	95.5	67,870	711	12,404
3	89.0	60,492	679	11,428
Average	91.8	65,195	710	11,848
STDEV	3.3	4,086	30.5	502
CV	0.036	0.063	0.043	0.042

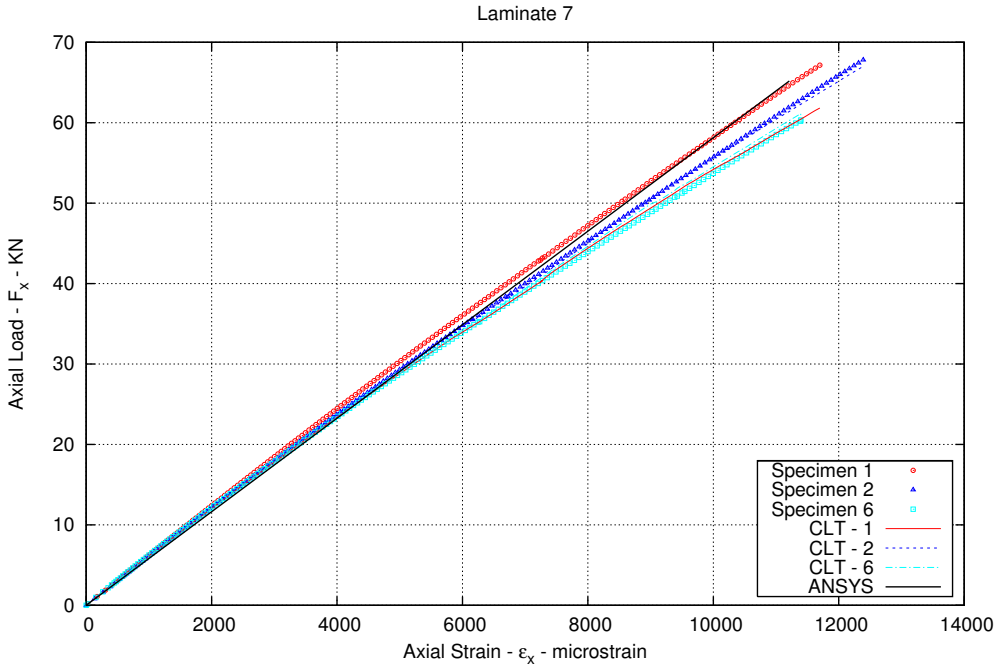


Figure A.63: Laminate 7 axial strain induced with an axial tensile load.

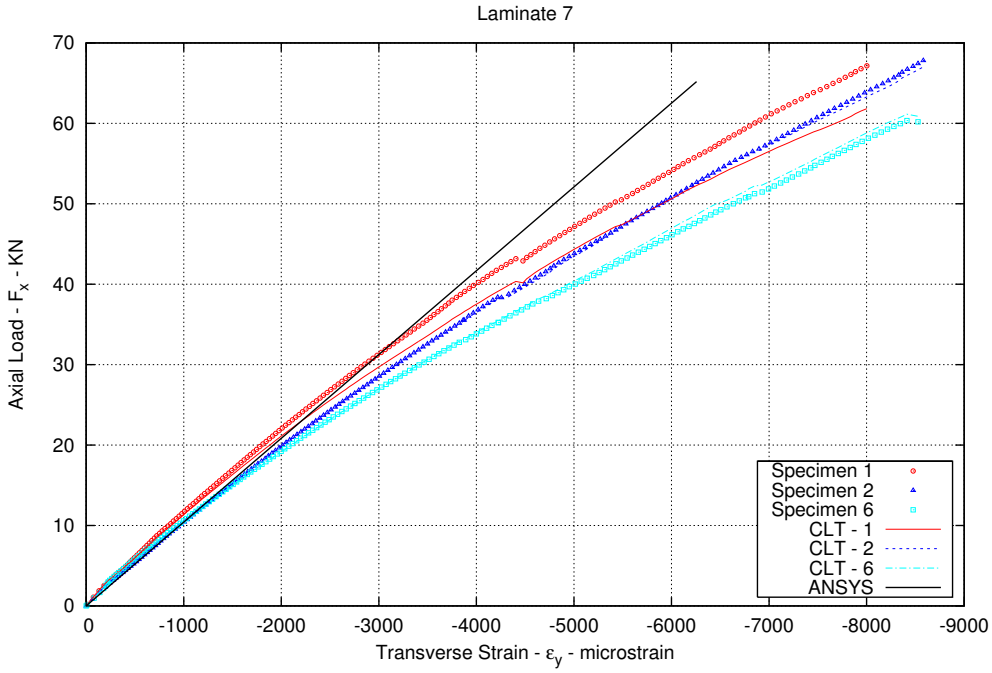


Figure A.64: Laminate 7 transverse strain induced with an axial tensile load.

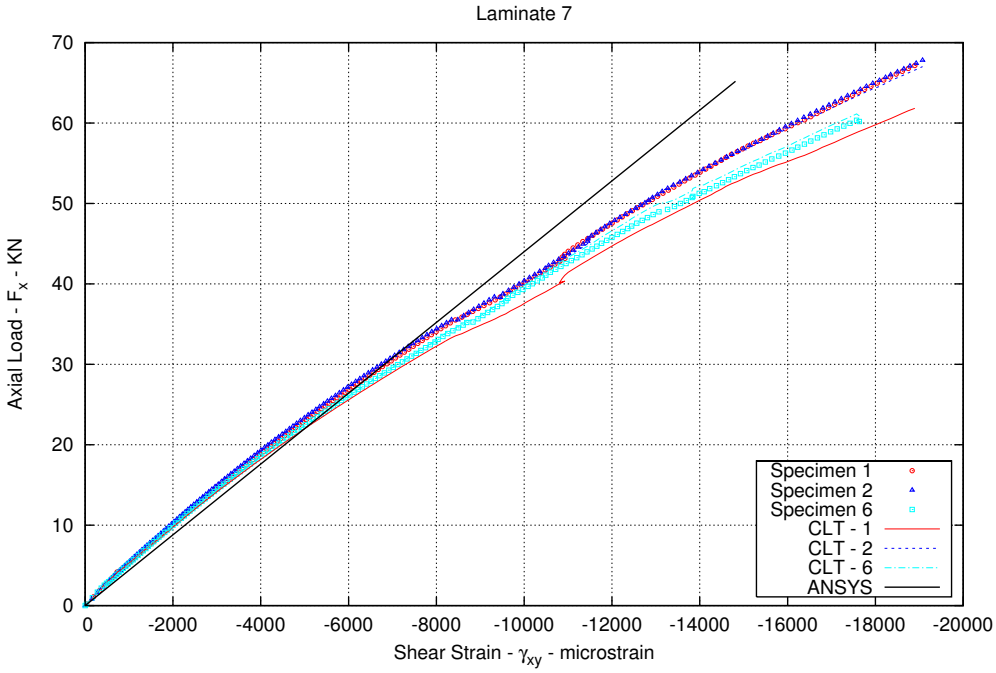


Figure A.65: Laminate 7 shear strain induced with an axial tensile load.

A.8.2 Tenion 90

Table A.134: Laminate 7 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.8	3.7	3.6	25.3	25.3	25.4	25	43	AGM
5	3.6	3.5	3.6	25.4	25.4	25.4	25	43	LGM
7	3.6	3.7	3.6	25.5	25.5	25.5	25	43	LGM

Table A.135: Laminate 7 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.1016	0.027	25.4	0.0073	0.000	93.8
5	3.5	0.0427	0.012	25.4	0.0000	0.000	89.8
7	3.6	0.0495	0.014	25.5	0.0000	0.000	92.4

Table A.136: Laminate 7 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	9.9	0.999890	0.00095	0.083	0.999521	0.00199
5	11.0	0.999872	0.00116	0.094	0.999875	0.00115
7	10.5	0.999707	0.00145	0.089	0.999803	0.00119

Table A.137: Laminate 7 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	93.8	5,255	56.0	5,953
2	89.8	4,956	55.2	5,368
3	92.4	5,247	56.8	5,861
Average	92.0	5,153	56.0	5,728
STDEV	2.0	171	0.79	315
CV	0.022	0.033	0.014	0.055

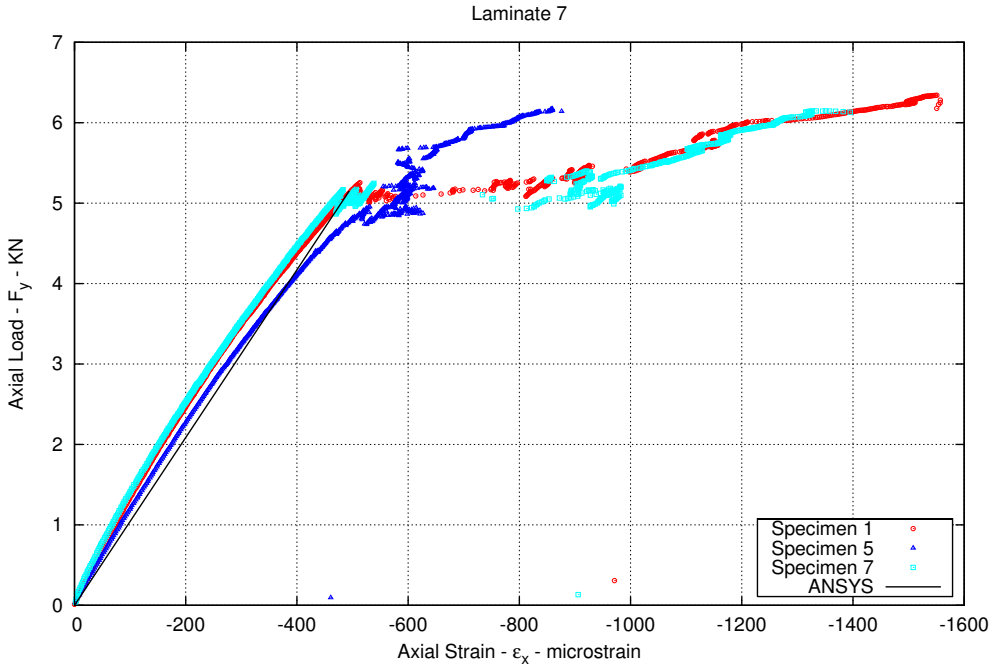


Figure A.66: Laminate 7 axial strain induced with a transverse tensile load.

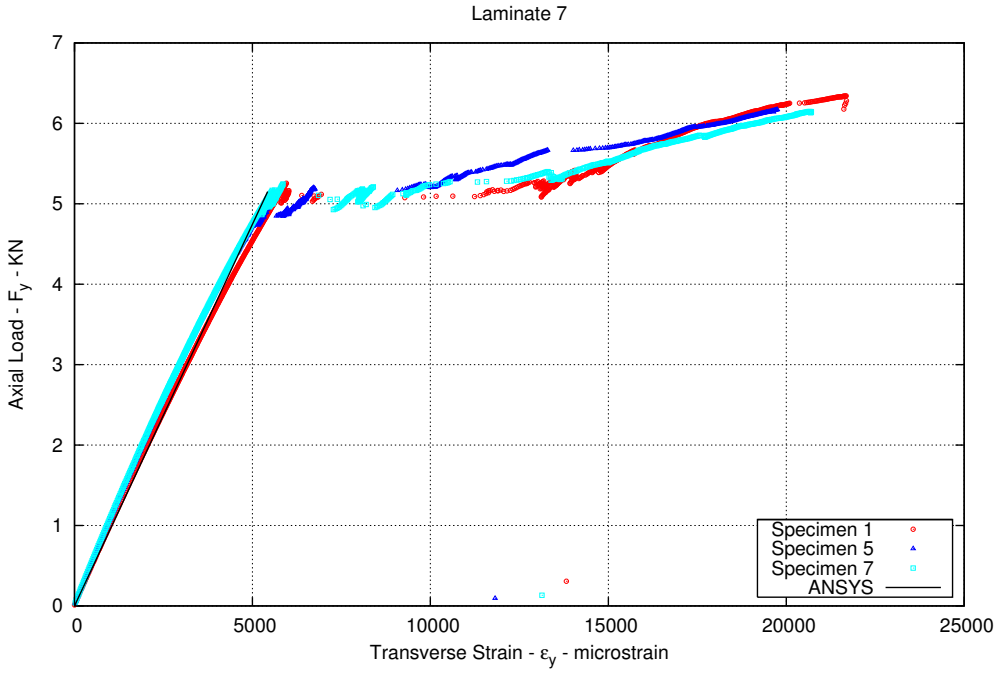


Figure A.67: Laminate 7 transverse strain induced with a transverse tensile load.

A.8.3 Compression

Table A.138: Laminate 7 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.6	3.7	12.8	12.8	23.9
2	3.7	3.6	12.8	12.8	23.9
3	3.6	3.5	12.8	12.8	23.9

Table A.139: Laminate 7 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0359	0.010	12.8	0.0000	0.000	46.4
2	3.7	0.0718	0.020	12.8	0.0000	0.000	46.8
3	3.5	0.0359	0.010	12.8	0.0000	0.000	45.1

Table A.140: Laminate 7 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	58.3	0.999646	0.00182
2	58.2	0.999626	0.00191
3	71.7	0.999906	0.00089

Table A.141: Laminate 7 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	12.6	12.6	23.9	0	BGM
2	3.5	3.6	12.6	12.6	23.9	0	BGM
3	3.5	3.4	12.6	12.6	23.9	0	BGM

Table A.142: Laminate 7 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.6	0.0126	0.004	12.6	0.0000	0.000	45.4
2	3.6	0.0260	0.007	12.6	0.0000	0.000	44.8
3	3.4	0.0853	0.025	12.6	0.0000	0.000	43.1

Table A.143: Laminate 7 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	45.4	24,562	541	8,620
2	44.8	24,430	545	8,691
3	43.1	23,503	546	8,701
Average	444	24,165	544	8,671
STDEV	1.2	577	2.7	44
CV	0.028	0.024	0.005	0.005

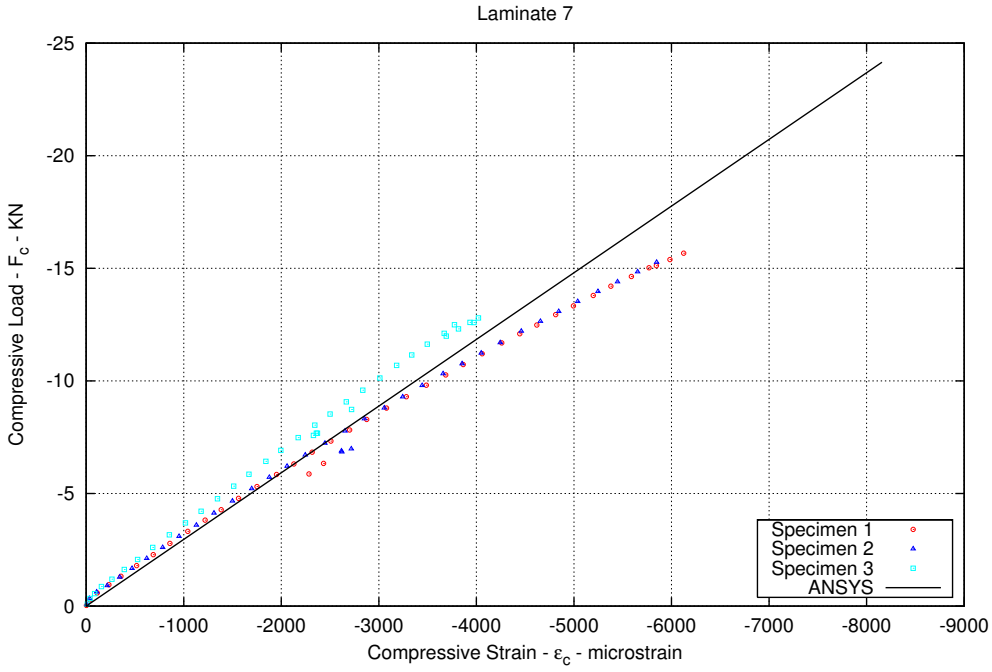


Figure A.68: Laminate 7 axial strain induced with an axial compressive load.

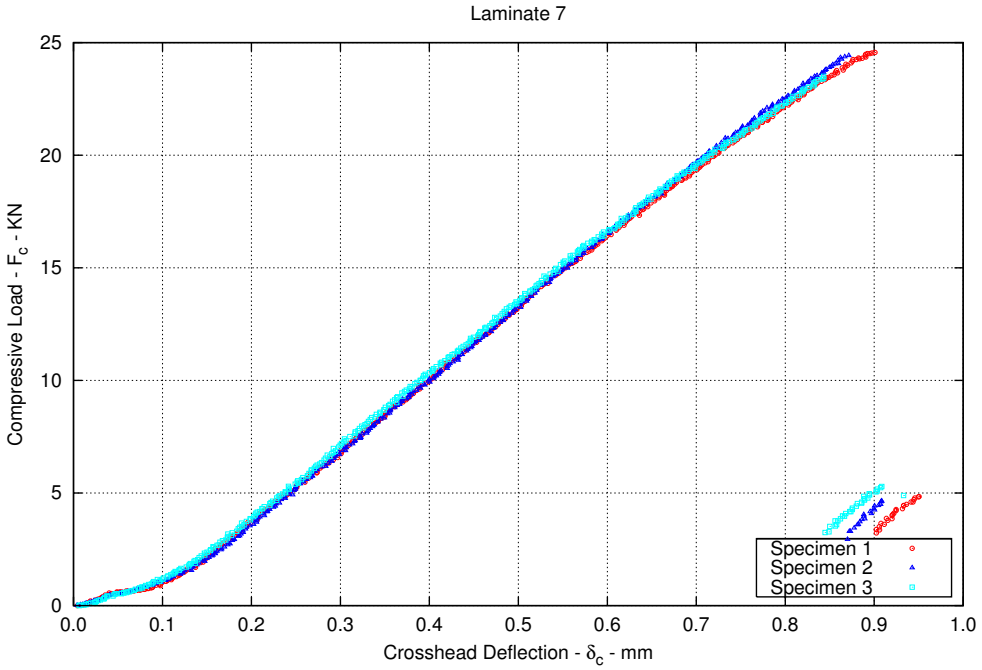


Figure A.69: Response of Laminate 7 to compressive loading.

A.8.4 In-Plane Shear

Table A.144: Laminate 7 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.5	11.4	11.4	24.4	30	null
2	3.6	3.6	11.3	11.4	24.4	30	null
3	3.5	3.5	11.3	11.3	24.4	30	null

Table A.145: Laminate 7 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0180	0.005	11.4	0.0359	0.003	40.0
2	3.6	0.0180	0.005	11.4	0.0718	0.006	40.8
3	3.5	0.0359	0.010	11.3	0.0180	0.002	39.7

Table A.146: Laminate 7 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	10.0	0.9984	0.0035
2	9.0	0.9999	0.0012
3	8.8	0.9977	0.0041

Table A.147: Laminate 7 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.0	5,462	136	20,236
2	40.8	5,967	146	26,767
3	39.7	4,281	108	15,318
Average	40.2	5,237	130	20,774
STDEV	0.6	865	19.9	5,743
CV	0.015	0.165	0.153	0.276

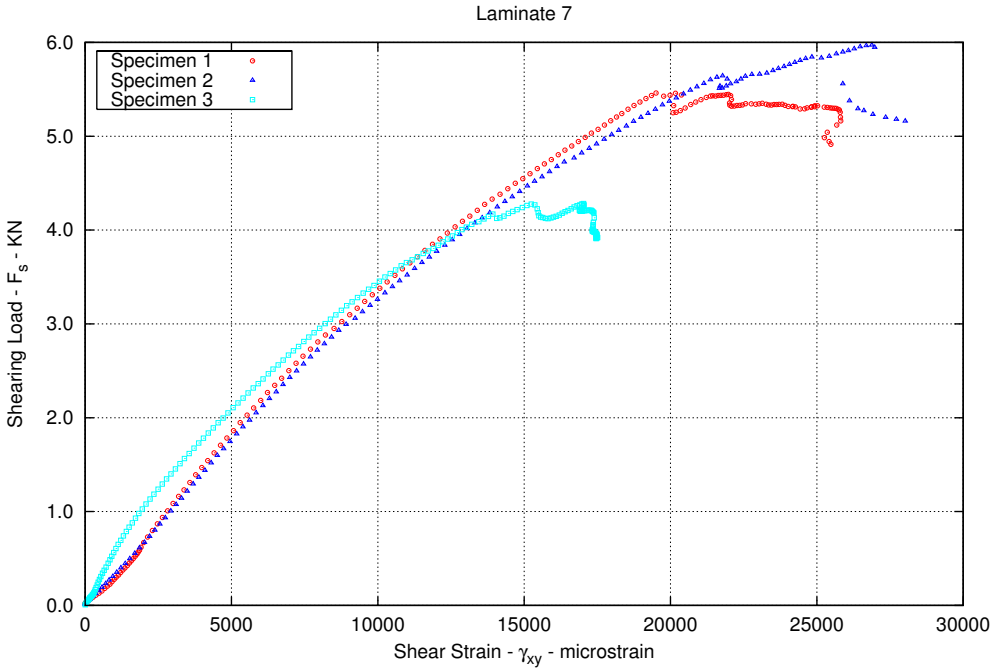


Figure A.70: Laminate 7 shear strain induced with an in-plane shear load.

A.8.5 Interlaminar Shear

Table A.148: Laminate 7 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.6	6.4	6.4	25	40	Interlaminar Shear
2	3.6	3.6	6.3	6.3	25	40	Interlaminar Shear
3	3.4	3.5	6.4	6.4	25	40	Interlaminar Shear

Table A.149: Laminate 7 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0557	0.016	6.4	0.0000	0.000	22.8
2	3.6	0.0314	0.009	6.3	0.0180	0.003	22.8
3	3.5	0.0467	0.014	6.4	0.0000	0.000	22.0

Table A.150: Laminate 7 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.8	1546.9	51.7
2	22.8	1472.7	49.2
3	22.0	1452.2	50.2

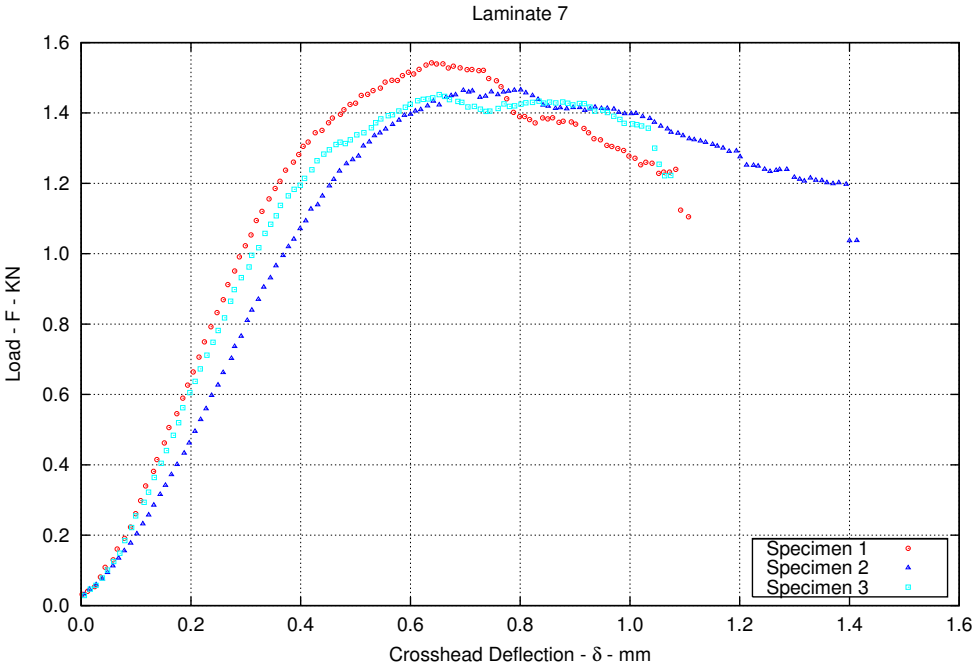
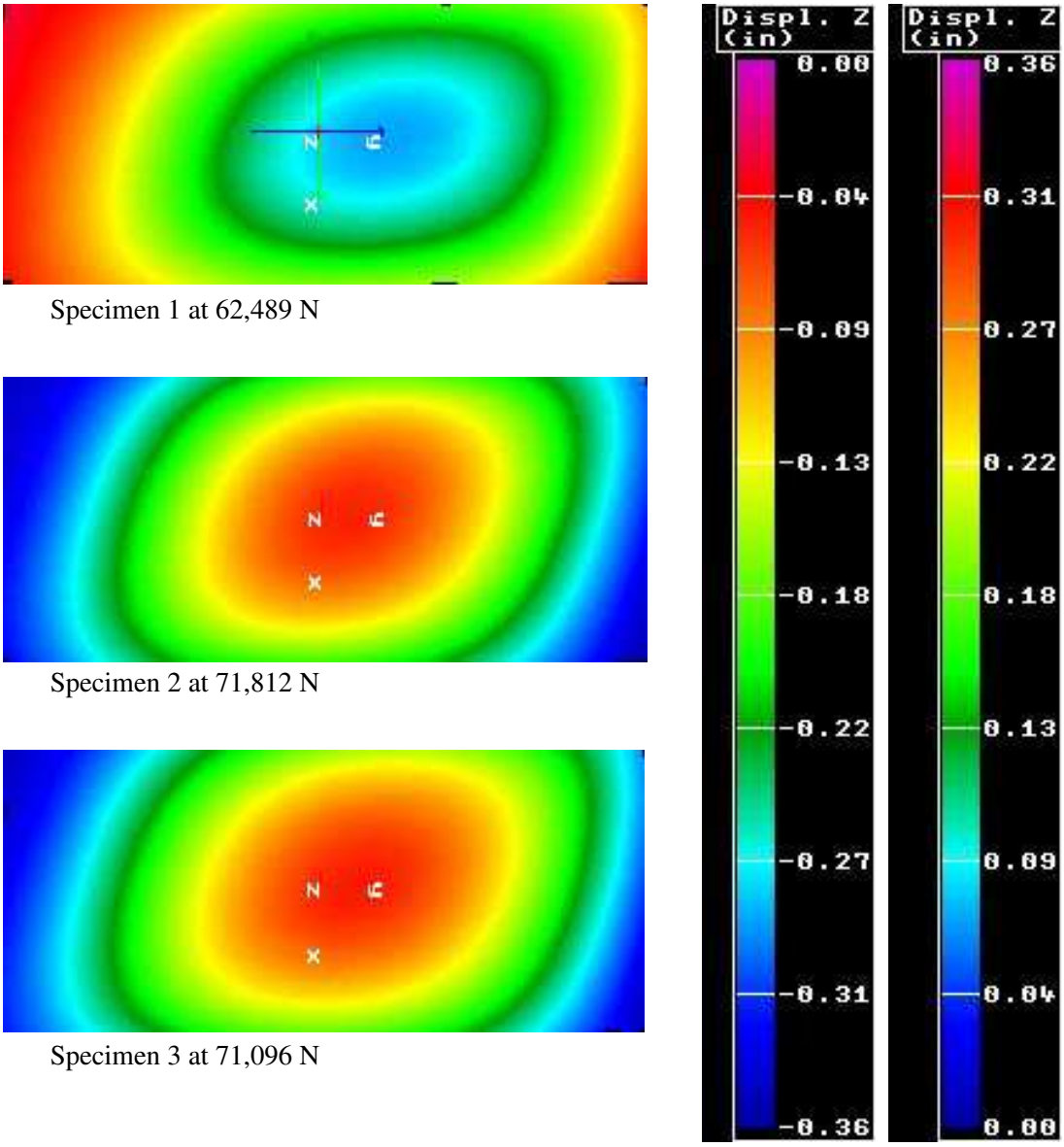


Figure A.71: Laminate 7 interlaminar shear response.

A.8.6 Edgewise Compression



Specimen 1 at 62,489 N

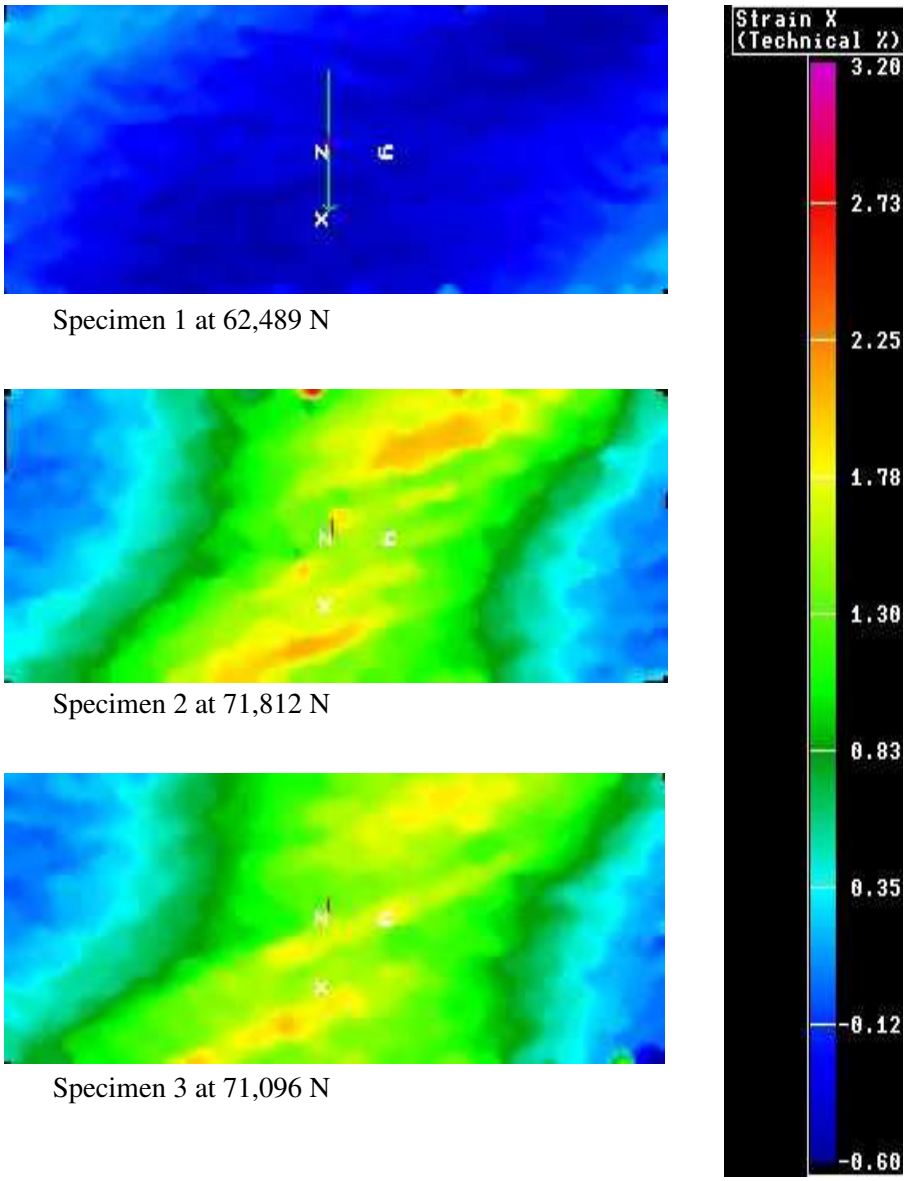
Specimen 2 at 71,812 N

Specimen 3 at 71,096 N

Specimen 1

Specimen 2
Specimen 3

Figure A.72: Laminate 7 out-of-plane displacement due to edgewise compression.

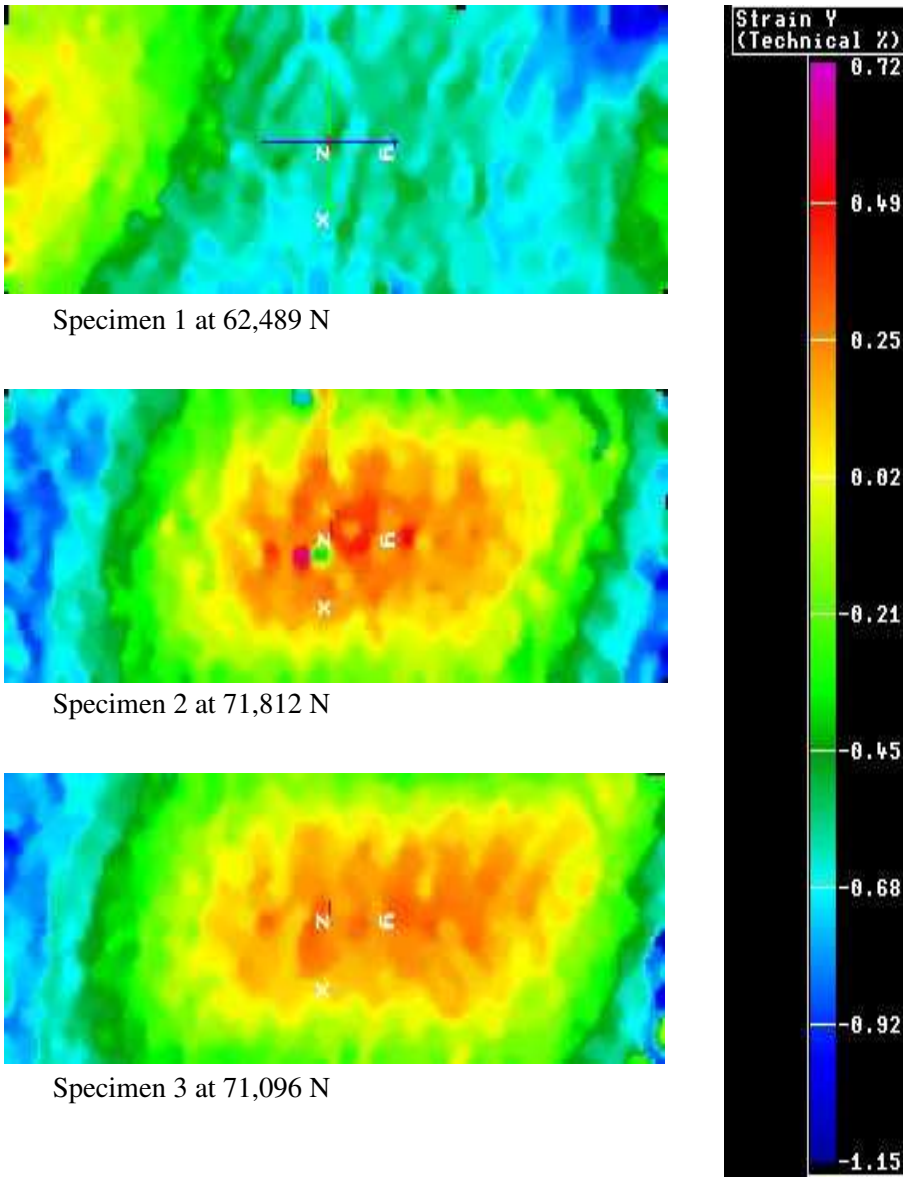


Specimen 1 at 62,489 N

Specimen 2 at 71,812 N

Specimen 3 at 71,096 N

Figure A.73: Laminate 7 axial strain displacement due to edgewise compression.

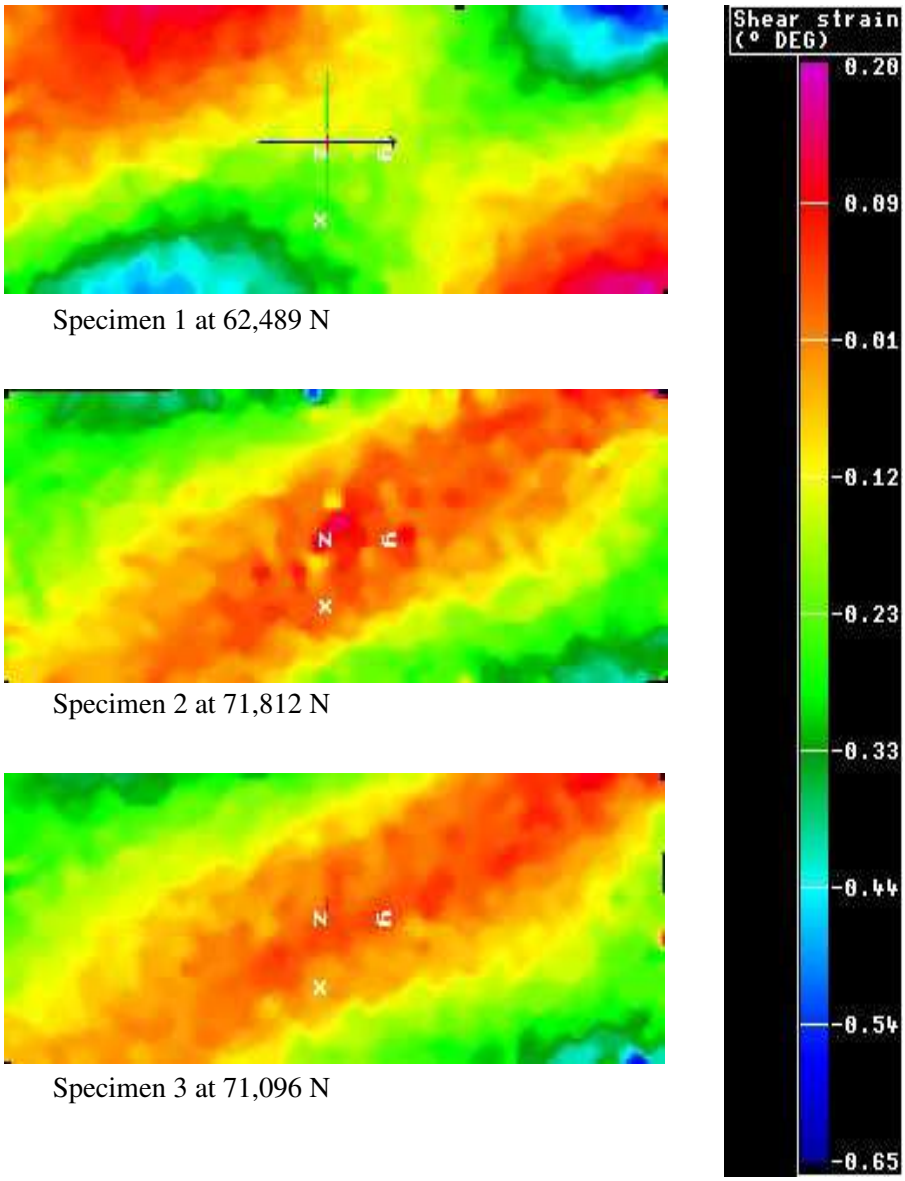


Specimen 1 at 62,489 N

Specimen 2 at 71,812 N

Specimen 3 at 71,096 N

Figure A.74: Laminate 7 transverse strain displacement due to edgewise compression.



Specimen 1 at 62,489 N

Specimen 2 at 71,812 N

Specimen 3 at 71,096 N

Figure A.75: Laminate 7 shear strain displacement due to edgewise compression.

A.9 Laminate 8 - 15CUD/70C20/15GDB - $[\pm 45_{DB}/(20_C)_2/0_C/(20_C)_3/\mp 45_{DB}]$

A.9.1 Tension 0

Table A.151: Laminate 8 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.4	3.6	3.7	25.4	25.4	25.4	24.4	51	AAB
2	3.4	3.6	3.6	25.4	25.4	25.4	24.4	51	AWB
3	3.3	3.3	3.4	25.4	25.4	25.4	24.4	51	AWB

Table A.152: Laminate 8 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.1729	0.048	25.4	0.0000	0.000	90.8
2	3.5	0.1173	0.034	25.4	0.0000	0.000	88.7
3	3.3	0.0762	0.023	25.4	0.0000	0.000	84.6

Table A.153: Laminate 8 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	51.1	0.999736	0.00124	0.635	0.999889	0.00080
2	49.9	0.999705	0.00134	0.524	0.999914	0.00072
3	50.7	0.999628	0.00152	0.627	0.999578	0.00162

Table A.154: Laminate 8 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	90.8	40,762	449	10,472
2	88.7	41,145	464	11,381
3	84.6	40,462	478	11,143
Average	88.0	40,790	464	10,999
STDEV	3.2	342	14.8	471
CV	0.036	0.008	0.032	0.043

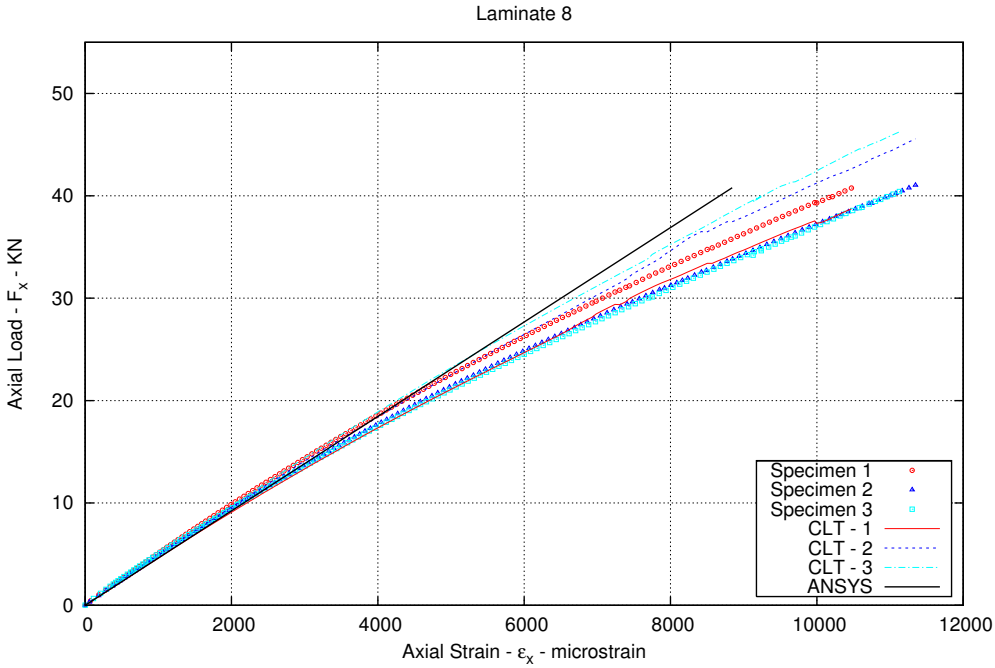


Figure A.76: Laminate 8 axial strain induced with an axial tensile load.

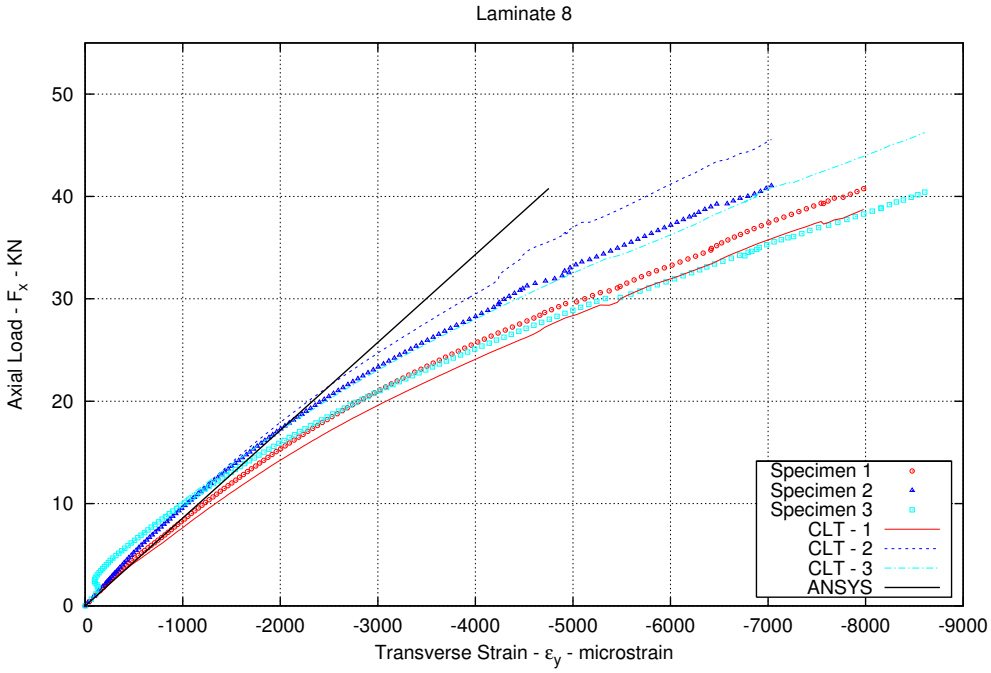


Figure A.77: Laminate 8 transverse strain induced with an axial tensile load.

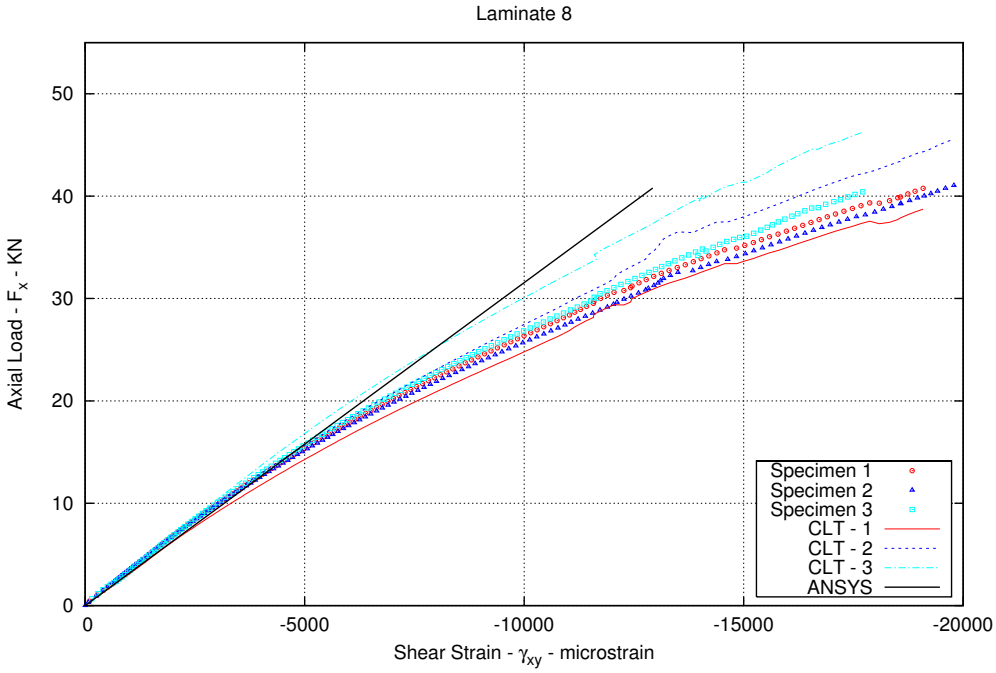


Figure A.78: Laminate 8 shear strain induced with an axial tensile load.

A.9.2 Tenion 90

Table A.155: Laminate 8 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	3.5	25.4	25.4	25.4	24.4	45	AGT
2	3.4	3.5	3.5	25.3	25.3	25.3	24.4	45	AWT
3	3.3	3.5	3.6	25.4	25.4	25.4	24.4	45	AWB

Table A.156: Laminate 8 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0440	0.012	25.4	0.0000	0.000	89.7
2	3.5	0.0639	0.018	25.3	0.0000	0.000	87.9
3	3.5	0.1444	0.041	25.4	0.0000	0.000	88.6

Table A.157: Laminate 8 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	9.8	0.999926	0.00076	0.116	0.999757	0.00138
2	10.3	0.999838	0.00113	0.143	0.999974	0.00046
3	10.1	0.999868	0.00108	0.139	0.999870	0.00107

Table A.158: Laminate 8 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	89.7	4,896	54.6	5,942
2	87.9	4,768	54.2	5,626
3	88.6	4,718	53.2	5,686
Average	88.7	4,794	54.0	5,751
STDEV	0.9	92	0.70	168
CV	0.010	0.019	0.013	0.029

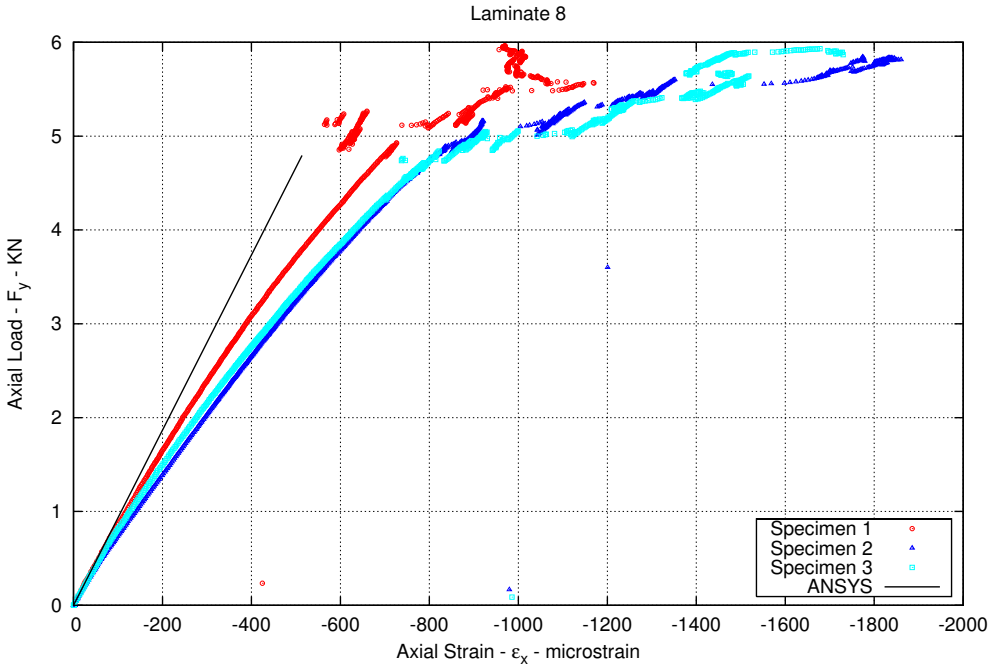


Figure A.79: Laminate 8 axial strain induced with a transverse tensile load.

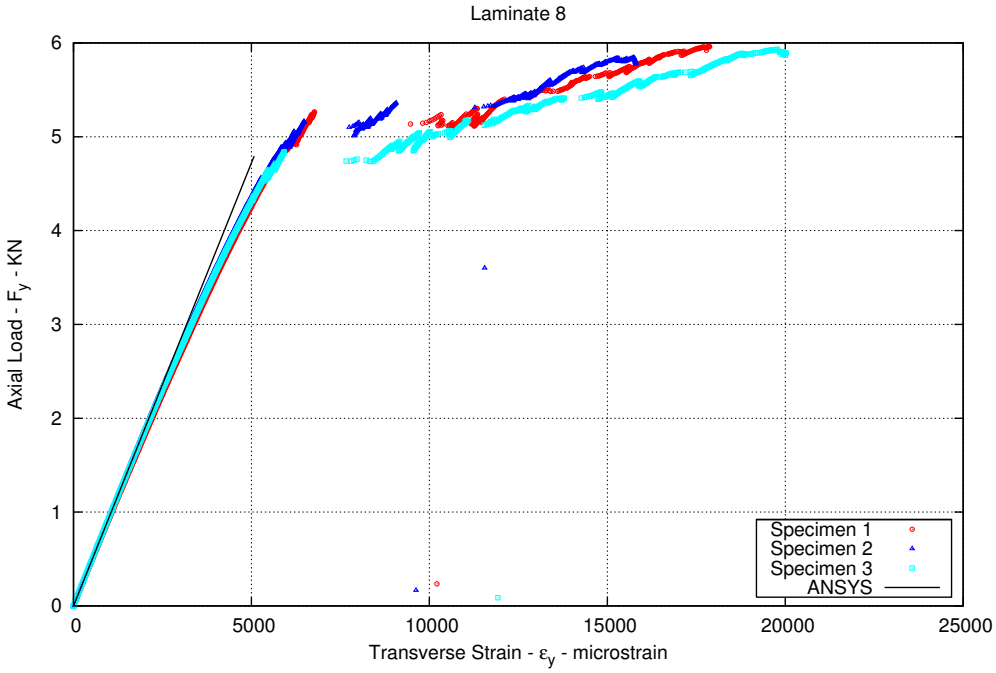


Figure A.80: Laminate 8 transverse strain induced with a transverse tensile load.

A.9.3 Compression

Table A.159: Laminate 8 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.5	3.4	12.7	12.7	23.3
2	3.5	3.5	12.7	12.7	23.3
3	3.7	3.4	12.7	12.7	23.3

Table A.160: Laminate 8 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0898	0.026	12.7	0.0000	0.000	43.8
2	3.5	0.0000	0.000	12.7	0.0000	0.000	43.9
3	3.5	0.2335	0.066	12.7	0.0000	0.000	45.0

Table A.161: Laminate 8 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	49.6	0.999275	0.00271
2	50.7	0.999548	0.00209
3	49.4	0.999206	0.00273

Table A.162: Laminate 8 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.5	12.8	12.8	23.9	25	TAT
2	3.5	3.6	12.8	12.8	23.9	25	TAT
3	3.7	3.6	12.8	12.8	23.9	25	TAT
4	3.9	3.8	12.8	12.8	23.9	25	TAT

Table A.163: Laminate 8 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.6	0.0548	0.015	12.8	0.0000	0.000	45.6
2	3.6	0.0350	0.010	12.8	0.0000	0.000	45.4
3	3.7	0.0494	0.014	12.8	0.0000	0.000	46.8
4	3.9	0.0251	0.007	12.8	0.0000	0.000	49.2

Table A.164: Laminate 8 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	45.6	19,595	430	8,615
2	45.4	18,469	407	8,153
3	46.8	15,985	342	6,851
4	49.2	20,114	408	8,188
Average	46.8	18,541	397	7,952
STDEV	1.8	1,837	38.0	763
CV	0.038	0.099	0.096	0.096

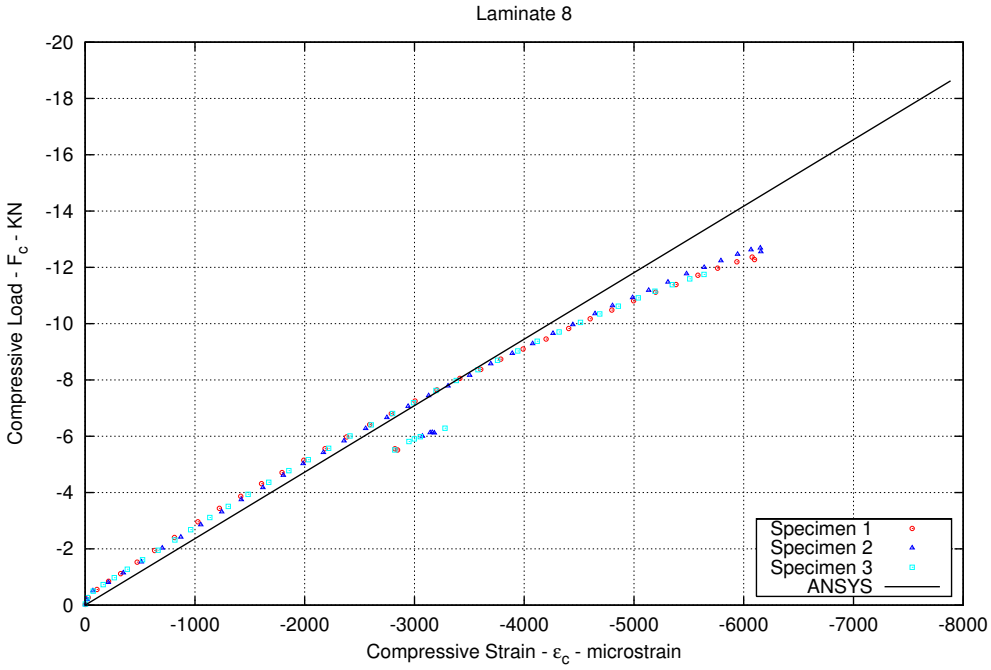


Figure A.81: Laminate 8 axial strain induced with an axial compressive load.

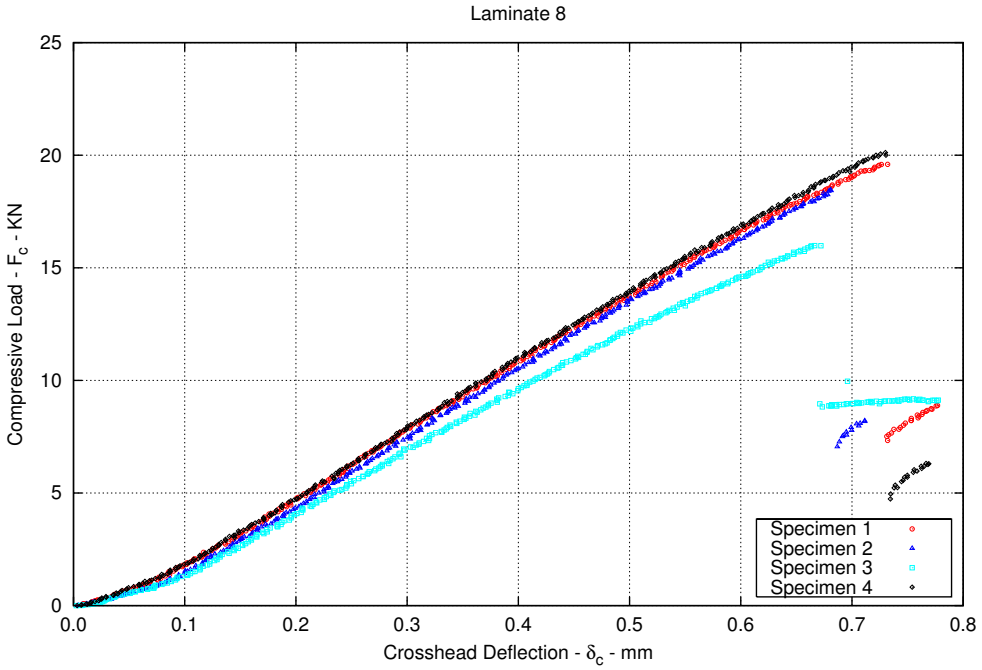


Figure A.82: Response of Laminate 8 to compressive loading.

A.9.4 In-Plane Shear

Table A.165: Laminate 8 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.5	11.4	11.4	22.8	64	null
2	3.2	3.6	11.4	11.4	22.8	64	null
3	3.4	3.5	11.4	11.4	22.8	64	null

Table A.166: Laminate 8 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0359	0.010	11.4	0.0359	0.003	40.2
2	3.4	0.2514	0.074	11.4	0.0180	0.002	38.7
3	3.5	0.0359	0.010	11.4	0.0000	0.000	39.2

Table A.167: Laminate 8 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	9.1	0.9988	0.0034
2	8.9	0.9983	0.0040
3	8.9	0.9989	0.0033

Table A.168: Laminate 8 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.2	5,591	139	24,411
2	38.7	5,801	150	28,740
3	39.2	5,757	147	26,077
Average	394	5,716	145	26,409
STDEV	0.8	111	5.5	2,184
CV	0.019	0.019	0.038	0.083

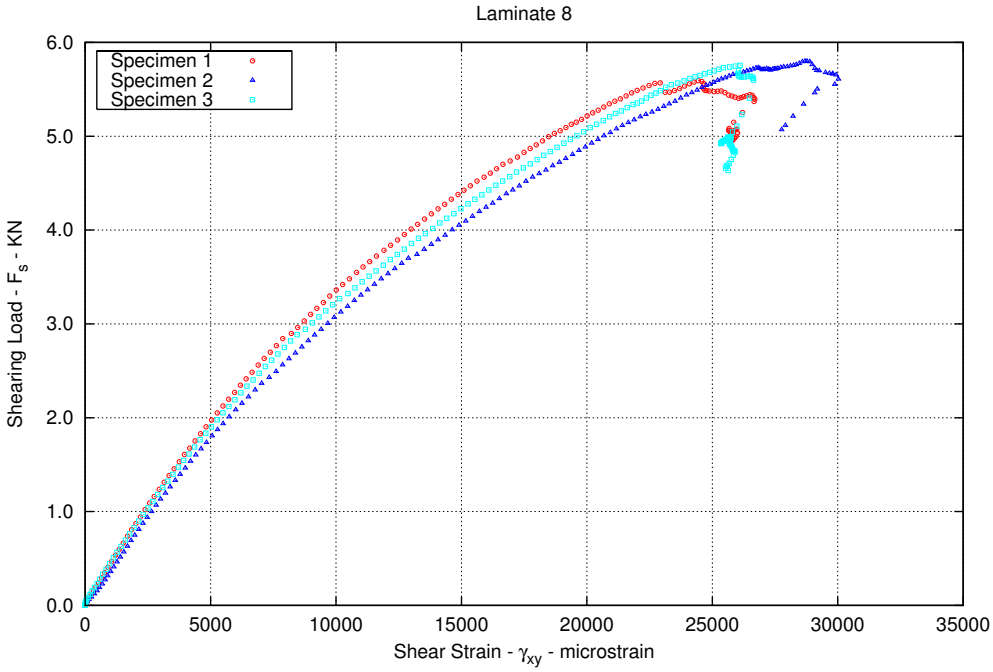


Figure A.83: Laminate 8 shear strain induced with an in-plane shear load.

A.9.5 Interlaminar Shear

Table A.169: Laminate 8 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.5	6.4	6.4	24.4	46	Interlaminar Shear
2	3.5	3.5	6.4	6.4	24.4	46	Interlaminar Shear
3	3.5	3.4	6.4	6.4	24.4	46	Interlaminar Shear

Table A.170: Laminate 8 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0090	0.003	6.4	0.0090	0.001	22.0
2	3.5	0.0063	0.002	6.4	0.0000	0.000	22.4
3	3.4	0.0898	0.026	6.4	0.0000	0.000	21.8

Table A.171: Laminate 8 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.0	1515.8	52.4
2	22.4	1627.5	55.1
3	21.8	1562.6	54.5

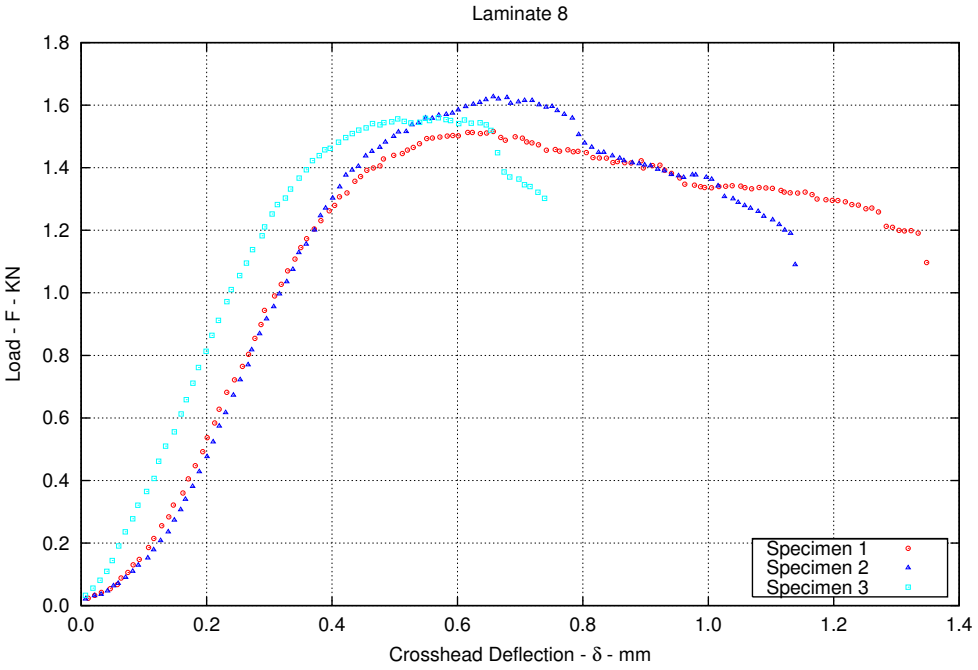
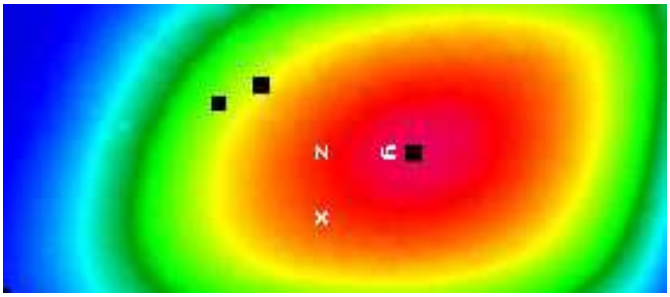
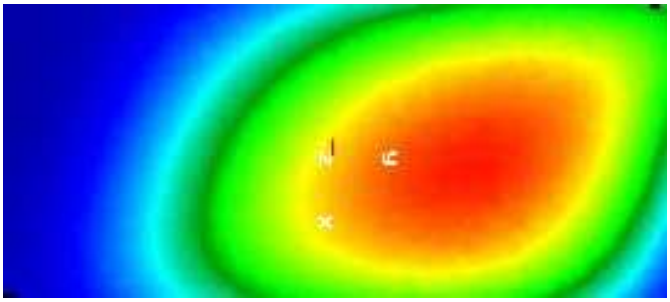


Figure A.84: Laminate 8 interlaminar shear response.

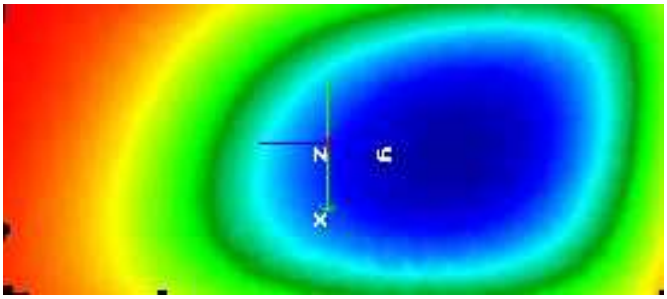
A.9.6 Edgewise Compression



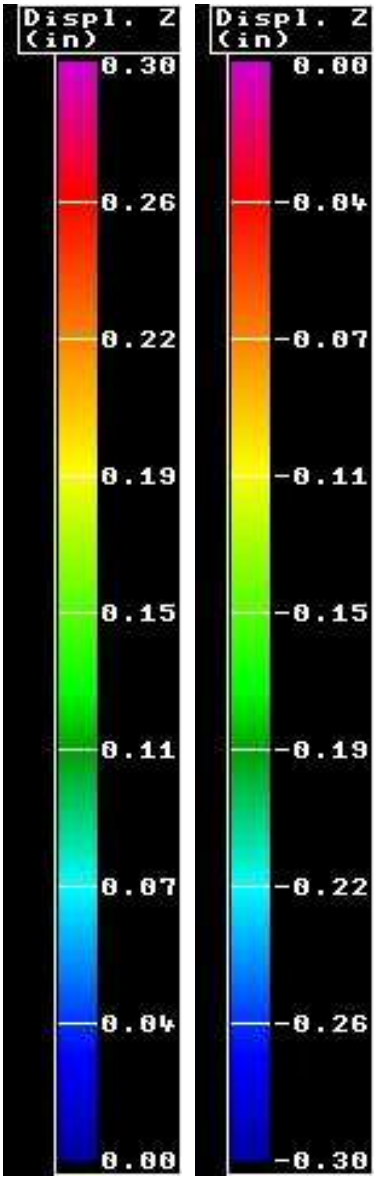
Specimen 1 at 72,876 N



Specimen 2 at 60,340 N

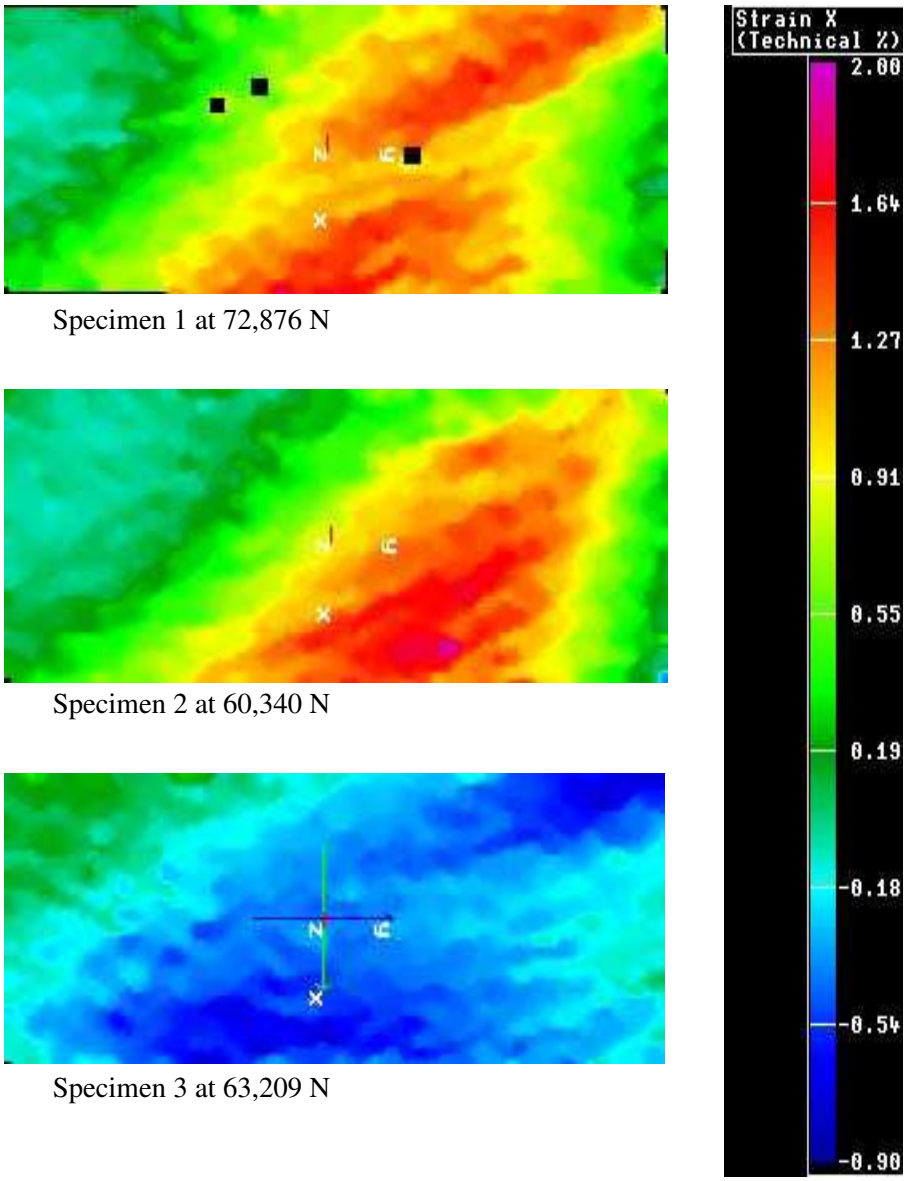


Specimen 3 at 63,209 N



Specimen 1 Specimen 3
Specimen 2

Figure A.85: Lamiante 8 out-of-plane displacement due to edgewise compression.

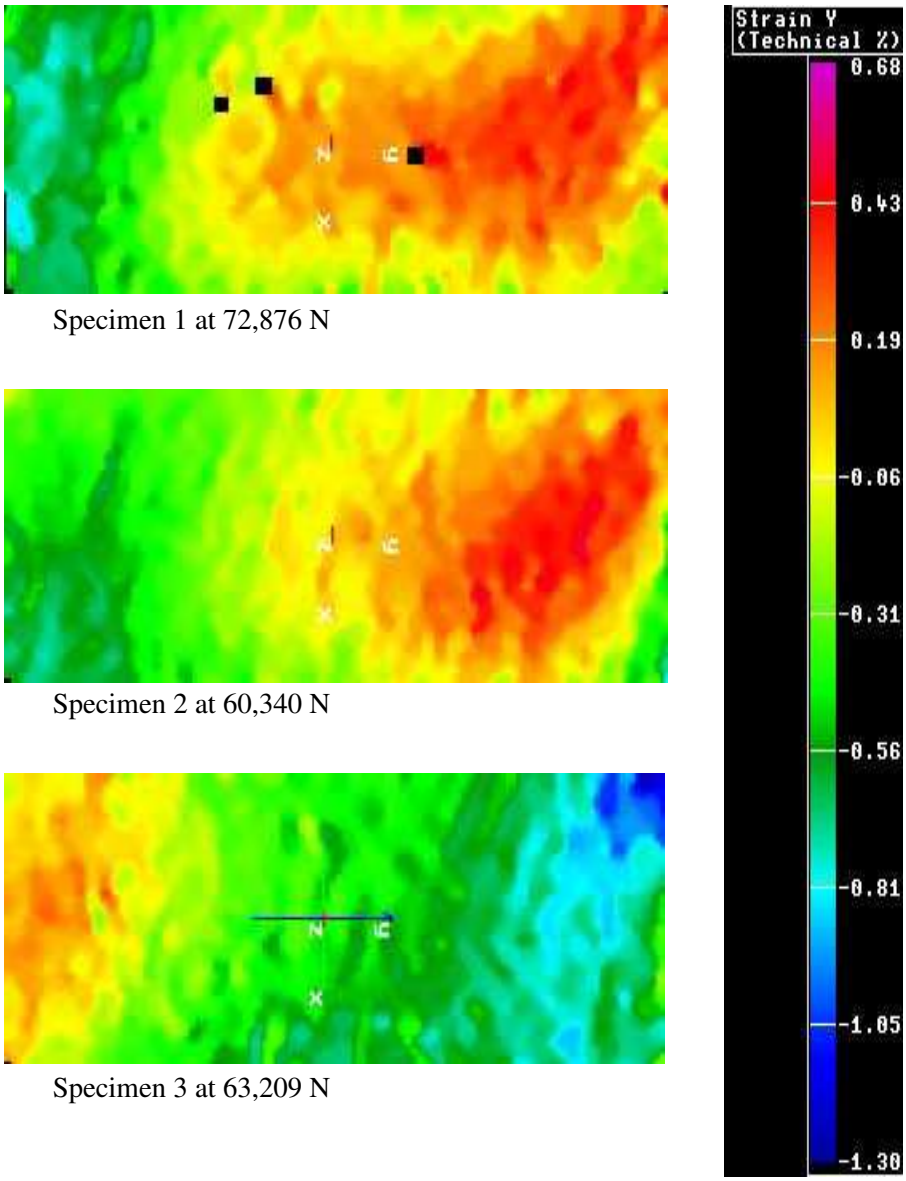


Specimen 1 at 72,876 N

Specimen 2 at 60,340 N

Specimen 3 at 63,209 N

Figure A.86: Lamiante 8 axial strain displacement due to edgewise compression.

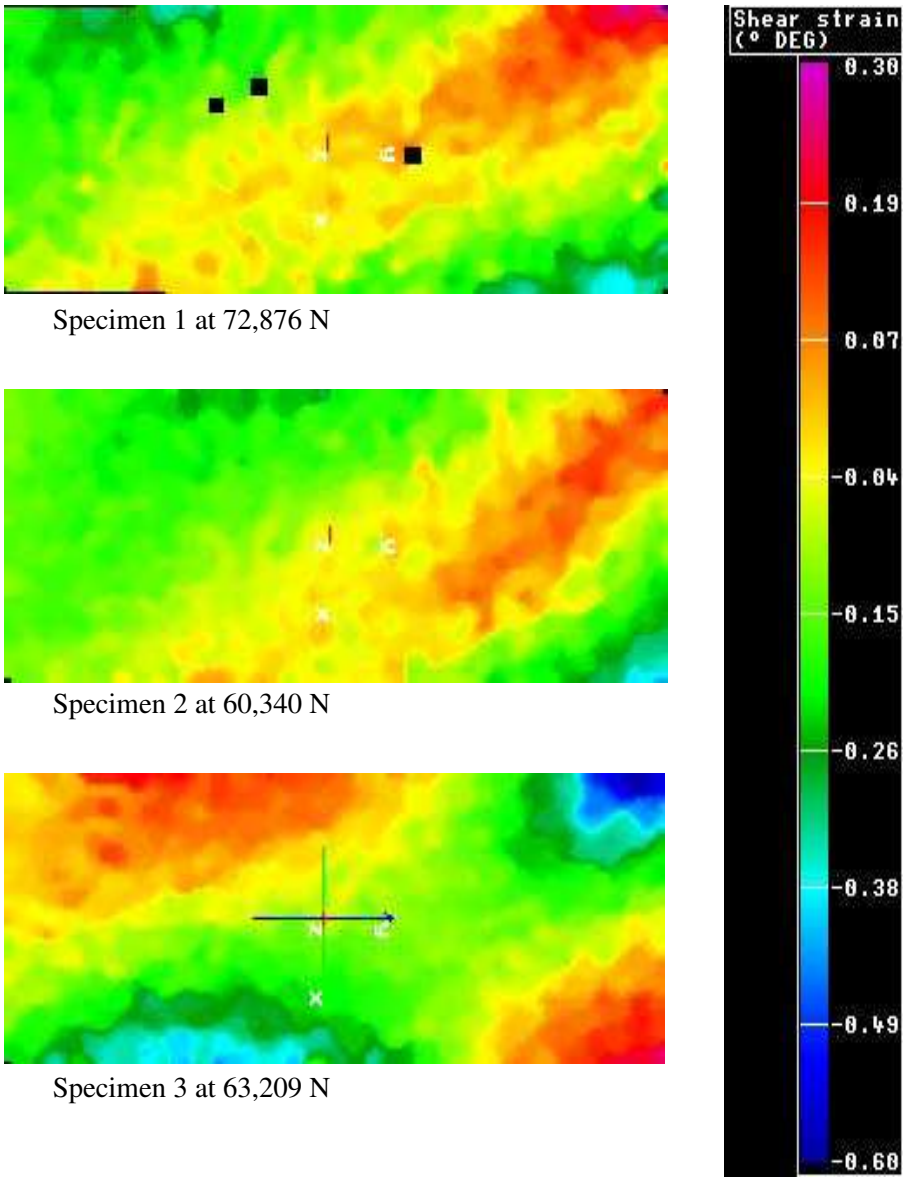


Specimen 1 at 72,876 N

Specimen 2 at 60,340 N

Specimen 3 at 63,209 N

Figure A.87: Lamiante 8 transverse strain displacement due to edgewise compression.



Specimen 1 at 72,876 N

Specimen 2 at 60,340 N

Specimen 3 at 63,209 N

Figure A.88: Lamiante 8 shear strain displacement due to edgewise compression.

A.10 Laminate 9 - 10GUD/75C20/15GDB - $[\pm 45_{DB}/(20_C)_2/0_G/(20_C)_3/\mp 45_{DB}]$

A.10.1 Tension 0

Table A.172: Laminate 9 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.0	4.0	3.9	25.4	25.4	25.4	23.9	53	AIT AGT AWT AAT
2	4.0	4.0	4.0	25.4	25.4	25.4	23.9	53	AIT AGT AWT AAT
3	4.0	4.0	3.9	25.3	25.3	25.3	23.9	53	AIT AGT AWT AAT

Table A.173: Laminate 9 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.0	0.0440	0.011	25.4	0.0000	0.000	100.6
2	4.0	0.0388	0.010	25.4	0.0000	0.000	101.4
3	4.0	0.0508	0.013	25.3	0.0000	0.000	101.0

Table A.174: Laminate 9 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	29.4	0.999518	0.00194	0.639	0.999912	0.00083
2	28.6	0.999532	0.00194	0.626	0.999936	0.00072
3	29.4	0.999602	0.00176	0.507	0.998086	0.00387

Table A.175: Laminate 9 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	101	26,477	263	12,061
2	101	27,313	269	13,305
3	101	27,847	276	13,369
Average	101	27,212	269	12,912
STDEV	0.4	690	6.3	737
CV	0.0038	0.025	0.024	0.057

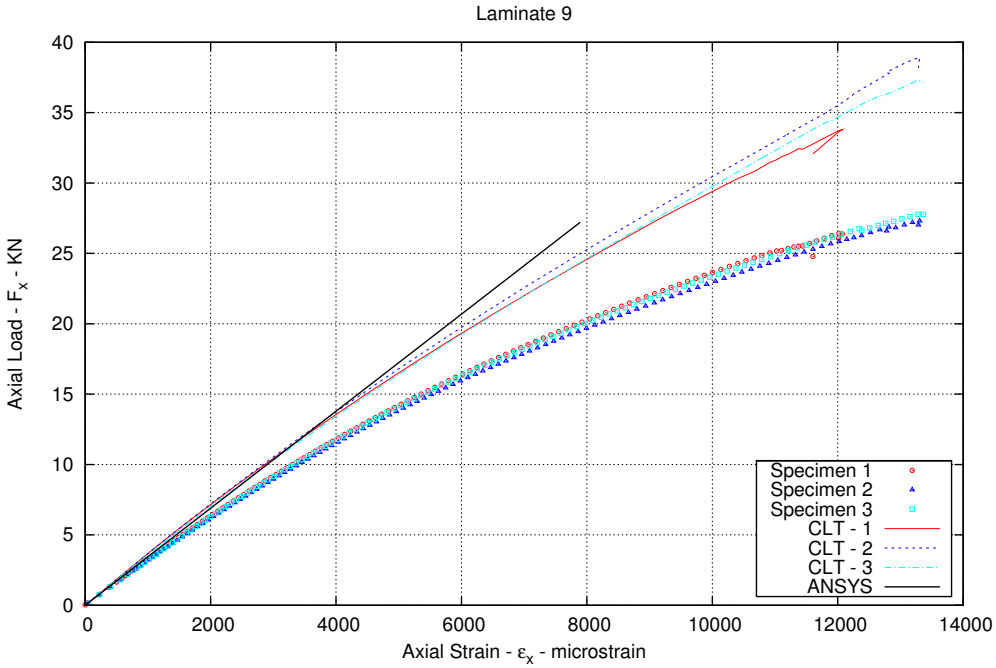


Figure A.89: Laminate 9 axial strain induced with an axial tensile load.

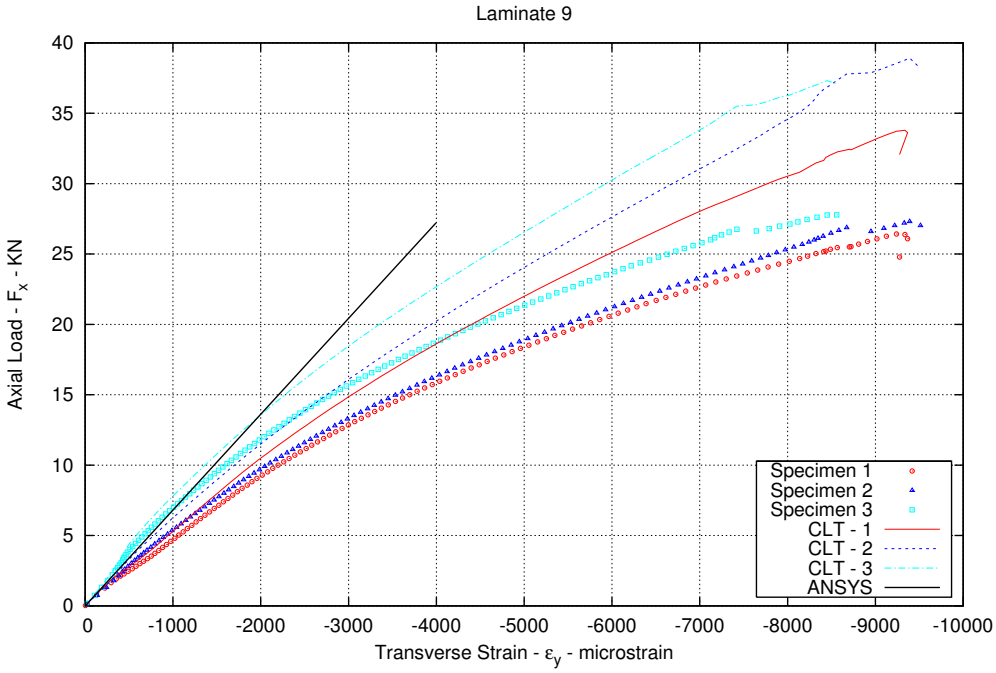


Figure A.90: Laminate 9 transverse strain induced with an axial tensile load.

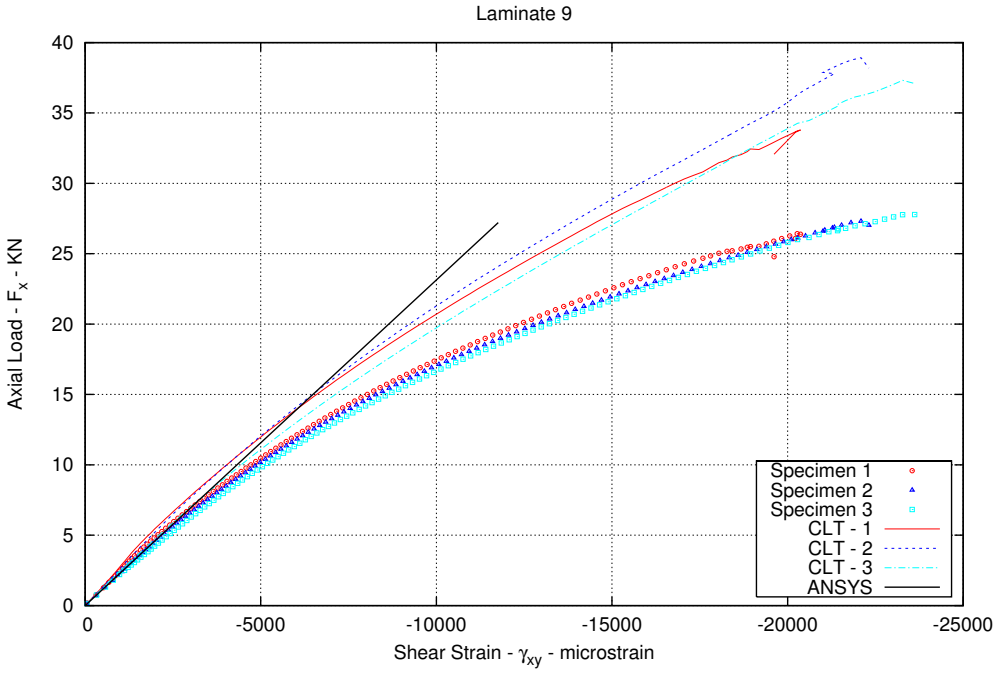


Figure A.91: Laminate 9 shear strain induced with an axial tensile load.

A.10.2 Tenion 90

Table A.176: Laminate 9 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.0	4.1	4.1	25.5	25.5	25.5	24.4	45	AWB
2	3.9	4.0	4.1	25.4	25.4	25.4	24.4	45	AWT
3	3.9	4.0	4.1	25.5	25.5	25.5	24.4	45	AWT

Table A.177: Laminate 9 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.1	0.0388	0.010	25.5	0.0000	0.000	103.6
2	4.0	0.0892	0.022	25.4	0.0000	0.000	101.8
3	4.0	0.1027	0.026	25.5	0.0000	0.000	101.3

Table A.178: Laminate 9 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	8.8	0.999891	0.00105	0.157	0.999970	0.00055
2	9.5	0.999895	0.00094	0.187	0.999981	0.00040
3	9.7	0.999802	0.00125	0.168	0.999760	0.00138

Table A.179: Laminate 9 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	104	5,422	52.3	6,469
2	102	5,709	56.0	6,459
3	101	5,579	55.0	6,147
Average	102	5,570	54.5	6,358
STDEV	1.2	143	1.9	183
CV	0.012	0.026	0.036	0.029

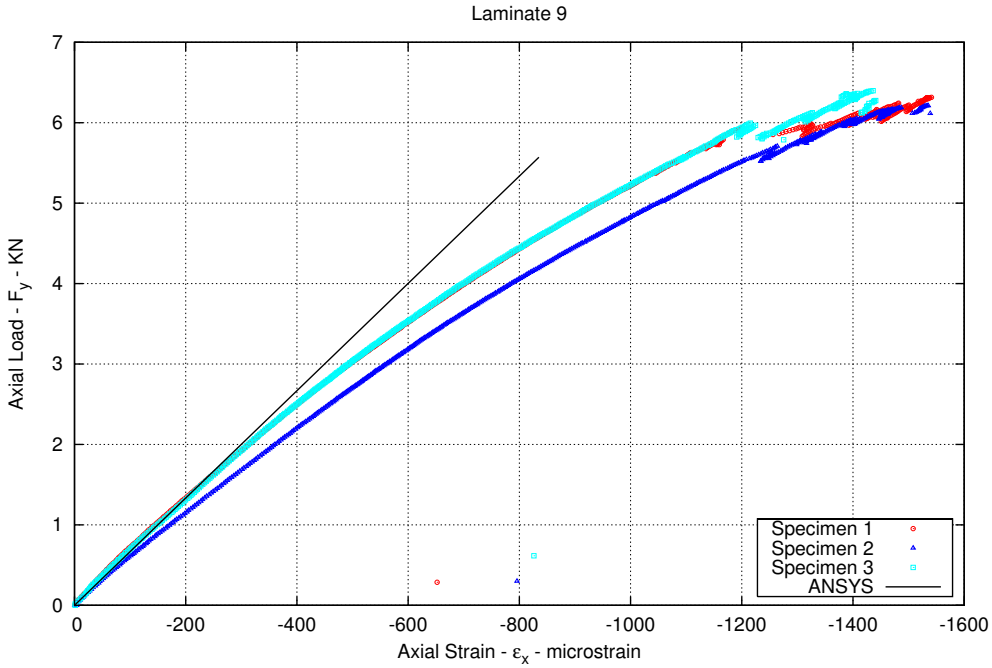


Figure A.92: Laminate 9 axial strain induced with a transverse tensile load.

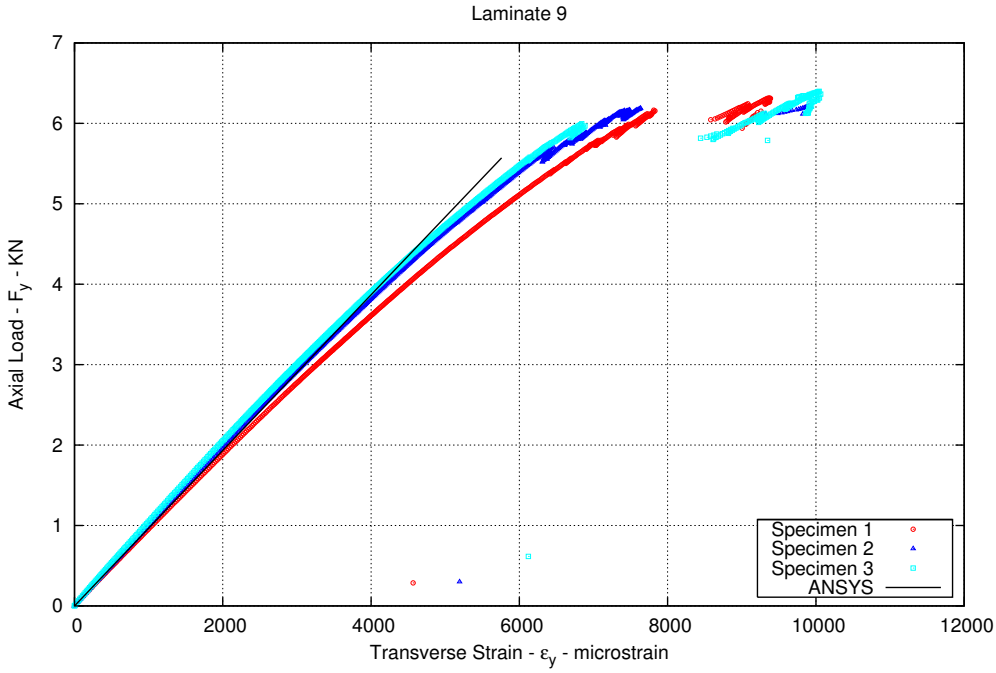


Figure A.93: Laminate 9 transverse strain induced with a transverse tensile load.

A.10.3 Compression

Table A.180: Laminate 9 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$
1	4.0	4.1	12.8	12.8	25
2	4.1	4.2	12.8	12.8	25
3	4.0	4.1	12.8	12.8	25
91	4.1	4.0	12.7	12.7	23.9
92	4.0	4.0	12.7	12.7	23.9
93	4.0	4.0	12.7	12.7	23.9

Table A.181: Laminate 9 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.0	0.0718	0.018	12.8	0.0000	0.000	51.7
2	4.1	0.0539	0.013	12.8	0.0000	0.000	52.7
3	4.0	0.1078	0.027	12.8	0.0000	0.000	51.6
91	4.1	0.0359	0.009	12.7	0.0000	0.000	51.5
92	4.0	0.0000	0.000	12.7	0.0000	0.000	50.2
93	4.0	0.0180	0.005	12.7	0.0000	0.000	50.5

Table A.182: Laminate 9 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	31.4	0.999478	0.00237
2	30.0	0.999456	0.00246
3	33.9	0.999591	0.00201
91	32.3	0.999323	0.00260
92	30.4	0.999365	0.00259
93	29.7	0.999590	0.00210

Table A.183: Laminate 9 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.1	4.1	12.8	12.8	23.9	38	TAT
2	3.9	3.8	12.8	12.8	23.9	38	TAT
3	4.0	4.0	12.8	12.8	23.9	38	TAT

Table A.184: Laminate 9 geometric summary data for compression strength testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.1	0.0117	0.003	12.8	0.0000	0.000	52.4
2	3.8	0.0449	0.012	12.8	0.0000	0.000	49.1
3	4.0	0.0260	0.007	12.8	0.0000	0.000	51.0

Table A.185: Laminate 9 compression failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	52.4	16,997	325	10,384
2	49.1	16,700	340	10,890
3	51.0	16,527	324	10,374
Average	50.8	16,741	330	10,550
STDEV	1.7	238	9.2	295
CV	0.033	0.014	0.028	0.028

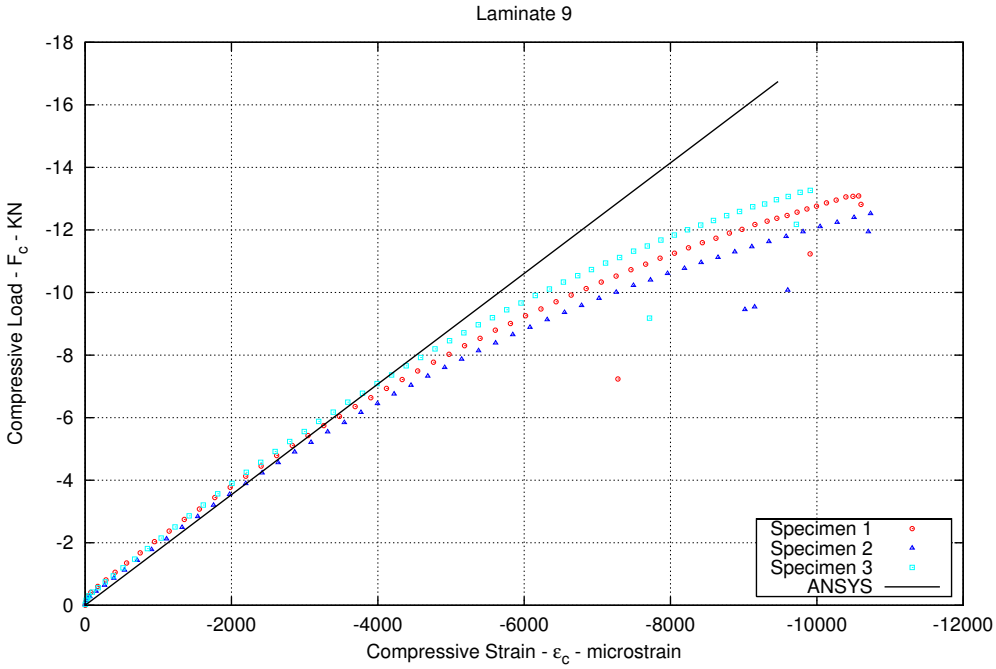


Figure A.94: Laminate 9 axial strain induced with an axial compressive load.

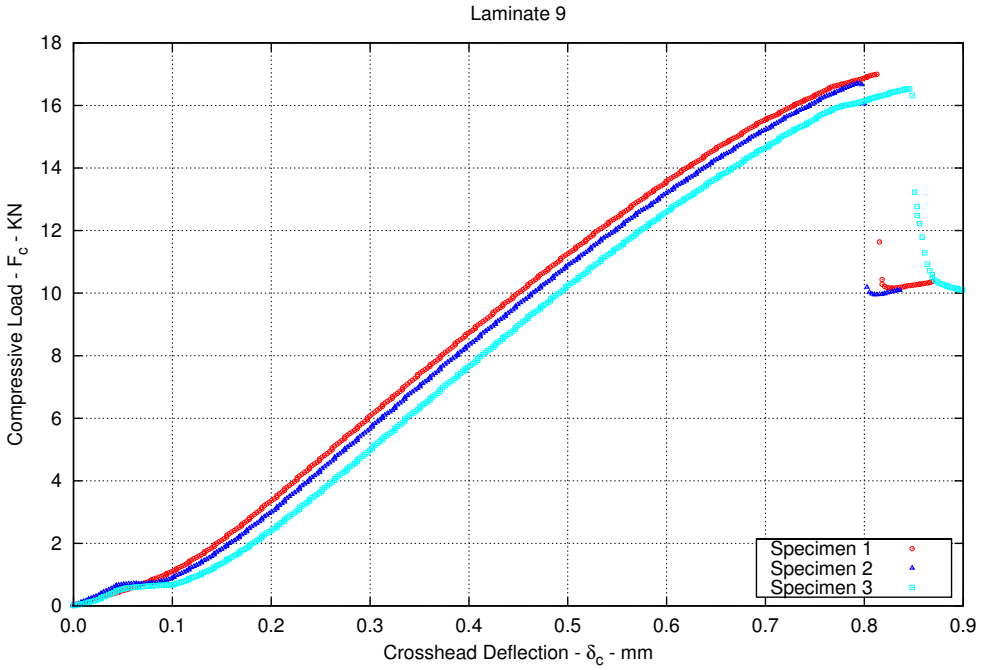


Figure A.95: Response of Laminate 9 to compressive loading.

A.10.4 In-Plane Shear

Table A.186: Laminate 9 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
3	4.0	4.0	11.5	11.5	22.8	45	null
5	4.0	4.1	11.5	11.4	22.8	45	null
6	4.1	4.1	11.5	11.5	22.8	45	null

Table A.187: Laminate 9 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
3	4.0	0.0539	0.013	11.5	0.0000	0.000	46.0
5	4.1	0.0180	0.004	11.4	0.0180	0.002	46.4
6	4.1	0.0359	0.009	11.5	0.0000	0.000	47.1

Table A.188: Laminate 9 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
3	6.7	0.9978	0.0050
5	6.4	0.9986	0.0040
6	6.4	0.9978	0.0050

Table A.189: Laminate 9 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
3	46.0	5,444	118	30,000
5	46.4	5,424	117	30,020
6	47.1	5,334	113	29,982
Average	46.5	5,401	116	30,001
STDEV	0.5	59	2.6	19
CV	0.011	0.011	0.022	0.001

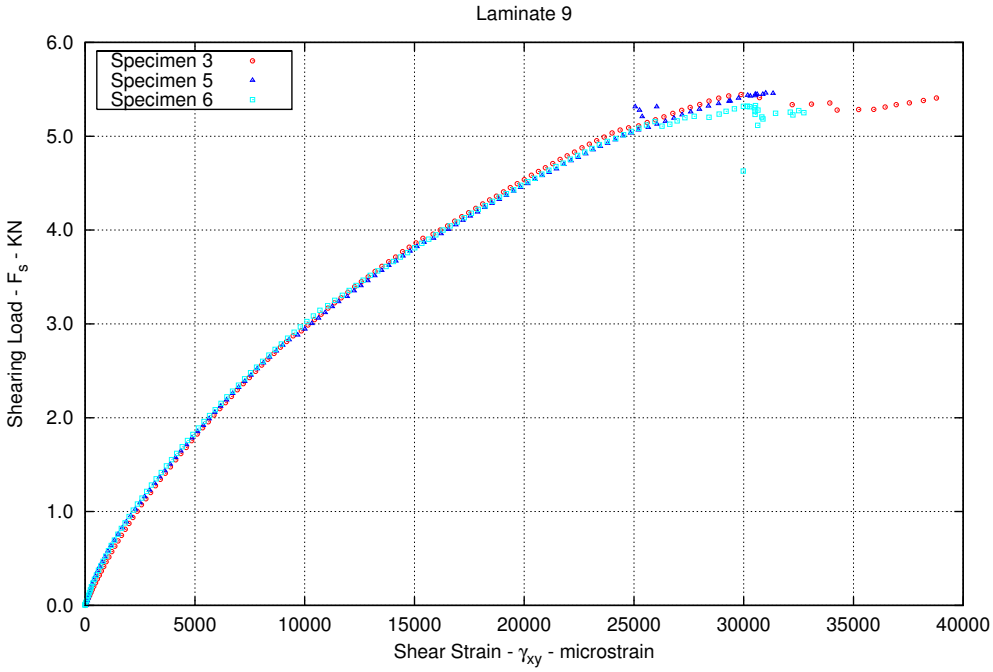


Figure A.96: Laminate 9 shear strain induced with an in-plane shear load.

A.10.5 Interlaminar Shear

Table A.190: Laminate 9 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.9	4.0	6.4	6.4	25	40	Interlaminar Shear
3	3.9	3.8	6.4	6.4	25	40	Interlaminar Shear
4	3.9	3.9	6.4	6.4	25	40	Interlaminar Shear

Table A.191: Laminate 9 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.0	0.0350	0.009	6.4	0.0000	0.000	25.1
3	3.8	0.0566	0.015	6.4	0.0180	0.003	24.4
4	3.9	0.0090	0.002	6.4	0.0000	0.000	24.9

Table A.192: Laminate 9 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	25.1	1754.2	53.0
3	24.4	1645.1	51.4
4	24.9	1646.9	50.2

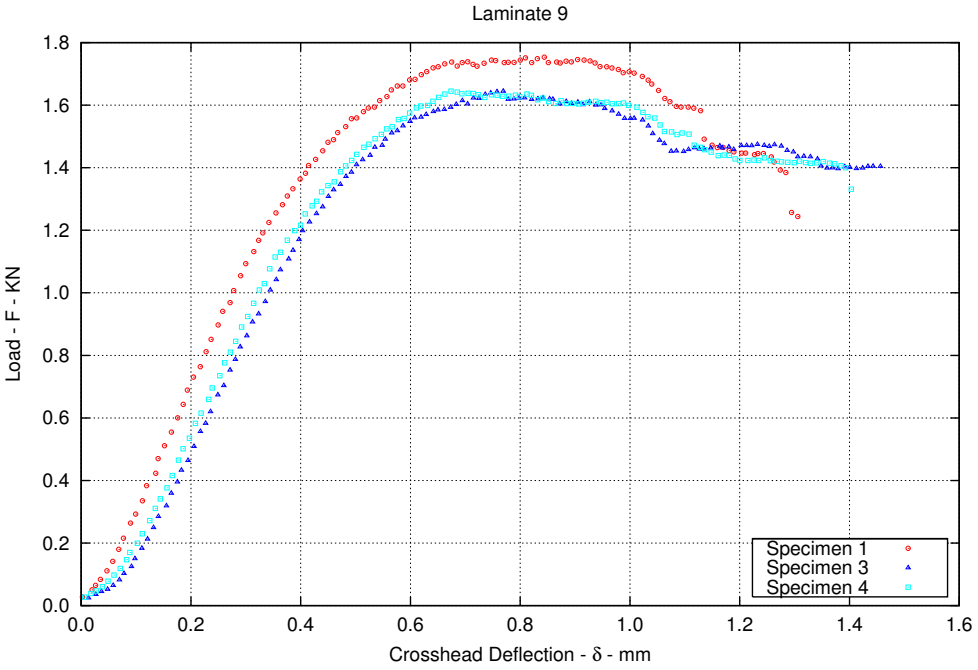
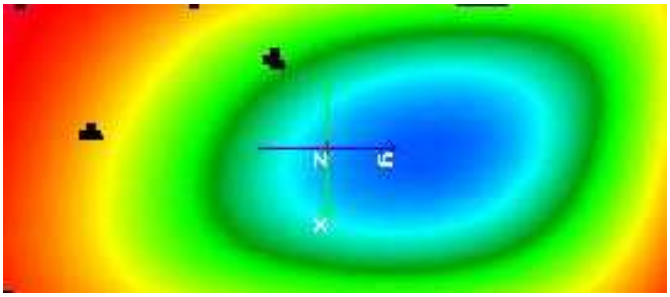
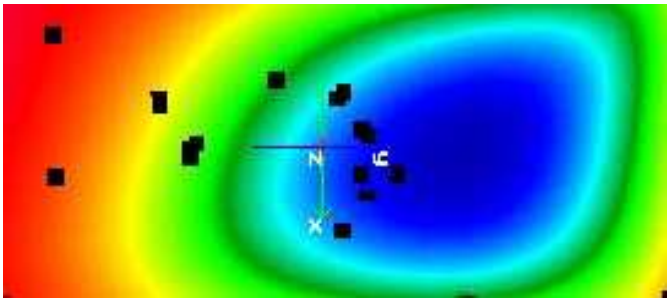


Figure A.97: Laminate 9 interlaminar shear response.

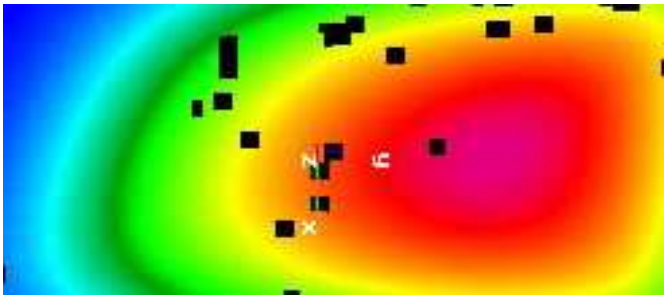
A.10.6 Edgewise Compression



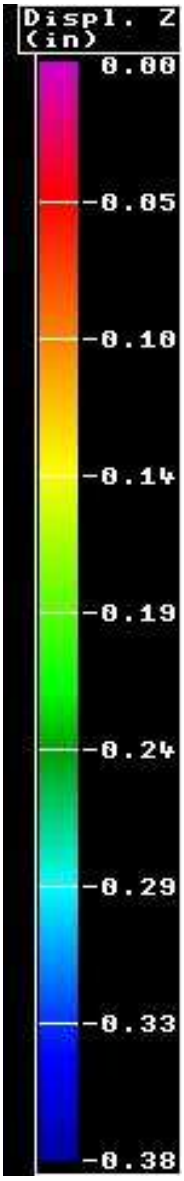
Specimen 1 at 56,755 N



Specimen 2 at 54,606 N

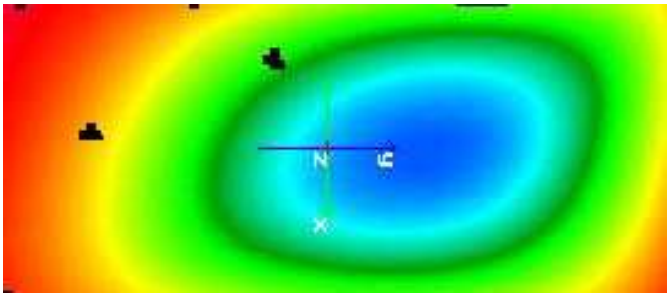


Specimen 3 at 53,410 N

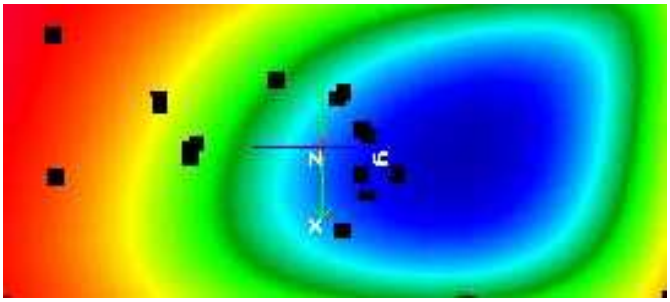


Specimen 1 Specimen 3
Specimen 2

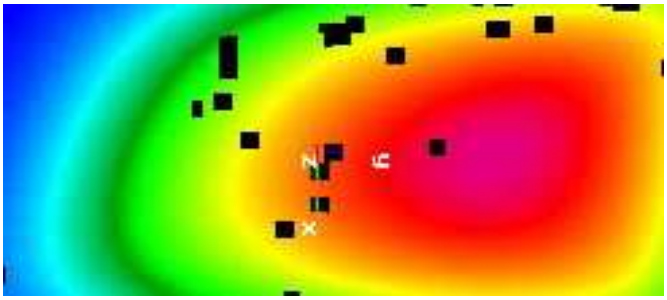
Figure A.98: Laminate 9 out-of-plane displacement due to edgewise compression.



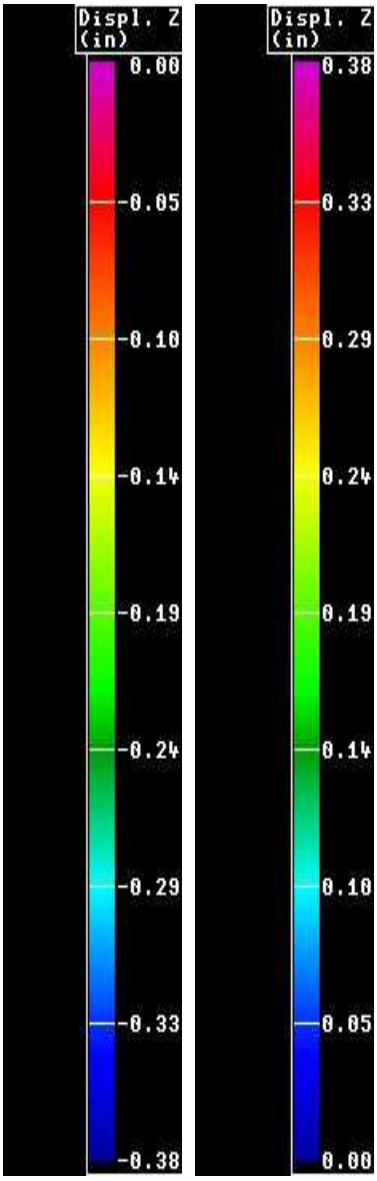
Specimen 1 at 56,755 N



Specimen 2 at 54,606 N

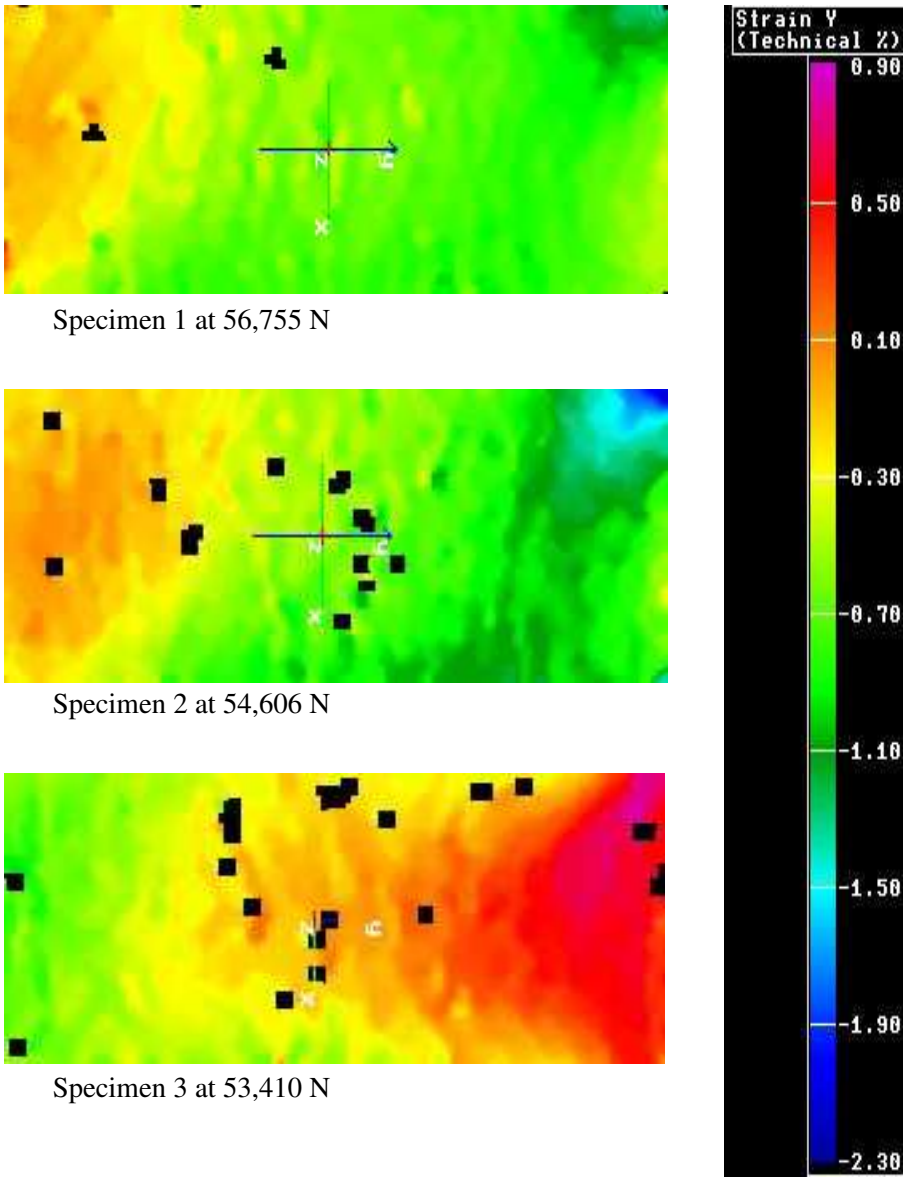


Specimen 3 at 53,410 N



Specimen 1 Specimen 3
Specimen 2

Figure A.99: Laminate 9 axial strain displacement due to edgewise compression.

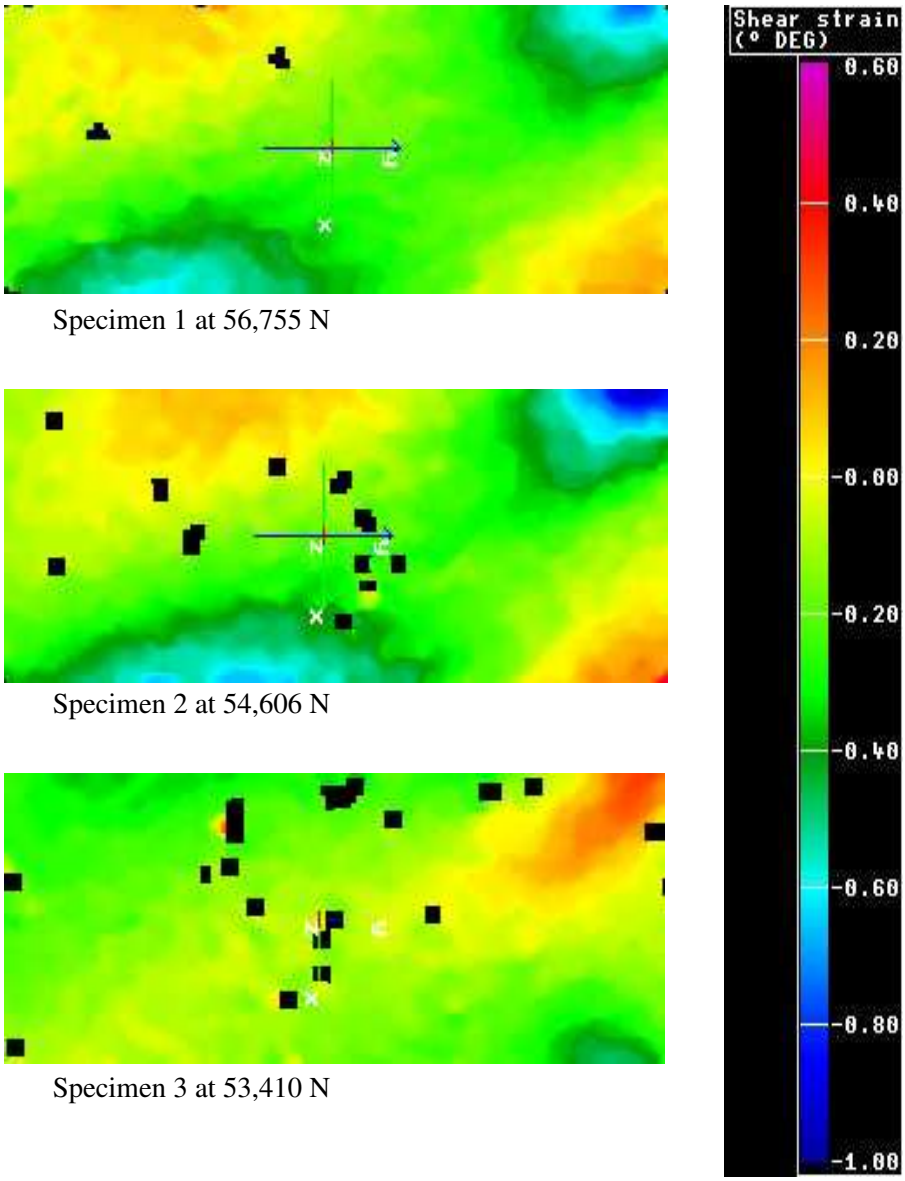


Specimen 1 at 56,755 N

Specimen 2 at 54,606 N

Specimen 3 at 53,410 N

Figure A.100: Laminate 9 transverse strain displacement due to edgewise compression.



Specimen 1 at 56,755 N

Specimen 2 at 54,606 N

Specimen 3 at 53,410 N

Figure A.101: Laminate 9 shear strain displacement due to edgewise compression.

A.11 Laminate 10 - 30CUD/55C10/15GDB - $[\pm 45_{DB}/(10_C)_2/0_C]_s$

A.11.1 Tension 0

Table A.193: Laminate 10 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.3	3.4	3.5	25.5	25.5	25.5	24.4	53	AIT AGM AIB
2	3.6	3.7	3.5	25.5	25.5	25.5	24.4	53	AIT AGM AIB
3	3.5	3.6	3.5	25.5	25.5	25.5	24.4	53	DGM AGM

Table A.194: Laminate 10 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.1278	0.038	25.5	0.0000	0.000	86.5
2	3.6	0.0962	0.027	25.5	0.0000	0.000	91.5
3	3.5	0.0587	0.017	25.5	0.0000	0.000	90.3

Table A.195: Laminate 10 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	93.0	0.999996	0.00019	0.500	0.999365	0.00229
2	87.7	0.999989	0.00030	0.603	0.999751	0.00145
3	85.9	0.999980	0.00042	0.456	0.999967	0.00054

Table A.196: Laminate 10 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	86.5	73,990	855	9,611
2	91.5	74,046	810	10,122
3	90.3	73,493	814	10,256
Average	89.4	73,843	826	9,996
STDEV	2.6	305	25.2	340
CV	0.029	0.004	0.030	0.034

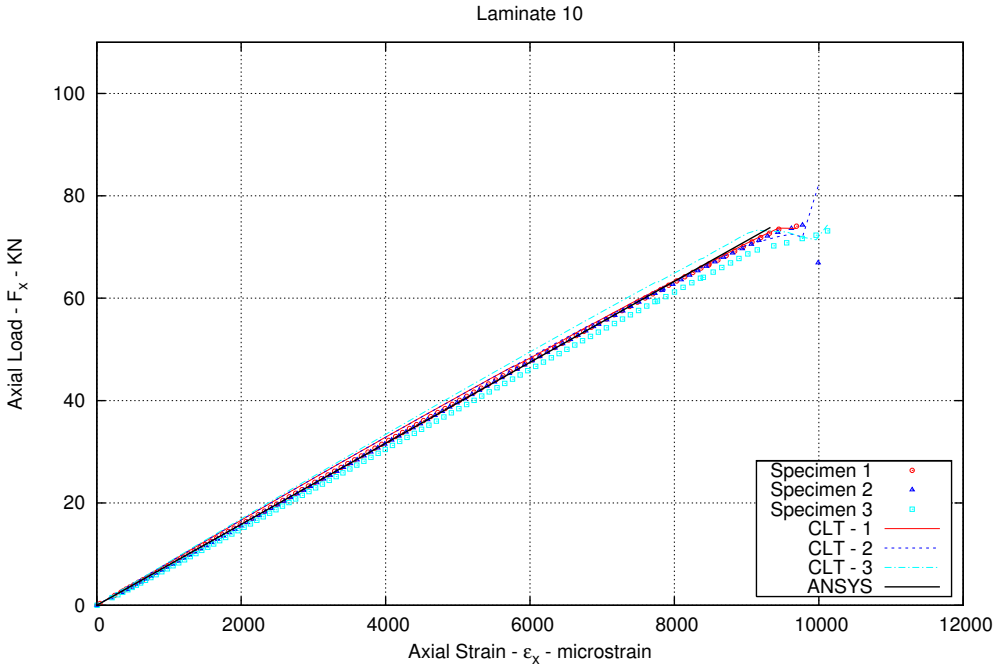


Figure A.102: Laminate 10 axial strain induced with an axial tensile load.

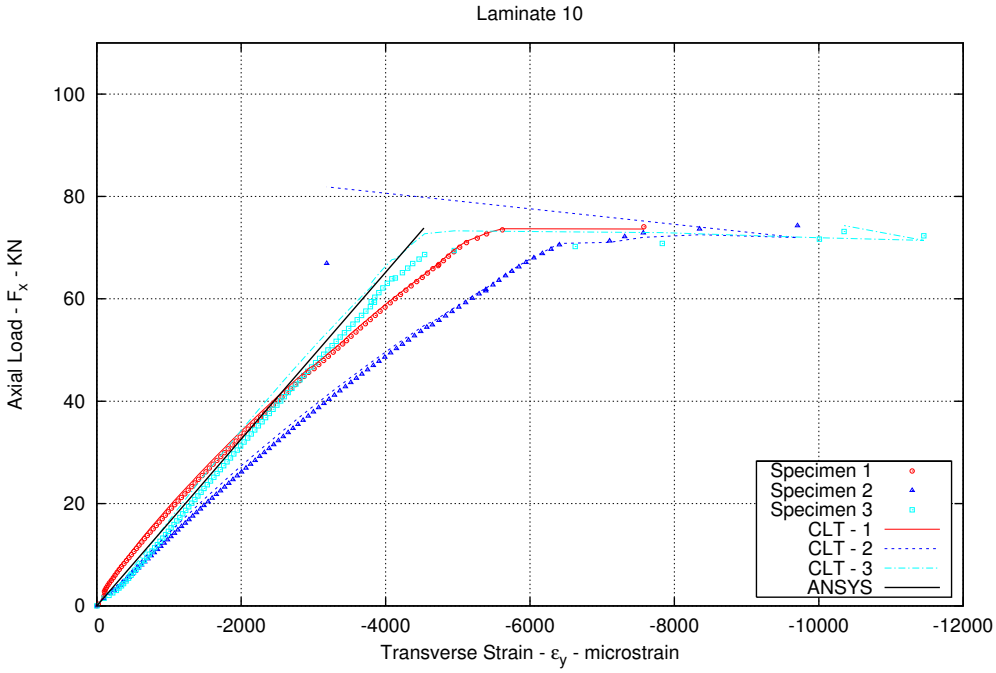


Figure A.103: Laminate 10 transverse strain induced with an axial tensile load.

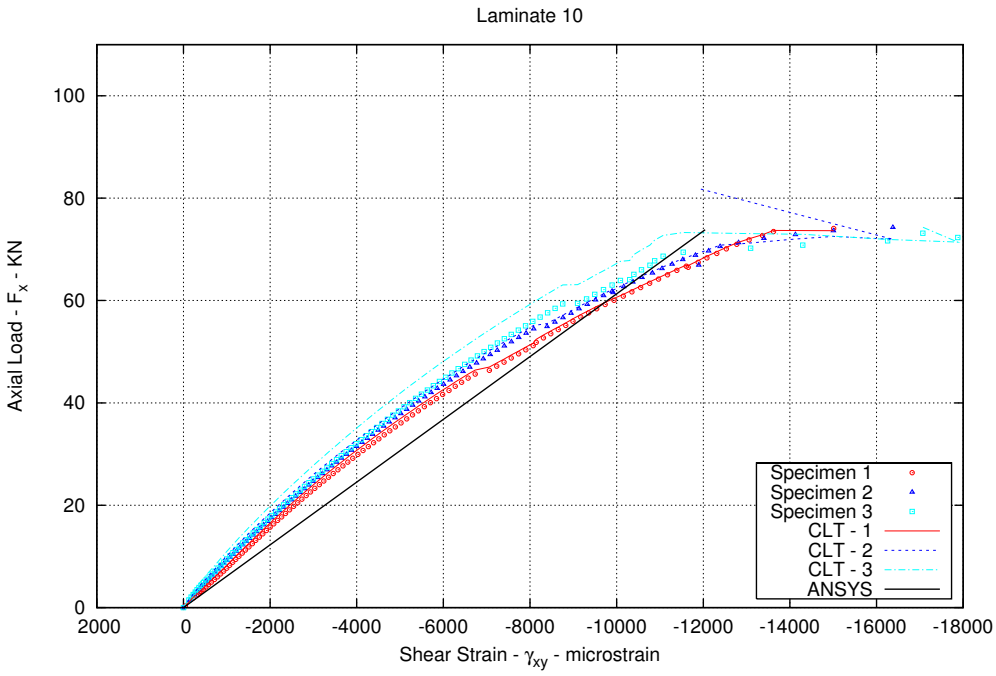


Figure A.104: Laminate 10 shear strain induced with an axial tensile load.

A.11.2 Tenion 90

Table A.197: Laminate 10 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.4	3.4	3.6	25.5	25.5	25.5	25.6	40	DGM
2	3.6	3.5	3.5	25.5	25.5	25.5	25.6	40	DGM XGM
3	3.4	3.5	3.5	25.4	25.4	25.4	25.6	40	DGM XGM

Table A.198: Laminate 10 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0733	0.021	25.5	0.0000	0.000	88.3
2	3.5	0.0254	0.007	25.5	0.0000	0.000	89.9
3	3.4	0.0388	0.011	25.4	0.0000	0.000	87.6

Table A.199: Laminate 10 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	10.2	0.999632	0.00168	0.066	0.904555	0.02838
2	9.7	0.999659	0.00188	0.061	0.916322	0.03084
3	10.2	0.999746	0.00174	0.070	0.929733	0.03000

Table A.200: Laminate 10 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	88.3	4,678	104	5,369
2	89.9	4,692	107	5,641
3	87.6	4,484	96.5	5,226
Average	88.6	4,618	103	5,412
STDEV	1.2	116	5.6	211
CV	0.013	0.025	0.054	0.039

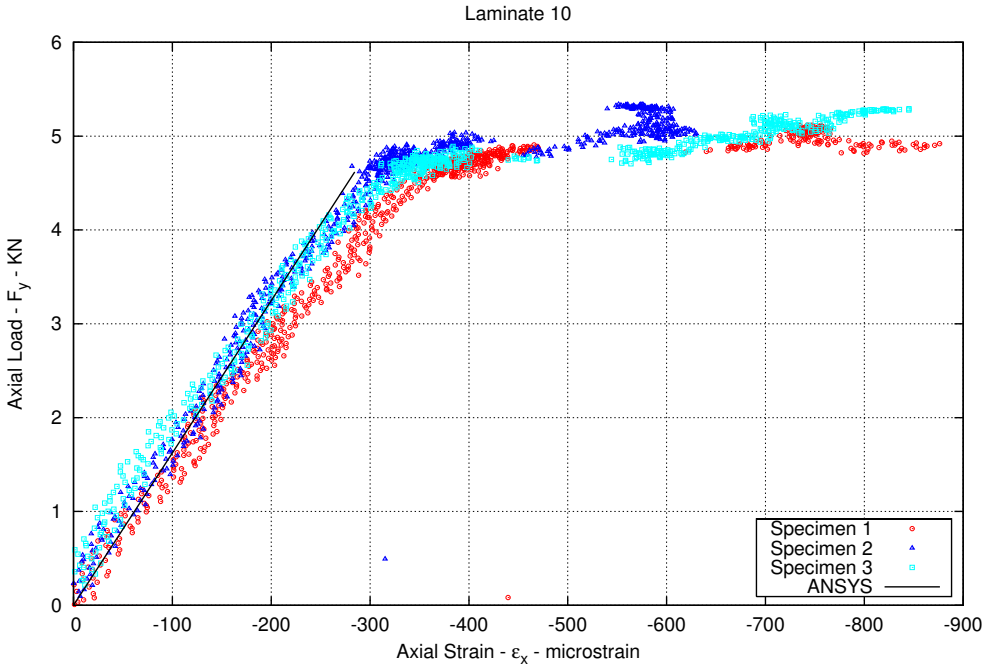


Figure A.105: Laminate 10 axial strain induced with a transverse tensile load.

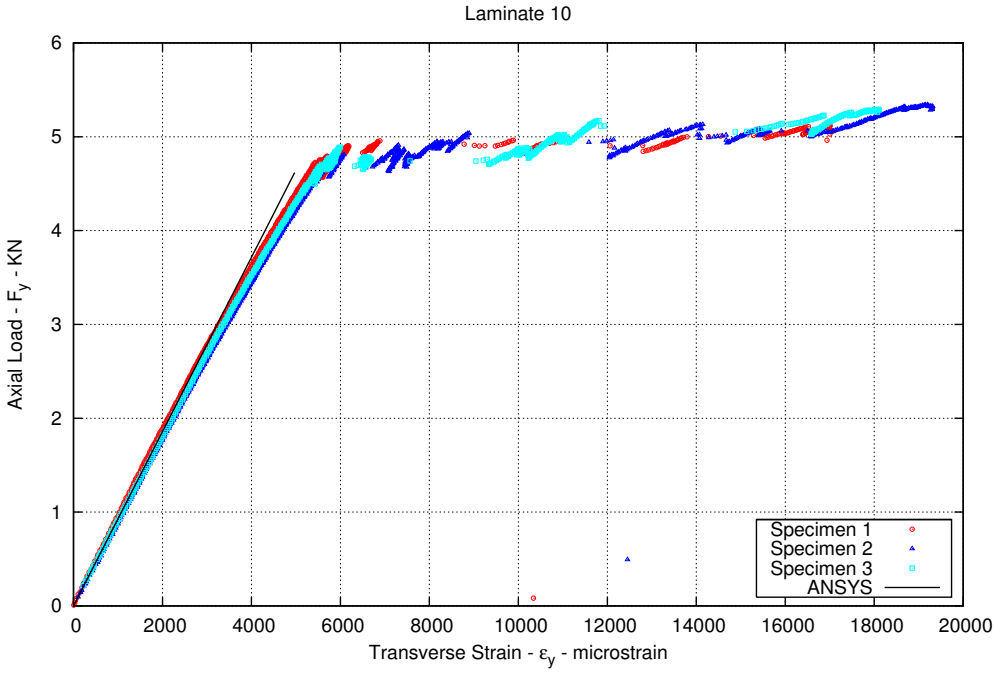


Figure A.106: Laminate 10 transverse strain induced with a transverse tensile load.

A.11.3 Compression

Table A.201: Laminate 10 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.4	3.5	12.6	12.6	23.9
2	3.5	3.4	12.7	12.7	23.9
3	3.4	3.6	12.7	12.7	23.9

Table A.202: Laminate 10 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0898	0.026	12.6	0.0000	0.000	43.9
2	3.5	0.0359	0.010	12.7	0.0000	0.000	43.8
3	3.5	0.1437	0.041	12.7	0.0000	0.000	44.7

Table A.203: Laminate 10 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	112.2	0.999971	0.00045
2	91.1	0.999884	0.00100
3	85.6	0.999896	0.00097

Table A.204: Laminate 10 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.5	3.6	12.7	12.7	23.9	25	TAT
2	3.4	3.4	12.7	12.7	23.9	25	TAT
3	3.6	3.7	12.7	12.7	23.9	25	TAT

Table A.205: Laminate 10 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.5	0.0494	0.014	12.7	0.0000	0.000	45.0
2	3.4	0.0009	0.000	12.7	0.0000	0.000	43.7
3	3.7	0.0108	0.003	12.7	0.0000	0.000	46.5

Table A.206: Laminate 10 compression failure allowables.

Specimen	Area (mm^2)	Load (lbf)	Stress (MPa)	Strain $(\mu strain)$
1	45.0	34,324	763	7,925
2	43.7	34,448	789	8,192
3	46.5	35,474	764	7,931
Average	45.0	34,749	772	8,016
STDEV	1.4	631	14.7	152
CV	0.031	0.018	0.019	0.019

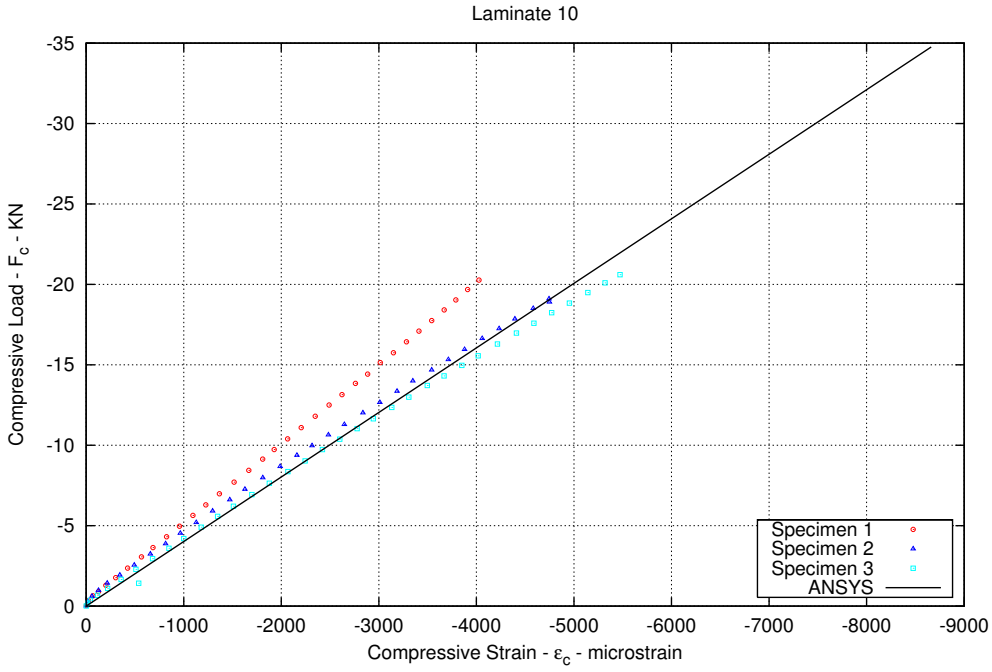


Figure A.107: Laminate 10 axial strain induced with an axial compressive load.

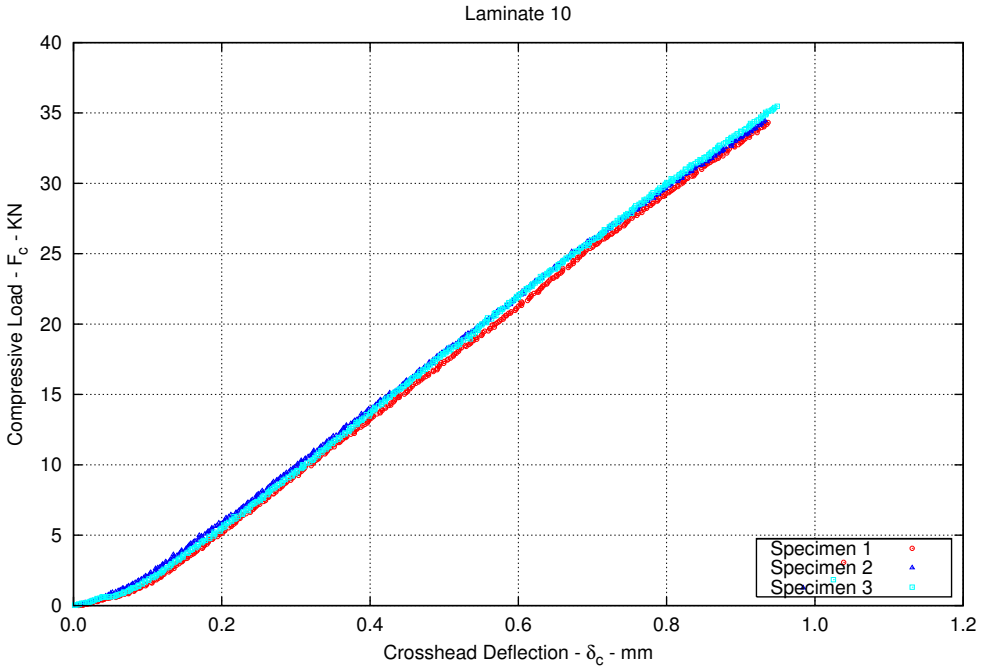


Figure A.108: Response of Laminate 10 to compressive loading.

A.11.4 In-Plane Shear

Table A.207: Laminate 10 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.4	11.5	11.5	23.3	31	null
2	3.4	3.3	11.5	11.5	23.3	31	null
3	3.4	3.3	11.5	11.5	23.3	31	null

Table A.208: Laminate 10 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.1616	0.047	11.5	0.0180	0.002	39.8
2	3.4	0.0718	0.021	11.5	0.0000	0.000	38.9
3	3.4	0.0718	0.021	11.5	0.0000	0.000	38.9

Table A.209: Laminate 10 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	6.5	0.9979	0.0050
2	6.6	0.9967	0.0062
3	7.1	0.9971	0.0053

Table A.210: Laminate 10 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	39.8	4,725	119	27,601
2	38.9	4,982	128	31,811
3	38.9	5,077	131	34,992
Average	39.2	4928	126	31,468
STDEV	0.6	182	6.4	3,707
CV	0.014	0.037	0.051	0.118

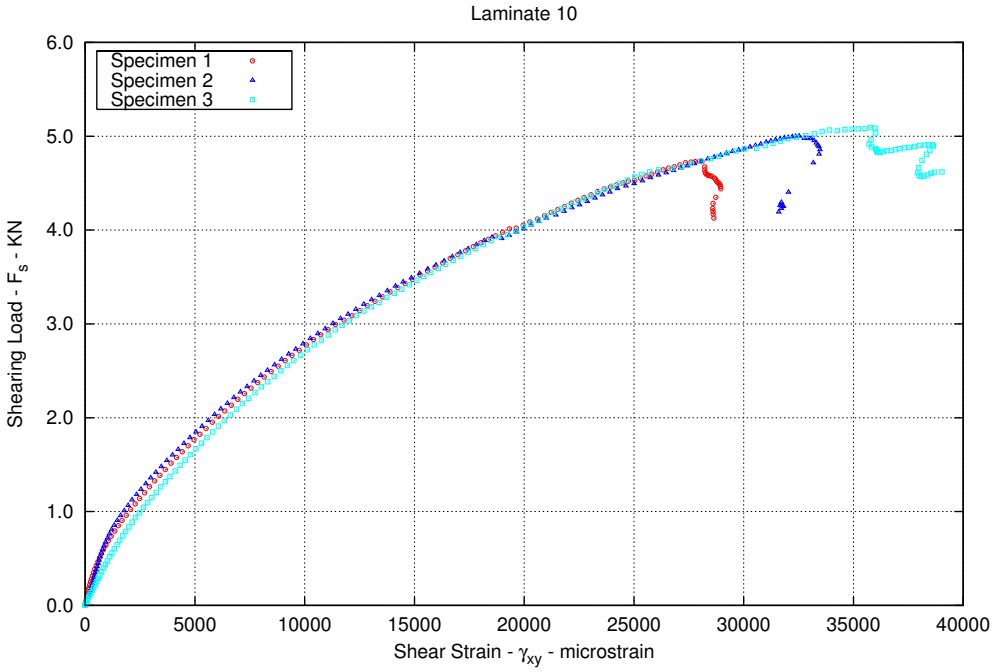


Figure A.109: Laminate 10 shear strain induced with an in-plane shear load.

A.11.5 Interlaminar Shear

Table A.211: Laminate 10 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.6	6.4	6.3	24.4	40	Interlaminar Shear
2	3.6	3.6	6.4	6.4	24.4	40	Interlaminar Shear
4	3.5	3.5	6.4	6.4	24.4	40	Interlaminar Shear

Table A.212: Laminate 10 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0817	0.023	6.3	0.0090	0.001	22.6
2	3.6	0.0108	0.003	6.4	0.0000	0.000	22.8
4	3.5	0.0099	0.003	6.4	0.0090	0.001	22.2

Table A.213: Laminate 10 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.6	1633.1	55.0
2	22.8	1589.4	53.1
4	22.2	1591.0	54.6

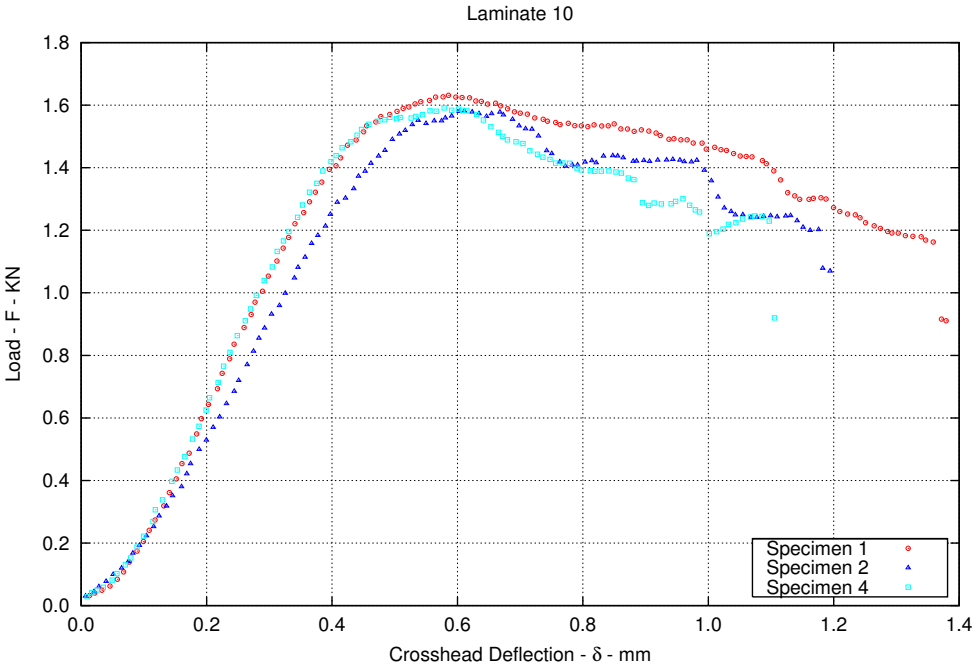
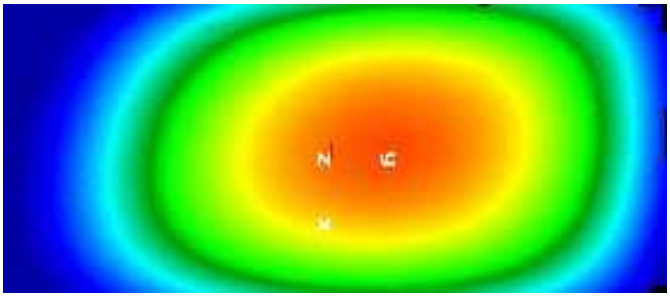
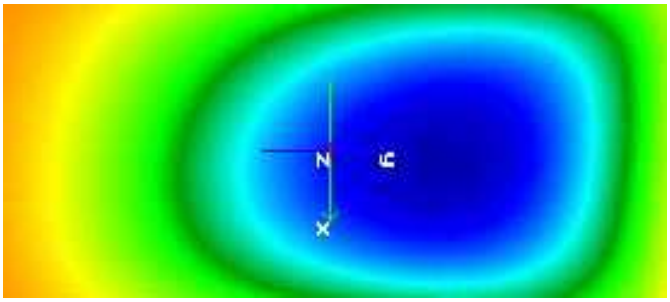


Figure A.110: Laminate 10 interlaminar shear response.

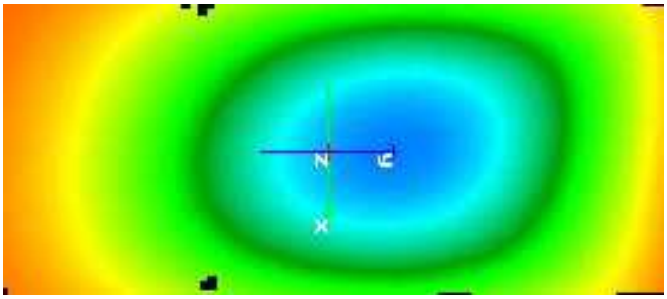
A.11.6 Edgewise Compression



Specimen 1 at 80,655 N

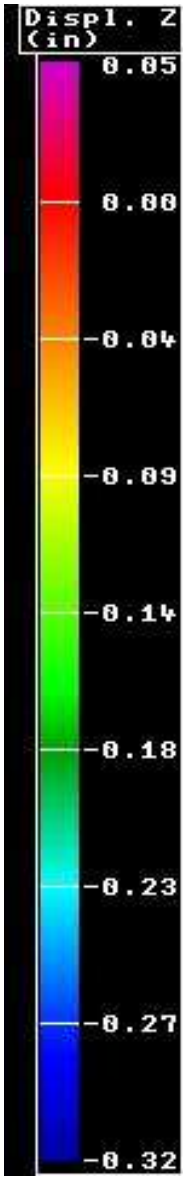


Specimen 2 at 61,296 N



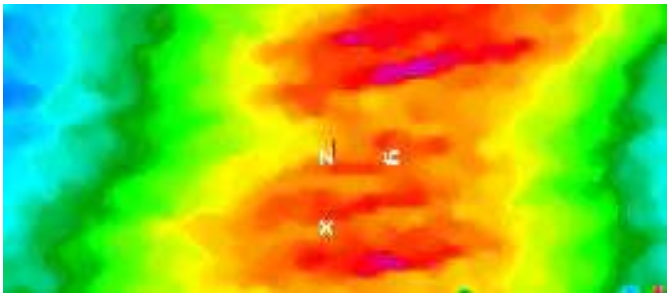
Specimen 3 at 66,554 N

Specimen 1

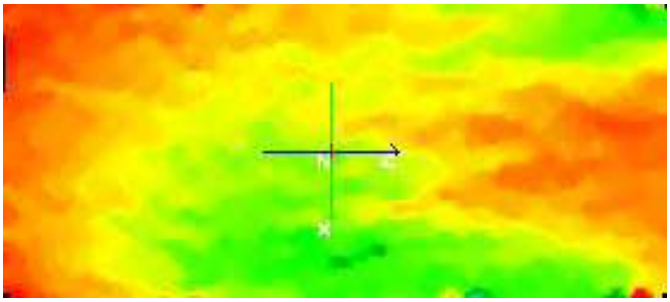


Specimen 2
Specimen 3

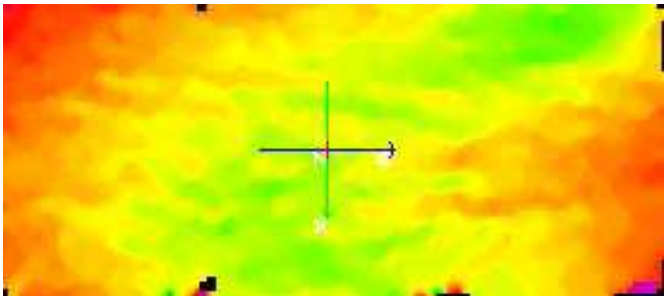
Figure A.111: Laminate 10 out-of-plane displacement due to edgewise compression.



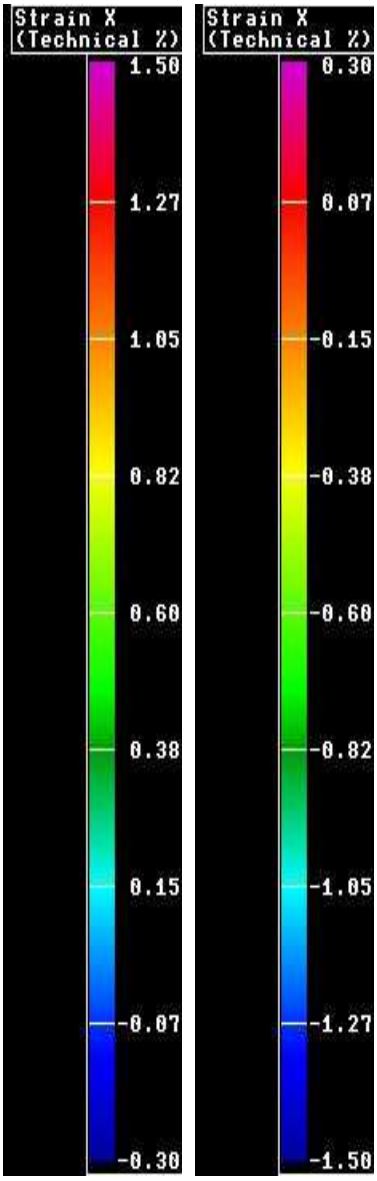
Specimen 1 at 80,655 N



Specimen 2 at 61,296 N



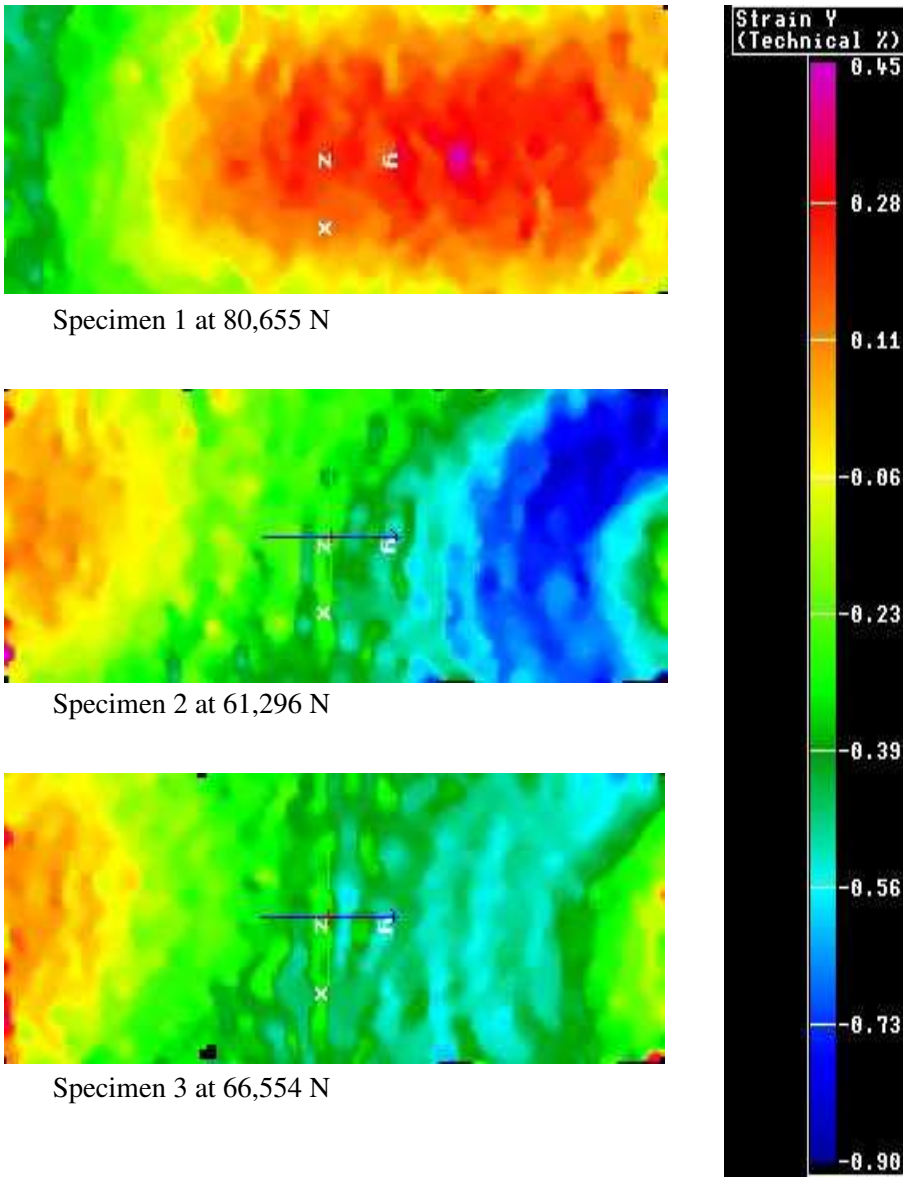
Specimen 3 at 66,554 N



Specimen 1

Specimen 2
Specimen 3

Figure A.112: Laminate 10 axial strain displacement due to edgewise compression.

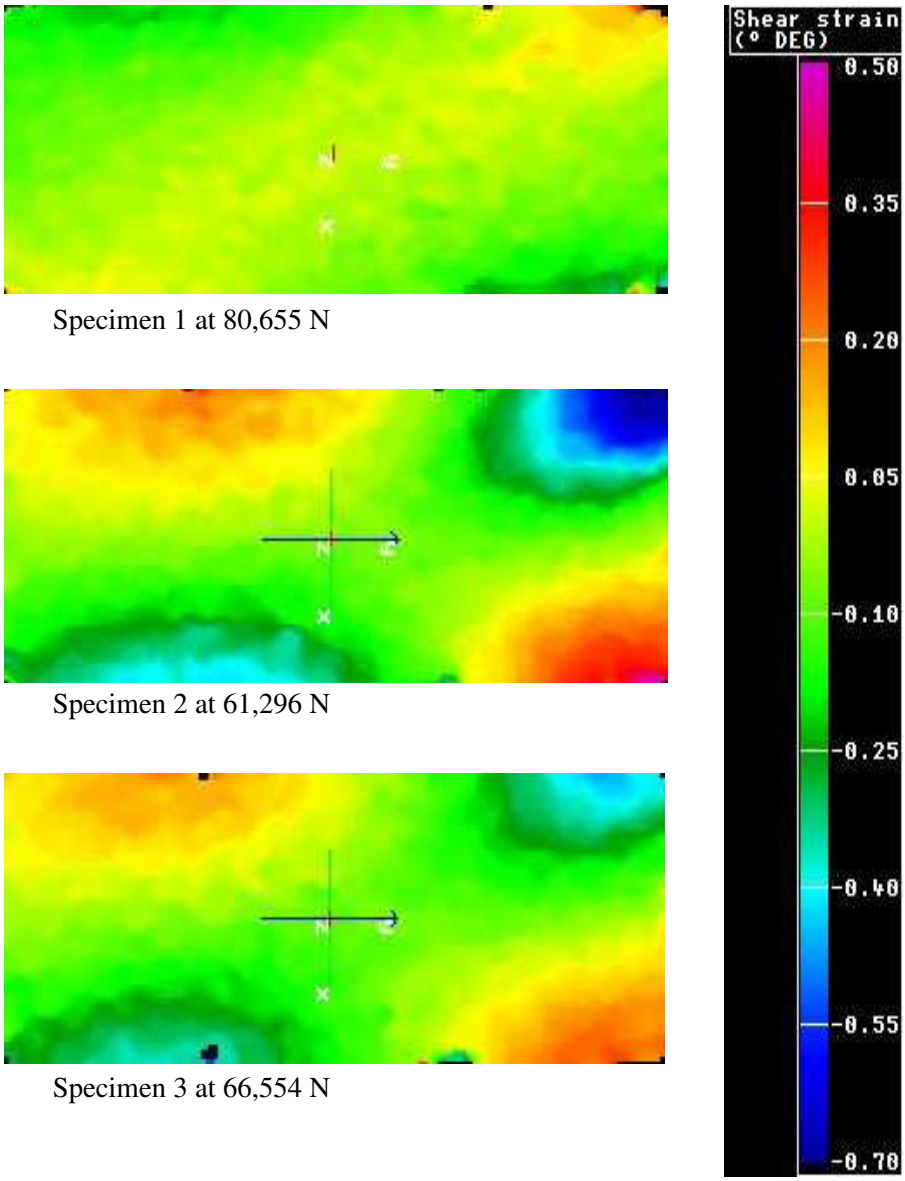


Specimen 1 at 80,655 N

Specimen 2 at 61,296 N

Specimen 3 at 66,554 N

Figure A.113: Laminate 10 transverse strain displacement due to edgewise compression.



Specimen 1 at 80,655 N

Specimen 2 at 61,296 N

Specimen 3 at 66,554 N

Figure A.114: Laminate 10 shear strain displacement due to edgewise compression.

A.12 Laminate 11 - 30CUD/55C15/15GDB - $[\pm 45_{DB}/(15_C)_2/0_C]_s$

A.12.1 Tension 0

Table A.214: Laminate 11 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.7	3.8	3.8	25.5	25.5	25.5	24.4	55	AGM XGM
2	3.5	3.5	3.6	25.5	25.5	25.5	24.4	55	AIB AWB AGB
3	3.4	3.6	3.7	25.5	25.5	25.5	24.4	55	AIT AWT AGT

Table A.215: Laminate 11 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.0639	0.017	25.5	0.0000	0.000	95.6
2	3.5	0.0529	0.015	25.5	0.0000	0.000	89.4
3	3.6	0.1666	0.047	25.5	0.0000	0.000	91.1

Table A.216: Laminate 11 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	66.6	0.999995	0.00022	0.610	0.999887	0.00107
2	72.5	0.999986	0.00037	0.576	0.999898	0.00100
3	71.6	0.999991	0.00030	0.536	0.999654	0.00184

Table A.217: Laminate 11 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	95.6	73,681	770	13,058
2	89.4	71,196	796	13,881
3	91.1	74,679	819	13,001
Average	92.1	73,186	795	13,313
STDEV	3.2	1,794	24.5	492
CV	0.035	0.025	0.031	0.037

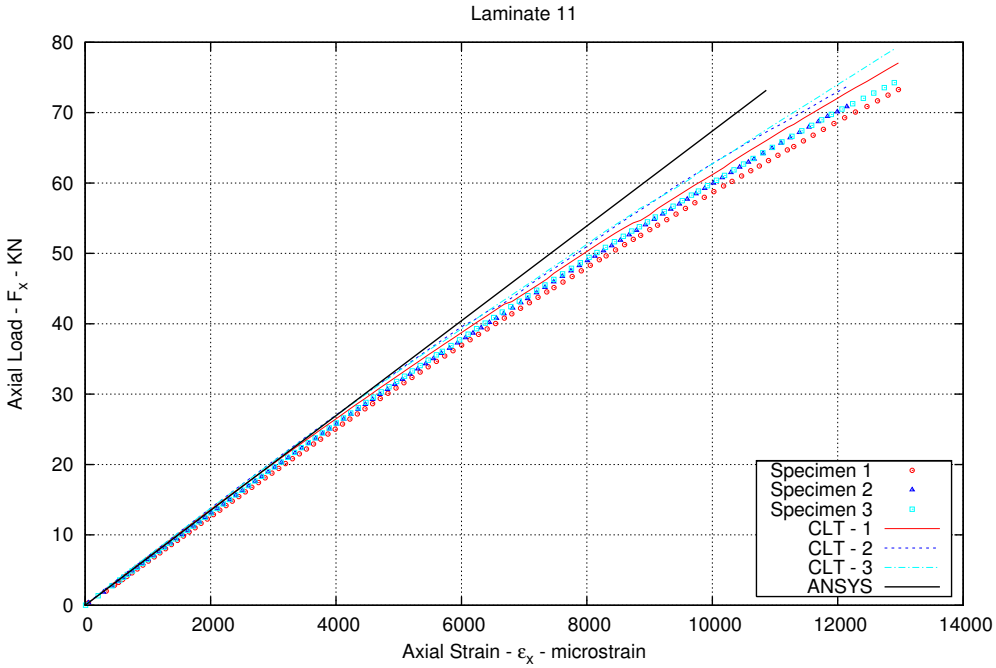


Figure A.115: Laminate 11 axial strain induced with an axial tensile load.

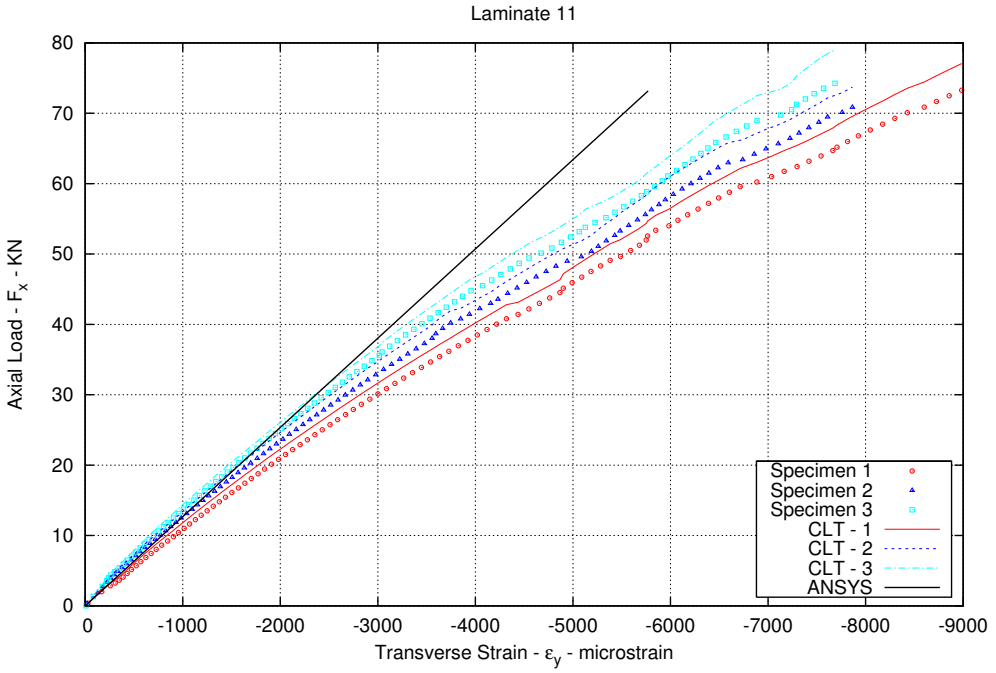


Figure A.116: Laminate 11 transverse strain induced with an axial tensile load.

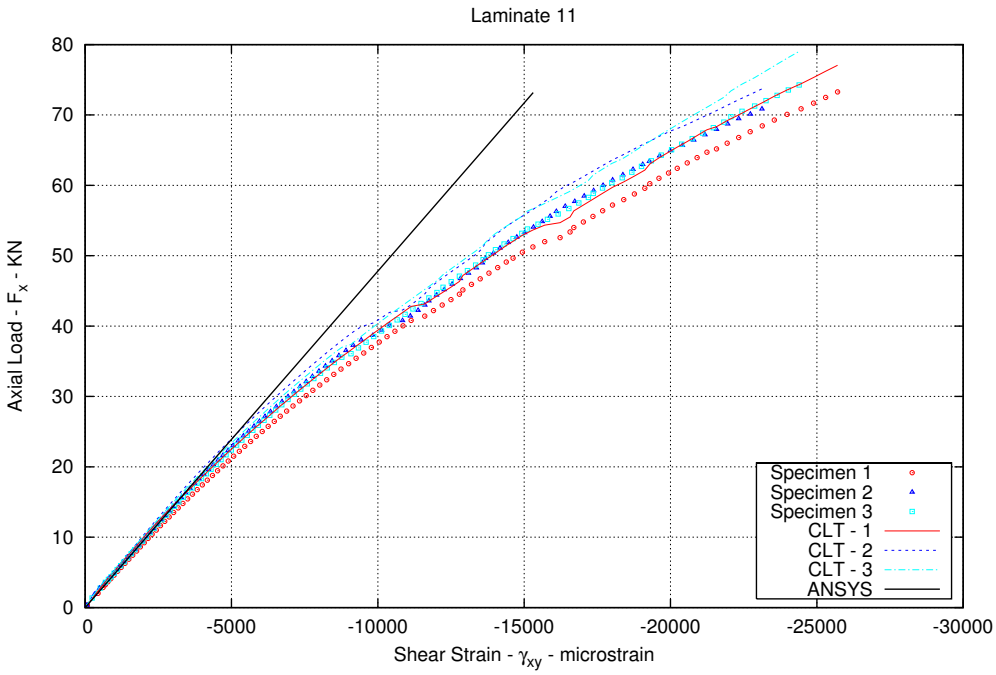


Figure A.117: Laminate 11 shear strain induced with an axial tensile load.

A.12.2 Tenion 90

Table A.218: Laminate 11 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.7	3.6	3.7	25.5	25.5	25.5	22.8	35	LWT
2	3.6	3.5	3.5	25.5	25.5	25.5	22.8	35	AWT
3	3.4	3.6	3.6	25.5	25.5	25.5	22.8	35	AGM
4	3.6	3.7	3.7	25.5	25.5	25.5	22.8	35	AGM

Table A.219: Laminate 11 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.0254	0.007	25.5	0.0000	0.000	93.3
2	3.6	0.0587	0.016	25.5	0.0000	0.000	90.8
3	3.5	0.1027	0.029	25.5	0.0000	0.000	90.5
4	3.6	0.0529	0.015	25.5	0.0000	0.000	92.8

Table A.220: Laminate 11 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	9.9	0.999895	0.00124	0.066	0.996069	0.00762
2	10.4	0.999827	0.00158	0.079	0.995811	0.00781
3	10.4	0.999852	0.00147	0.015	0.920560	0.03536
4	1.1	0.534087	0.33022	0.416	0.082548	1.17868

Table A.221: Laminate 11 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	93.3	5,054	54.2	13,058
2	90.8	4,945	54.5	13,881
3	90.5	5,236	57.9	13,001
Average	91.5	5,079	55.5	13,313
STDEV	1.5	147	2.1	492
CV	0.017	0.029	0.037	0.037

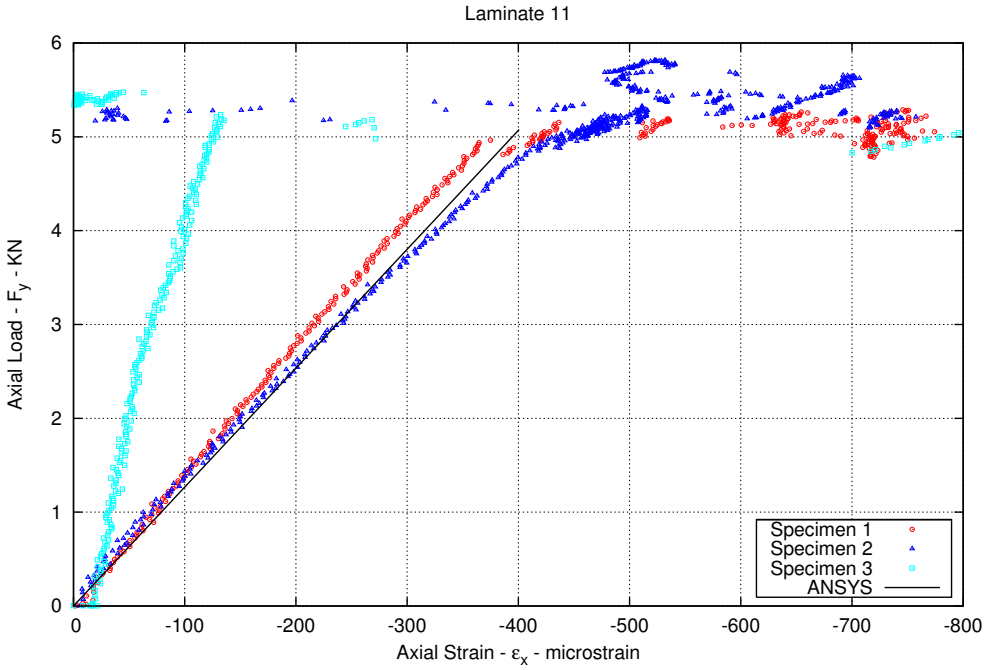


Figure A.118: Laminate 11 axial strain induced with a transverse tensile load.

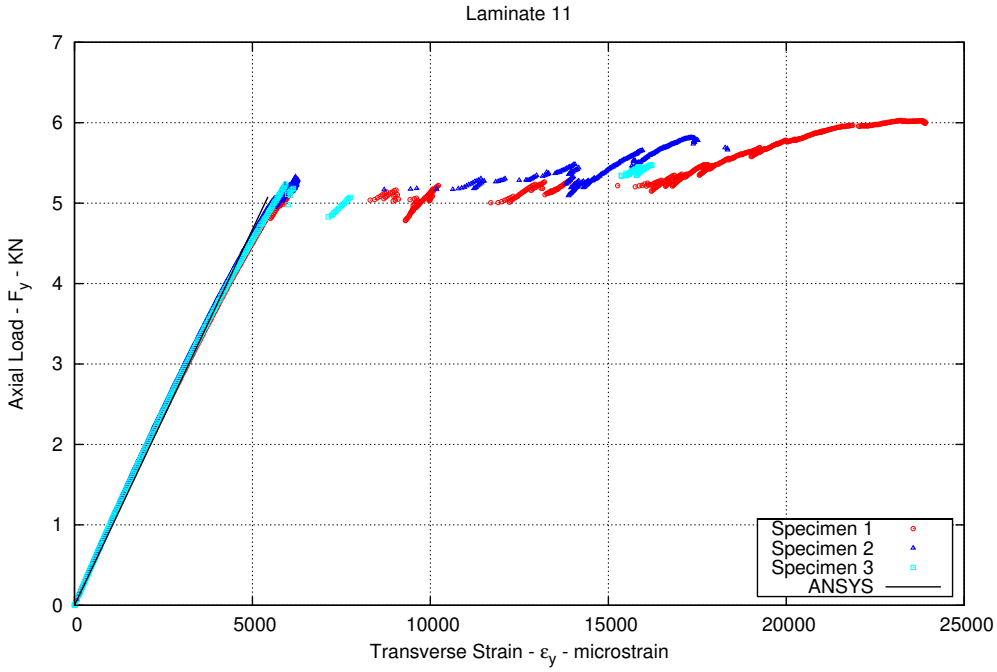


Figure A.119: Laminate 11 transverse strain induced with a transverse tensile load.

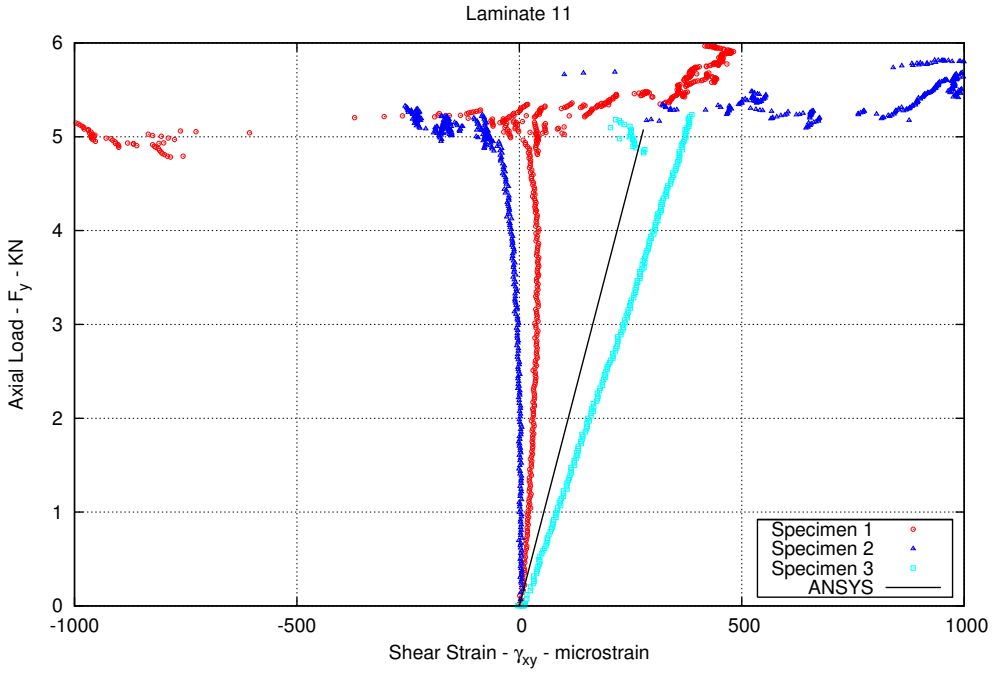


Figure A.120: Laminate 11 shear strain induced with a transverse tensile load.

A.12.3 Compression

Table A.222: Laminate 11 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.7	3.7	12.8	12.8	23.9
2	3.6	3.5	12.8	12.8	23.9
3	3.6	3.5	12.8	12.8	23.9

Table A.223: Laminate 11 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.7	0.0180	0.005	12.8	0.0000	0.000	47.1
2	3.6	0.0359	0.010	12.8	0.0000	0.000	45.3
3	3.5	0.0359	0.010	12.8	0.0000	0.000	45.0

Table A.224: Laminate 11 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	65.7	0.999745	0.00157
2	72.0	0.999823	0.00128
3	70.3	0.999843	0.00120

Table A.225: Laminate 11 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	12.8	12.8	23.9	25	TAT
2	3.5	3.5	12.8	12.8	23.9	25	TAT
3	3.5	3.5	12.8	12.8	23.9	25	TAT

Table A.226: Laminate 11 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.6	0.0063	0.002	12.8	0.0000	0.000	45.7
2	3.5	0.0126	0.004	12.8	0.0000	0.000	44.5
3	3.5	0.0198	0.006	12.8	0.0000	0.000	44.5

Table A.227: Laminate 11 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	45.7	27,786	608	8,770
2	44.5	28,050	631	9,099
3	44.5	26,909	604	8,718
Average	44.9	27,582	614	8,862
STDEV	0.7	597	14.3	206
CV	0.015	0.022	0.023	0.023

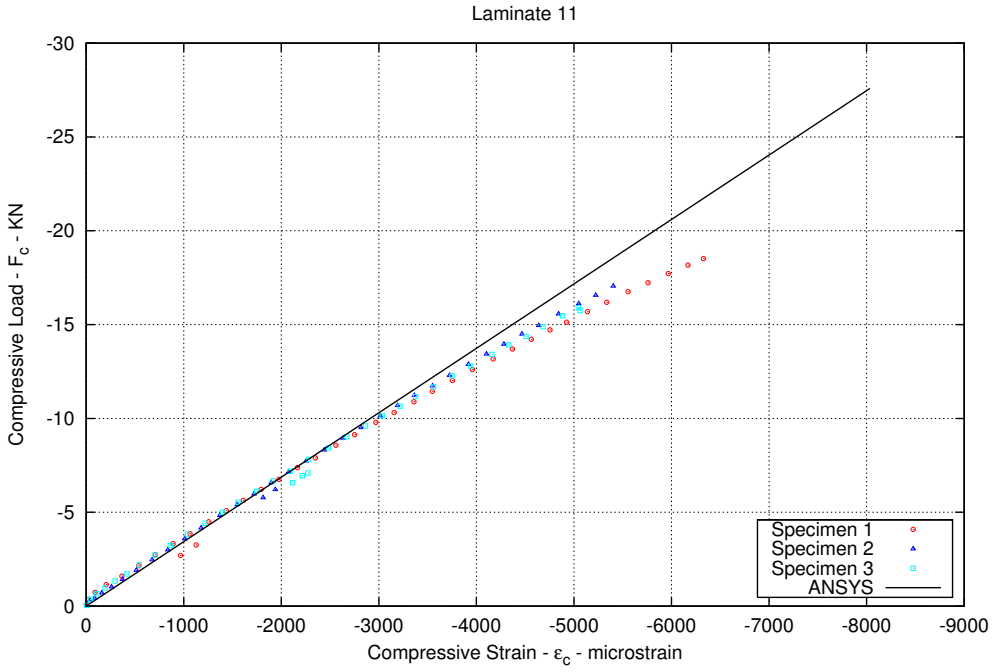


Figure A.121: Laminate 11 axial strain induced with an axial compressive load.

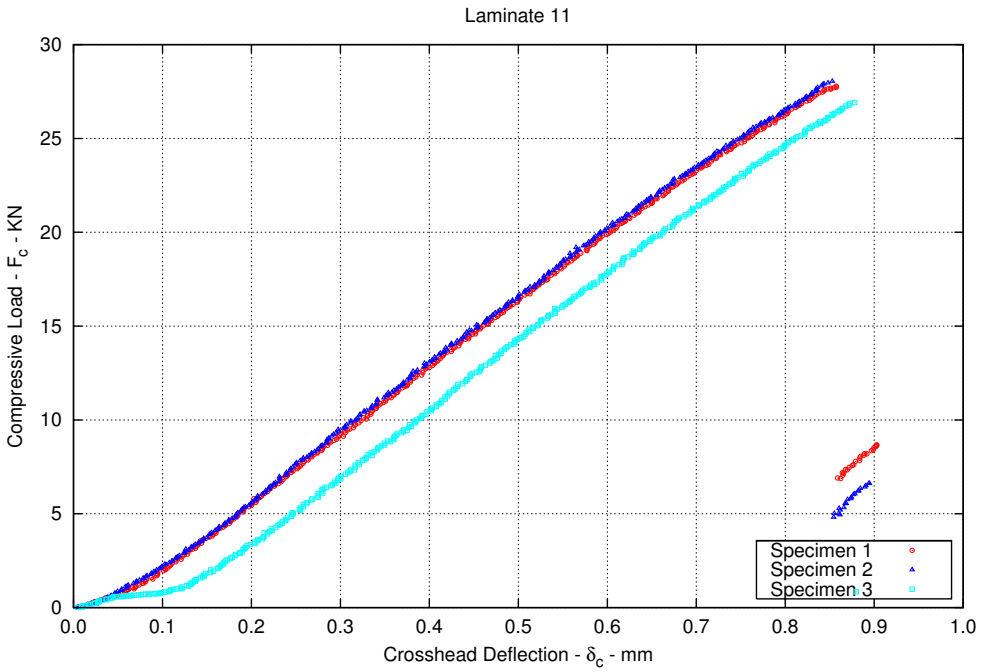


Figure A.122: Response of Laminate 11 to compressive loading.

A.12.4 In-Plane Shear

Table A.228: Laminate 11 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.6	11.4	11.5	23.9	61	null
2	3.8	3.5	11.5	11.5	23.9	61	null
3	3.6	3.5	11.5	11.5	23.9	61	null

Table A.229: Laminate 11 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0539	0.015	11.4	0.0180	0.002	41.1
2	3.6	0.1616	0.044	11.5	0.0000	0.000	41.8
3	3.6	0.0718	0.020	11.5	0.0000	0.000	41.1

Table A.230: Laminate 11 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	7.3	0.9976	0.0051
2	7.2	0.9977	0.0052
3	8.1	0.9920	0.0086

Table A.231: Laminate 11 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	41.1	5,558	135	26,809
2	41.8	5,428	130	26,317
3	41.1	5,174	126	25,584
Average	41.3	5,387	130	26,237
STDEV	0.4	196	4.7	616
CV	0.009	0.036	0.036	0.023

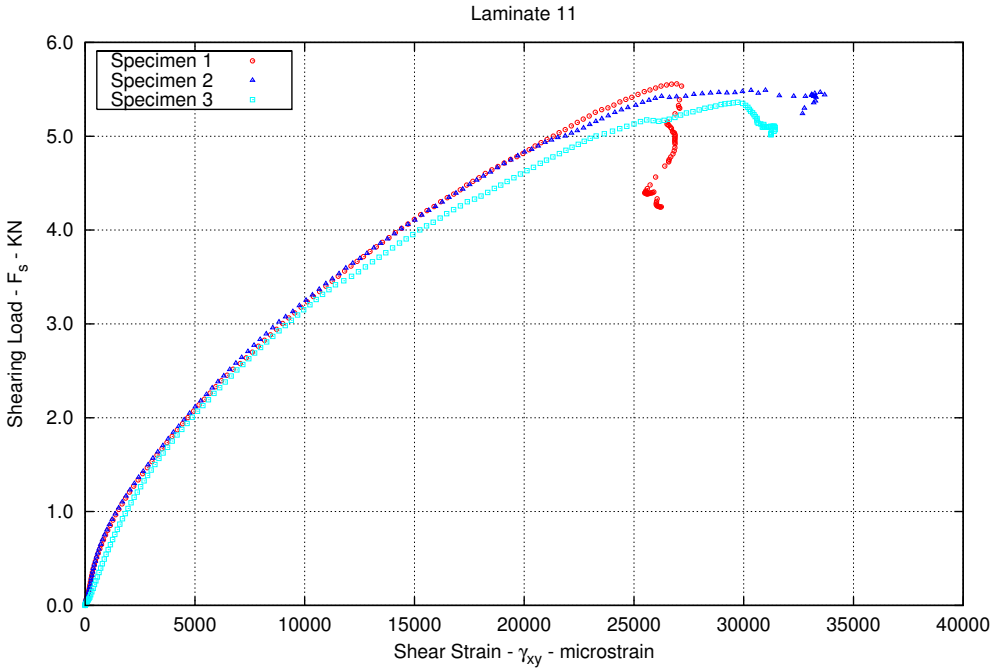


Figure A.123: Laminate 11 shear strain induced with an in-plane shear load.

A.12.5 Interlaminar Shear

Table A.232: Laminate 11 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.7	6.4	6.4	24.4	40	Interlaminar Shear
2	3.6	3.5	6.3	6.3	24.4	40	Interlaminar Shear
4	3.6	3.6	6.4	6.4	24.4	40	Interlaminar Shear

Table A.233: Laminate 11 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0135	0.004	6.4	0.0000	0.000	23.1
2	3.5	0.0629	0.018	6.3	0.0000	0.000	22.4
4	3.6	0.0233	0.006	6.4	0.0090	0.001	22.9

Table A.234: Laminate 11 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	23.1	1645.4	54.1
2	22.4	1507.2	51.1
4	22.9	1622.8	54.0

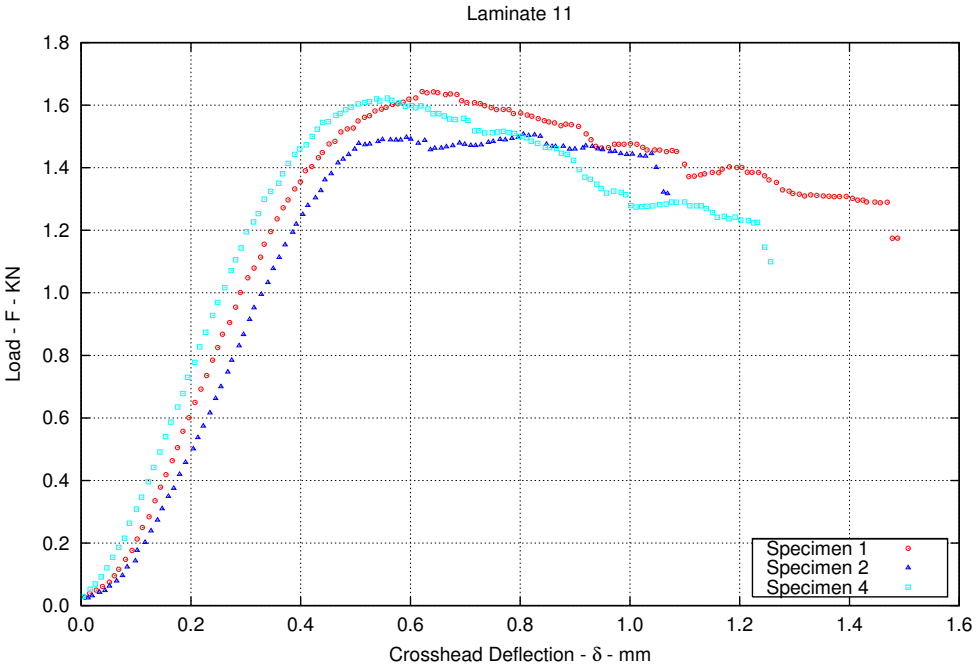
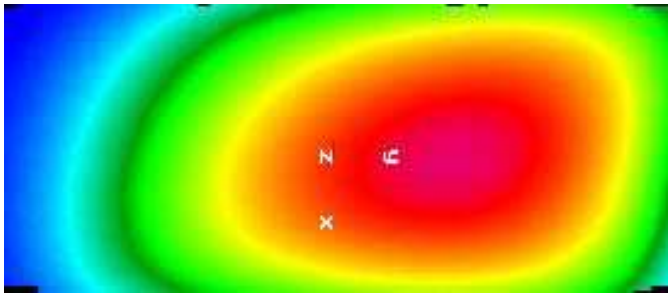
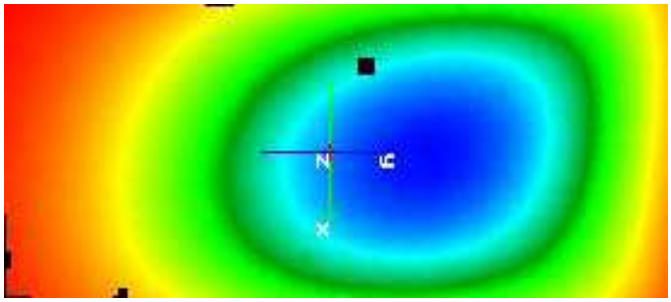


Figure A.124: Laminate 11 interlaminar shear response.

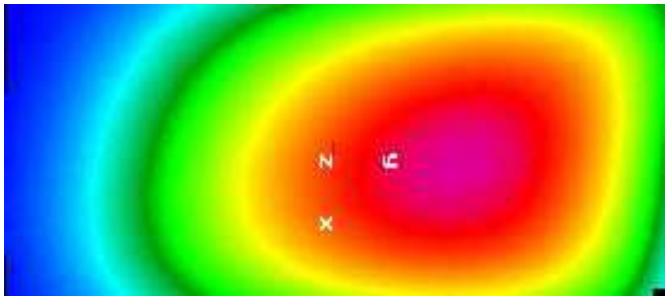
A.12.6 Edgewise Compression



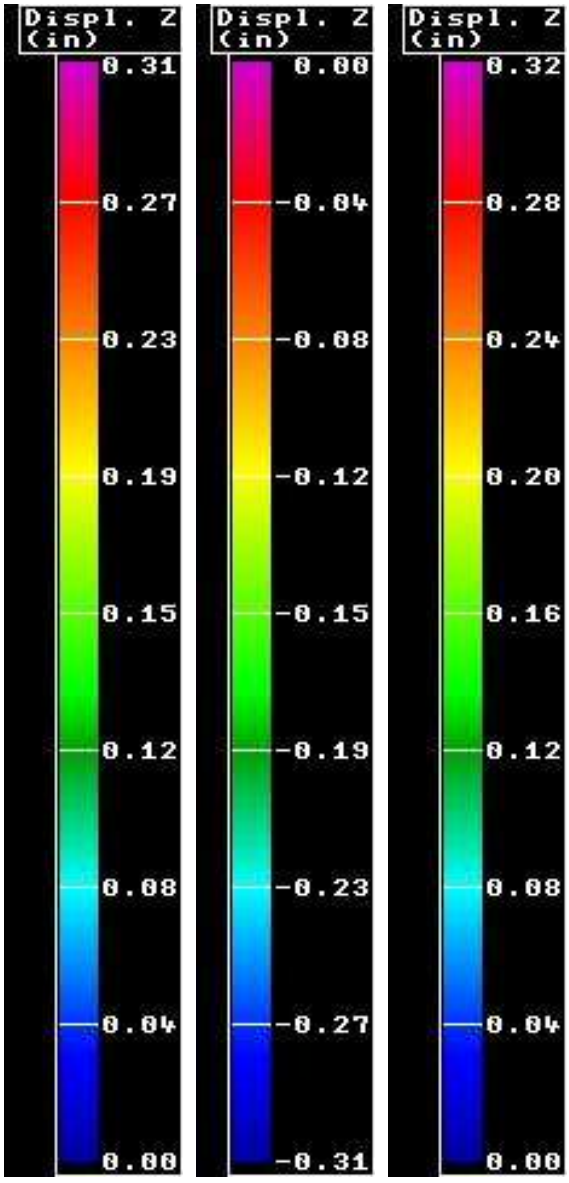
Specimen 1 at 70,616 N



Specimen 2 at 64,166 N

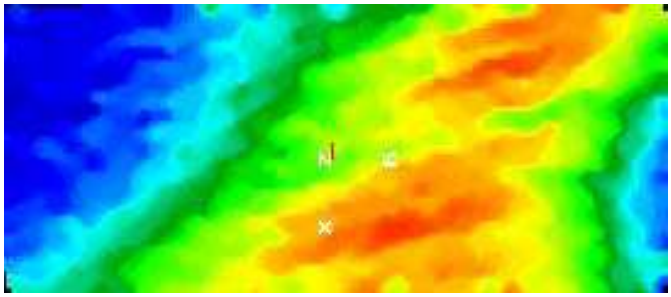


Specimen 3 at 59,624 N

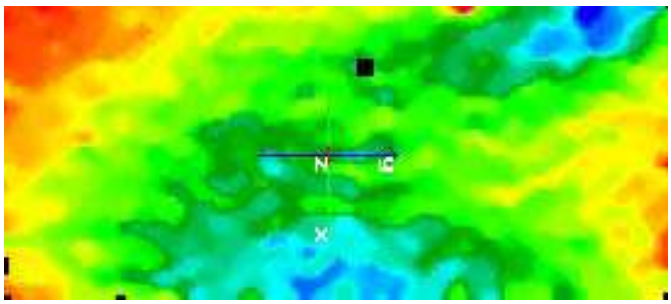


Specimen 1 Specimen 2 Specimen 3

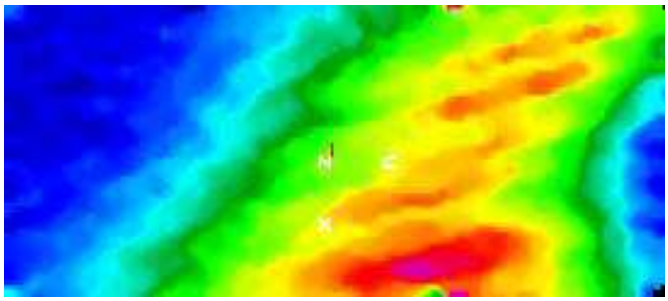
Figure A.125: Laminate 11 out-of-plane displacement due to edgewise compression.



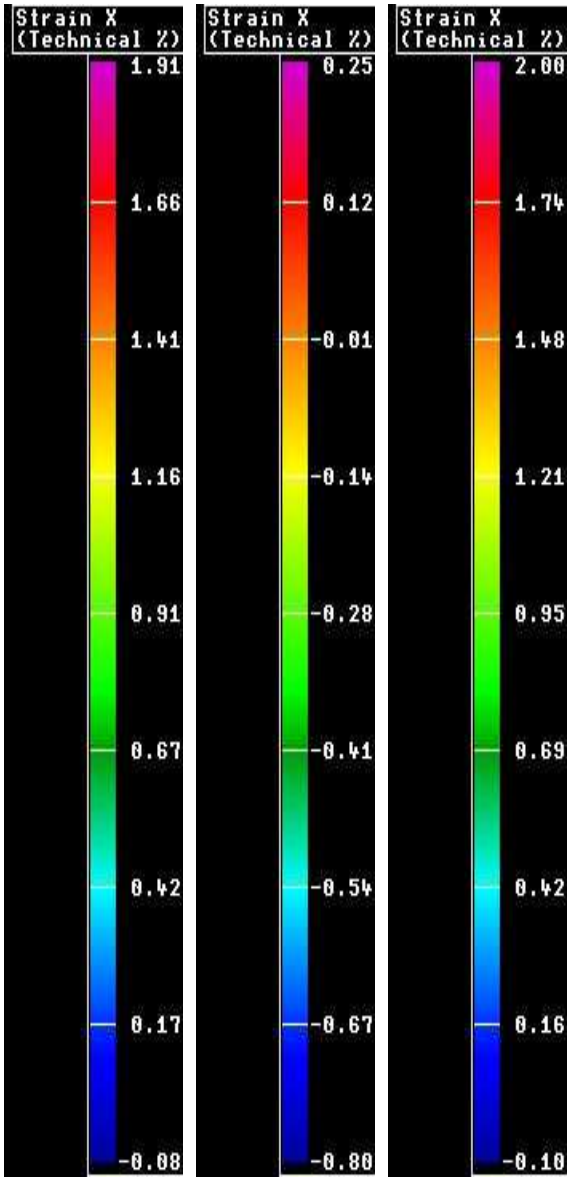
Specimen 1 at 70,616 N



Specimen 2 at 64,166 N

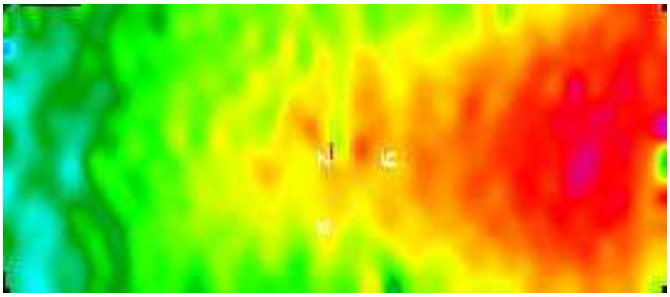


Specimen 3 at 59,624 N

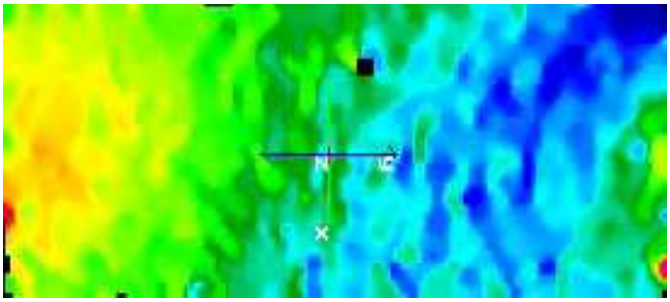


Specimen 1 Specimen 2 Specimen 3

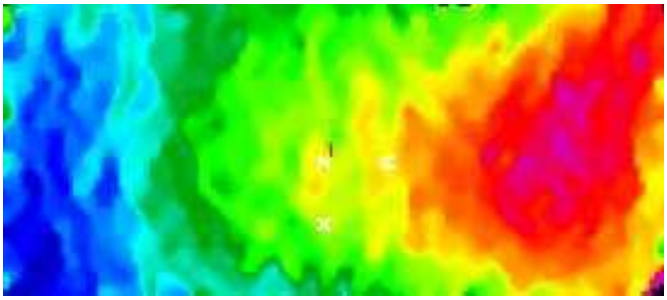
Figure A.126: Laminate 11 axial strain displacement due to edgewise compression.



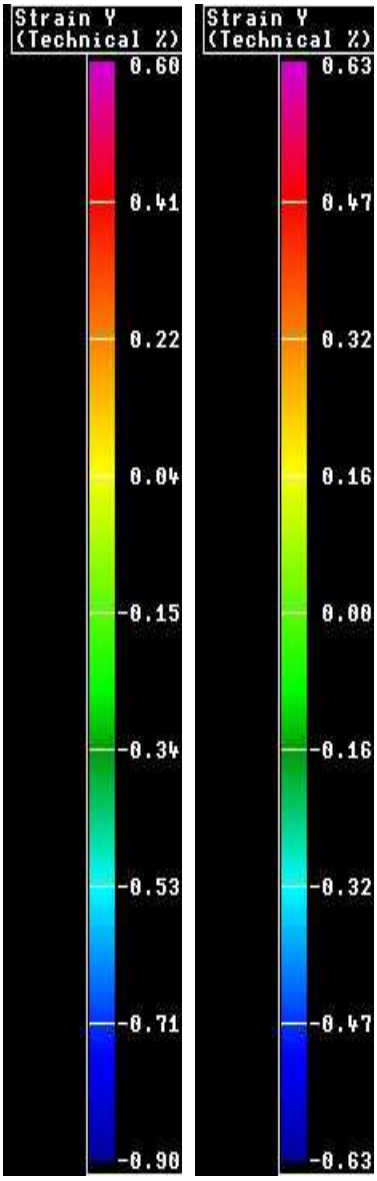
Specimen 1 at 70,616 N



Specimen 2 at 64,166 N



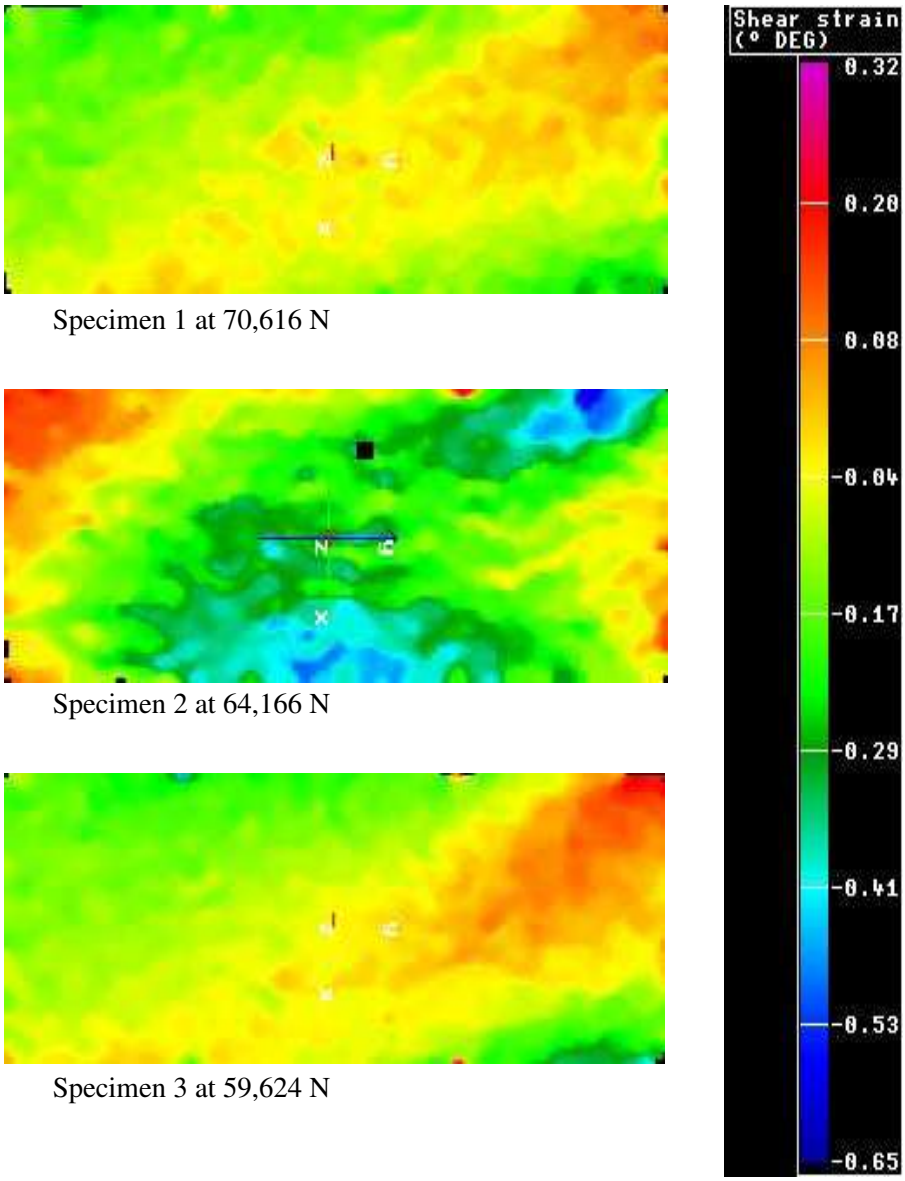
Specimen 3 at 59,624 N



Specimen 1
Specimen 2

Specimen 3

Figure A.127: Laminate 11 transverse strain displacement due to edgewise compression.



Specimen 1 at 70,616 N

Specimen 2 at 64,166 N

Specimen 3 at 59,624 N

Figure A.128: Laminate 11 shear strain displacement due to edgewise compression.

A.13 Laminate 12 - 30CUD/55C25/15GDB - $[\pm 45_{DB}/(25_C)_2/0_C]_s$

A.13.1 Tension 0

Table A.235: Laminate 12 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.4	3.5	3.5	25.5	25.5	25.5	25.6	30	AWT
2	3.5	3.6	3.5	25.5	25.5	25.5	25.6	30	AAT
3	3.6	3.4	3.6	25.5	25.5	25.5	25.6	30	AWT

Table A.236: Laminate 12 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0892	0.026	25.5	0.0000	0.000	87.8
2	3.5	0.0892	0.025	25.5	0.0000	0.000	90.2
3	3.5	0.1303	0.037	25.5	0.0000	0.000	89.7

Table A.237: Laminate 12 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	52.9	0.999986	0.00029	0.579	0.999399	0.00188
2	58.0	0.999991	0.00022	0.589	0.999414	0.00178
3	56.3	0.999980	0.00033	0.599	0.999669	0.00136

Table A.238: Laminate 12 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	87.8	59,475	677	13,582
2	90.2	58,641	650	11,678
3	89.7	60,650	676	12,690
Average	89.2	59,589	668	12,650
STDEV	1.3	1,009	15.2	953
CV	0.014	0.017	0.023	0.075

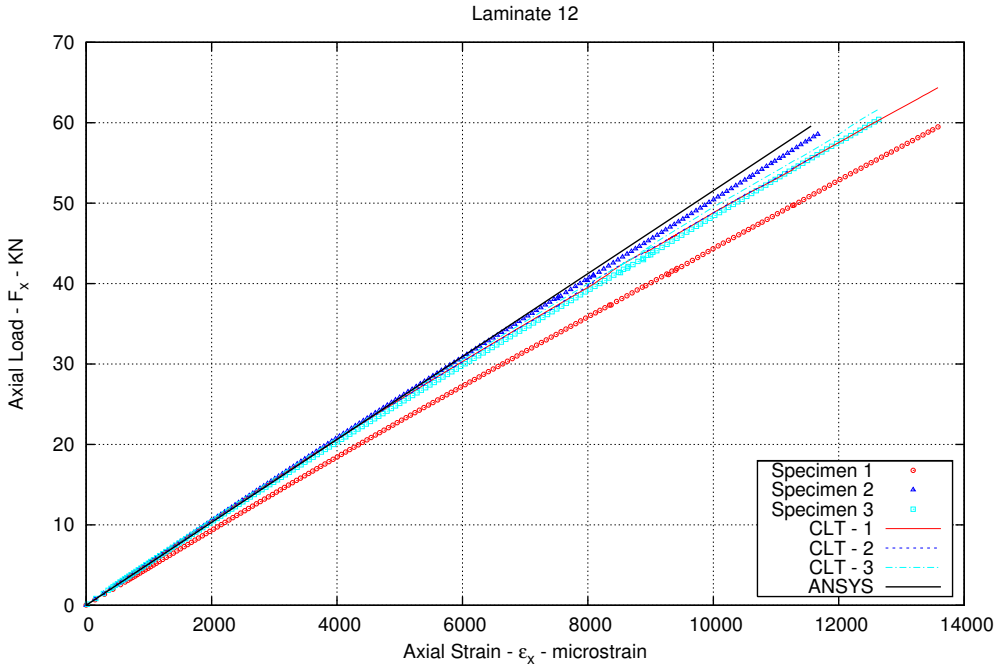


Figure A.129: Laminate 12 axial strain induced with an axial tensile load.

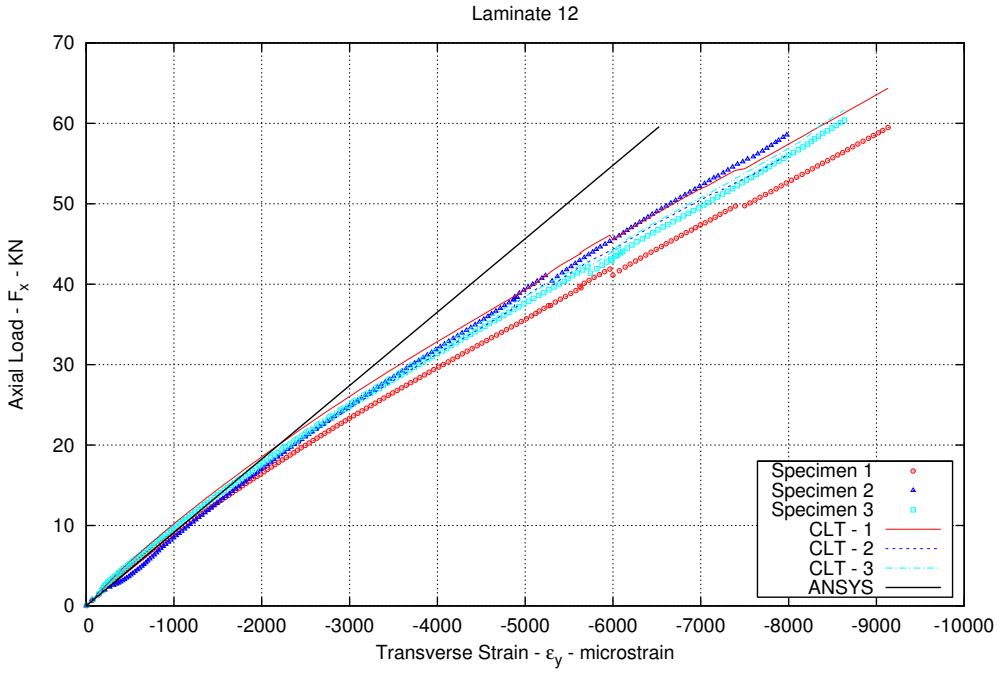


Figure A.130: Laminate 12 transverse strain induced with an axial tensile load.

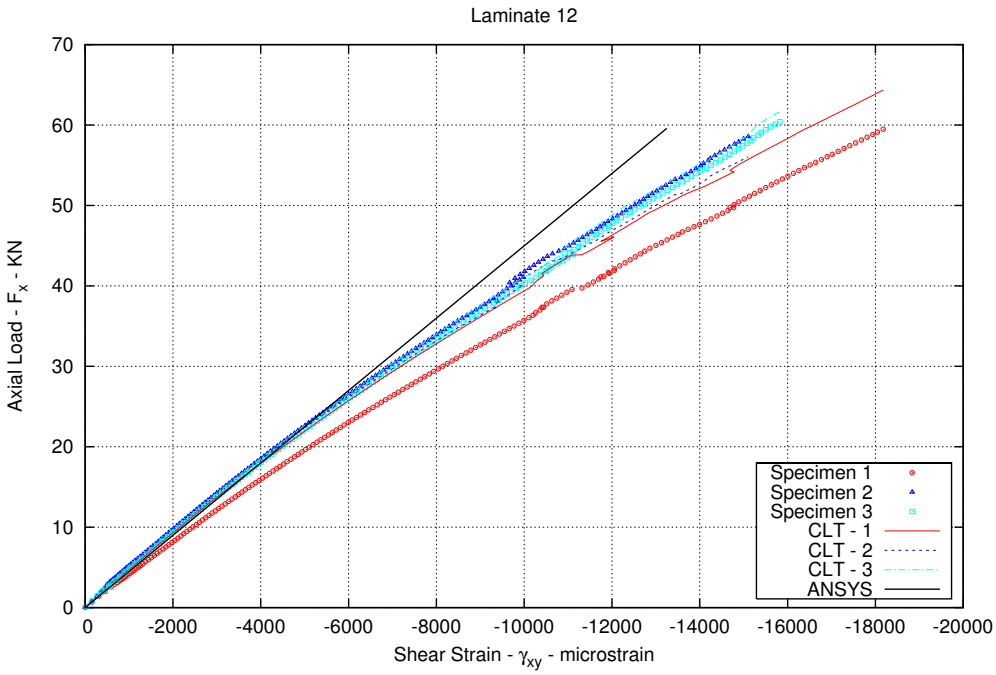


Figure A.131: Laminate 12 shear strain induced with an axial tensile load.

A.13.2 Tenion 90

Table A.239: Laminate 12 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.5	3.6	25.4	25.4	25.4	22.8	33	AWT
2	3.5	3.5	3.5	25.4	25.4	25.4	22.8	33	AGB
3	3.6	3.7	3.5	25.4	25.4	25.4	22.8	33	LGM

Table A.240: Laminate 12 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0388	0.011	25.4	0.0000	0.000	90.6
2	3.5	0.0440	0.013	25.4	0.0000	0.000	88.5
3	3.6	0.0816	0.023	25.4	0.0000	0.000	91.5

Table A.241: Laminate 12 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	10.8	0.999779	0.00179	0.063	0.994843	0.00867
2	11.2	0.999807	0.00165	0.118	0.998692	0.00429
3	10.8	0.999803	0.00168	0.072	0.994417	0.00896

Table A.242: Laminate 12 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	90.6	5,076	56.0	5,488
2	88.5	5,086	57.5	5,433
3	91.5	5,206	56.9	5,653
Average	90.2	5,123	56.8	5,524
STDEV	1.6	72	0.7	115
CV	0.017	0.014	0.013	0.021

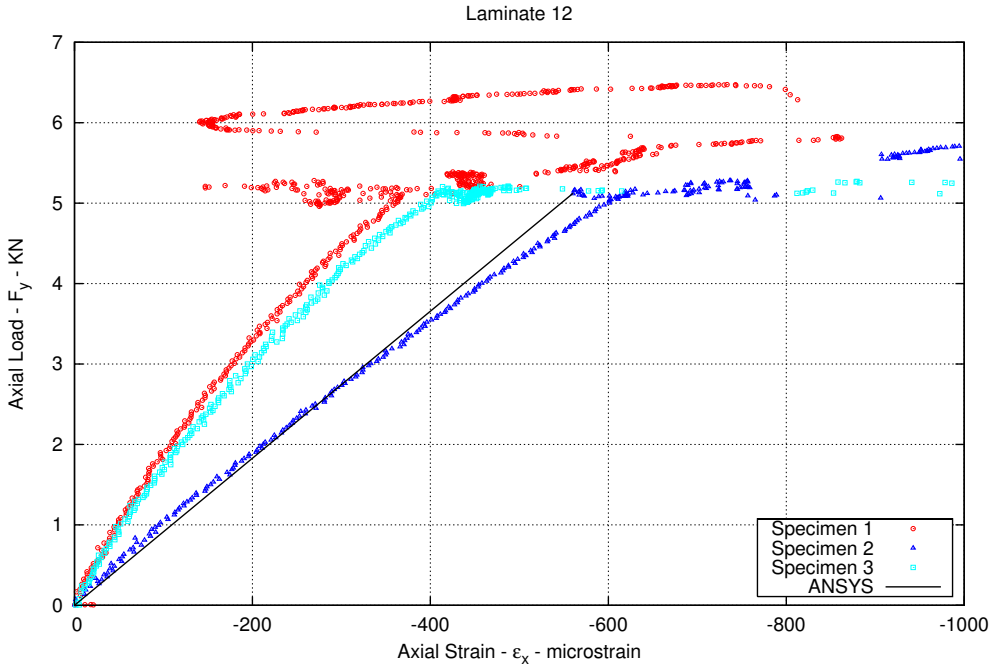


Figure A.132: Laminate 12 axial strain induced with a transverse tensile load.

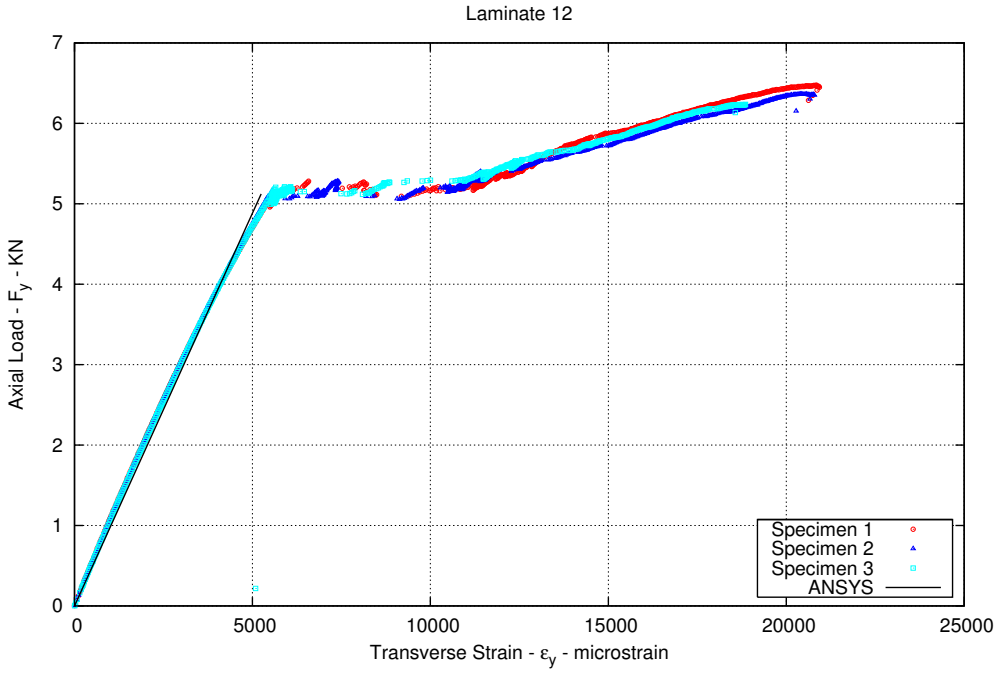


Figure A.133: Laminate 12 transverse strain induced with a transverse tensile load.

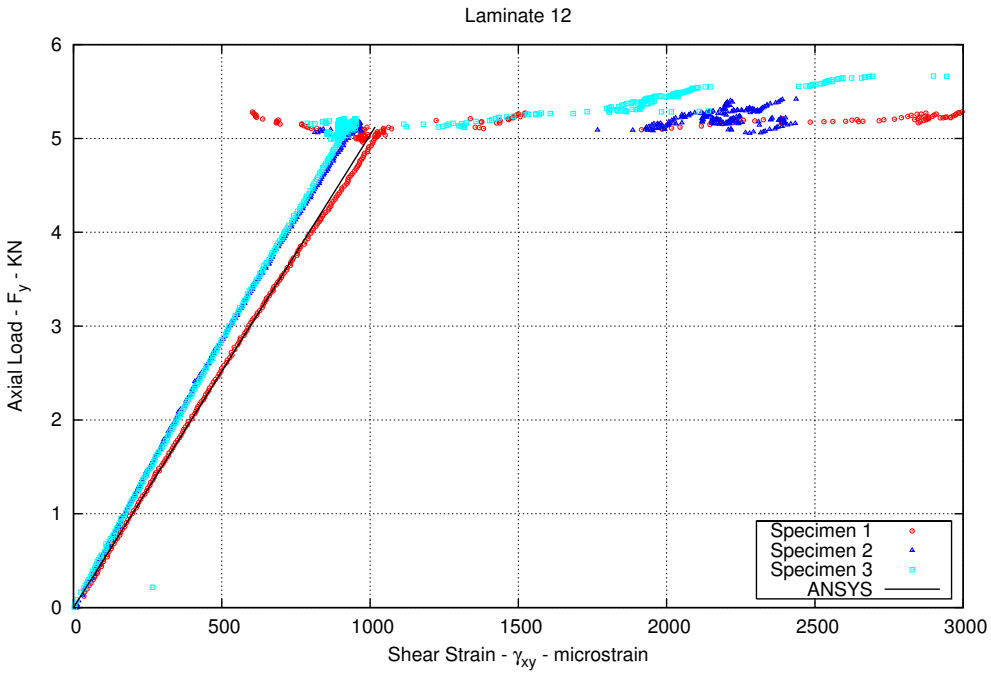


Figure A.134: Laminate 12 shear strain induced with a transverse tensile load.

A.13.3 Compression

Table A.243: Laminate 12 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.5	3.5	12.6	12.6	23.9
2	3.5	3.5	12.6	12.6	23.9
3	3.4	3.5	12.6	12.6	23.9

Table A.244: Laminate 12 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0539	0.015	12.6	0.0000	0.000	44.2
2	3.5	0.0359	0.010	12.6	0.0000	0.000	44.2
3	3.4	0.0898	0.026	12.6	0.0000	0.000	43.5

Table A.245: Laminate 12 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	54.0	0.999828	0.00132
2	51.5	0.999711	0.00176
3	58.3	0.999755	0.00152

Table A.246: Laminate 12 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.3	3.4	12.8	12.8	23.9	25	BGM
2	3.5	3.5	12.8	12.8	23.9	25	BGM
3	3.5	3.4	12.8	12.8	23.9	25	TAT
4	3.6	3.6	12.8	12.8	23.9	25	BGM

Table A.247: Laminate 12 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.4	0.0225	0.007	12.8	0.0000	0.000	42.8
2	3.5	0.0198	0.006	12.8	0.0000	0.000	44.8
3	3.5	0.0233	0.007	12.8	0.0000	0.000	44.2
4	3.6	0.0144	0.004	12.8	0.0000	0.000	45.7

Table A.248: Laminate 12 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	42.8	23,161	541	9,906
2	44.8	23,458	524	9,589
4	45.7	22,819	500	9,152
Average	44.4	23,146	521	9,549
STDEV	1.5	320	20.7	378
CV	0.033	0.014	0.040	0.040

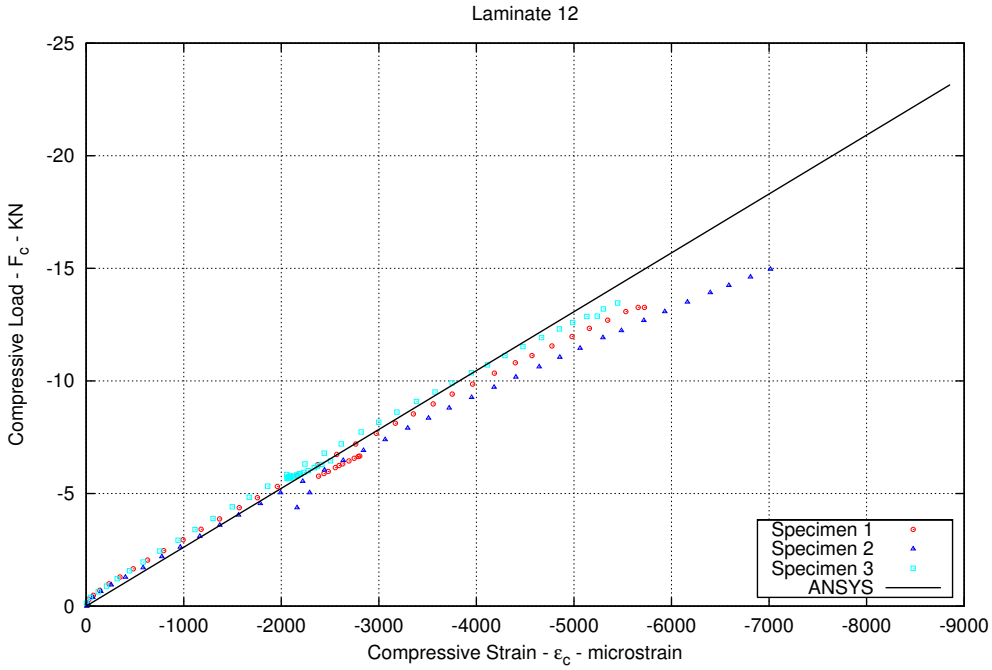


Figure A.135: Laminate 12 axial strain induced with an axial compressive load.

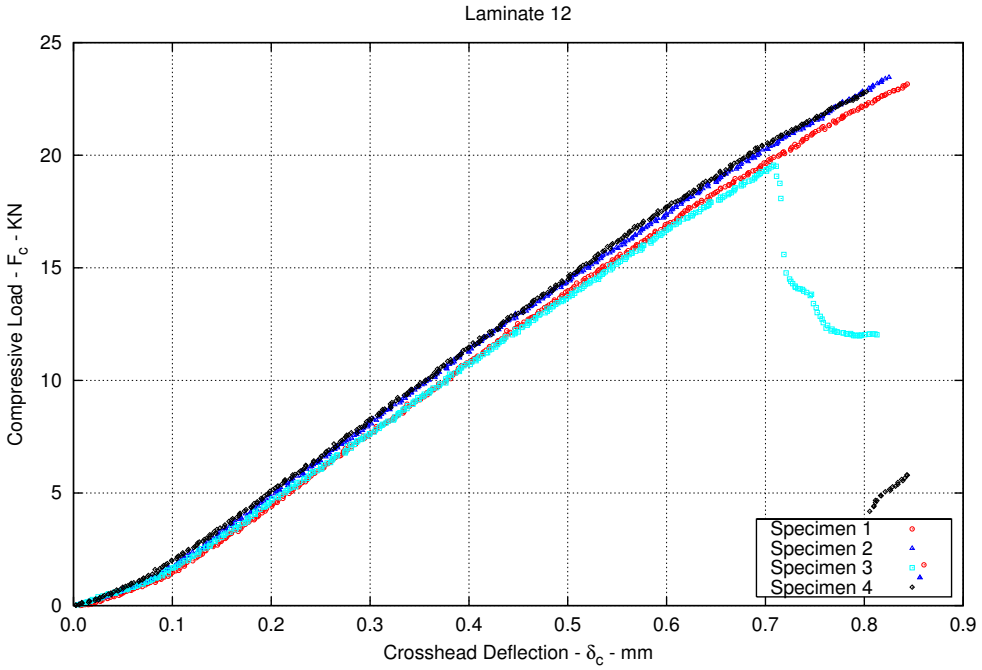


Figure A.136: Response of Laminate 12 to compressive loading.

A.13.4 In-Plane Shear

Table A.249: Laminate 12 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.6	11.5	11.5	25	49	null
2	3.5	3.5	11.4	11.4	25	49	null
3	3.6	3.6	11.4	11.4	25	49	null

Table A.250: Laminate 12 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0718	0.020	11.5	0.0000	0.000	40.5
2	3.5	0.0359	0.010	11.4	0.0180	0.002	40.0
3	3.6	0.0359	0.010	11.4	0.0180	0.002	40.9

Table A.251: Laminate 12 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	11.1	0.9981	0.0041
2	10.5	0.9969	0.0054
3	11.4	0.9993	0.0020

Table A.252: Laminate 12 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.5	5,705	141	15,053
2	40.0	5,364	134	15,035
3	40.9	5,406	132	16,202
Average	40.5	5,492	136	15,430
STDEV	0.4	186	4.5	669
CV	0.011	0.034	0.033	0.043

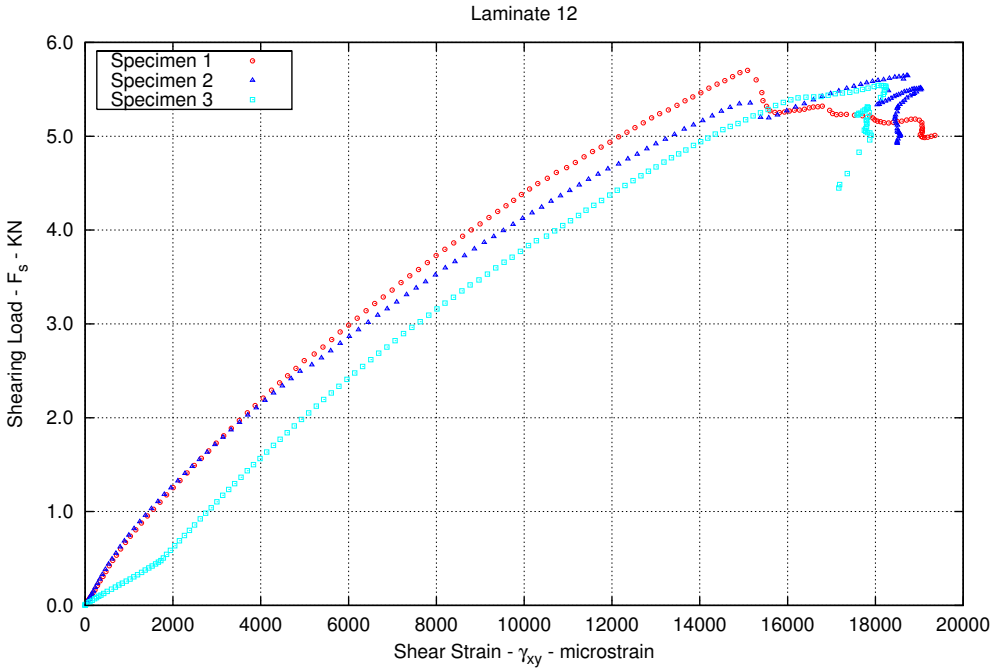


Figure A.137: Laminate 12 shear strain induced with an in-plane shear load.

A.13.5 Interlaminar Shear

Table A.253: Laminate 12 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.5	6.4	6.4	23.3	60	Interlaminar Shear
2	3.6	3.4	6.4	6.4	23.3	60	Interlaminar Shear
3	3.3	3.5	6.4	6.4	23.3	60	Interlaminar Shear

Table A.254: Laminate 12 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0036	0.001	6.4	0.0000	0.000	22.6
2	3.5	0.1167	0.033	6.4	0.0000	0.000	22.5
3	3.4	0.1105	0.033	6.4	0.0000	0.000	21.5

Table A.255: Laminate 12 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.6	1383.5	46.7
2	22.5	1330.4	45.1
3	21.5	1313.6	46.6

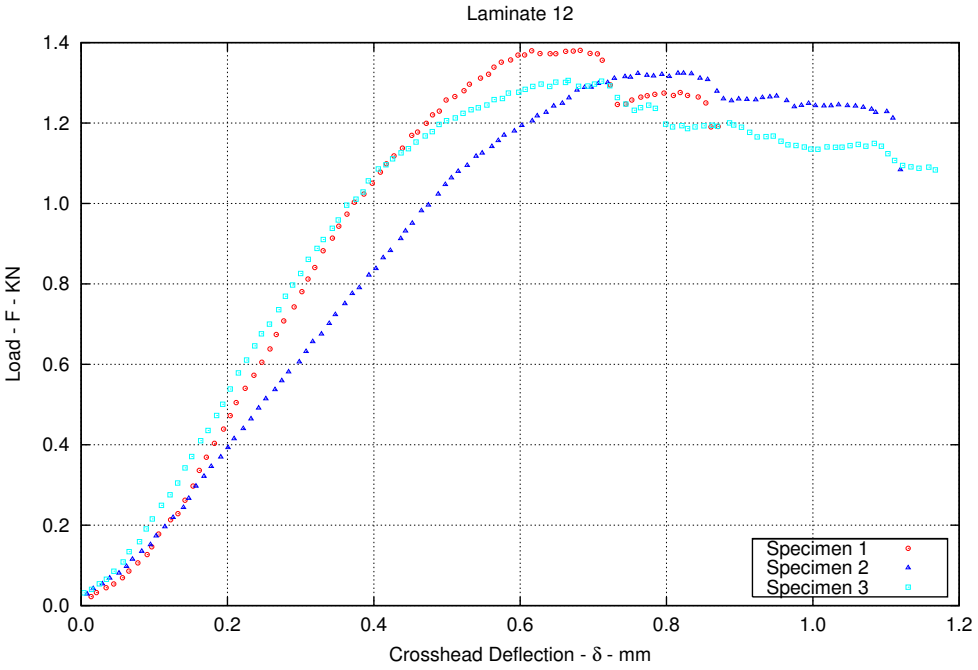
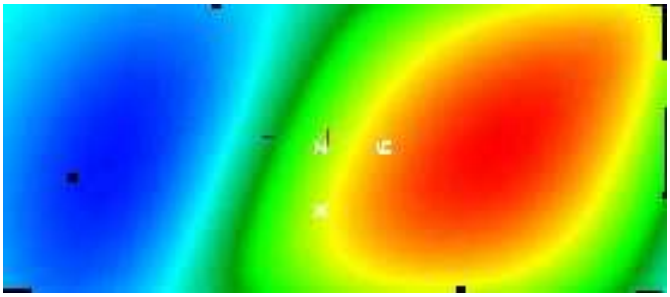
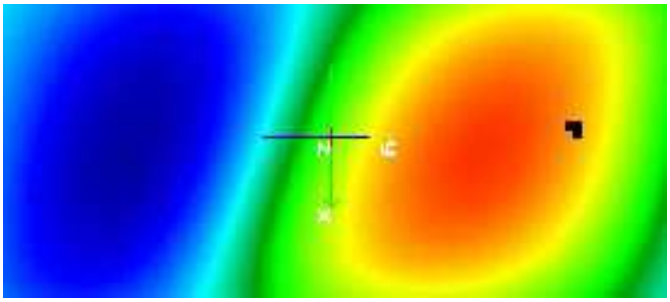


Figure A.138: Laminate 12 interlaminar shear response.

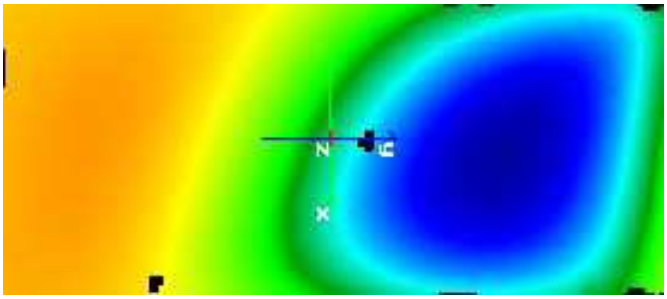
A.13.6 Edgewise Compression



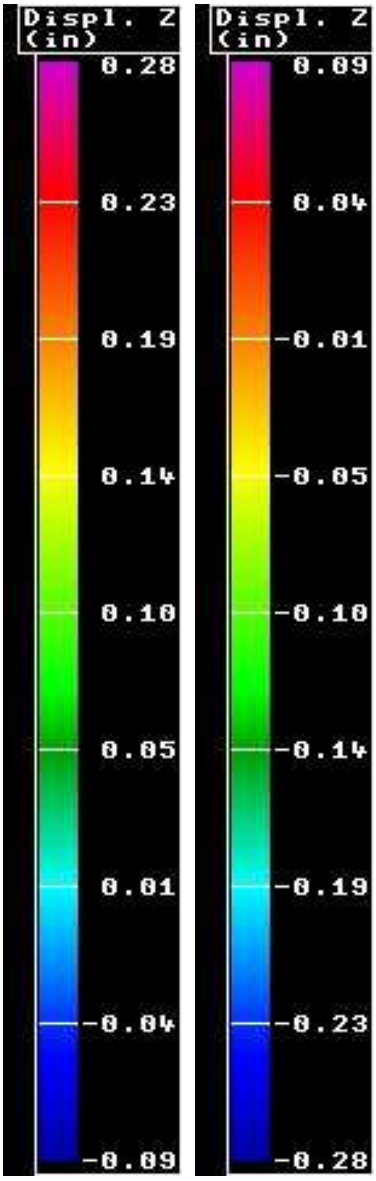
Specimen 1 at 64,352 N



Specimen 2 at 71,318 N

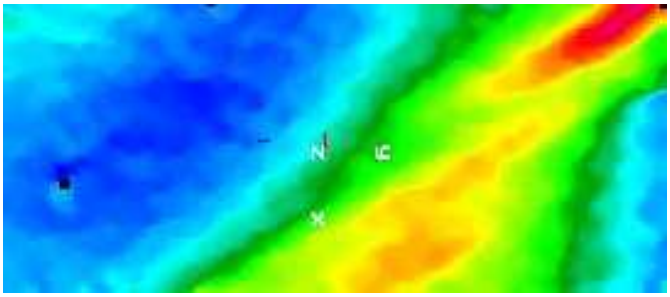


Specimen 3 at 54,122 N

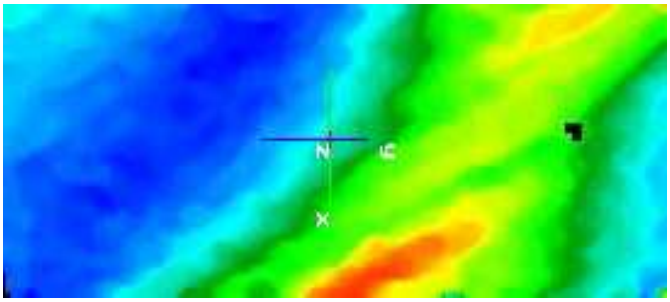


Specimen 1
Specimen 2 Specimen 3

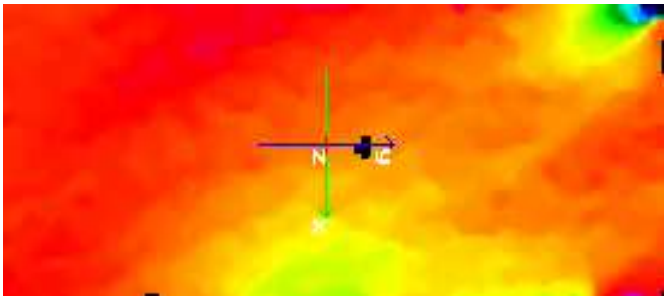
Figure A.139: Laminate 12 out-of-plane displacement due to edgewise compression.



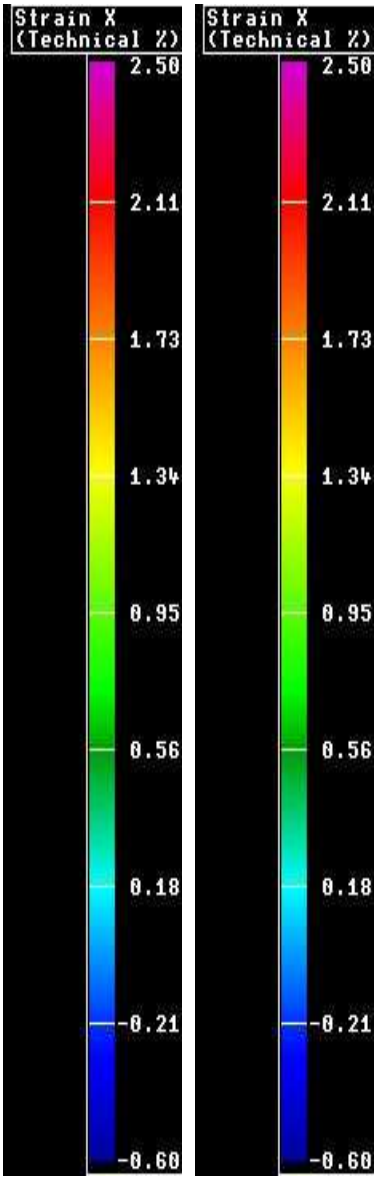
Specimen 1 at 64,352 N



Specimen 2 at 71,318 N



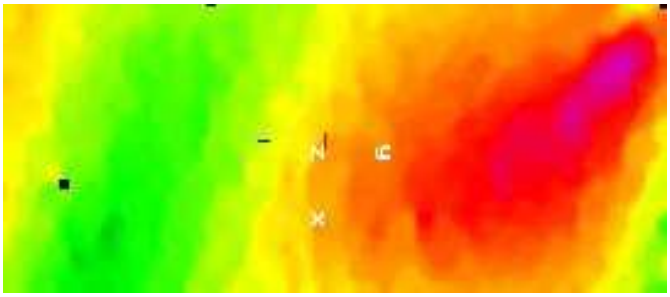
Specimen 3 at 54,122 N



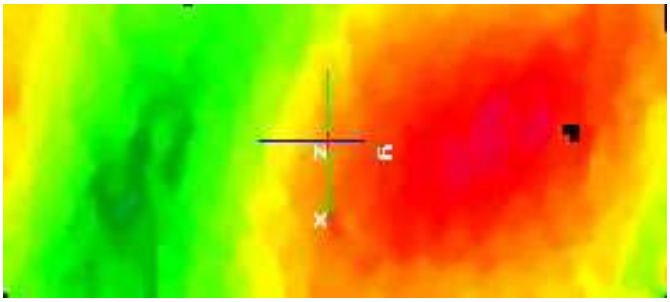
Specimen 1
Specimen 2

Specimen 3

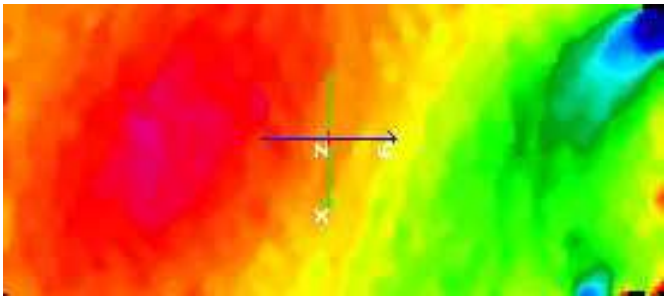
Figure A.140: Laminate 12 axial strain displacement due to edgewise compression.



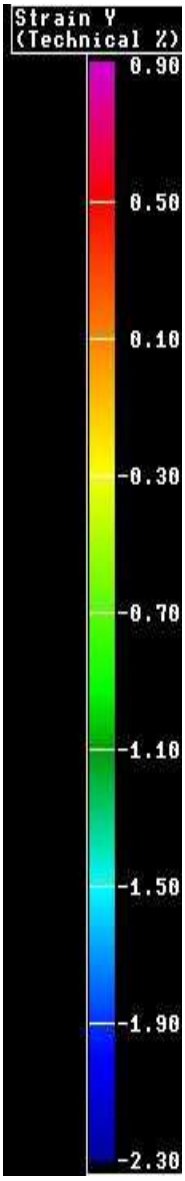
Specimen 1 at 64,352 N

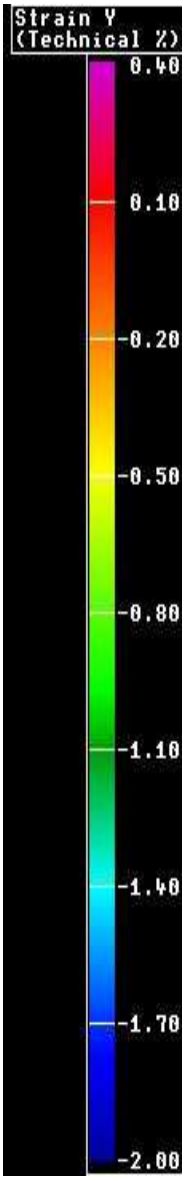


Specimen 2 at 71,318 N



Specimen 3 at 54,122 N

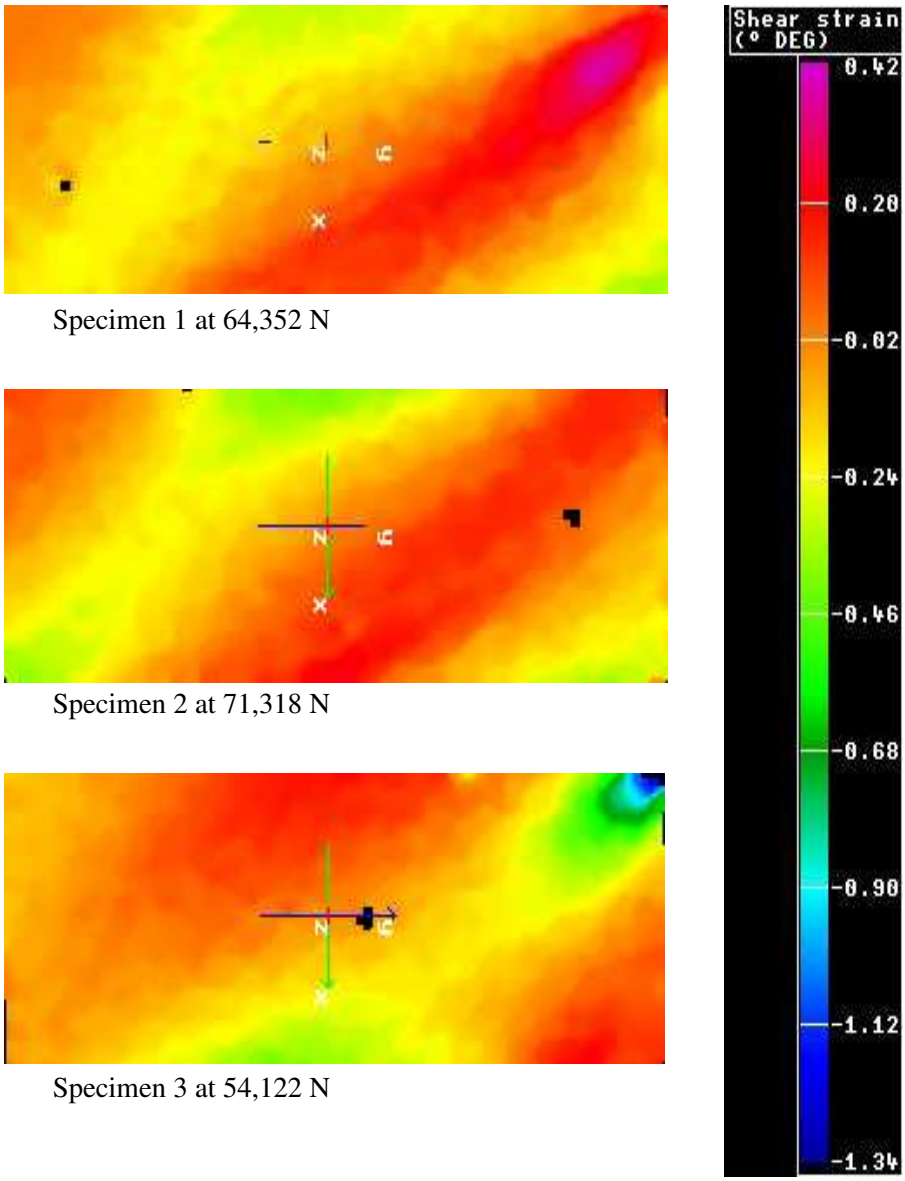




Specimen 1
Specimen 2

Specimen 3

Figure A.141: Laminate 12 transverse strain displacement due to edgewise compression.



Specimen 1 at 64,352 N

Specimen 2 at 71,318 N

Specimen 3 at 54,122 N

Figure A.142: Laminate 12 shear strain displacement due to edgewise compression.

A.14 Laminate 13 - 30CUD/55C20/15G75-55 - $[75^G/-55^G/(20_C)_2/0_C]_s$

A.14.1 Tension 0

Table A.256: Laminate 13 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.6	4.6	4.6	25.5	25.5	25.5	24.4	54	DWB
2	4.5	4.5	4.6	25.5	25.5	25.5	24.4	54	SIB
3	4.6	4.5	4.5	25.5	25.5	25.5	24.4	54	DWT SIT

Table A.257: Laminate 13 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0254	0.006	25.5	0.0000	0.000	117.0
2	4.5	0.0672	0.015	25.5	0.0000	0.000	115.7
3	4.6	0.0293	0.006	25.5	0.0000	0.000	116.1

Table A.258: Laminate 13 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	48.1	0.999938	0.00055	0.441	0.999811	0.00095
2	51.8	0.999926	0.00058	0.583	0.999977	0.00033
3	46.6	0.999954	0.00049	0.503	0.999726	0.00118

Table A.259: Laminate 13 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	117	50,726	434	9,705
2	116	55,371	479	9,862
3	116	56,462	486	11,408
Average	116	54,186	466	10,325
STDEV	0.7	3,046	28.4	941
CV	0.006	0.056	0.061	0.091

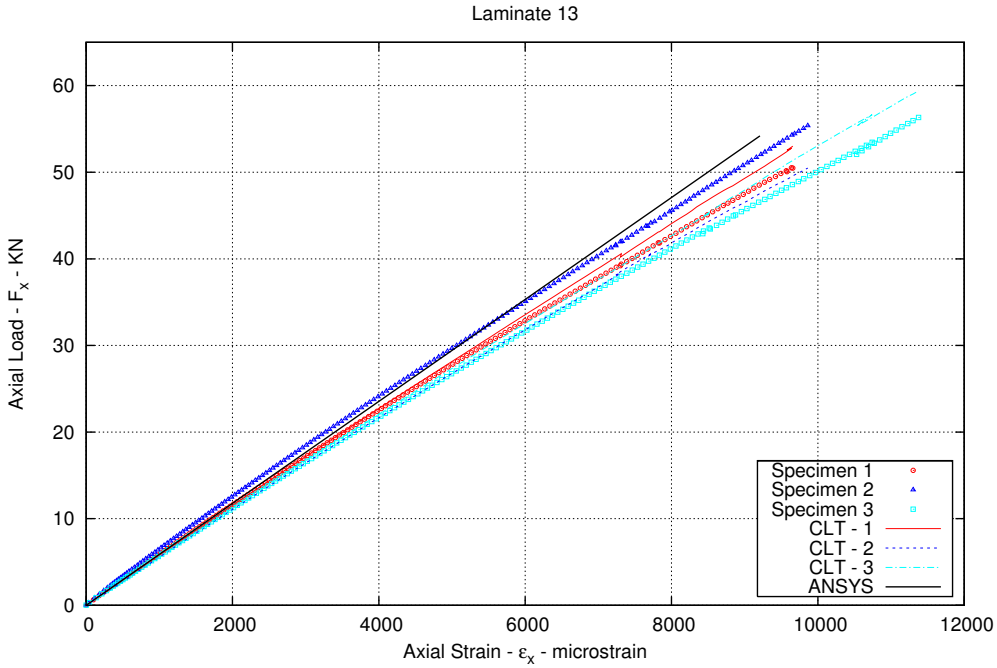


Figure A.143: Laminate 13 axial strain induced with an axial tensile load.

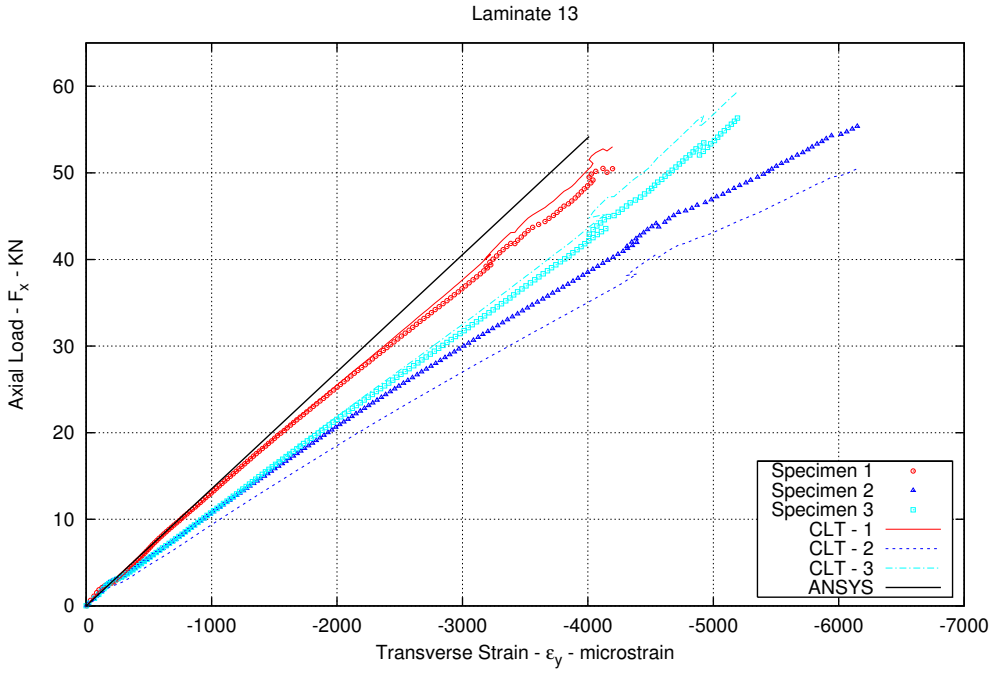


Figure A.144: Laminate 13 transverse strain induced with an axial tensile load.

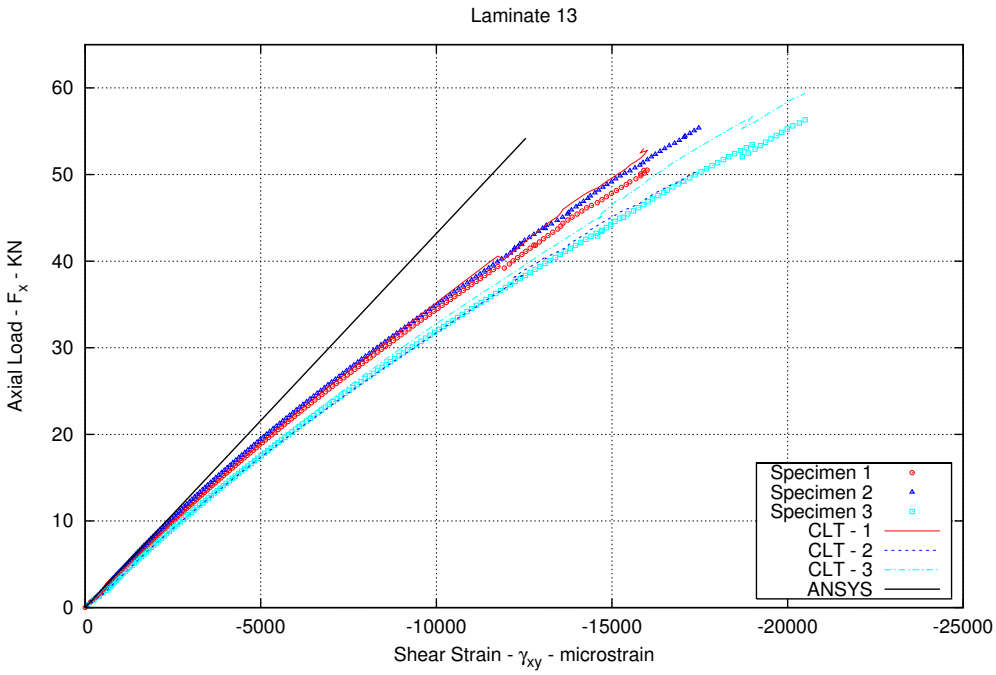


Figure A.145: Laminate 13 shear strain induced with an axial tensile load.

A.14.2 Tenion 90

Table A.260: Laminate 13 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.6	4.6	4.6	25.3	25.3	25.3	24.4	45	AGM
2	4.6	4.5	4.6	25.4	25.4	25.4	24.4	45	AIT
3	4.6	4.5	4.6	25.4	25.4	25.4	24.4	45	AGM

Table A.261: Laminate 13 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0293	0.006	25.3	0.0000	0.000	116.3
2	4.6	0.0388	0.008	25.4	0.0000	0.000	116.6
3	4.6	0.0880	0.019	25.4	0.0000	0.000	116.0

Table A.262: Laminate 13 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	11.0	0.999934	0.00087	0.098	0.999863	0.00125
2	10.9	0.999930	0.00094	0.099	0.999892	0.00117
3	11.2	0.999928	0.00097	0.120	0.999820	0.00153

Table A.263: Laminate 13 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	116	6,279	54.0	5,009
2	117	6,412	55.0	5,737
3	116	6,494	56.0	5,125
Average	116	6,395	55.0	5,290
STDEV	0.3	108	1.0	391
CV	0.002	0.017	0.018	0.074

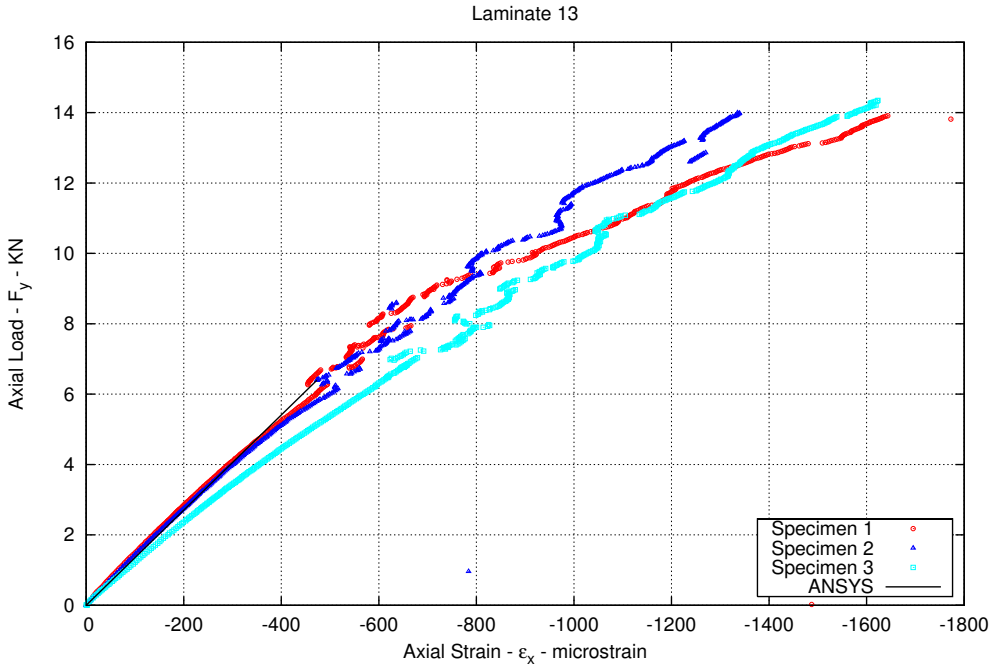


Figure A.146: Laminate 13 axial strain induced with a transverse tensile load.

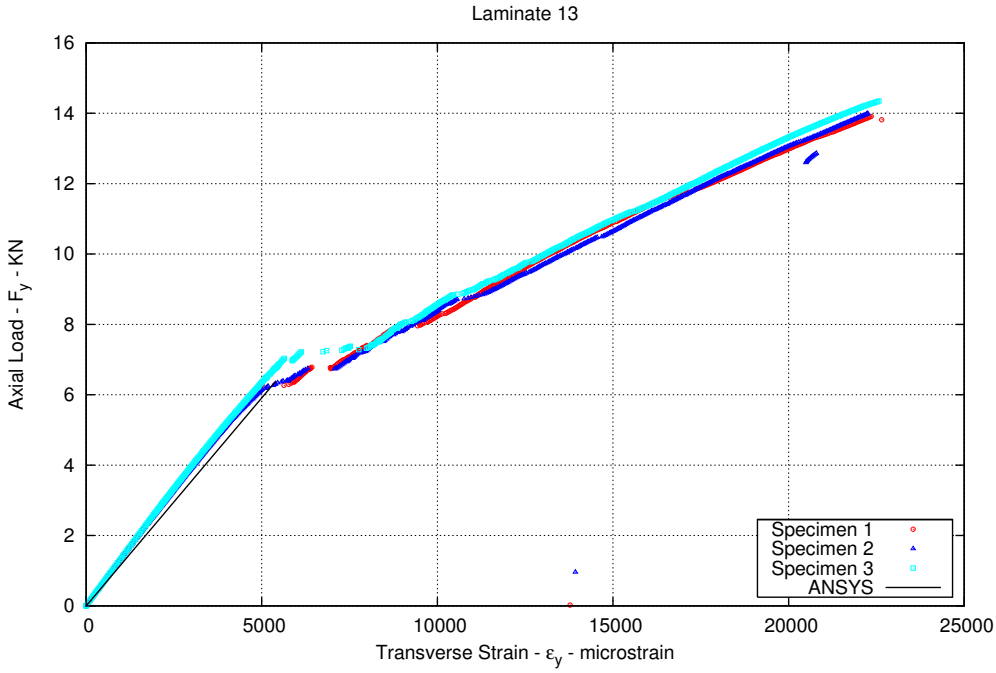


Figure A.147: Laminate 13 transverse strain induced with a transverse tensile load.

A.14.3 Compression

Table A.264: Laminate 13 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$
1	4.7	4.6	12.8	12.8	24.4
2	4.6	4.7	12.8	12.8	24.4
3	4.7	4.6	12.8	12.8	24.4

Table A.265: Laminate 13 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0539	0.012	12.8	0.0000	0.000	59.5
2	4.6	0.0539	0.012	12.8	0.0000	0.000	59.2
3	4.6	0.0359	0.008	12.8	0.0000	0.000	59.4

Table A.266: Laminate 13 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	48.1	0.999763	0.00152
2	53.6	0.999730	0.00155
3	50.2	0.999688	0.00169

Table A.267: Laminate 13 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.7	4.4	12.7	12.7	25	31	TAT
2	4.8	4.7	12.7	12.7	25	31	TAT
3	4.5	4.5	12.7	12.7	25	31	BGM/TAT
5	4.6	4.6	12.7	12.7	25	31	TAT

Table A.268: Laminate 13 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	4.6	0.1985	0.044	12.7	0.0000	0.000	57.9
2	4.7	0.0665	0.014	12.7	0.0000	0.000	60.0
3	4.5	0.0395	0.009	12.7	0.0000	0.000	57.2
5	4.6	0.0090	0.002	12.7	0.0000	0.000	58.9

Table A.269: Laminate 13 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	57.9	21,786	376	7,433
2	60.0	26,889	448	8,855
3	57.2	23,823	416	8,221
Average	58.4	24,166	414	8,170
STDEV	1.4	2,569	36.0	712
CV	0.025	0.106	0.087	0.087

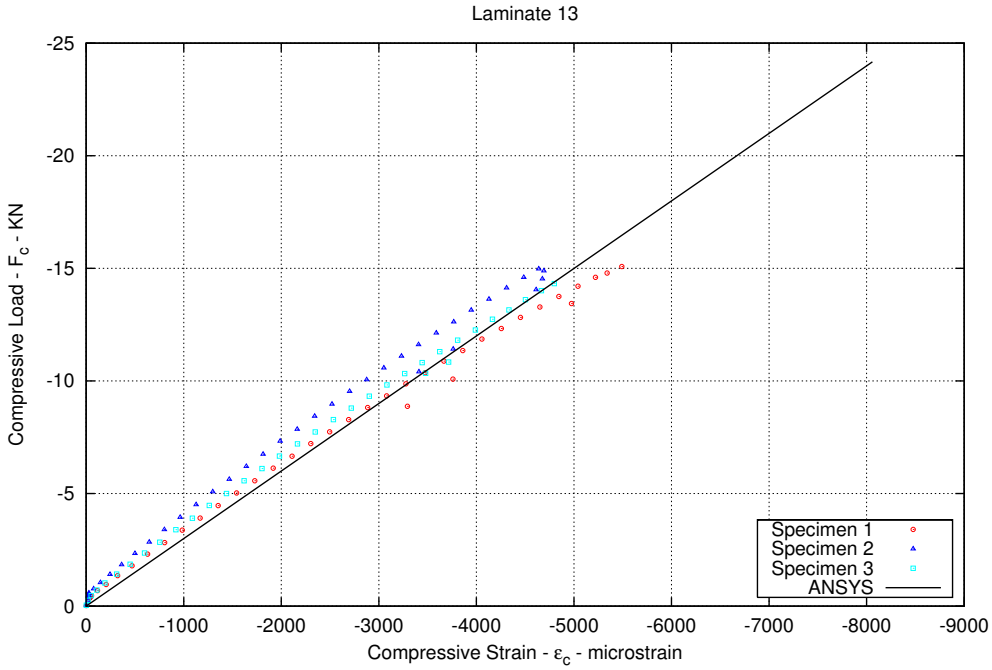


Figure A.148: Laminate 13 axial strain induced with an axial compressive load.

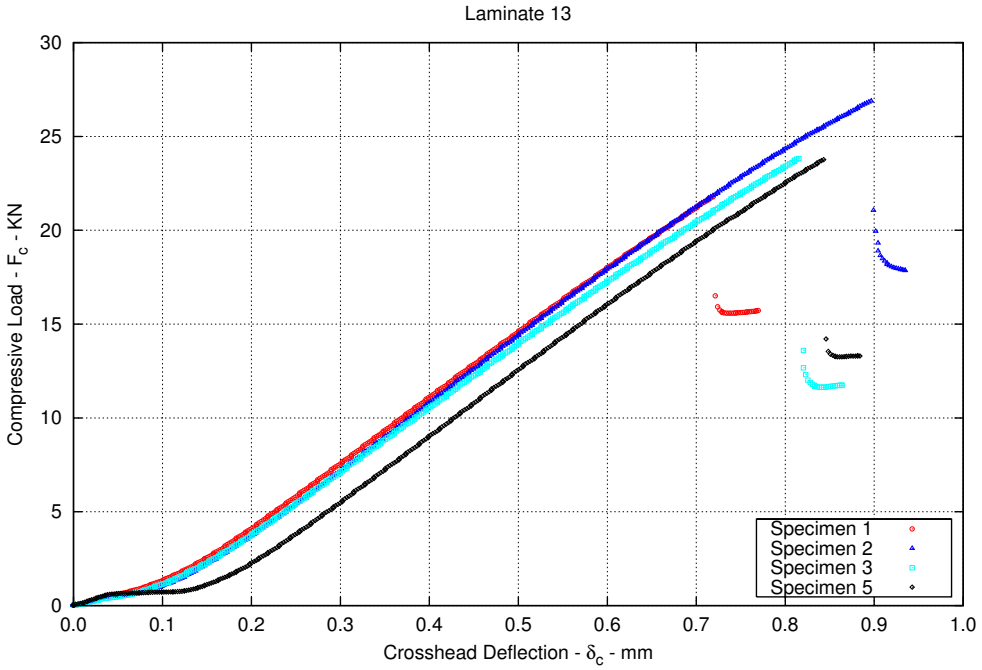


Figure A.149: Response of Laminate 13 to compressive loading.

A.14.4 In-Plane Shear

Table A.270: Laminate 13 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.6	4.5	11.5	11.5	25	50	null
2	4.4	4.6	11.5	11.5	25	50	null
3	4.6	4.5	11.5	11.5	25	50	null

Table A.271: Laminate 13 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0539	0.012	11.5	0.0000	0.000	52.3
2	4.5	0.1078	0.024	11.5	0.0000	0.000	51.6
3	4.6	0.0359	0.008	11.5	0.0000	0.000	52.4

Table A.272: Laminate 13 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	8.5	0.9939	0.0072
2	6.9	0.9985	0.0040
3	7.7	0.9987	0.0035

Table A.273: Laminate 13 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	52.3	6,317	121	23,121
2	51.6	6,602	128	29,200
3	52.4	6,439	123	26,251
Average	52.1	6,453	124	26,191
STDEV	0.4	143	3.7	3,040
CV	0.008	0.022	0.030	0.116

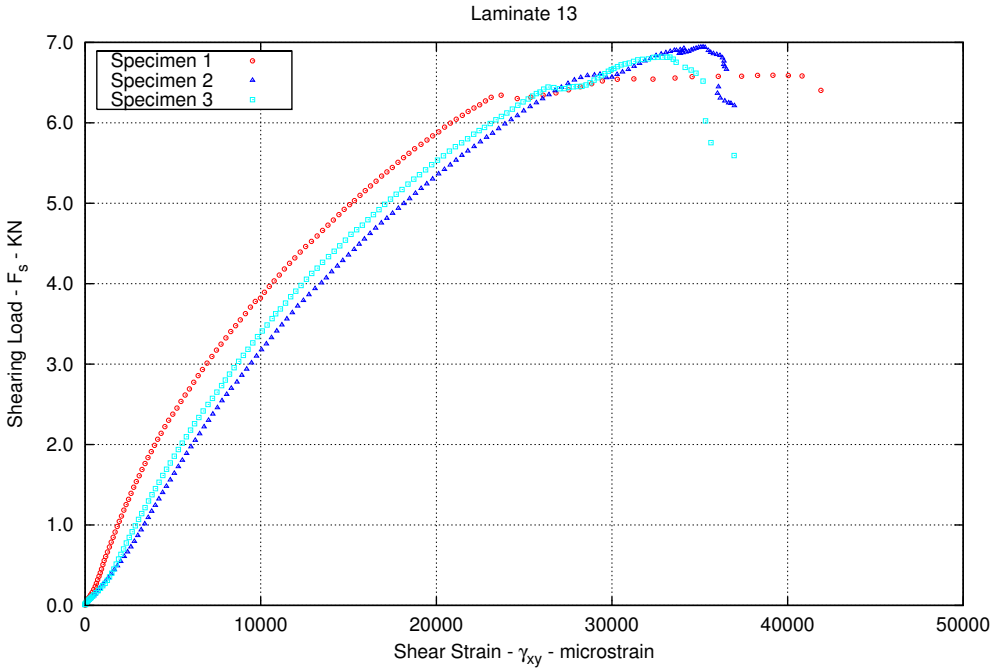


Figure A.150: Laminate 13 shear strain induced with an in-plane shear load.

A.14.5 Interlaminar Shear

Table A.274: Laminate 13 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.5	4.5	6.4	6.4	26.7	49	Interlaminar Shear
2	4.6	4.6	6.4	6.4	26.7	49	Interlaminar Shear
3	4.5	4.6	6.4	6.4	26.7	49	Interlaminar Shear

Table A.275: Laminate 13 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.5	0.0269	0.006	6.4	0.0000	0.000	28.5
2	4.6	0.0368	0.008	6.4	0.0000	0.000	29.2
3	4.6	0.0934	0.020	6.4	0.0000	0.000	29.1

Table A.276: Laminate 13 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	28.5	1552.0	41.5
2	29.2	1588.6	41.4
3	29.1	1507.0	39.4

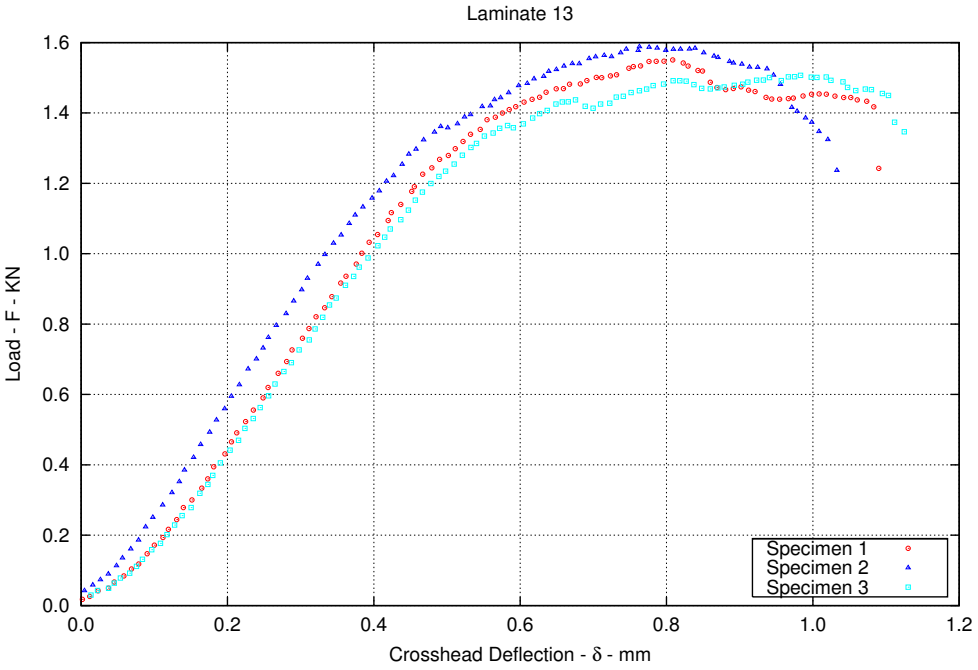
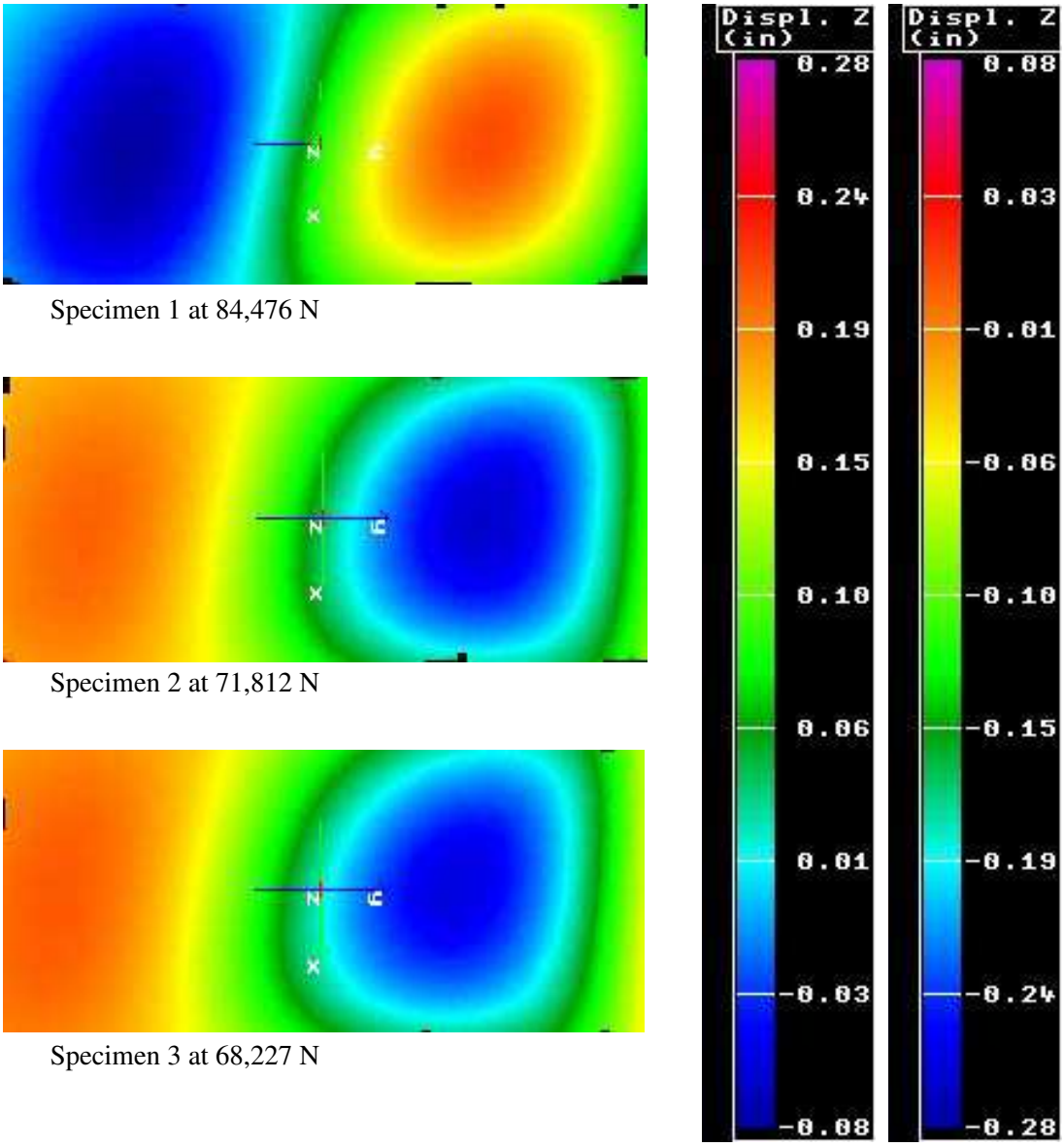


Figure A.151: Laminate 13 interlaminar shear response.

A.14.6 Edgewise Compression



Specimen 1 at 84,476 N

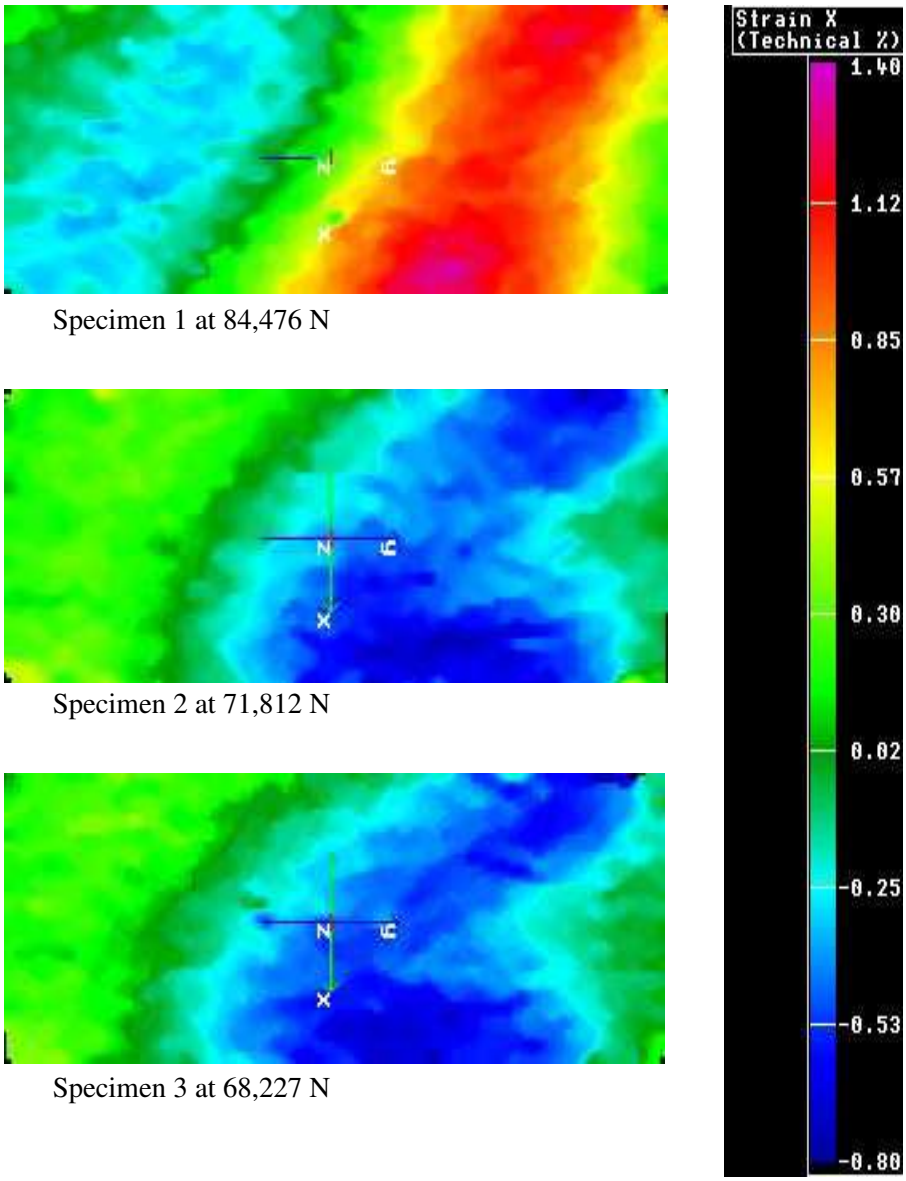
Specimen 2 at 71,812 N

Specimen 3 at 68,227 N

Specimen 1

Specimen 2
Specimen 3

Figure A.152: Laminate 13 out-of-plane displacement due to edgewise compression.

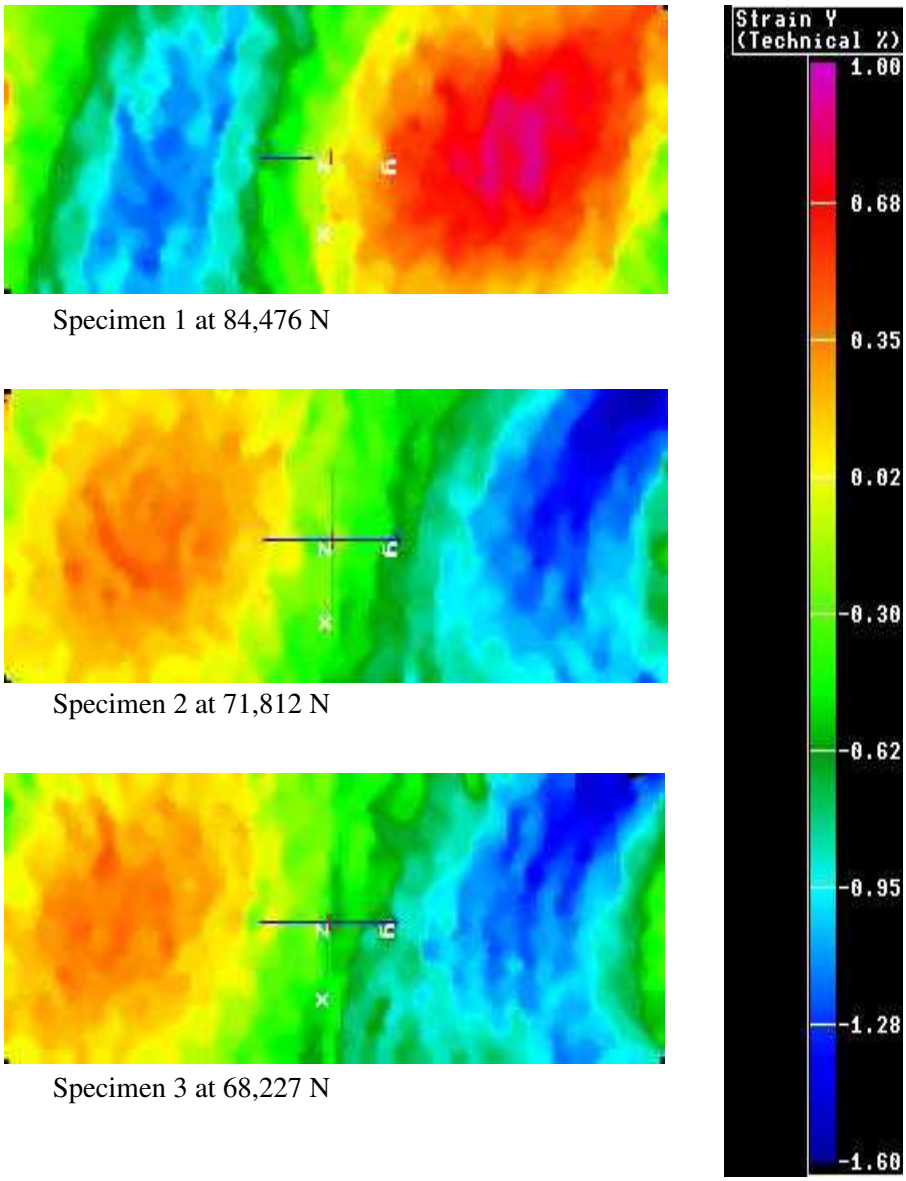


Specimen 1 at 84,476 N

Specimen 2 at 71,812 N

Specimen 3 at 68,227 N

Figure A.153: Laminate 13 axial strain displacement due to edgewise compression.

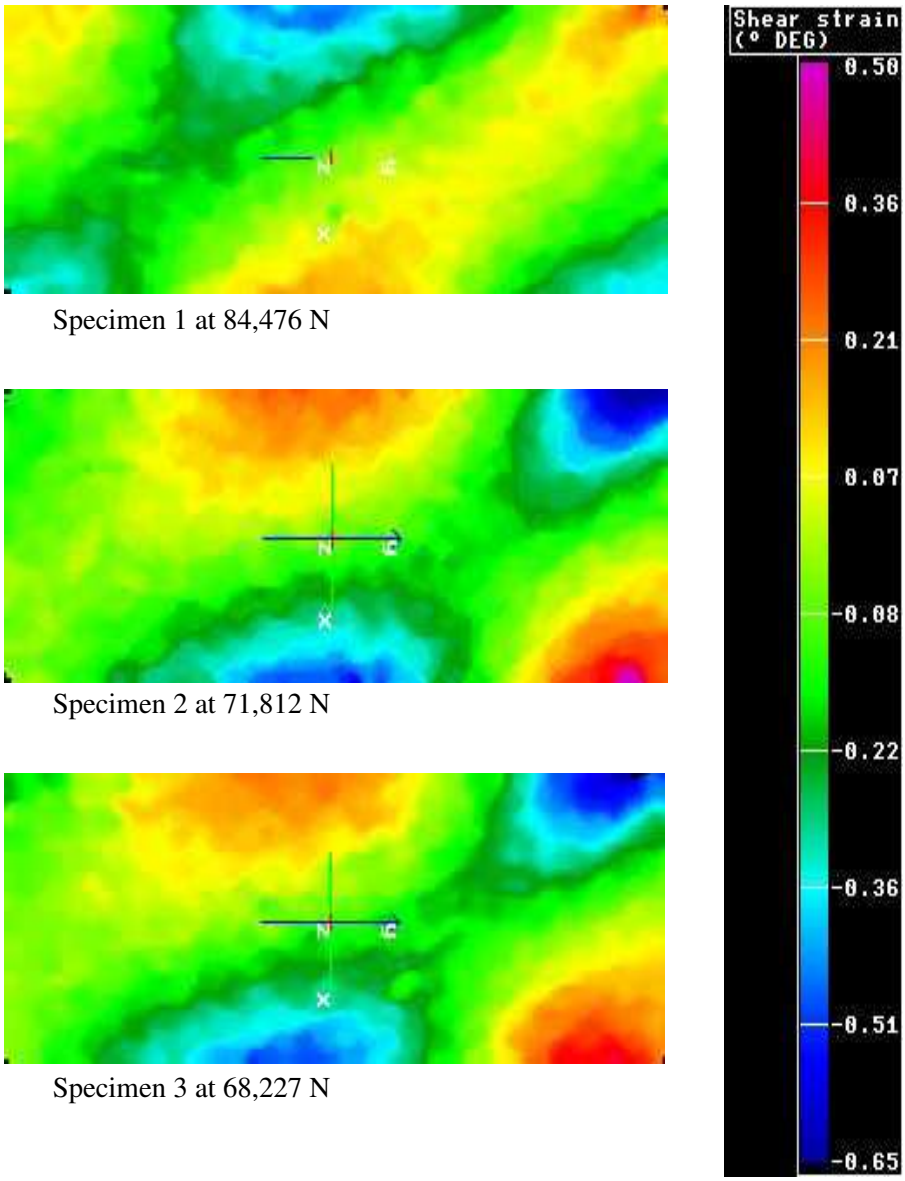


Specimen 1 at 84,476 N

Specimen 2 at 71,812 N

Specimen 3 at 68,227 N

Figure A.154: Laminate 13 transverse strain displacement due to edgewise compression.



Specimen 1 at 84,476 N

Specimen 2 at 71,812 N

Specimen 3 at 68,227 N

Figure A.155: Laminate 13 shear strain displacement due to edgewise compression.

A.15 Laminate 14 - 85CUD/15G20-70 - $[(+20/-70)_{DB}/(0_C)_3]_s$

A.15.1 Tension 0

Table A.277: Laminate 14 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.6	3.6	3.6	25.5	25.5	25.5	24.4	51	LAT LIB DGM
2	3.5	3.6	3.6	25.5	25.5	25.5	24.4	51	AAB
3	3.6	3.6	3.6	25.5	25.5	25.5	24.4	51	LIB

Table A.278: Laminate 14 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0147	0.004	25.5	0.0000	0.000	91.6
2	3.6	0.0587	0.016	25.5	0.0000	0.000	91.2
3	3.6	0.0254	0.007	25.5	0.0000	0.000	91.3

Table A.279: Laminate 14 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	107.0	0.999970	0.00046	0.259	0.999972	0.00045
2	108.3	0.999977	0.00040	0.252	0.999936	0.00067
3	107.8	0.999982	0.00036	0.291	0.999979	0.00038

Table A.280: Laminate 14 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	91.6	121,267	1,323	11,668
2	91.2	111,442	1,222	10,668
3	91.3	123,339	1,350	11,737
Average	91.4	118,682	1,299	11,358
STDEV	0.2	6,355	67.8	598
CV	0.002	0.054	0.052	0.053

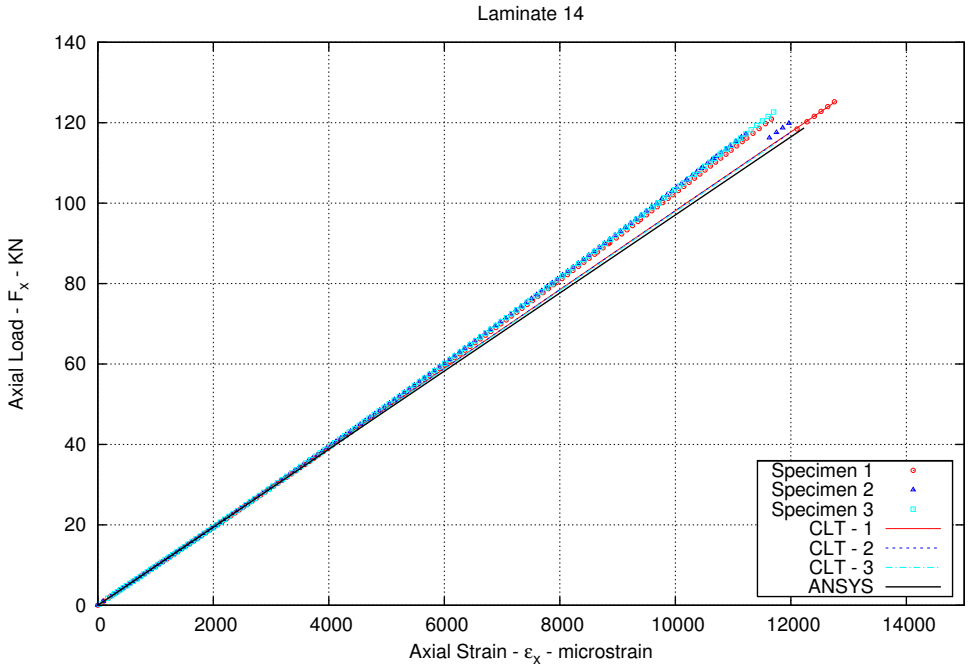


Figure A.156: Laminate 14 axial strain induced with an axial tensile load.

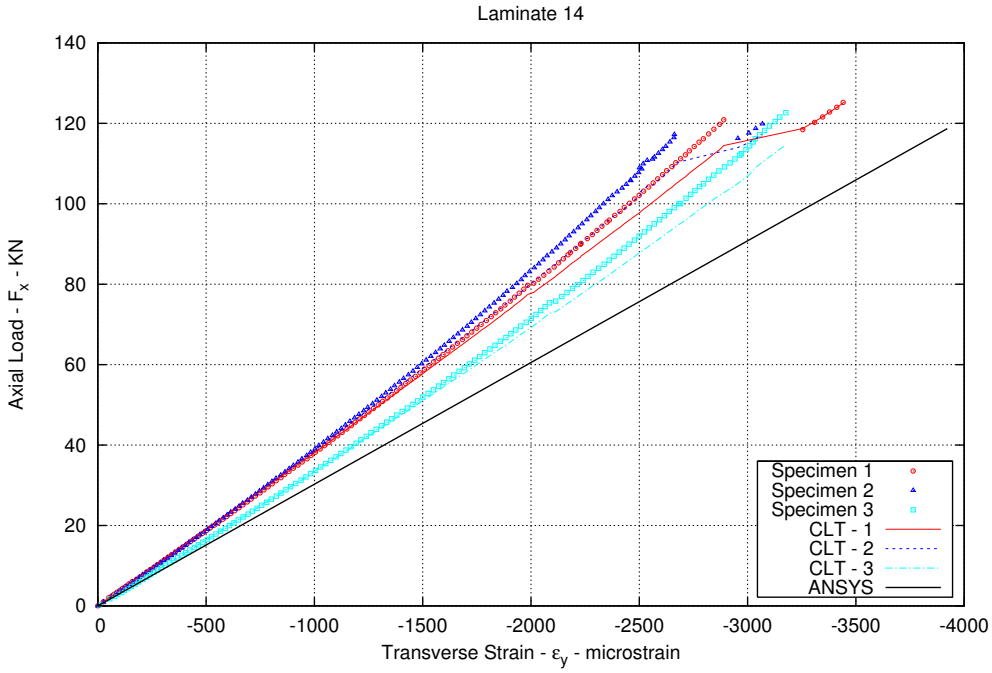


Figure A.157: Laminate 14 transverse strain induced with an axial tensile load.

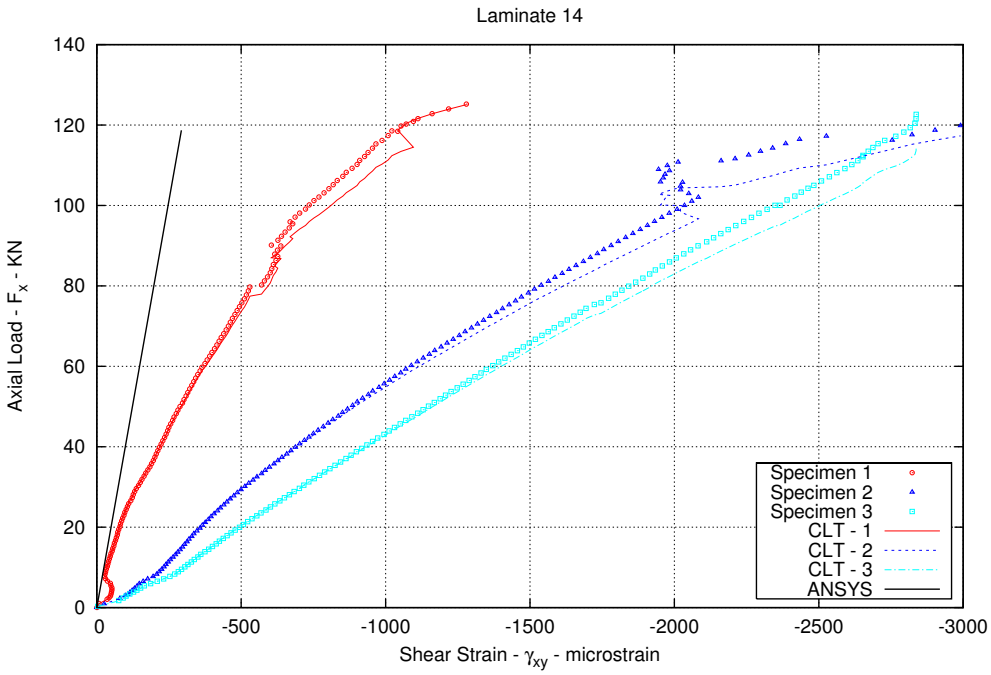


Figure A.158: Laminate 14 shear strain induced with an axial tensile load.

A.15.2 Tenion 90

Table A.281: Laminate 14 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	3.5	25.5	25.5	25.5	24.4	40	LGM
2	3.6	3.8	3.5	25.5	25.5	25.5	24.4	40	LGM
3	3.6	3.7	3.6	25.5	25.5	25.5	24.4	40	LAB

Table A.282: Laminate 14 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0388	0.011	25.5	0.0000	0.000	90.8
2	3.6	0.1164	0.032	25.5	0.0000	0.000	92.5
3	3.6	0.0639	0.018	25.5	0.0000	0.000	92.3

Table A.283: Laminate 14 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	10.1	0.999895	0.00099	0.035	0.999360	0.00246
2	10.1	0.999899	0.00094	0.037	0.999429	0.00223
3	10.2	0.999958	0.00063	0.036	0.999433	0.00230

Table A.284: Laminate 14 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	90.8	5,434	59.8	6,164
2	92.5	5,411	58.5	6,152
3	92.3	4,975	53.9	5,460
Average	91.9	5,273	57.4	5,925
STDEV	0.9	258	3.1	403
CV	0.010	0.049	0.054	0.068

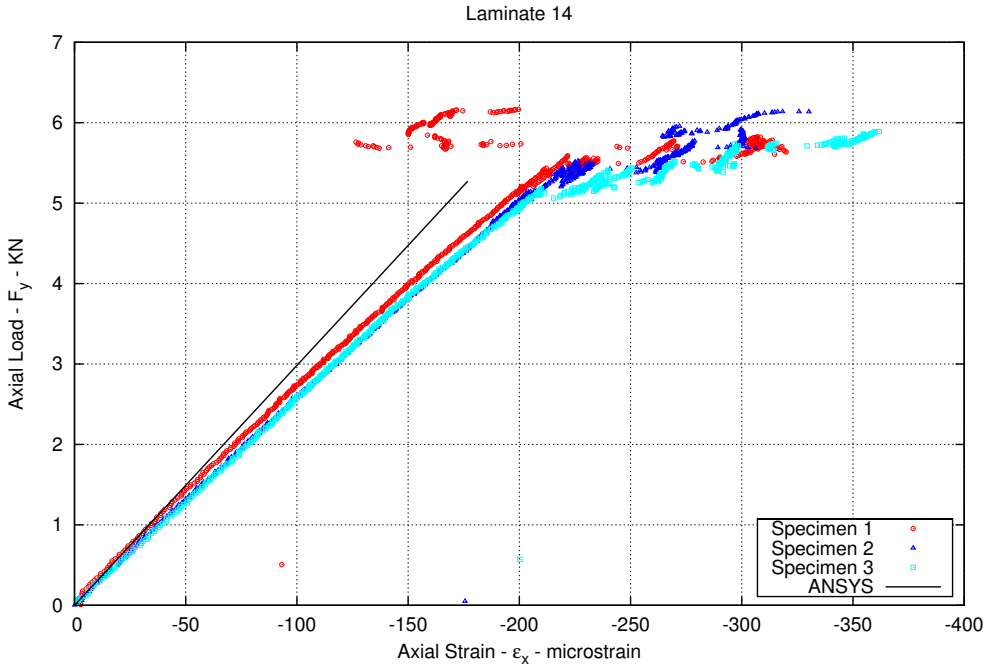


Figure A.159: Laminate 14 axial strain induced with a transverse tensile load.

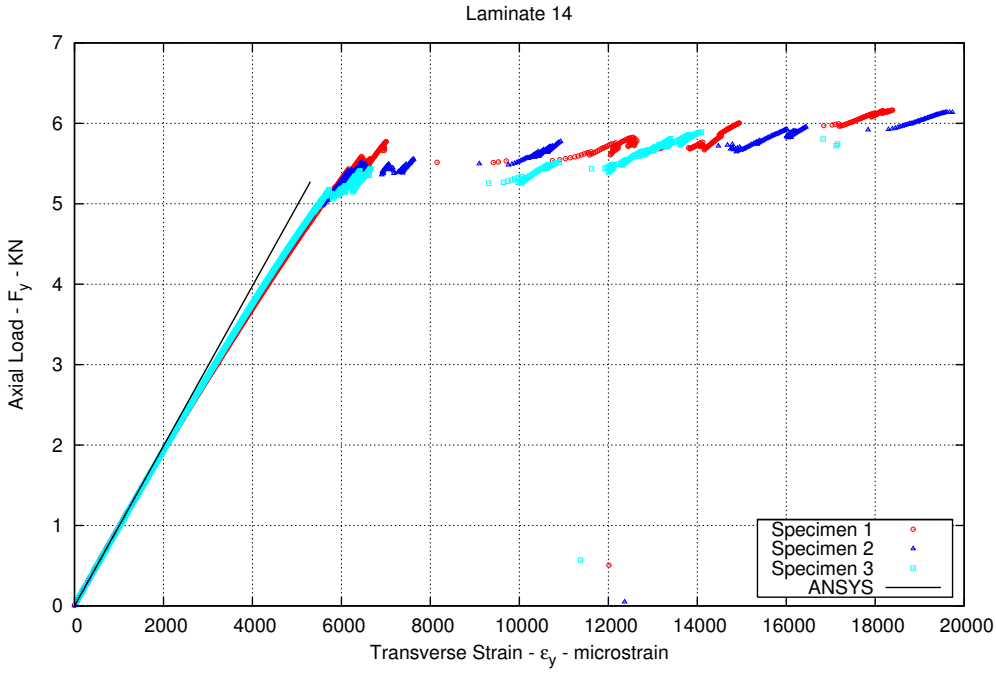


Figure A.160: Laminate 14 transverse strain induced with a transverse tensile load.

A.15.3 Compression

Table A.285: Laminate 14 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.6	3.6	12.7	12.7	23.9
3	3.6	3.7	12.7	12.7	23.9
4	3.6	3.4	12.7	12.7	23.9

Table A.286: Laminate 14 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0180	0.005	12.7	0.0000	0.000	45.6
3	3.6	0.0359	0.010	12.7	0.0000	0.000	46.1
4	3.5	0.1078	0.031	12.7	0.0000	0.000	44.6

Table A.287: Laminate 14 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	98.6	0.999944	0.00069
3	100.2	0.999861	0.00106
4	92.3	0.999943	0.00072

Table A.288: Laminate 14 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
2	3.5	3.5	12.8	12.8	23.9	25	BGM
3	3.6	3.6	12.6	12.6	23.9	25	BGM
6	3.5	3.5	12.7	12.7	23.9	25	BGM

Table A.289: Laminate 14 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
2	3.5	0.0018	0.001	12.8	0.0000	0.000	44.8
3	3.6	0.0009	0.000	12.6	0.0000	0.000	44.9
6	3.5	0.0413	0.012	12.7	0.0000	0.000	44.4

Table A.290: Laminate 14 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
2	44.8	43,299	967	9,963
3	44.9	48,743	1,086	11,199
6	63.8	48,442	759	7,828
Average	51.2	46,828	937	9,663
STDEV	10.9	3,060	165	1,705
CV	0.214	0.065	0.176	0.176

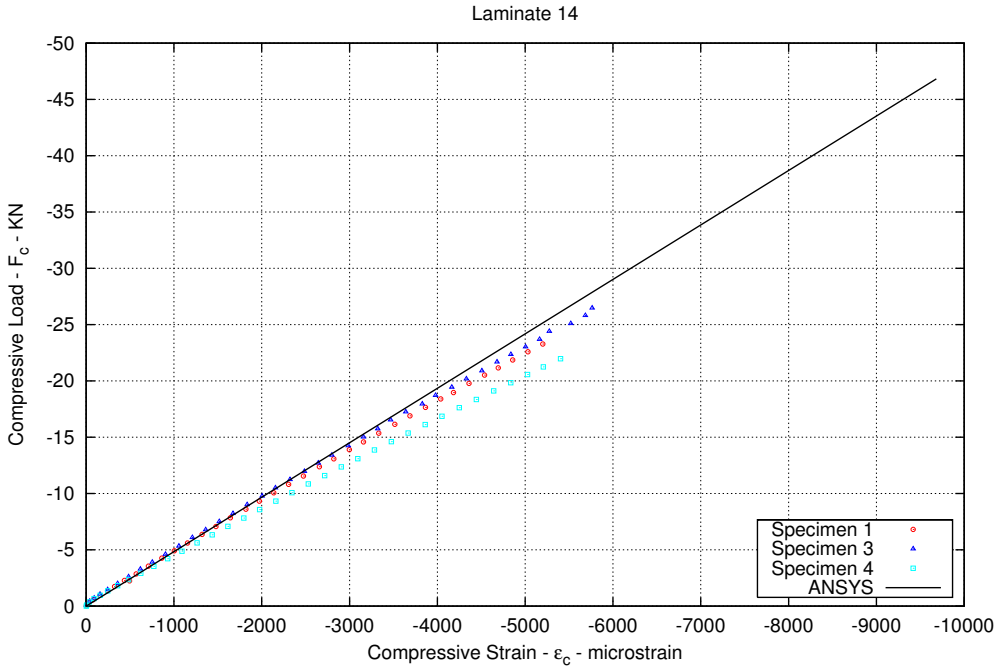


Figure A.161: Laminate 14 axial strain induced with an axial compressive load.

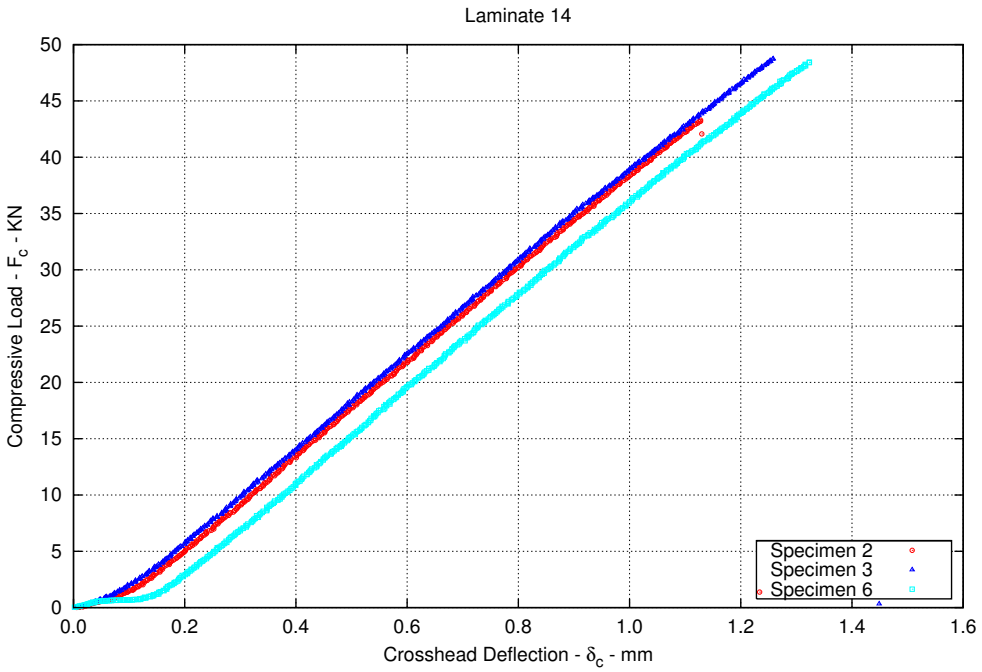


Figure A.162: Response of Laminate 14 to compressive loading.

A.15.4 In-Plane Shear

Table A.291: Laminate 14 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.5	11.5	11.5	22.2	53	null
3	3.6	3.8	11.4	11.4	22.2	53	null
4	3.6	3.6	11.5	11.5	22.2	53	null

Table A.292: Laminate 14 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0180	0.005	11.5	0.0000	0.000	40.1
3	3.7	0.1437	0.039	11.4	0.0359	0.003	41.7
4	3.6	0.0359	0.010	11.5	0.0000	0.000	41.4

Table A.293: Laminate 14 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	5.5	0.9965	0.0066
3	5.1	0.9986	0.0045
4	5.1	0.9989	0.0039

Table A.294: Laminate 14 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.1	3,945	98.4	49,887
2	41.7	3,990	95.7	49,235
3	41.4	3,887	93.9	48,069
Average	41.1	3,941	96.0	49,064
STDEV	0.9	52	2.3	921
CV	0.021	0.013	0.024	0.019

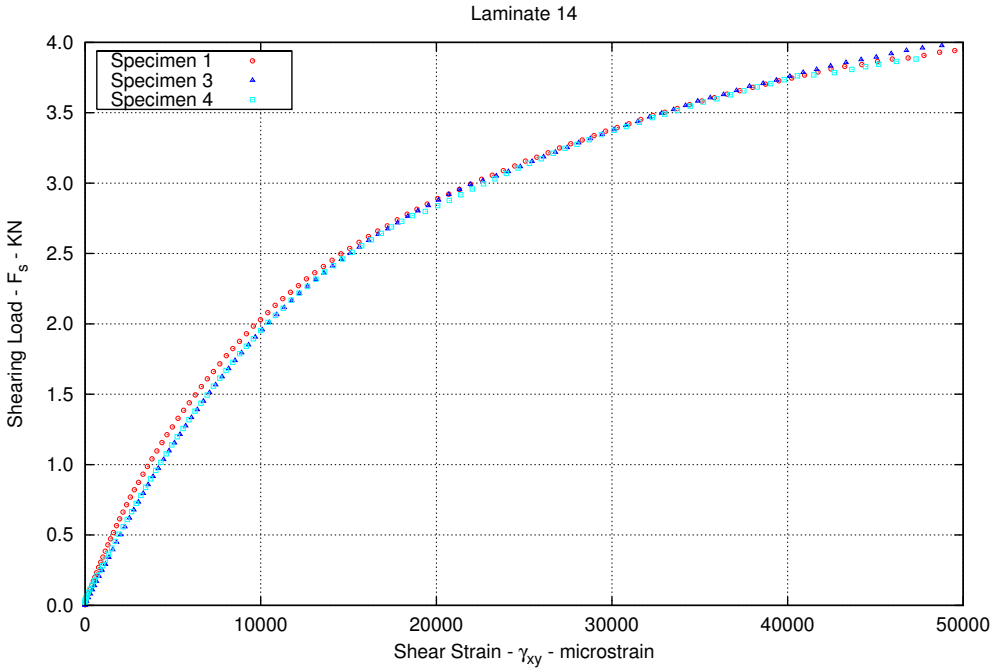


Figure A.163: Laminate 14 shear strain induced with an in-plane shear load.

A.15.5 Interlaminar Shear

Table A.295: Laminate 14 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.6	3.6	6.4	6.4	23.3	60	Interlaminar Shear
2	3.5	3.6	6.4	6.4	23.3	60	Interlaminar Shear
3	3.6	3.5	6.4	6.4	23.3	60	Interlaminar Shear

Table A.296: Laminate 14 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.6	0.0090	0.003	6.4	0.0000	0.000	22.7
2	3.6	0.0898	0.025	6.4	0.0000	0.000	22.7
3	3.5	0.0090	0.003	6.4	0.0000	0.000	22.6

Table A.297: Laminate 14 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.7	1730.3	57.9
2	22.7	1811.6	60.6
3	22.6	1790.8	60.3

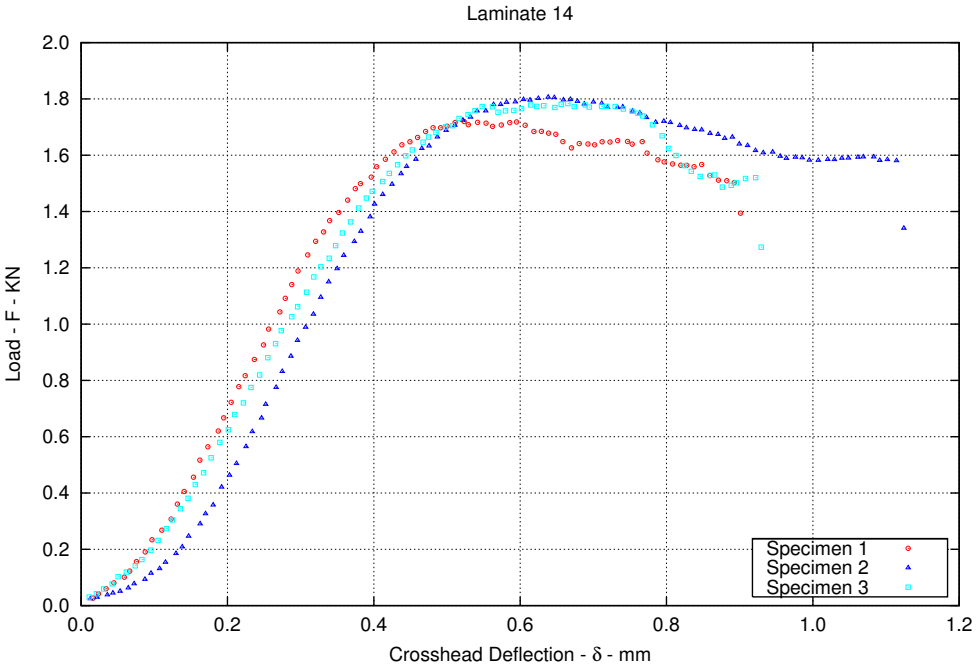
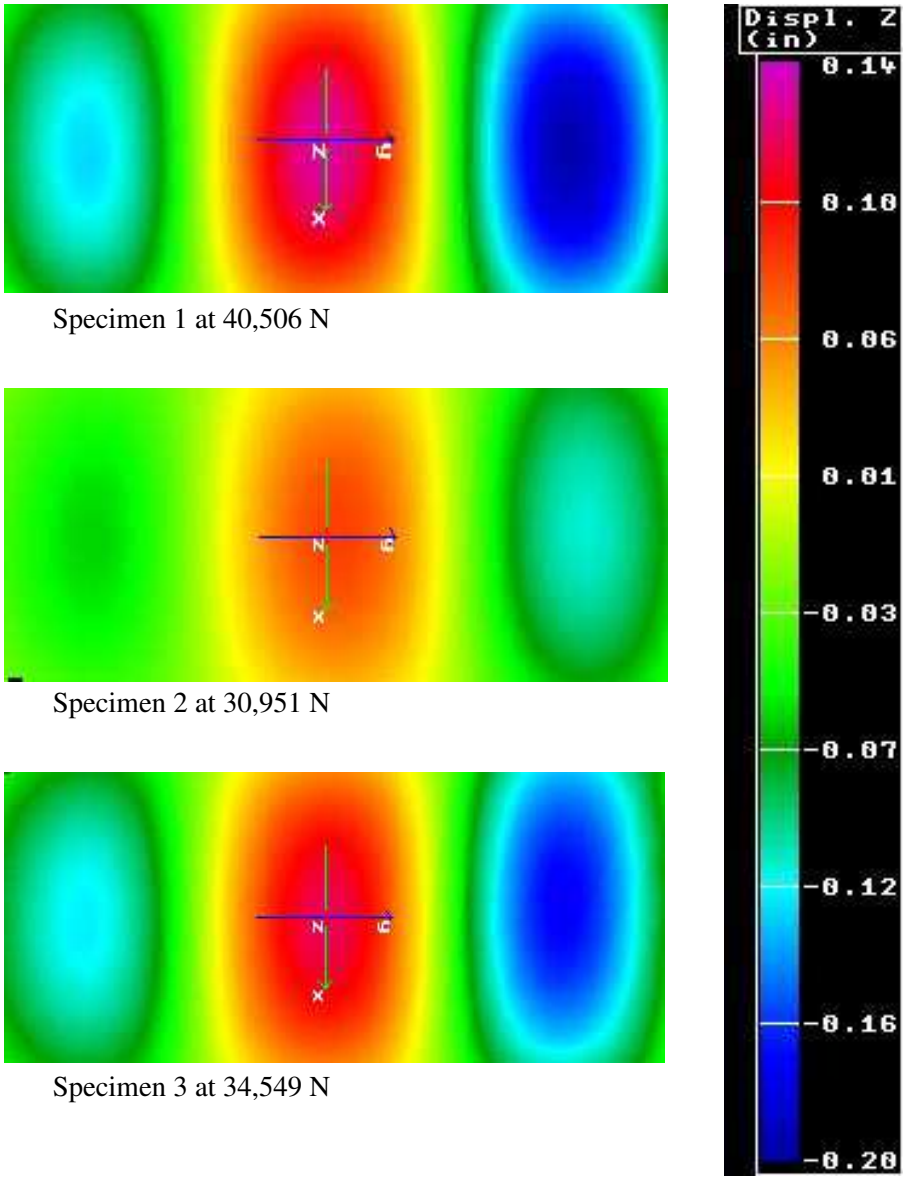


Figure A.164: Laminate 14 interlaminar shear response.

A.15.6 Edgewise Compression

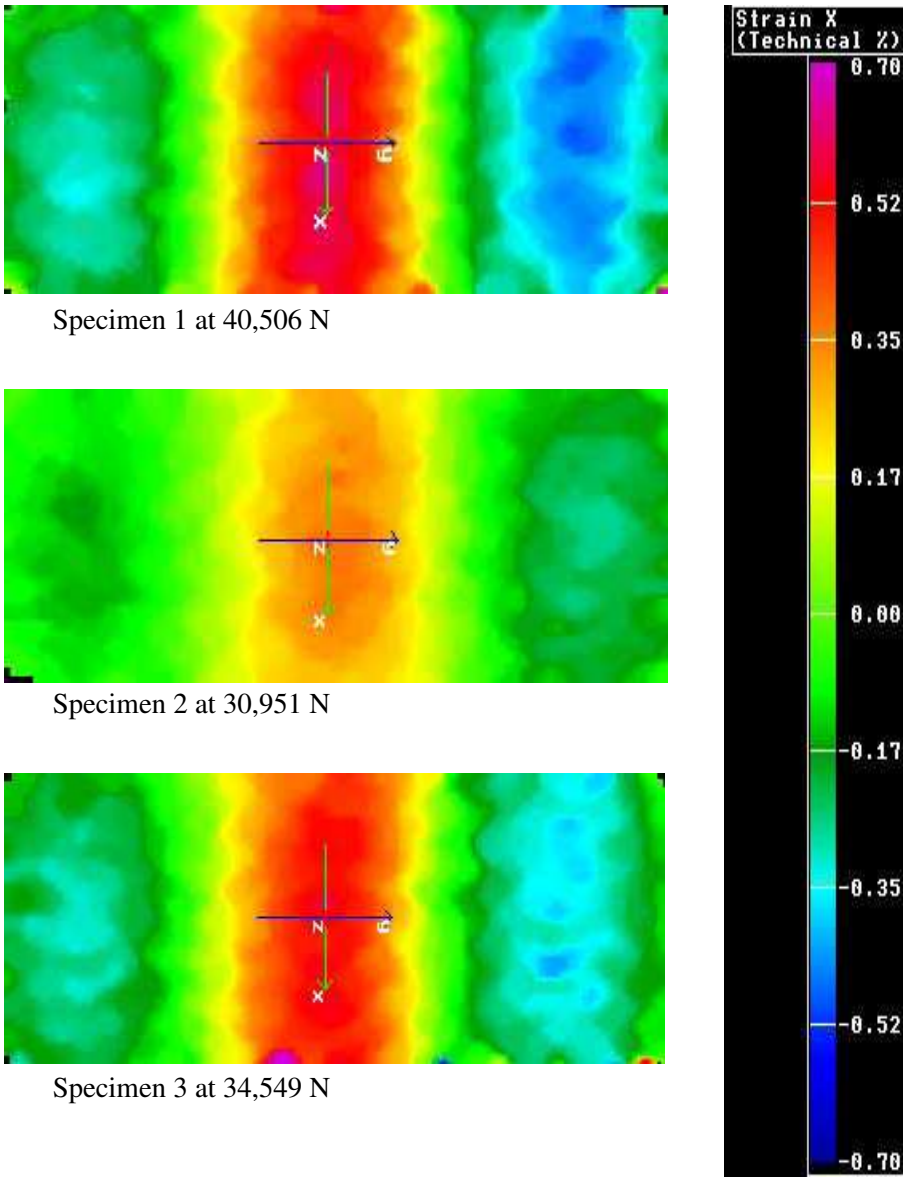


Specimen 1 at 40,506 N

Specimen 2 at 30,951 N

Specimen 3 at 34,549 N

Figure A.165: Laminate 14 out-of-plane displacement due to edgewise compression.

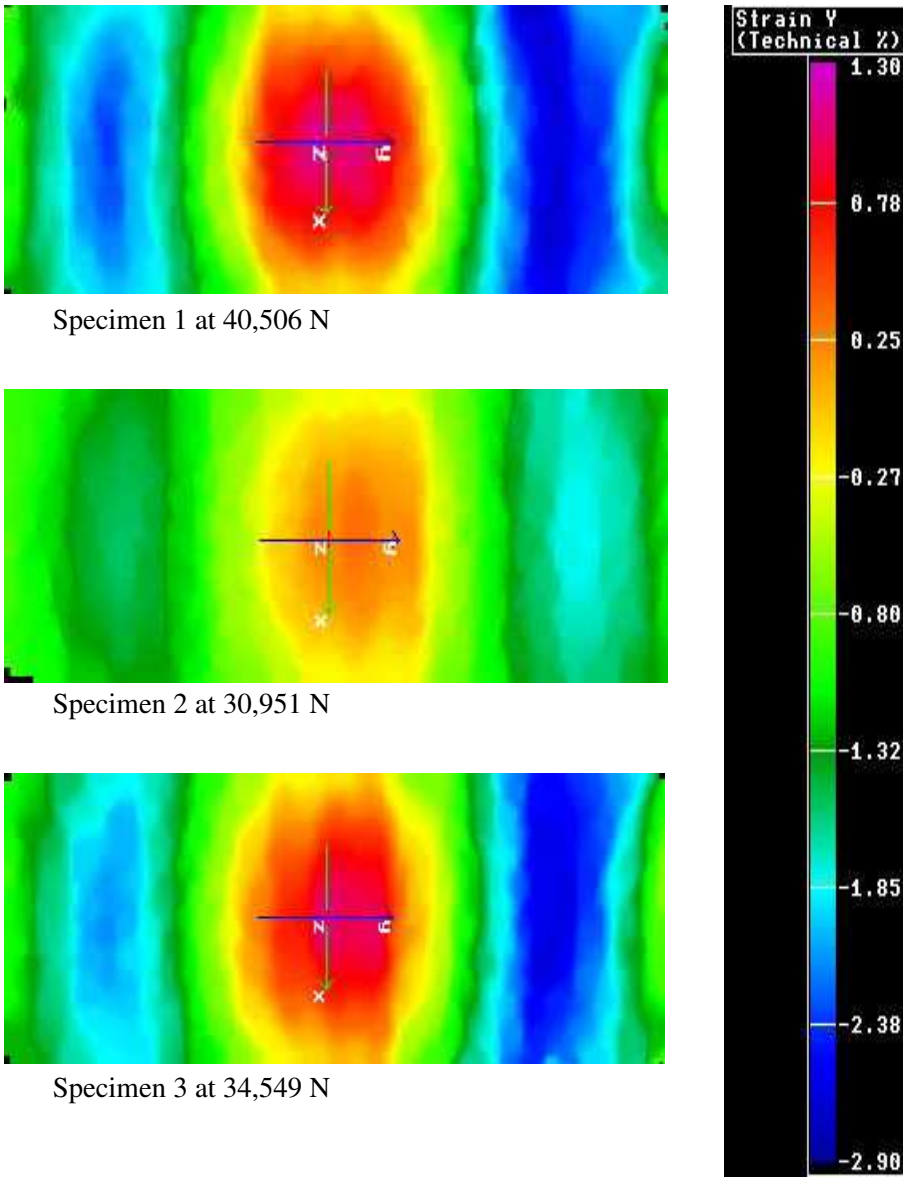


Specimen 1 at 40,506 N

Specimen 2 at 30,951 N

Specimen 3 at 34,549 N

Figure A.166: Laminate 14 axial strain displacement due to edgewise compression.

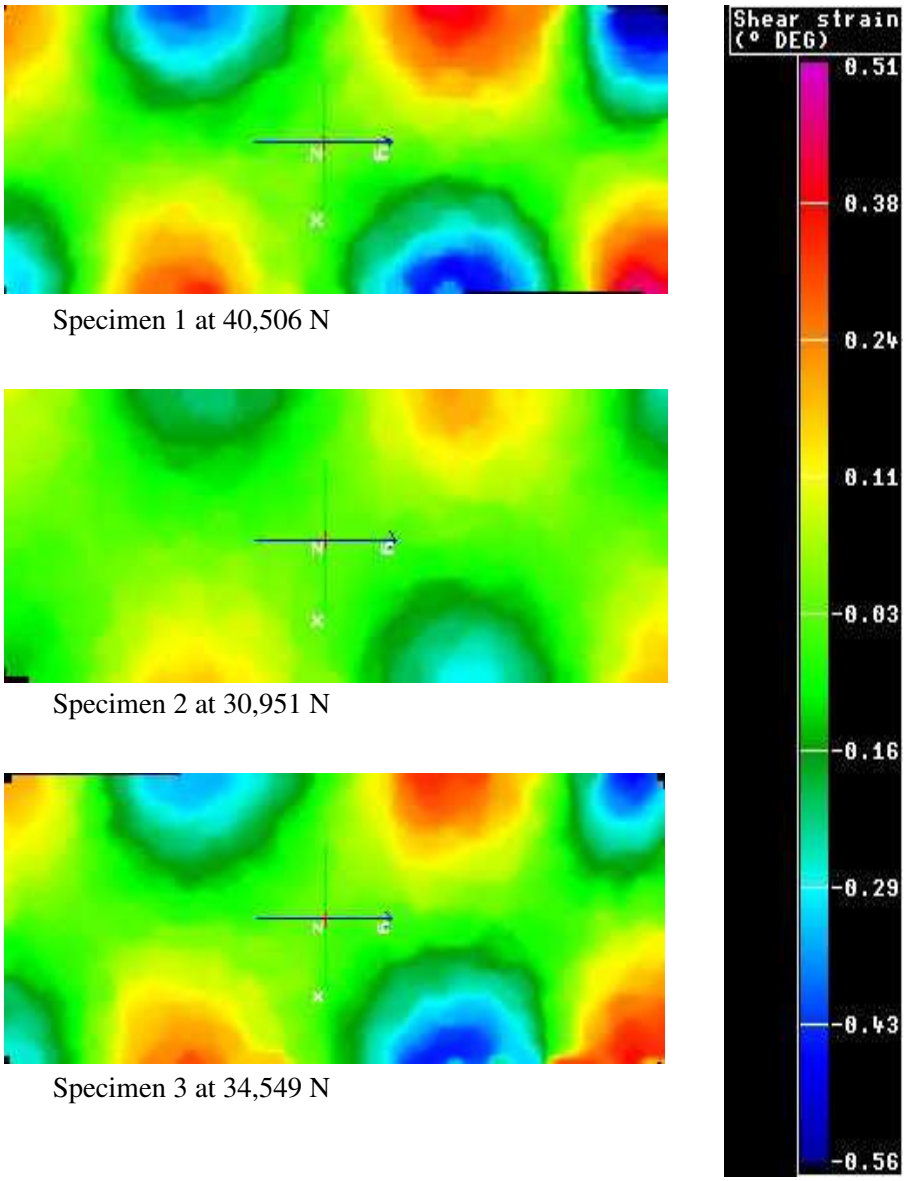


Specimen 1 at 40,506 N

Specimen 2 at 30,951 N

Specimen 3 at 34,549 N

Figure A.167: Laminate 14 transverse strain displacement due to edgewise compression.



Specimen 1 at 40,506 N

Specimen 2 at 30,951 N

Specimen 3 at 34,549 N

Figure A.168: Laminate 14 shear strain displacement due to edgewise compression.

A.16 Laminate 15 - 30CUD/55C20/15G-70 - $[(-70_G)_2/(20_C)_2/0_C]_s$

A.16.1 Tension 0

Table A.298: Laminate 15 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.5	4.6	4.6	25.4	25.4	25.4	24.4	31	AWT DWT
2	4.6	4.5	4.4	25.4	25.4	25.4	24.4	31	AWT DWT
3	4.5	4.6	4.5	25.4	25.4	25.4	24.4	31	AWT DWT

Table A.299: Laminate 15 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0816	0.018	25.4	0.0147	0.001	116.0
2	4.5	0.0776	0.017	25.4	0.0000	0.000	114.6
3	4.5	0.0529	0.012	25.4	0.0000	0.000	115.2

Table A.300: Laminate 15 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	50.8	0.999963	0.00042	0.488	0.998394	0.00275
2	45.2	0.999965	0.00062	0.488	0.999696	0.00184
3	54.1	0.999703	0.00168	0.502	0.996875	0.00544

Table A.301: Laminate 15 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	116	57,721	498	10,872
2	115	60,968	532	13,432
3	115	62,858	546	12,614
Average	115	60,516	525	12,306
STDEV	0.7	2,598	24.7	1,308
CV	0.006	0.043	0.047	0.106

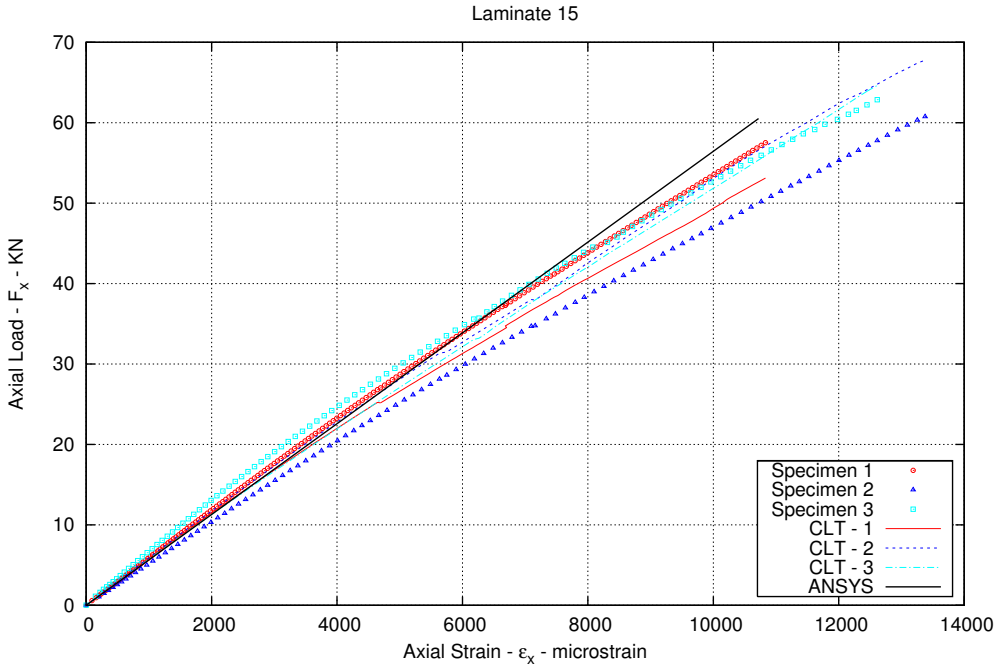


Figure A.169: Laminate 15 axial strain induced with an axial tensile load.

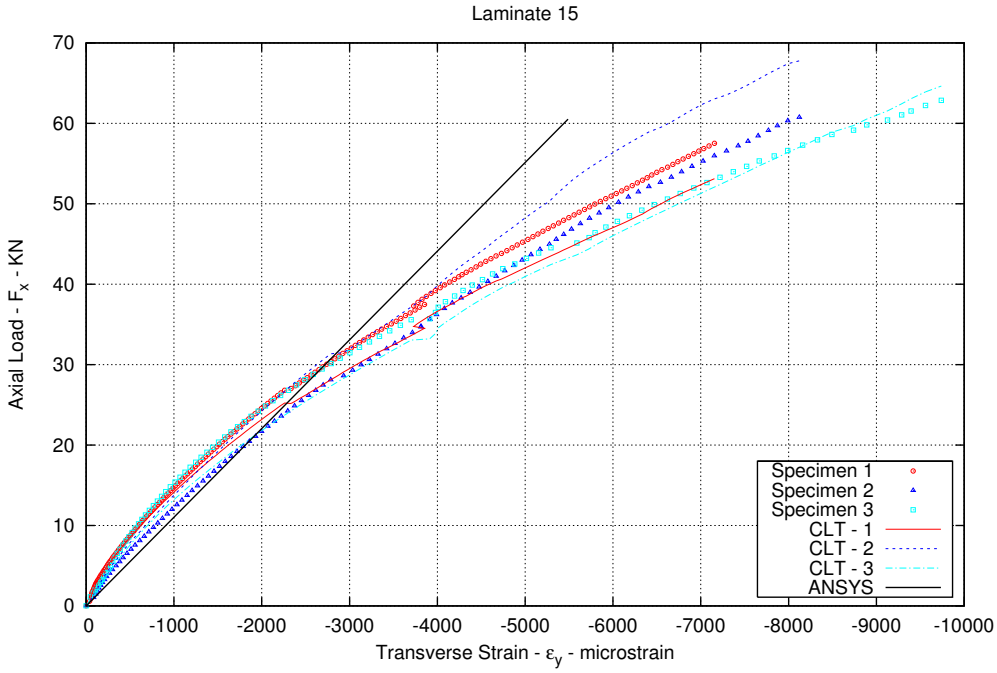


Figure A.170: Laminate 15 transverse strain induced with an axial tensile load.

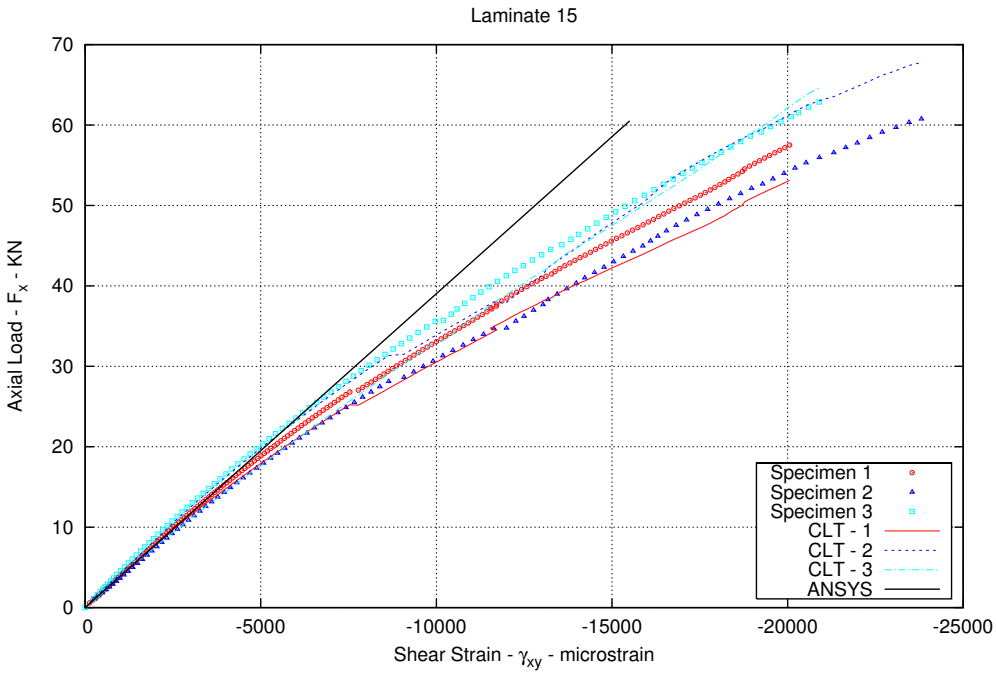


Figure A.171: Laminate 15 shear strain induced with an axial tensile load.

A.16.2 Tenion 90

Table A.302: Laminate 15 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.5	4.5	4.4	25.4	25.3	25.3	24.4	72	AGM
2	4.5	4.5	4.5	25.4	25.4	25.4	24.4	72	AWB
3	4.5	4.5	4.5	25.4	25.4	25.4	24.4	72	AGM

Table A.303: Laminate 15 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.5	0.0671	0.015	25.4	0.0408	0.002	113.4
2	4.5	0.0367	0.008	25.4	0.0000	0.000	114.2
3	4.5	0.0423	0.009	25.4	0.0000	0.000	114.6

Table A.304: Laminate 15 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	11.3	0.999736	0.00213	0.115	0.966868	0.02431
2	11.5	0.999721	0.00154	0.142	0.974000	0.01510
3	11.8	0.999471	0.00283	0.155	0.976661	0.01903

Table A.305: Laminate 15 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	113	7,263	64.0	6,079
3	114	6,712	58.8	5,432
4	115	7,450	65.0	5,859
Average	114	7,142	62.6	5,790
STDEV	0.6	384	3.3	329
CV	0.005	0.054	0.053	0.057

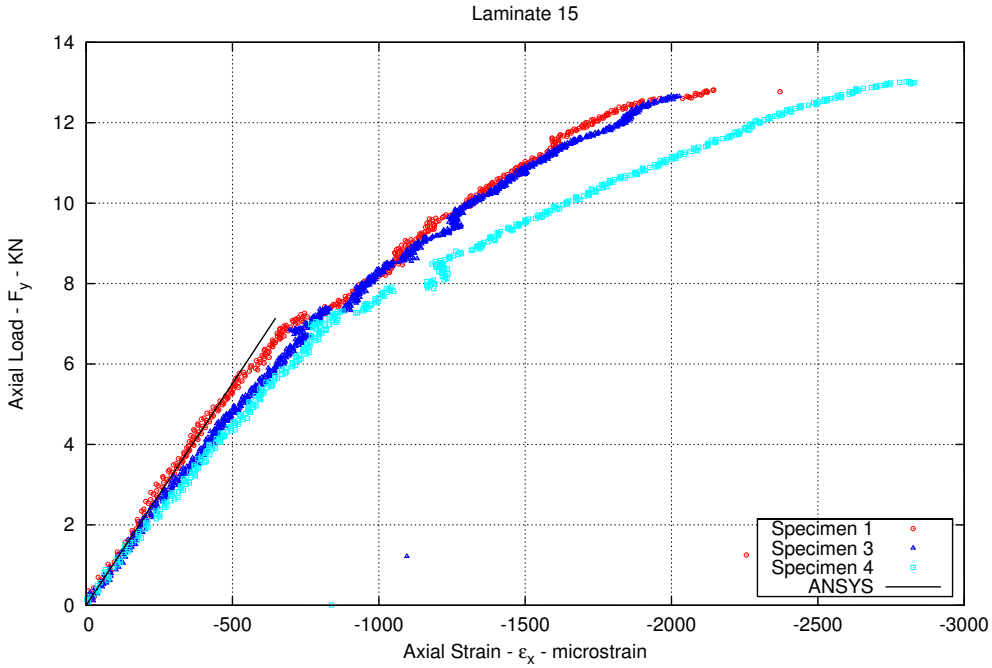


Figure A.172: Laminate 15 axial strain induced with a transverse tensile load.

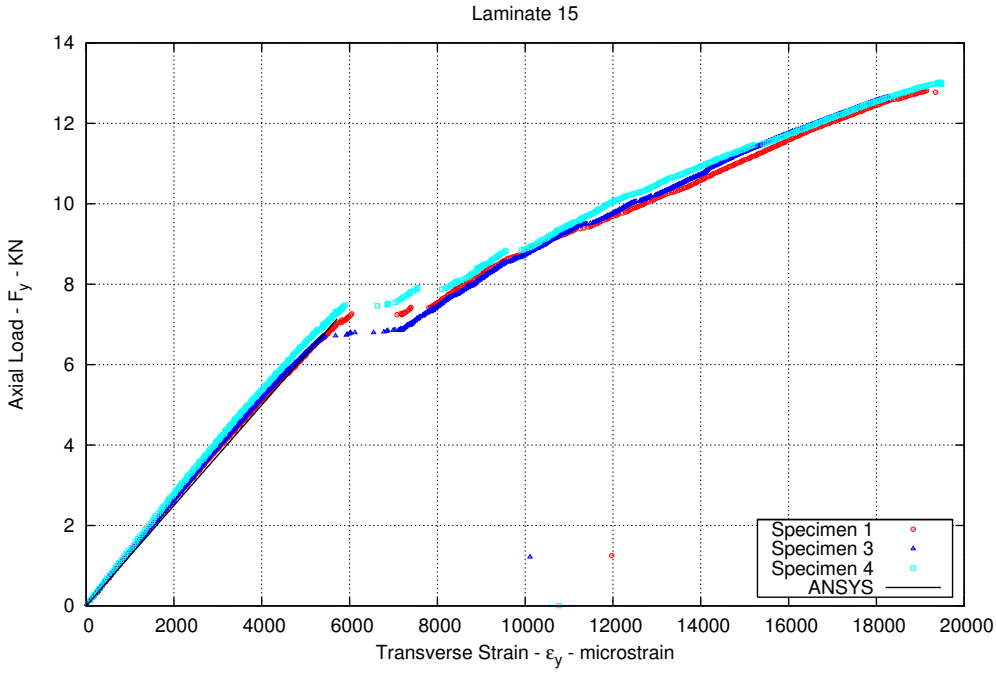


Figure A.173: Laminate 15 transverse strain induced with a transverse tensile load.

A.16.3 Compression

Table A.306: Laminate 15 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	4.7	4.6	12.8	12.8	25.6
2	4.5	4.5	12.8	12.8	25.6
3	4.5	4.6	12.8	12.8	25.6

Table A.307: Laminate 15 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0898	0.019	12.8	0.0000	0.000	59.2
2	4.5	0.0000	0.000	12.8	0.0000	0.000	57.3
3	4.6	0.0718	0.016	12.8	0.0000	0.000	58.4

Table A.308: Laminate 15 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	54.3	0.999492	0.00202
2	50.5	0.999638	0.00181
3	48.6	0.999685	0.00175

Table A.309: Laminate 15 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.5	4.4	12.7	12.7	25	31	TAT
2	4.5	4.7	12.7	12.7	25	31	TAT
3	4.6	4.6	12.7	12.7	25	31	TAT
4	4.5	4.6	12.7	12.7	25	31	TAT

Table A.310: Laminate 15 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	4.5	0.0593	0.013	12.7	0.0000	0.000	56.9
2	4.6	0.1338	0.029	12.7	0.0000	0.000	57.9
3	4.6	0.0117	0.003	12.7	0.0000	0.000	58.3
4	4.6	0.0287	0.006	12.7	0.0000	0.000	57.9

Table A.311: Laminate 15 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	56.9	23,441	412	8,065
2	57.9	23,280	402	7,865
3	58.3	19,914	341	6,678
4	57.9	22,476	388	7,601
Average	57.7	22,278	386	7,552
STDEV	0.3	1,758	31.9	623
CV	0.005	0.079	0.083	0.083

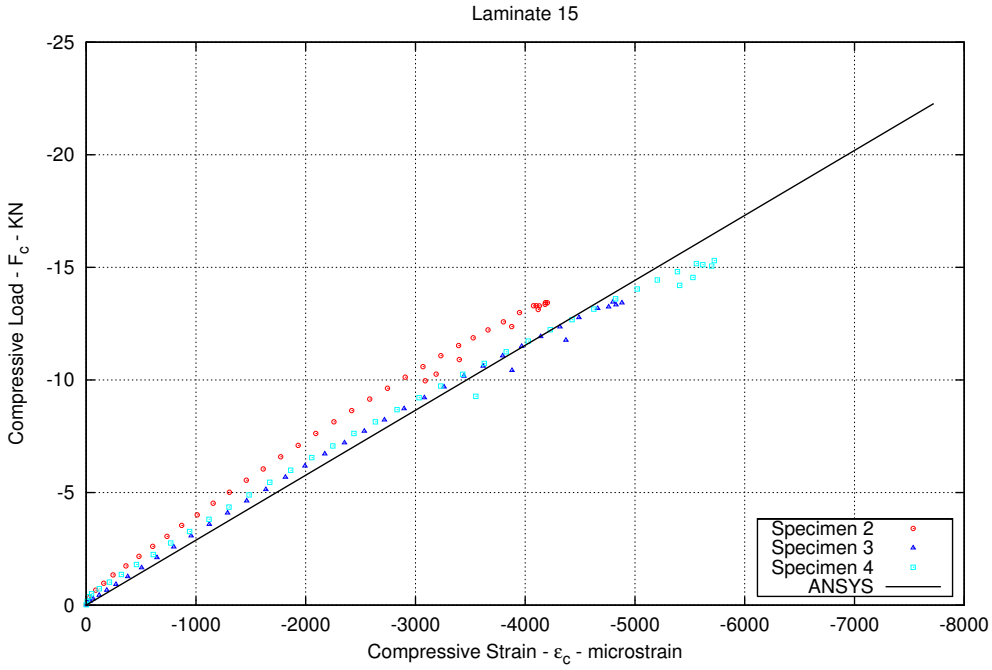


Figure A.174: Laminate 15 axial strain induced with an axial compressive load.

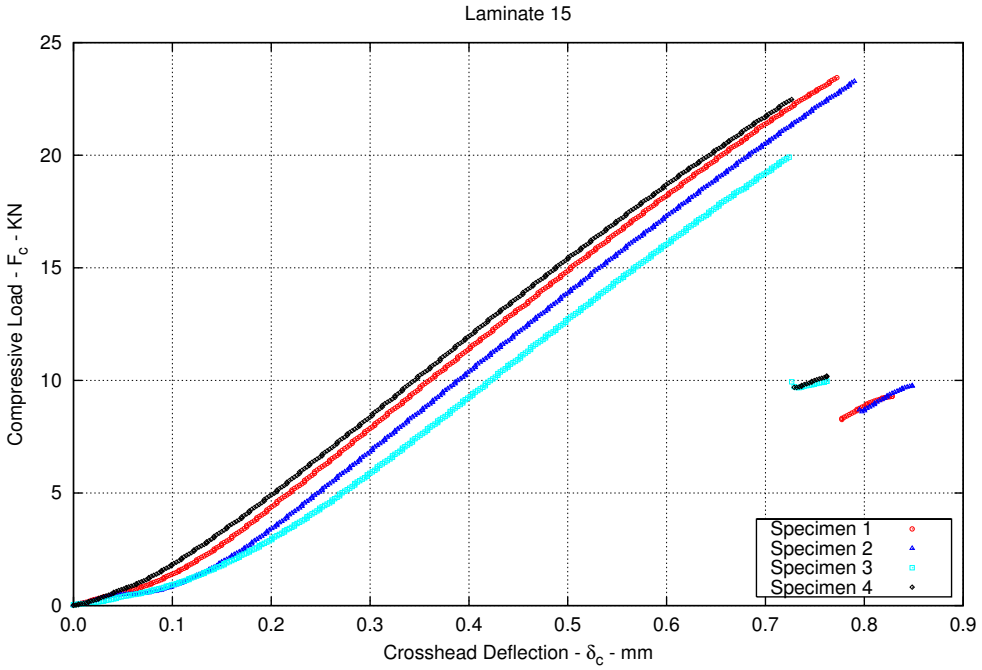


Figure A.175: Response of Laminate 15 to compressive loading.

A.16.4 In-Plane Shear

Table A.312: Laminate 15 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.5	4.5	11.5	11.5	25	49	null
2	4.5	4.5	11.4	11.4	25	49	null
3	4.7	4.7	11.5	11.5	25	49	null

Table A.313: Laminate 15 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.5	0.0000	0.000	11.5	0.0000	0.000	51.8
2	4.5	0.0180	0.004	11.4	0.0000	0.000	51.8
3	4.7	0.0000	0.000	11.5	0.0180	0.002	53.8

Table A.314: Laminate 15 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	6.6	0.9983	0.0044
2	6.7	0.9987	0.0039
3	6.5	0.9984	0.0043

Table A.315: Laminate 15 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	51.8	6,439	124	35,477
2	51.8	6,541	126	33,496
3	53.8	5,760	107	25,010
Average	525	6,247	119	31,328
STDEV	1.2	425	10.6	5,560
CV	0.022	0.068	0.089	0.177

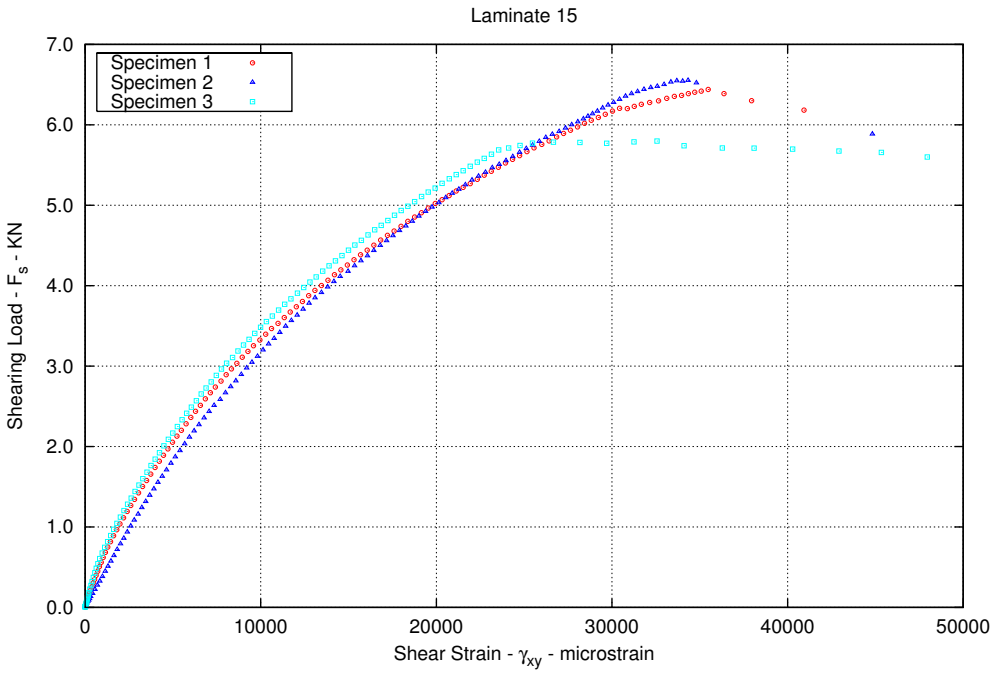


Figure A.176: Laminate 15 shear strain induced with an in-plane shear load.

A.16.5 Interlaminar Shear

Table A.316: Laminate 15 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
2	4.4	4.4	6.4	6.4	23.9	26	Interlaminar Shear
3	4.5	4.6	6.4	6.4	23.9	26	Interlaminar Shear
4	4.6	4.5	6.4	6.3	23.9	26	Interlaminar Shear

Table A.317: Laminate 15 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	4.4	0.0018	0.000	6.4	0.0000	0.000	27.8
3	4.6	0.0278	0.006	6.4	0.0000	0.000	29.0
4	4.6	0.0467	0.010	6.3	0.0090	0.001	28.9

Table A.318: Laminate 15 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
2	27.8	1543.6	42.3
3	29.0	1424.4	37.5
4	28.9	1532.5	40.4

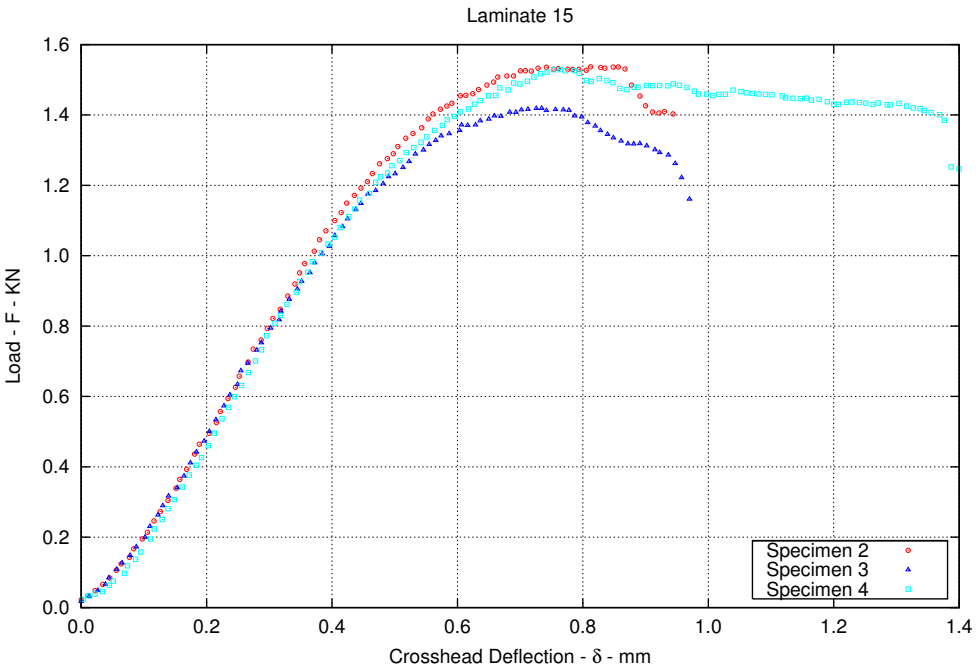
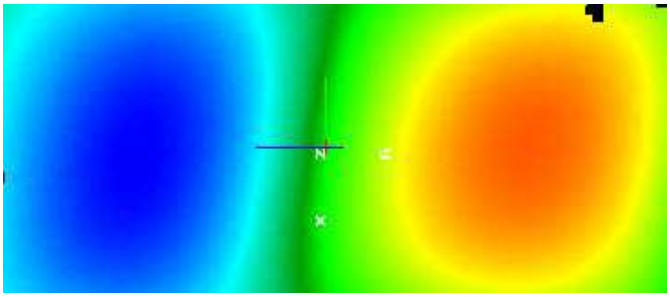
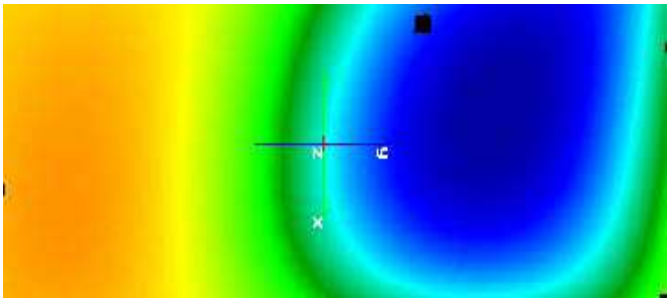


Figure A.177: Laminate 15 interlaminar shear response.

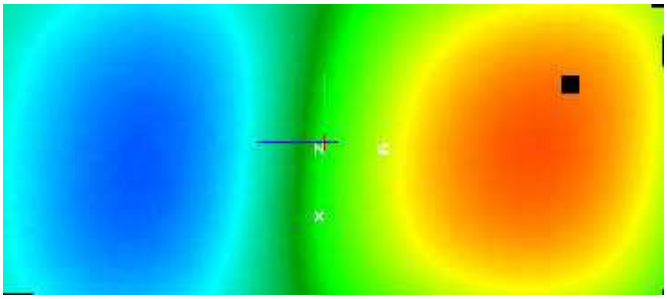
A.16.6 Edgewise Compression



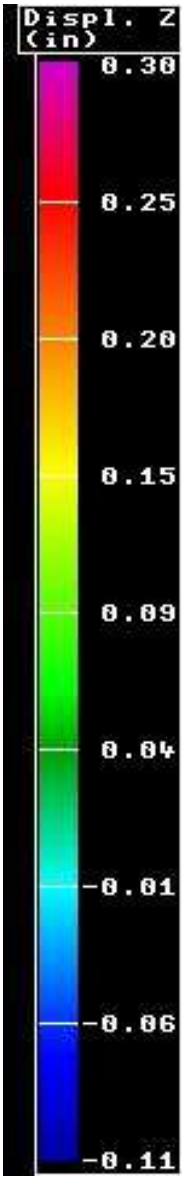
Specimen 1 at 82,568 N



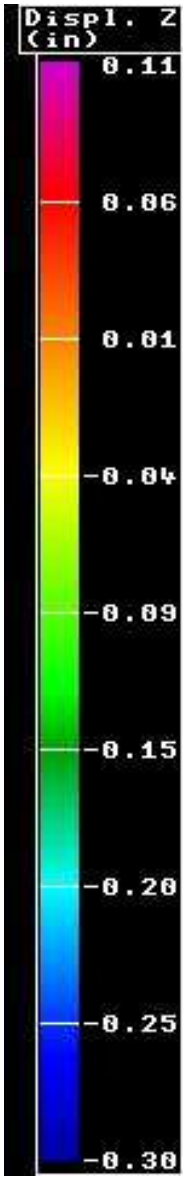
Specimen 2 at 64,882 N



Specimen 3 at 73,009 N



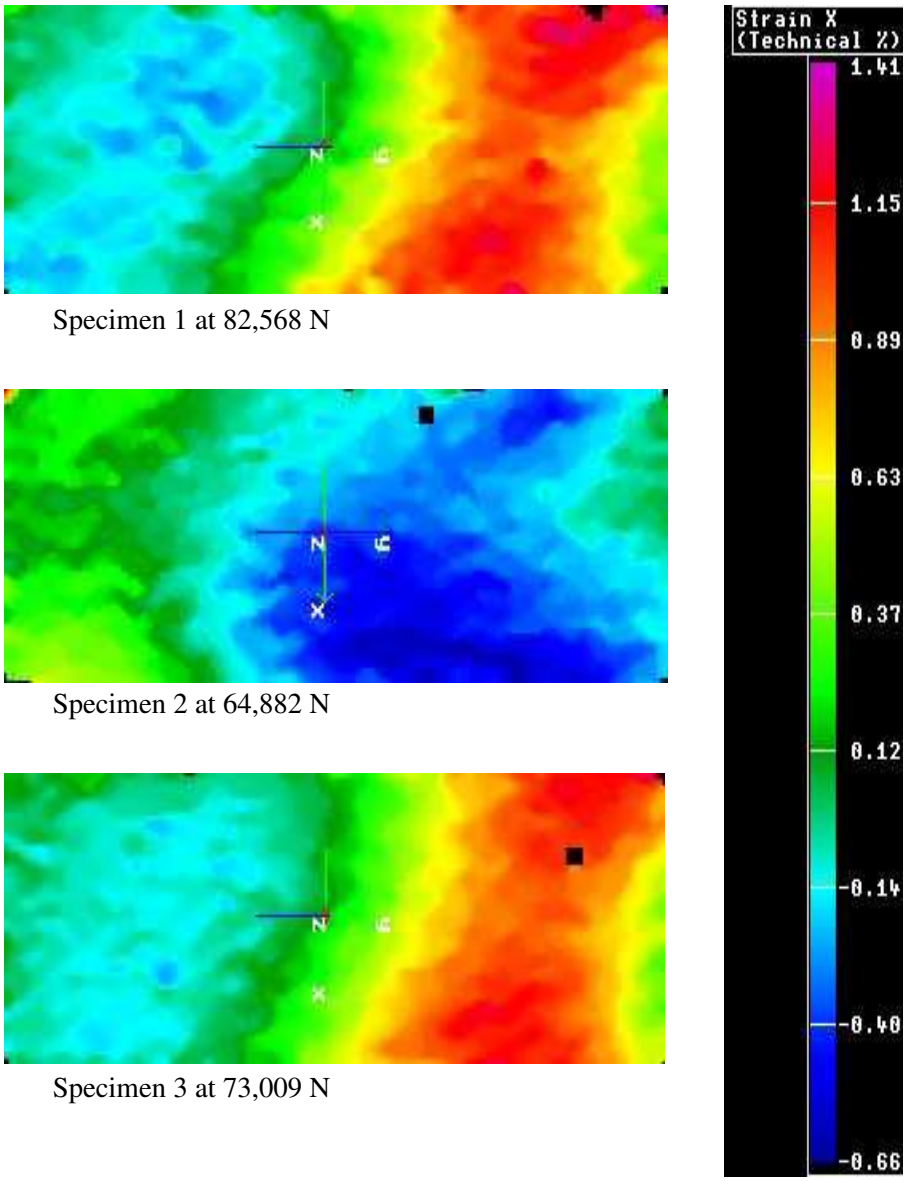
Specimen 1



Specimen 2

Specimen 3

Figure A.178: Laminate 15 out-of-plane displacement due to edgewise compression.

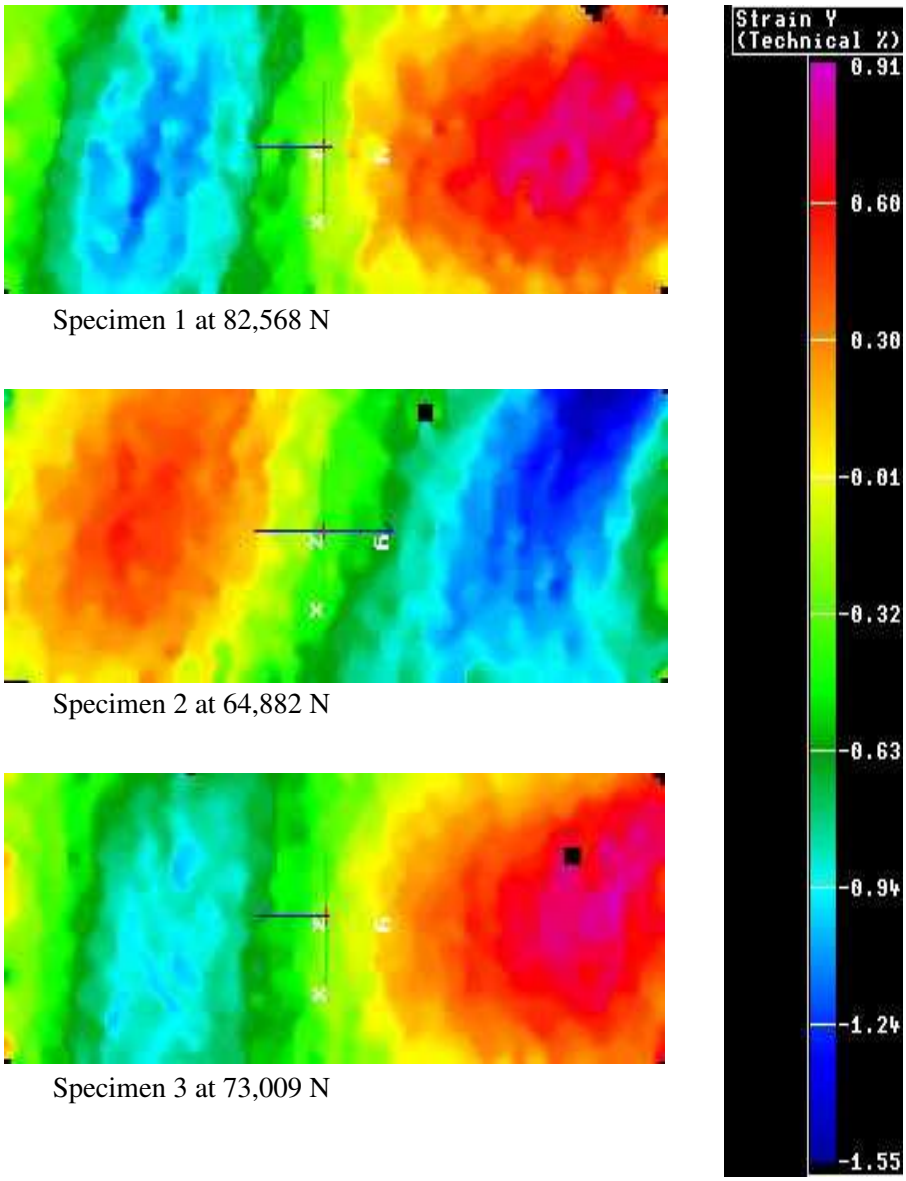


Specimen 1 at 82,568 N

Specimen 2 at 64,882 N

Specimen 3 at 73,009 N

Figure A.179: Laminate 15 axial strain displacement due to edgewise compression.

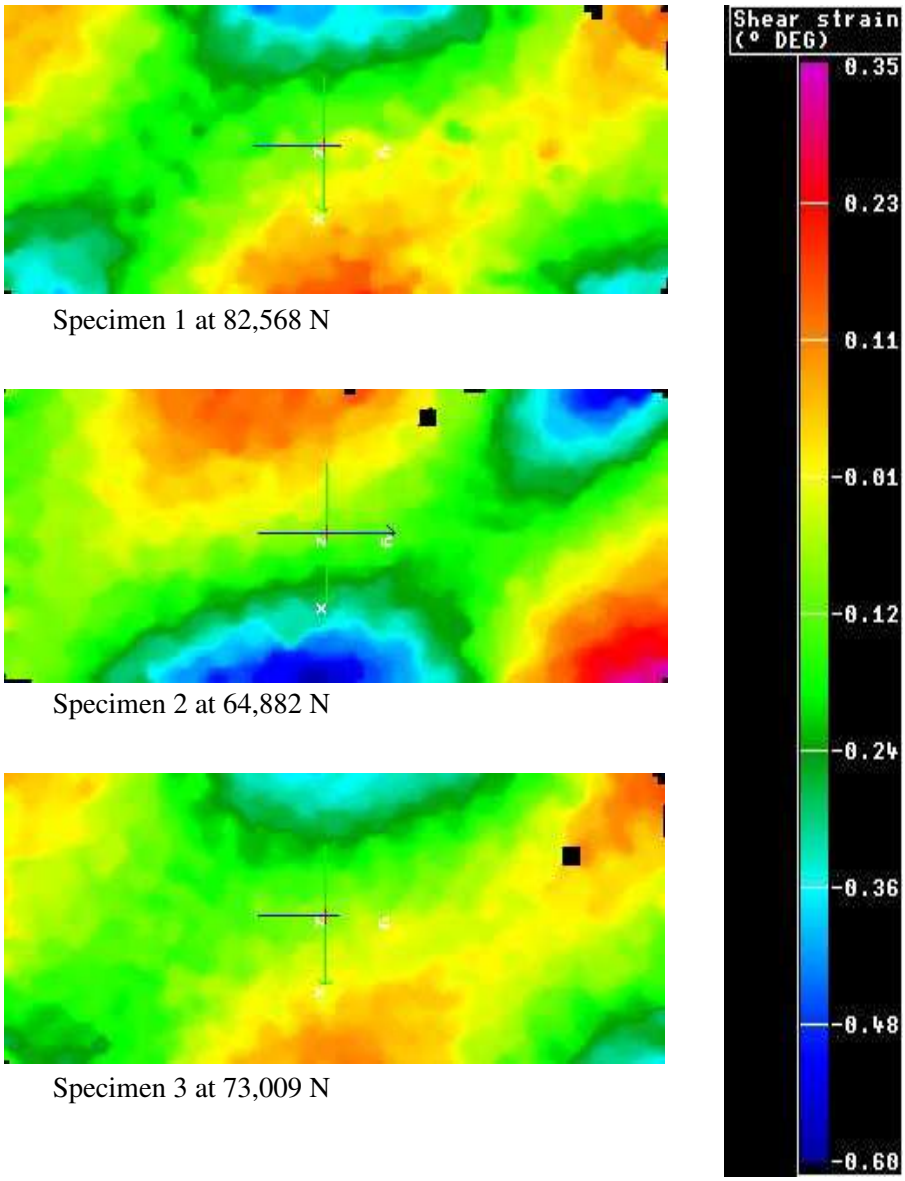


Specimen 1 at 82,568 N

Specimen 2 at 64,882 N

Specimen 3 at 73,009 N

Figure A.180: Laminate 15 transverse strain displacement due to edgewise compression.



Specimen 1 at 82,568 N

Specimen 2 at 64,882 N

Specimen 3 at 73,009 N

Figure A.181: Laminate 15 shear strain displacement due to edgewise compression.

A.17 Laminate 16 - 30CUD/55C20/15G90 - $[(90_G)_2/(20_C)_2/0_C]_s$

A.17.1 Tension 0

Table A.319: Laminate 16 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	4.6	4.6	4.7	25.4	25.4	25.4	23.9	32	AWT DWT
2	4.6	4.6	4.6	25.4	25.4	25.4	23.9	32	AWT DWT
3	4.5	4.5	4.6	25.4	25.4	25.4	23.9	32	AWT DWT

Table A.320: Laminate 16 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0508	0.011	25.4	0.0147	0.001	117.5
2	4.6	0.0388	0.008	25.4	0.0000	0.000	117.0
3	4.5	0.0587	0.013	25.4	0.0147	0.001	114.5

Table A.321: Laminate 16 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	50.8	0.999847	0.00085	0.265	0.998086	0.00299
2	52.2	0.999923	0.00060	0.326	0.999699	0.00118
3	53.5	0.999852	0.00083	0.285	0.999933	0.00056

Table A.322: Laminate 16 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	118	56,457	481	10,979
2	117	56,672	484	10,980
3	115	57,790	505	11,121
Average	116	56,973	490	11,027
STDEV	1.6	715	13.0	82
CV	0.014	0.013	0.026	0.007

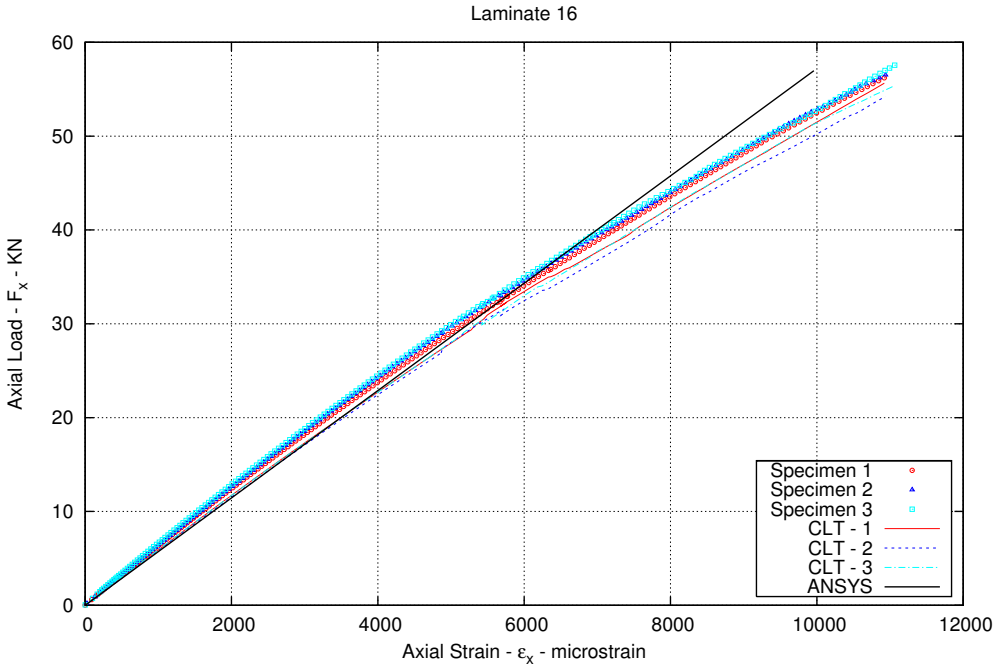


Figure A.182: Laminate 16 axial strain induced with an axial tensile load.

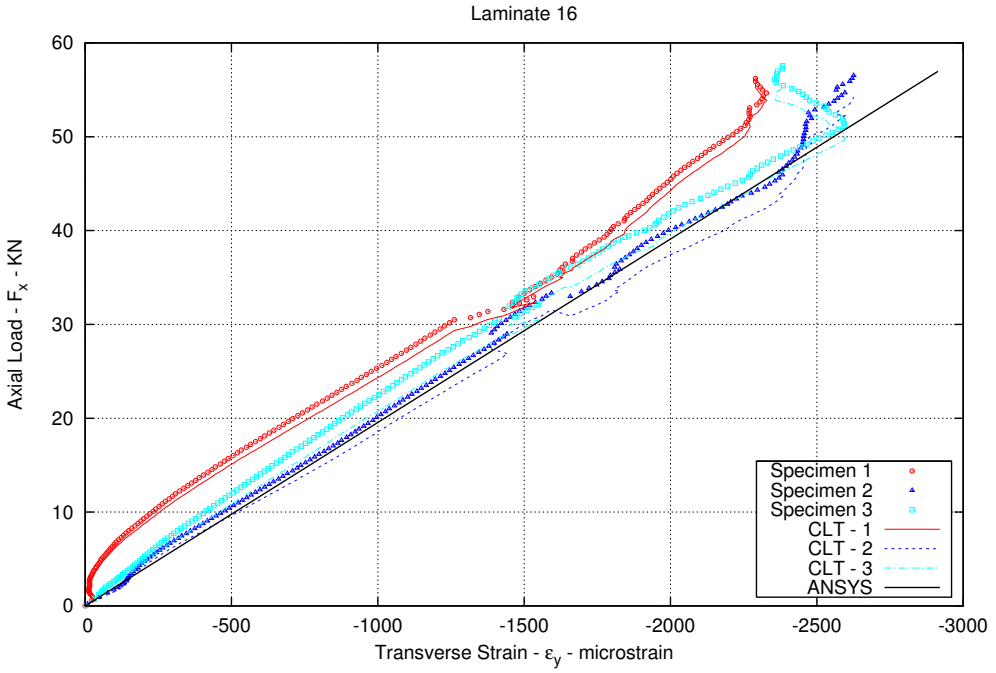


Figure A.183: Laminate 16 transverse strain induced with an axial tensile load.

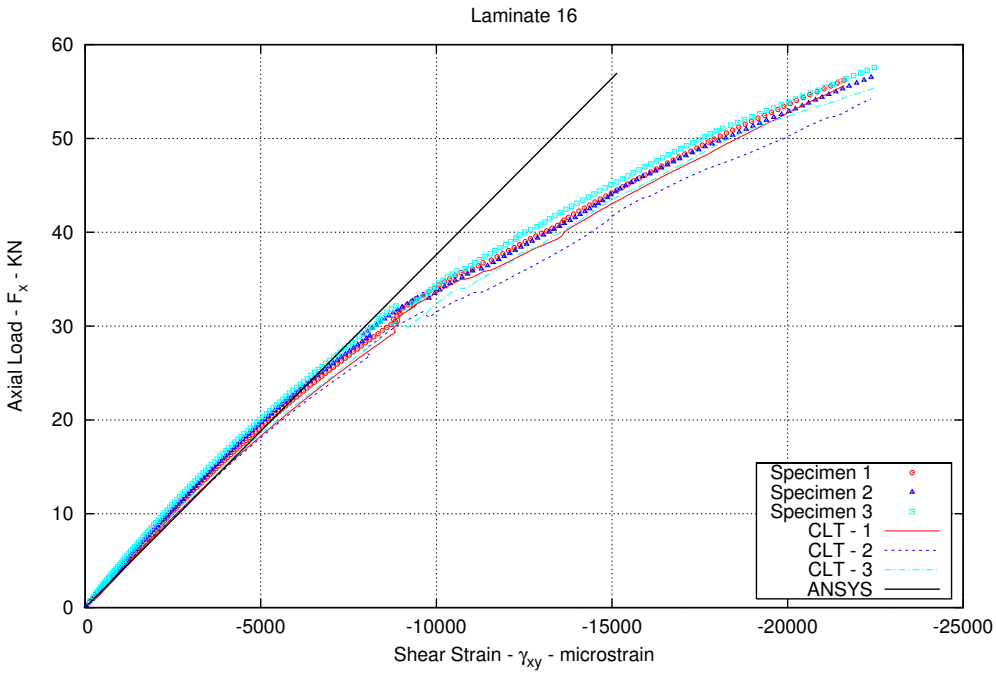


Figure A.184: Laminate 16 shear strain induced with an axial tensile load.

A.17.2 Tenion 90

Table A.323: Laminate 16 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
2	4.5	4.7	4.5	25.4	25.4	25.4	25	39	LAB
3	4.4	4.5	4.6	25.4	25.4	25.4	25	39	LAB
4	4.7	4.5	4.7	25.4	25.4	25.4	25	39	LAB

Table A.324: Laminate 16 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	4.6	0.1027	0.022	25.4	0.0000	0.000	116.0
3	4.5	0.0672	0.015	25.4	0.0000	0.000	114.8
4	4.7	0.1399	0.030	25.4	0.0000	0.000	118.2

Table A.325: Laminate 16 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
2	12.1	0.999997	0.00016	0.070	0.997509	0.00483
3	12.1	0.999975	0.00050	0.090	0.999903	0.00098
4	12.5	0.999993	0.00025	0.090	0.999848	0.00115

Table A.326: Laminate 16 transverse tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
2	116	7,426	64.0	5,570
3	115	7,382	64.3	5,552
4	118	7,330	62.0	5,147
Average	116	7379	63.4	5,423
STDEV	1.7	48	1.2	239
CV	0.014	0.006	0.019	0.044

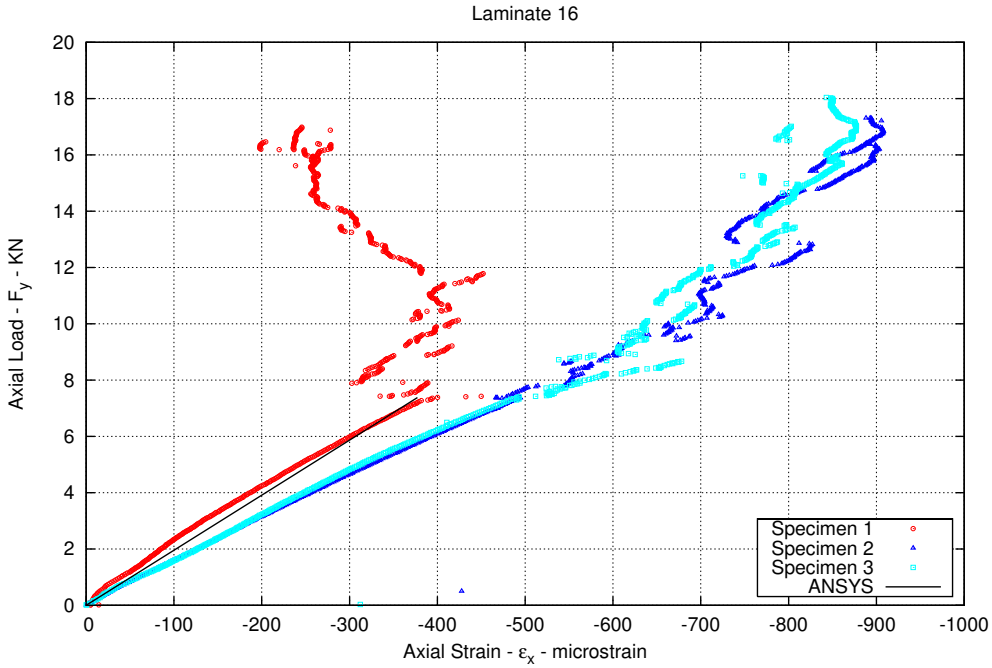


Figure A.185: Laminate 16 axial strain induced with a transverse tensile load.

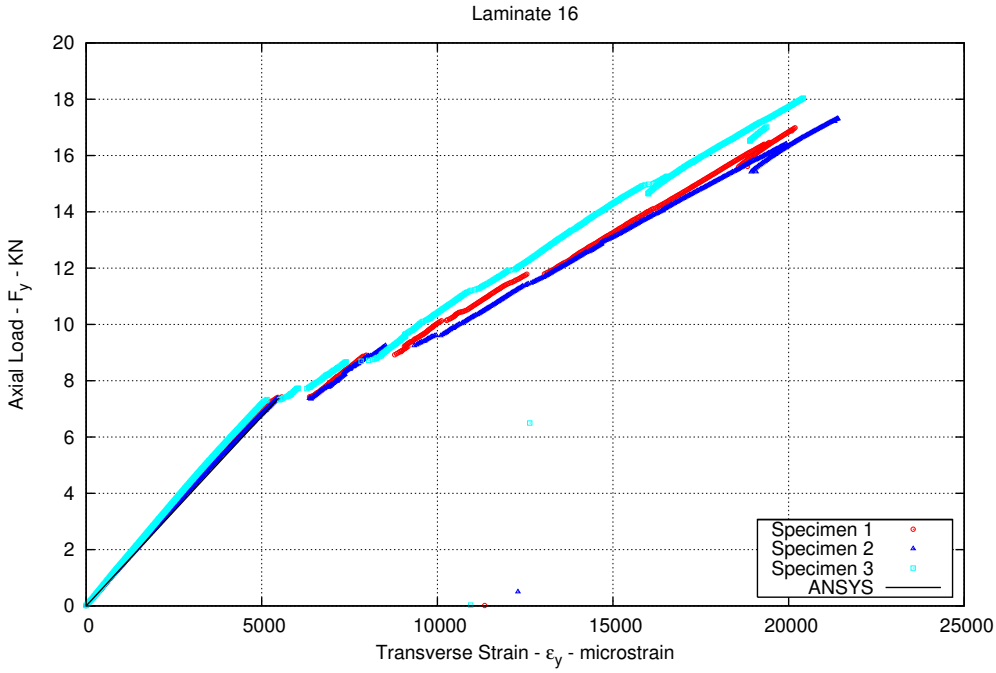


Figure A.186: Laminate 16 transverse strain induced with a transverse tensile load.

A.17.3 Compression

Table A.327: Laminate 16 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	4.6	4.6	12.8	12.8	25.6
2	4.7	4.6	12.8	12.8	25.6
3	4.5	4.7	12.8	12.8	25.6

Table A.328: Laminate 16 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.6	0.0000	0.000	12.8	0.0000	0.000	58.4
2	4.6	0.0718	0.016	12.8	0.0000	0.000	59.2
3	4.6	0.1078	0.023	12.8	0.0000	0.000	58.9

Table A.329: Laminate 16 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	50.7	0.999786	0.00143
2	55.5	0.999800	0.00131
3	50.1	0.999768	0.00151

Table A.330: Laminate 16 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	4.5	4.5	12.7	12.7	25	31	TAT
2	4.7	4.5	12.7	12.7	25	31	BGM
3	4.7	4.6	12.7	12.7	25	31	BGM

Table A.331: Laminate 16 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	4.5	0.0072	0.002	12.7	0.0000	0.000	57.6
2	4.6	0.1087	0.024	12.7	0.0000	0.000	58.2
3	4.7	0.0305	0.007	12.7	0.0000	0.000	59.1

Table A.332: Laminate 16 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	57.6	23,192	402	7,721
2	58.2	24,959	429	8,227
3	59.1	23,542	398	7,647
Average	58.3	23,898	410	7,865
STDEV	0.7	936	1.6468E+07	316
CV	0.012	0.039	0.040	0.040

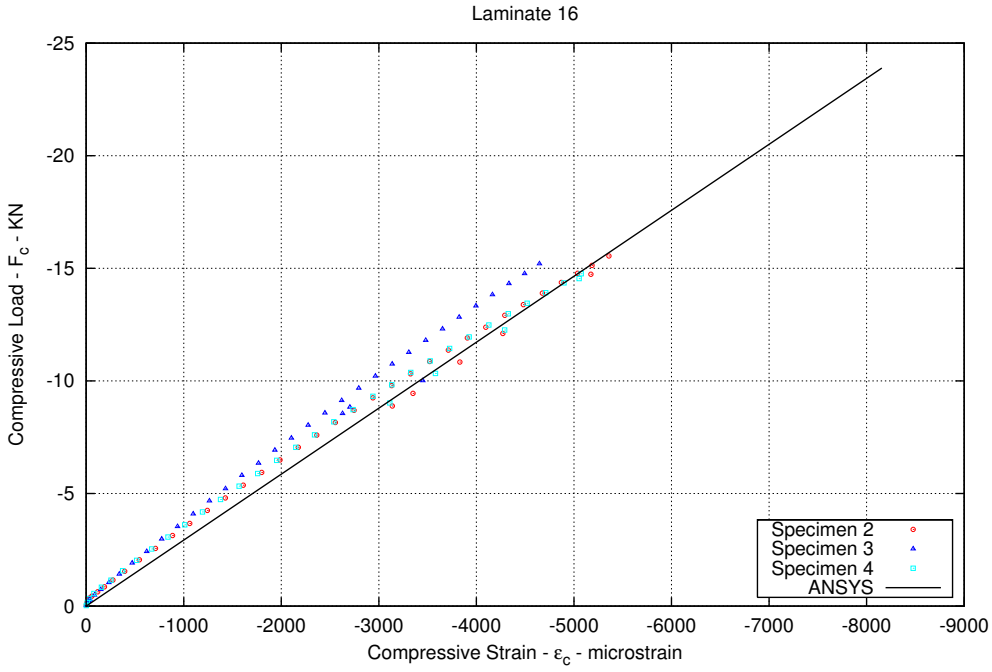


Figure A.187: Laminate 16 axial strain induced with an axial compressive load.

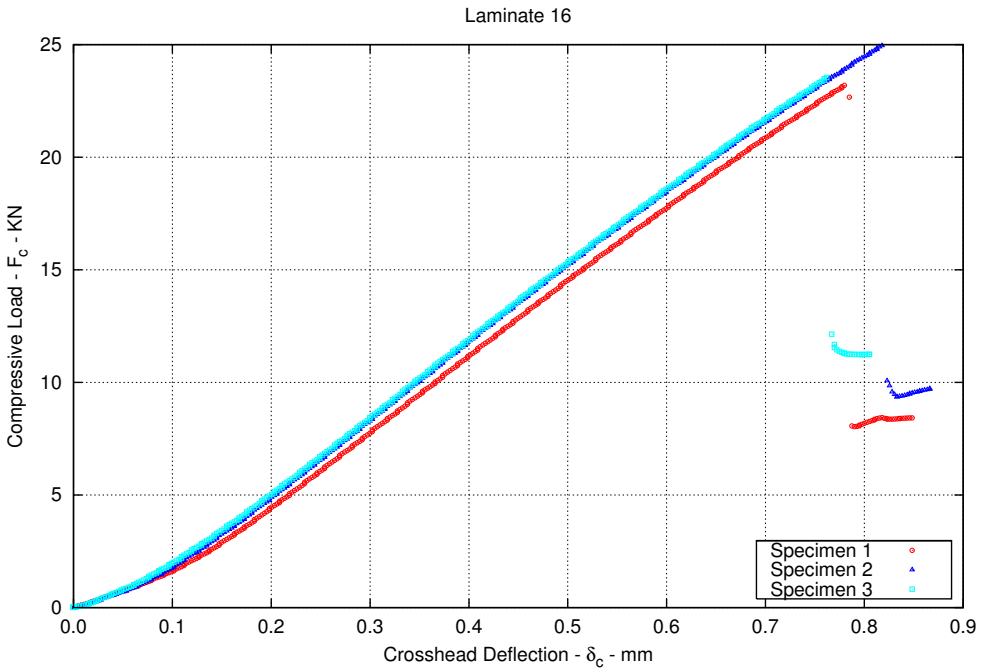


Figure A.188: Response of Laminate 16 to compressive loading.

A.17.4 In-Plane Shear

Table A.333: Laminate 16 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.5	4.6	11.5	11.5	24.4	50	null
2	4.6	4.6	11.5	11.4	24.4	50	null
3	4.6	4.6	11.4	11.5	24.4	50	null

Table A.334: Laminate 16 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.5	0.1078	0.024	11.5	0.0000	0.000	52.3
2	4.6	0.0180	0.004	11.5	0.0359	0.003	52.5
3	4.6	0.0359	0.008	11.4	0.0718	0.006	52.8

Table A.335: Laminate 16 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	5.9	0.9989	0.0037
2	6.8	0.9961	0.0066
3	6.2	0.9998	0.0016

Table A.336: Laminate 16 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	52.3	5,222	99.8	34,935
2	52.5	5,355	102	29,996
3	52.8	5,065	95.9	30,147
Average	52.6	5,214	99.2	31,693
STDEV	0.3	145	3.1	2,809
CV	0.005	0.028	0.031	0.089

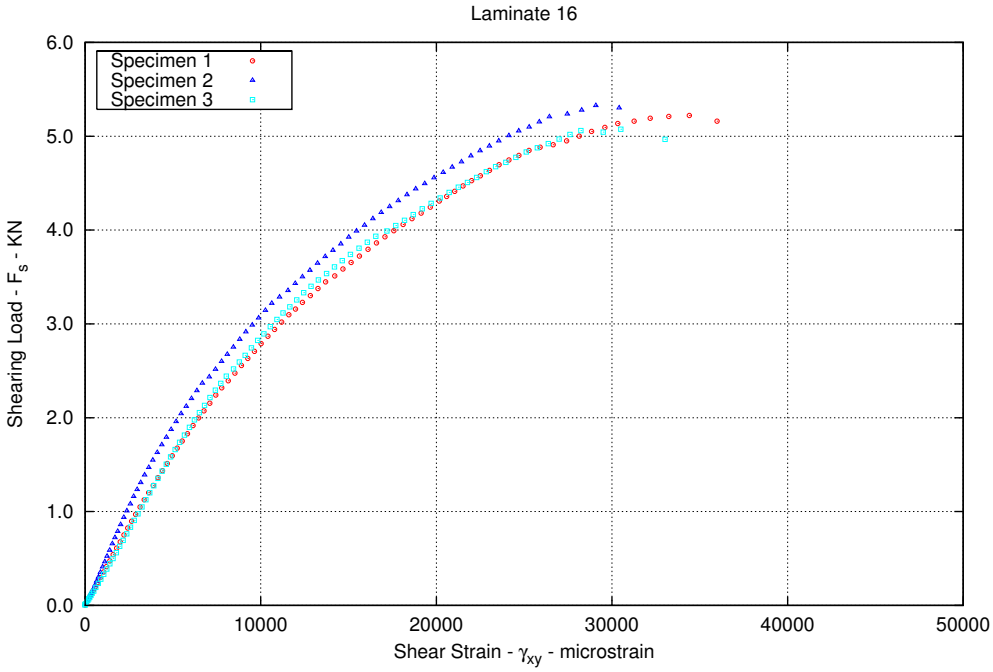


Figure A.189: Laminate 16 shear strain induced with an in-plane shear load.

A.17.5 Interlaminar Shear

Table A.337: Laminate 16 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	4.5	4.6	6.4	6.4	23.9	26	Interlaminar Shear
3	4.6	4.5	6.3	6.3	23.9	26	Interlaminar Shear
4	4.5	4.5	6.4	6.4	23.9	26	Interlaminar Shear

Table A.338: Laminate 16 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	4.5	0.0404	0.009	6.4	0.0000	0.000	28.7
3	4.6	0.0171	0.004	6.3	0.0000	0.000	28.8
4	4.5	0.0251	0.006	6.4	0.0000	0.000	28.7

Table A.339: Laminate 16 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	28.7	1576.0	41.7
3	28.8	1490.2	39.4
4	28.7	1394.8	37.0

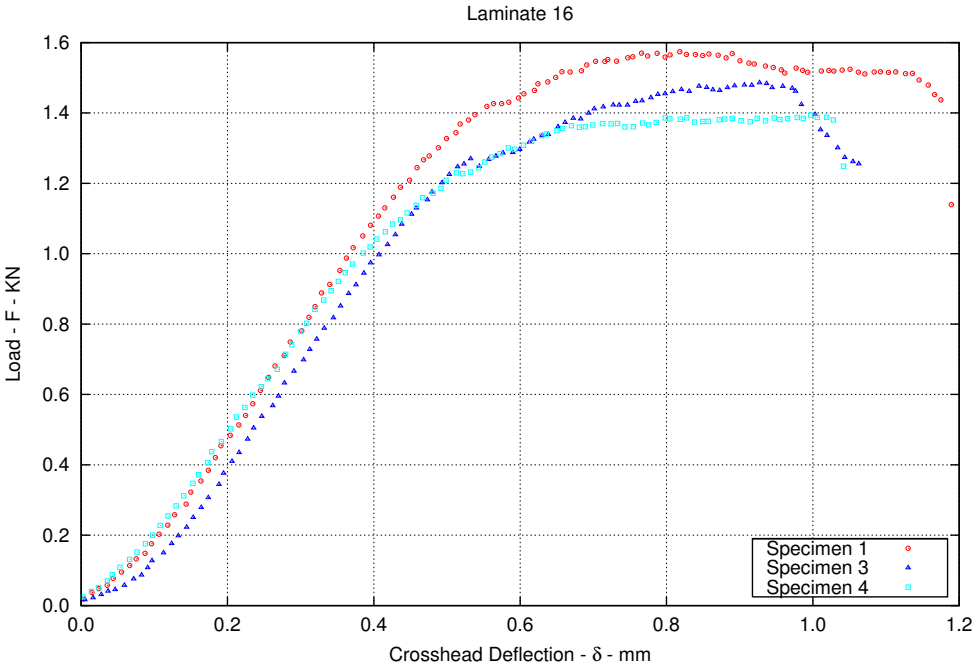
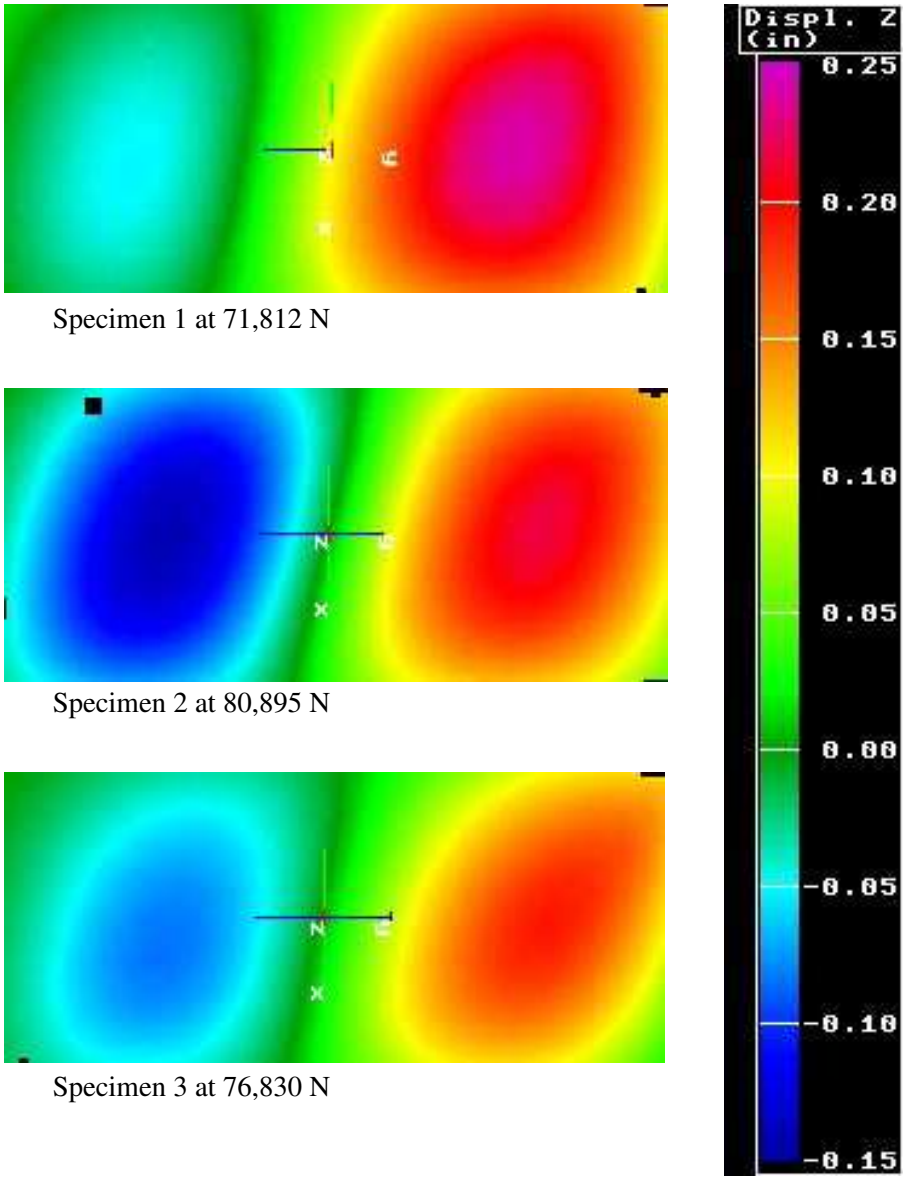


Figure A.190: Laminate 16 interlaminar shear response.

A.17.6 Edgewise Compression

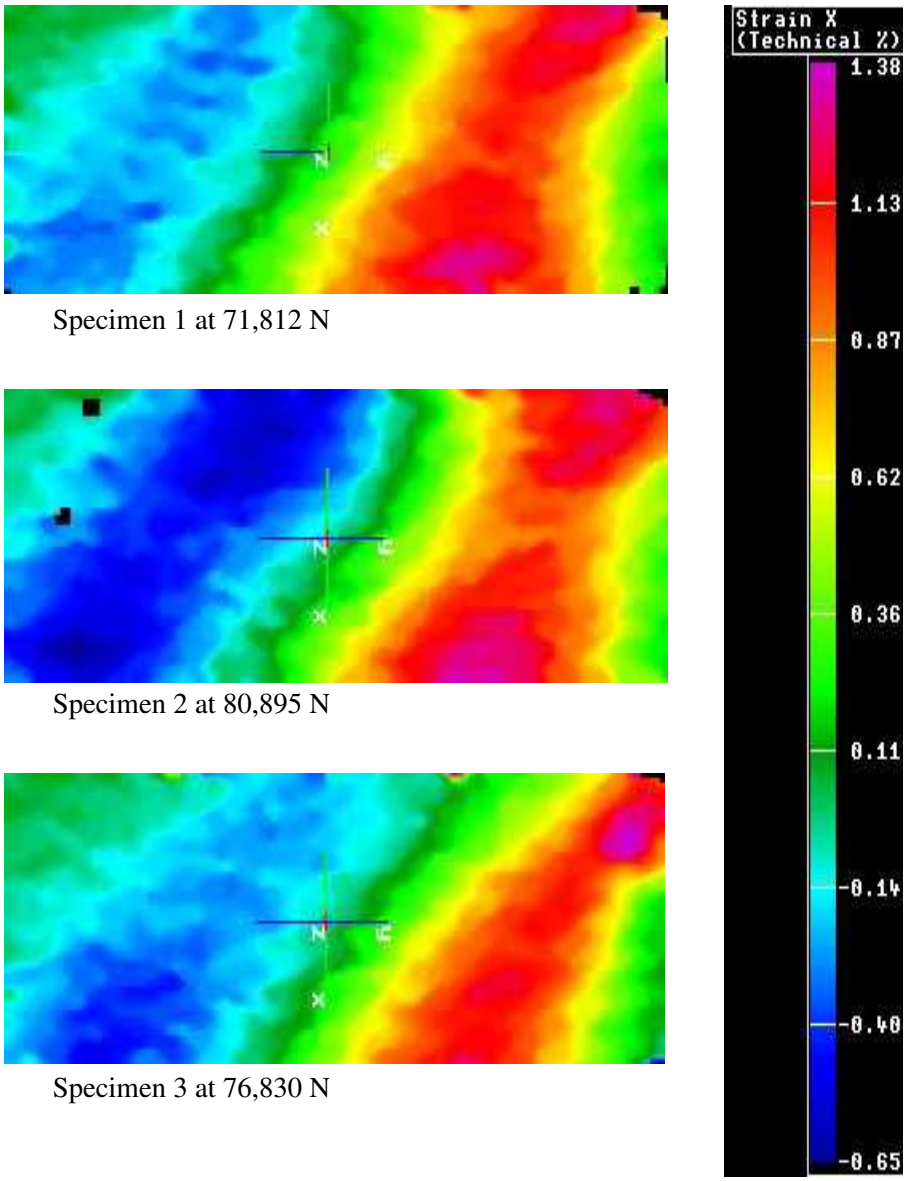


Specimen 1 at 71,812 N

Specimen 2 at 80,895 N

Specimen 3 at 76,830 N

Figure A.191: Laminate 16 out-of-plane displacement due to edgewise compression.

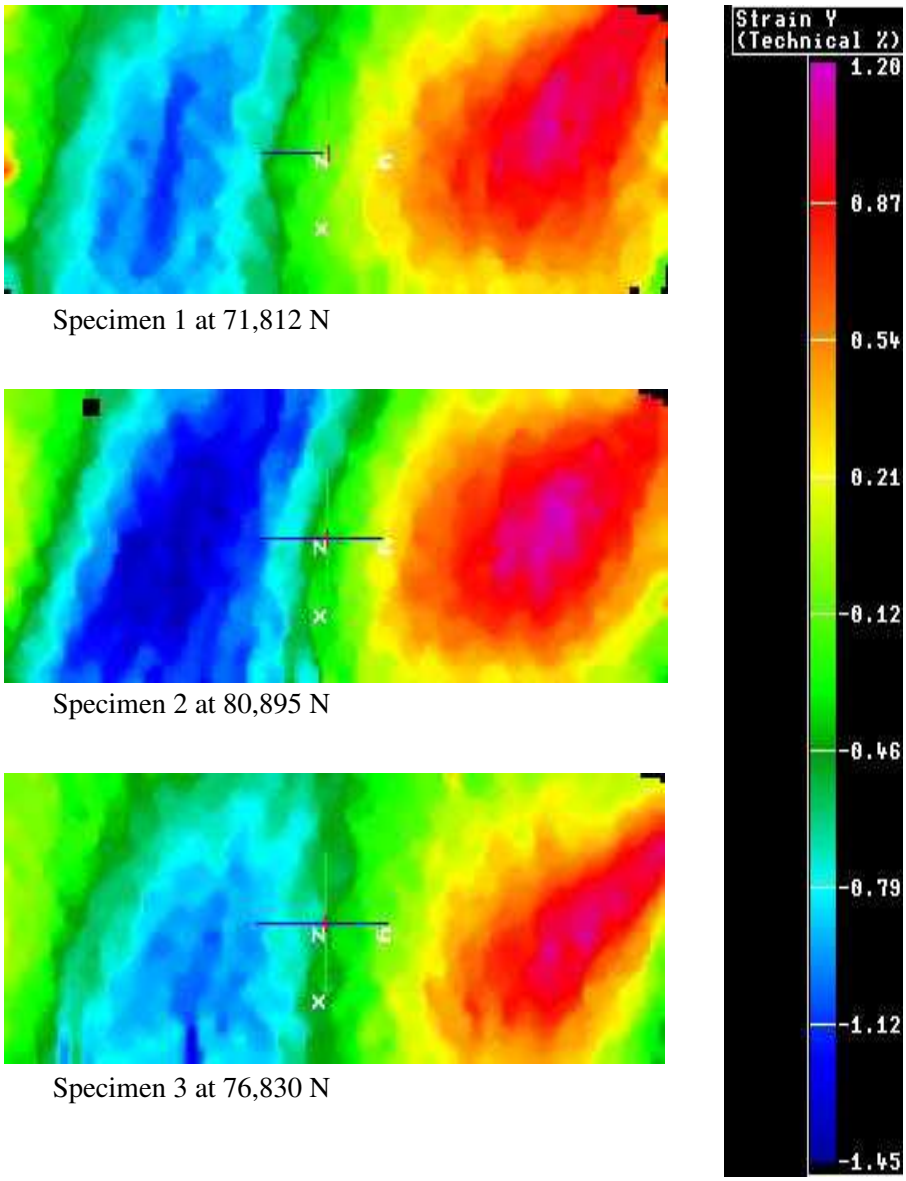


Specimen 1 at 71,812 N

Specimen 2 at 80,895 N

Specimen 3 at 76,830 N

Figure A.192: Laminate 16 axial strain displacement due to edgewise compression.

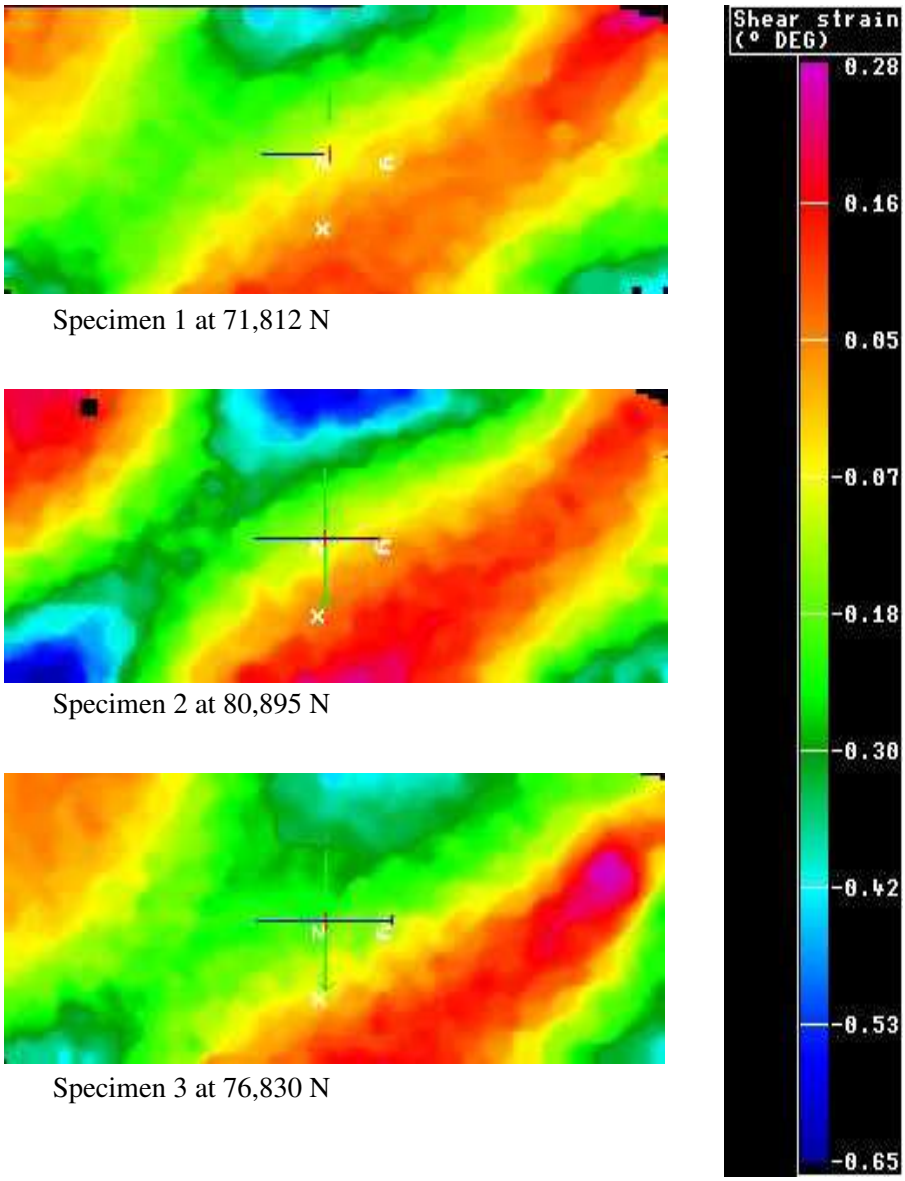


Specimen 1 at 71,812 N

Specimen 2 at 80,895 N

Specimen 3 at 76,830 N

Figure A.193: Laminate 16 transverse strain displacement due to edgewise compression.



Specimen 1 at 71,812 N

Specimen 2 at 80,895 N

Specimen 3 at 76,830 N

Figure A.194: Laminate 16 shear strain displacement due to edgewise compression.

A.18 Laminate 18 - SK/GDB12 - $[(\pm 45_{DB})_6]_s$

A.18.1 Tension 0

Table A.340: Laminate 18 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.8	3.8	3.7	25.4	25.4	25.4	23.9	41	AWT
2	4.0	3.9	3.9	25.4	25.4	25.4	23.9	41	AWT
3	3.7	3.8	3.9	25.4	25.4	25.4	23.9	41	AIB

Table A.341: Laminate 18 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.0529	0.014	25.4	0.0000	0.000	96.3
2	3.9	0.0508	0.013	25.4	0.0000	0.000	99.4
3	3.8	0.0816	0.022	25.4	0.0000	0.000	96.3

Table A.342: Laminate 18 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	11.5	0.998492	0.01078	0.564	0.999407	0.00675
2	10.7	0.998675	0.00940	0.523	0.999334	0.00667
3	11.0	0.998724	0.00842	0.581	0.999509	0.00523

Table A.343: Laminate 18 axial tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	96.3	11,073	115	49,916
2	99.4	11,551	116	49,979
3	96.3	10,203	106	32,305
Average	97.3	10,942	112	44,067
STDEV	1.7	683	5.6	10,186
CV	0.018	0.062	0.050	0.231

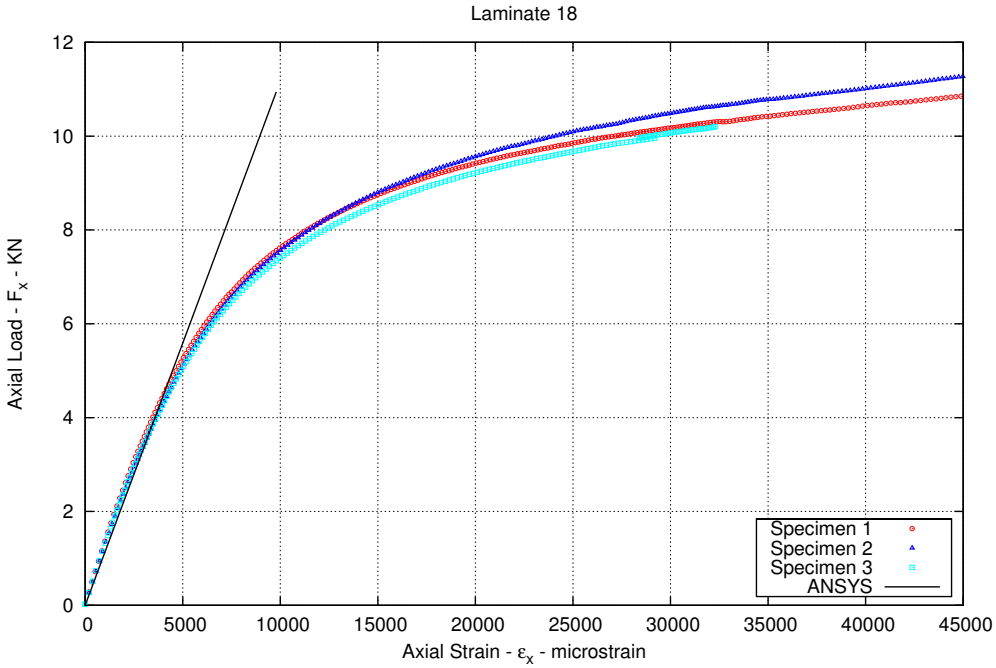


Figure A.195: Laminate 18 axial strain induced with an axial tensile load.

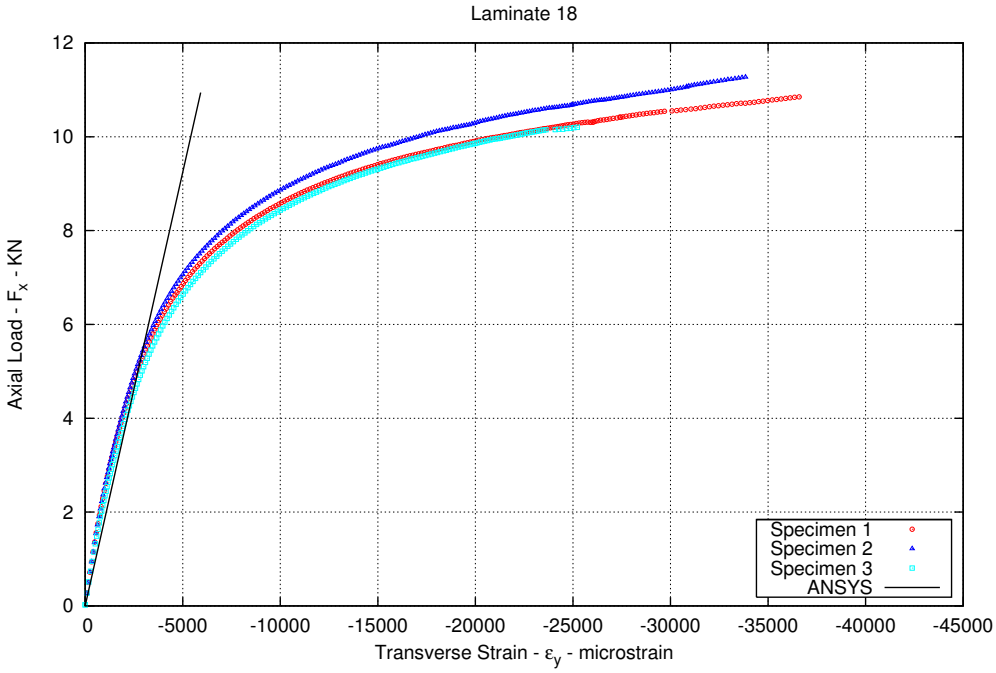


Figure A.196: Laminate 18 transverse strain induced with an axial tensile load.

A.18.2 Tenion 90

Table A.344: Laminate 18 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.9	3.8	3.8	25.4	25.4	25.4	25	41	LGM DGM
2	3.8	3.7	3.9	25.4	25.4	25.4	25	41	LGM LWT
3	4.0	4.0	4.1	25.3	25.3	25.3	25	41	AWB

Table A.345: Laminate 18 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.0672	0.018	25.4	0.0000	0.000	96.7
2	3.8	0.0762	0.020	25.4	0.0000	0.000	96.8
3	4.0	0.0508	0.013	25.3	0.0000	0.000	102.3

Table A.346: Laminate 18 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	11.4	0.998979	0.00754	0.756	0.999769	0.00358
2	11.2	0.997819	0.01169	0.609	0.999569	0.00519
3	10.8	0.998412	0.00967	0.595	0.999708	0.00415

Table A.347: Laminate 18 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	96.7	11,171	116	49,899
2	96.8	11,007	114	49,895
3	102	13,082	128	49,968
Average	98.6	11,753	119	49,921
STDEV	3.2	1,154	7.7	41
CV	0.032	0.098	0.065	0.001

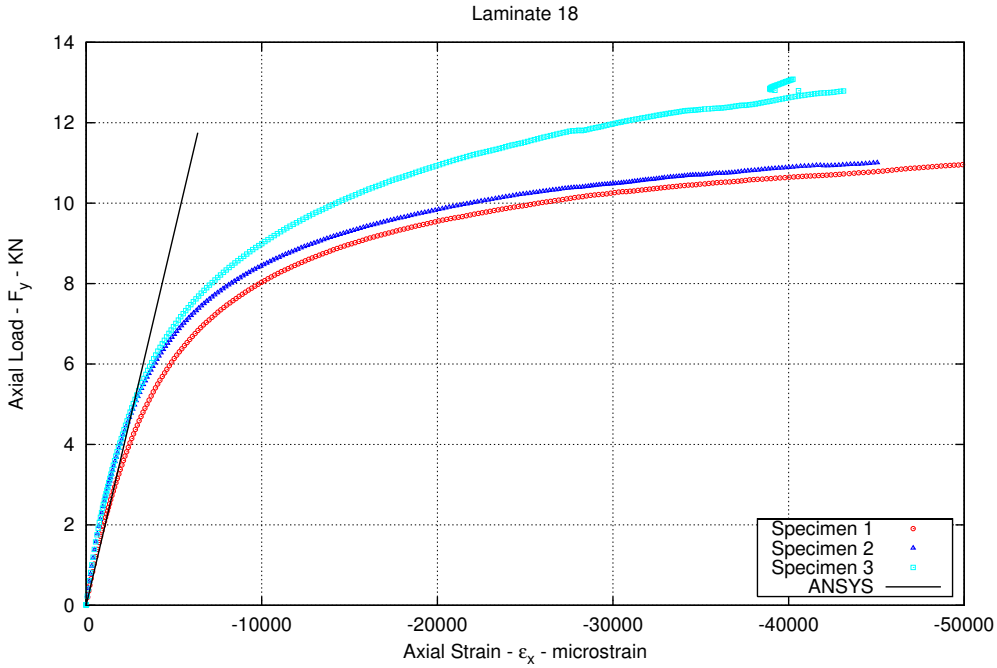


Figure A.197: Laminate 18 axial strain induced with a transverse tensile load.

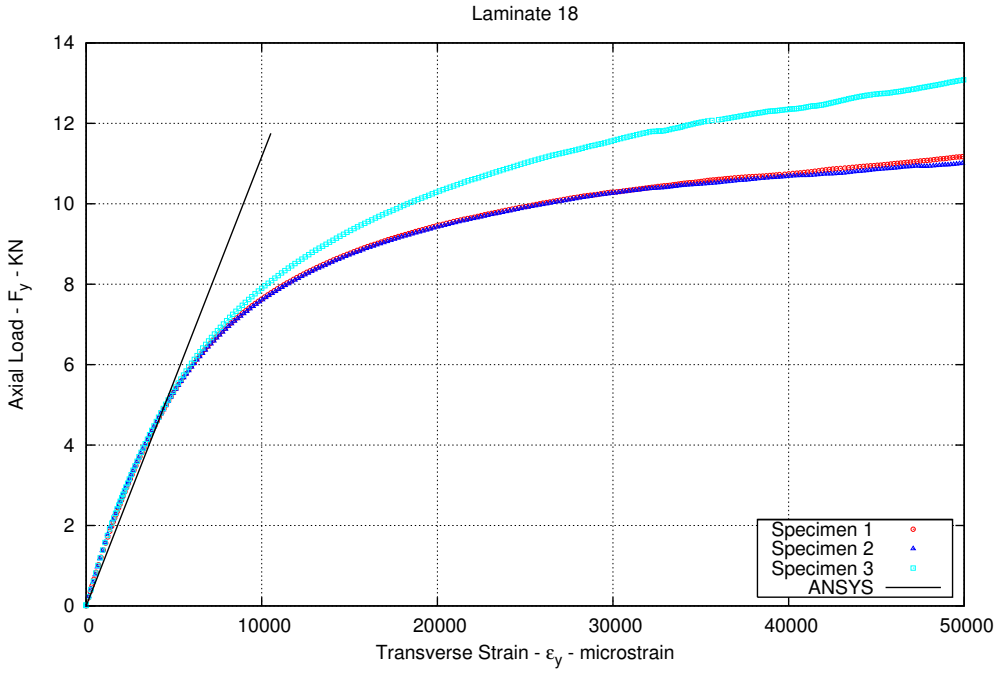


Figure A.198: Laminate 18 transverse strain induced with a transverse tensile load.

A.18.3 In-Plane Shear

Table A.348: Laminate 18 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.8	3.7	11.4	11.4	24.4	28	null
2	3.8	3.8	11.4	11.4	24.4	28	null
3	4.3	4.2	11.4	11.4	24.4	28	null

Table A.349: Laminate 18 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.0898	0.024	11.4	0.0180	0.002	43.0
2	3.8	0.0359	0.009	11.4	0.0180	0.002	43.5
3	4.2	0.0718	0.017	11.4	0.0180	0.002	48.4

Table A.350: Laminate 18 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	10.9	0.9996	0.0018
2	10.5	0.9998	0.0013
3	8.8	0.9998	0.0016

Table A.351: Laminate 18 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	43.0	5,425	126	11,337
2	43.5	5,275	121	10,675
3	48.4	5,825	120	14,489
Average	45.0	5,508	123	12,167
STDEV	3.0	284	3.2	2,038
CV	0.067	0.052	0.026	0.167

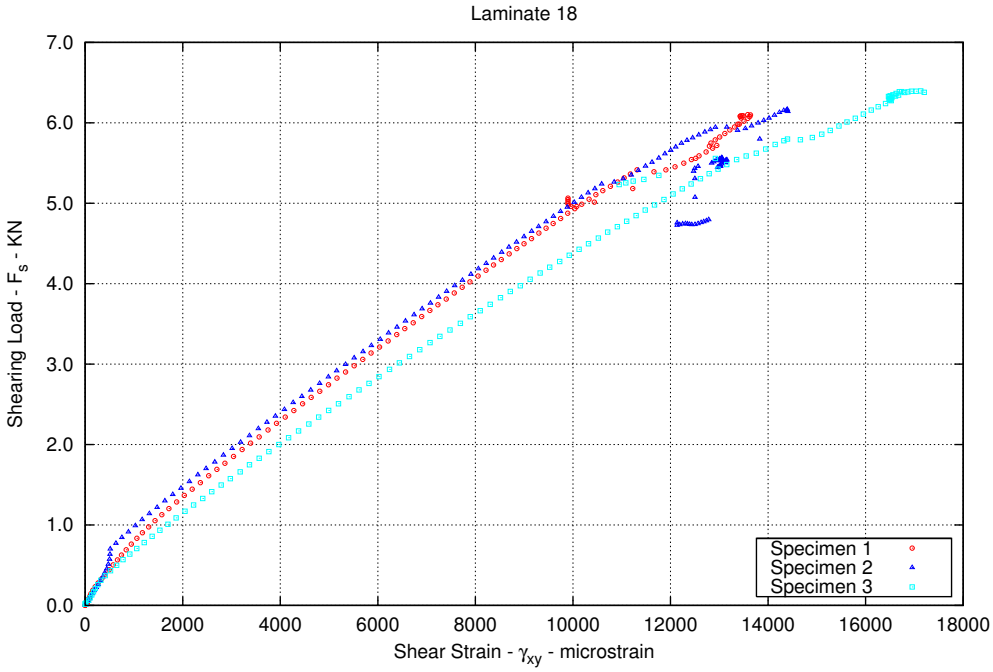


Figure A.199: Laminate 18 shear strain induced with an in-plane shear load.

A.18.4 Interlaminar Shear

Table A.352: Laminate 18 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
2	3.7	3.9	6.4	6.4	23.9	26	Interlaminar Shear
3	3.8	3.9	6.4	6.4	23.9	26	Interlaminar Shear
5	3.7	3.8	6.4	6.4	23.9	26	Interlaminar Shear

Table A.353: Laminate 18 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	3.8	0.1598	0.042	6.4	0.0000	0.000	24.1
3	3.8	0.0745	0.020	6.4	0.0000	0.000	24.3
5	3.8	0.0763	0.020	6.4	0.0000	0.000	24.0

Table A.354: Laminate 18 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
2	24.1	1186.4	37.7
3	24.3	1245.0	39.2
5	24.0	1223.1	39.0

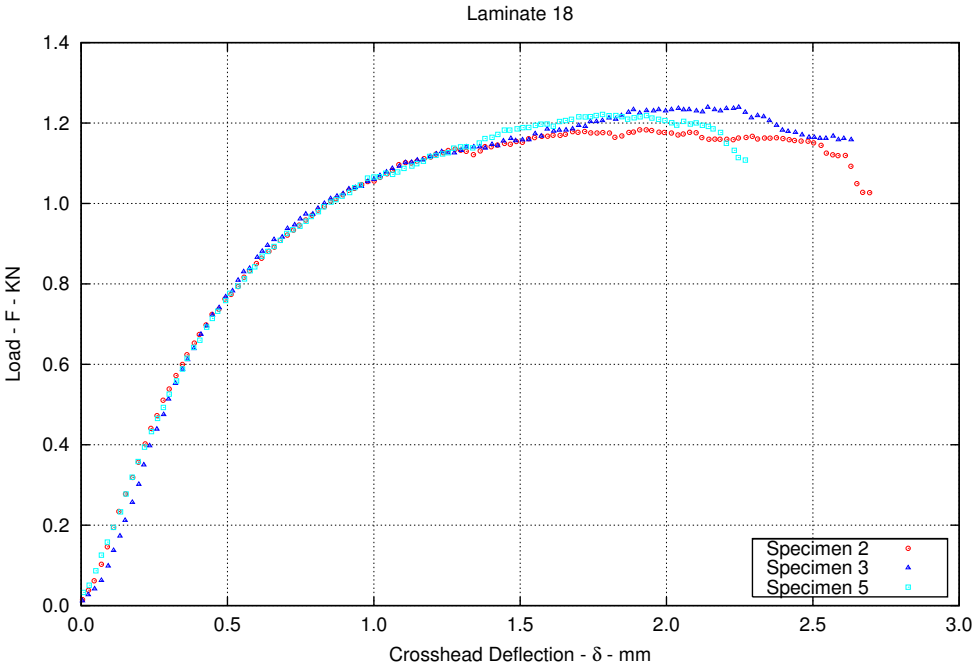


Figure A.200: Laminate 18 interlaminar shear response.

A.19 Laminate 20 - SK/GDB38 - $[(\pm 45_{DB})_2]_s$

A.19.1 Tension 0

Table A.355: Laminate 20 test log information for tension 0 testing.

	Thickness			Width					
Specimen	t1 (mm)	t2 (mm)	t3 (mm)	w1 (mm)	w2 (mm)	w3 (mm)	Temperature $(^{\circ}C)$	Humidity (%)	Failure
1	3.7	3.4	3.3	25.4	25.4	25.4	25.6	36	AGM
2	3.5	3.5	3.5	25.5	25.5	25.5	25.6	36	AGM
3	3.8	3.7	3.2	25.5	25.5	25.5	25.6	36	AWB

Table A.356: Laminate 20 geometric summary data for tension 0 testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.4	0.2544	0.074	25.4	0.0000	0.000	87.5
2	3.5	0.0388	0.011	25.5	0.0000	0.000	89.1
3	3.5	0.2832	0.080	25.5	0.0000	0.000	90.4

Table A.357: Laminate 20 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	13.0	0.998156	0.00707	0.703	0.999504	0.00366
2	12.1	0.997969	0.00722	0.627	0.999707	0.00274
3	11.9	0.998294	0.00731	0.571	0.999123	0.00524

Table A.358: Laminate 20 axial tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	87.5	9,688	111	49,935
2	89.1	9,120	102	49,931
3	90.4	9,158	101	49,949
Average	89.0	9,322	105	49,939
STDEV	1.4	317	5.1	9.0
CV	0.016	0.034	0.049	0.0

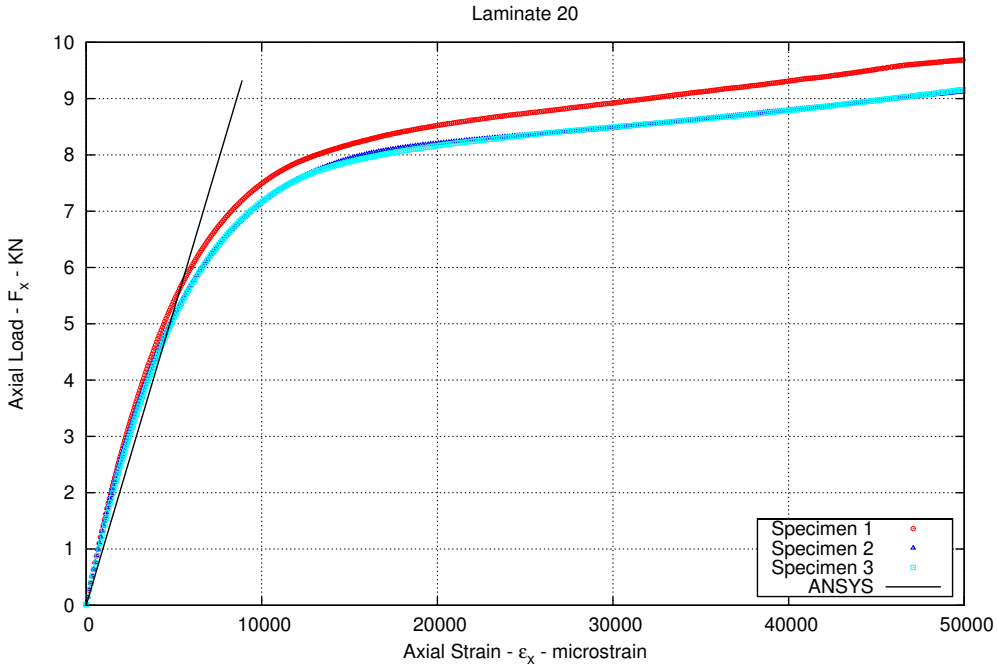


Figure A.201: Laminate 20 axial strain induced with an axial tensile load.

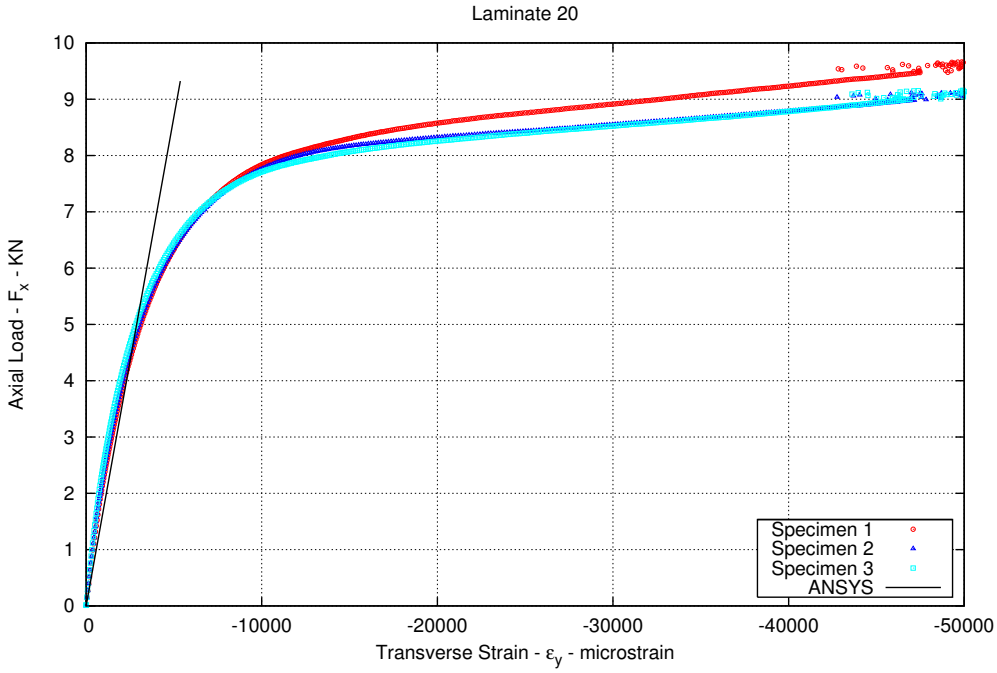


Figure A.202: Laminate 20 transverse strain induced with an axial tensile load.

A.19.2 Tenion 90

Table A.359: Laminate 20 test log information for tension 90 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.5	3.4	3.4	25.4	25.4	25.4	24.4	45	AAB
2	3.2	3.5	3.4	25.5	25.5	25.5	24.4	45	AAB
3	3.3	3.1	3.3	25.4	25.4	25.4	24.4	45	AAB

Table A.360: Laminate 20 geometric summary data for tension 90 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0776	0.023	25.4	0.0000	0.000	87.6
2	3.3	0.1552	0.046	25.5	0.0000	0.000	85.1
3	3.2	0.0962	0.030	25.4	0.0000	0.000	82.2

Table A.361: Laminate 20 elastic summary data for tension 90 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	12.4	0.997532	0.01206	0.533	0.999268	0.00656
2	12.2	0.997112	0.00951	0.584	0.999689	0.00312
3	12.4	0.996521	0.01639	0.604	0.999370	0.00696

Table A.362: Laminate 20 transverse tension failure allowables.

	Area	Load	Stress	Strain
Specimen	(mm^2)	(N)	(MPa)	$(\mu strain)$
1	87.6	8,222	93.8	49,959
2	85.1	8,090	95.0	49,989
3	82.2	7,940	96.6	49,923
Average	85.0	8,084	95.1	49,957
STDEV	2.7	141	1.4	33
CV	0.032	0.017	0.014	0.001

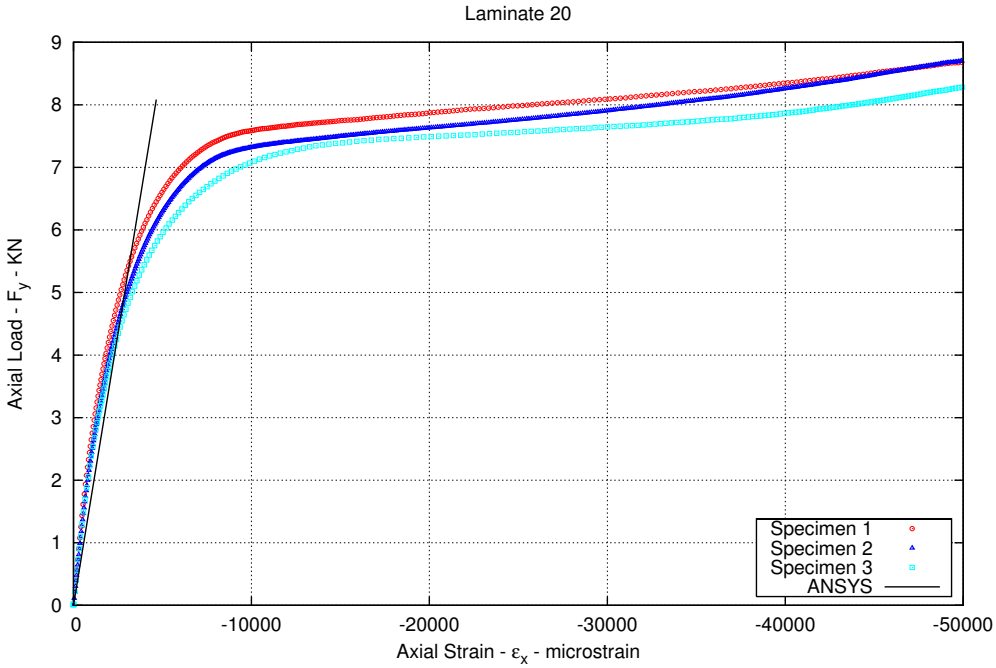


Figure A.203: Laminate 20 axial strain induced with a transverse tensile load.

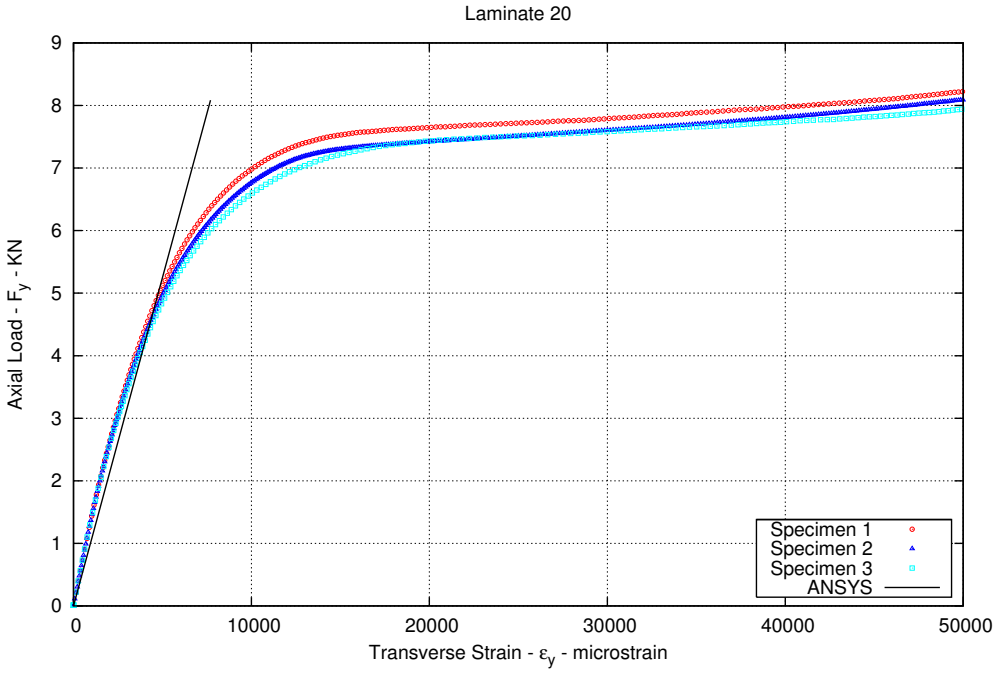


Figure A.204: Laminate 20 transverse strain induced with a transverse tensile load.

A.19.3 Compression

Table A.363: Laminate 20 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$
1	3.4	3.4	12.7	12.7	23.9
2	3.4	3.2	12.7	12.7	23.9
3	3.4	3.4	12.7	12.7	23.9

Table A.364: Laminate 20 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.4	0.0000	0.000	12.7	0.0000	0.000	43.5
2	3.3	0.1257	0.039	12.7	0.0000	0.000	41.5
3	3.4	0.0180	0.005	12.7	0.0000	0.000	42.7

Table A.365: Laminate 20 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	14.8	0.997507	0.00745
2	15.0	0.997530	0.00537
3	14.7	0.997116	0.00570

Table A.366: Laminate 20 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(^{\circ}C)$	(%)	Failure
1	3.6	3.6	12.7	12.7	23.9	25	DGM
2	3.5	3.5	12.7	12.7	23.9	25	DGM
3	3.6	3.6	12.7	12.7	23.9	25	DGM

Table A.367: Laminate 20 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.6	0.0359	0.010	12.7	0.0000	0.000	45.8
2	3.5	0.0054	0.002	12.7	0.0000	0.000	44.0
3	3.6	0.0099	0.003	12.7	0.0000	0.000	45.7

Table A.368: Laminate 20 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	45.8	7,693	168	11,299
2	44.0	7,532	171	11,503
3	45.7	7,580	166	11,145
Average	45.2	7,602	168	11,316
STDEV	1.0	83	2.7	179
CV	0.022	0.011	0.016	0.016

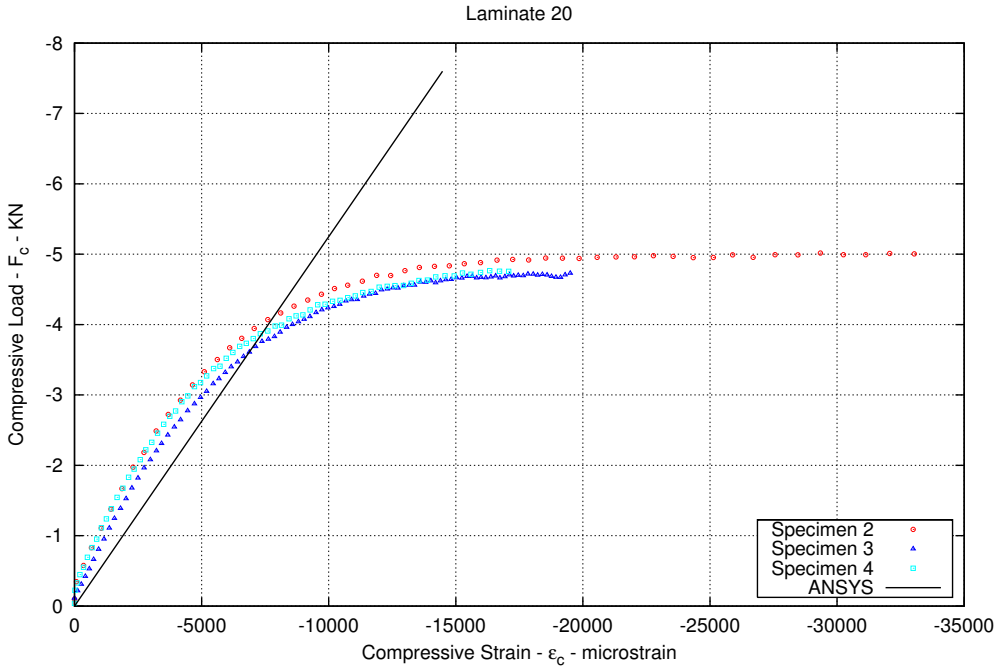


Figure A.205: Laminate 20 axial strain induced with an axial compressive load.

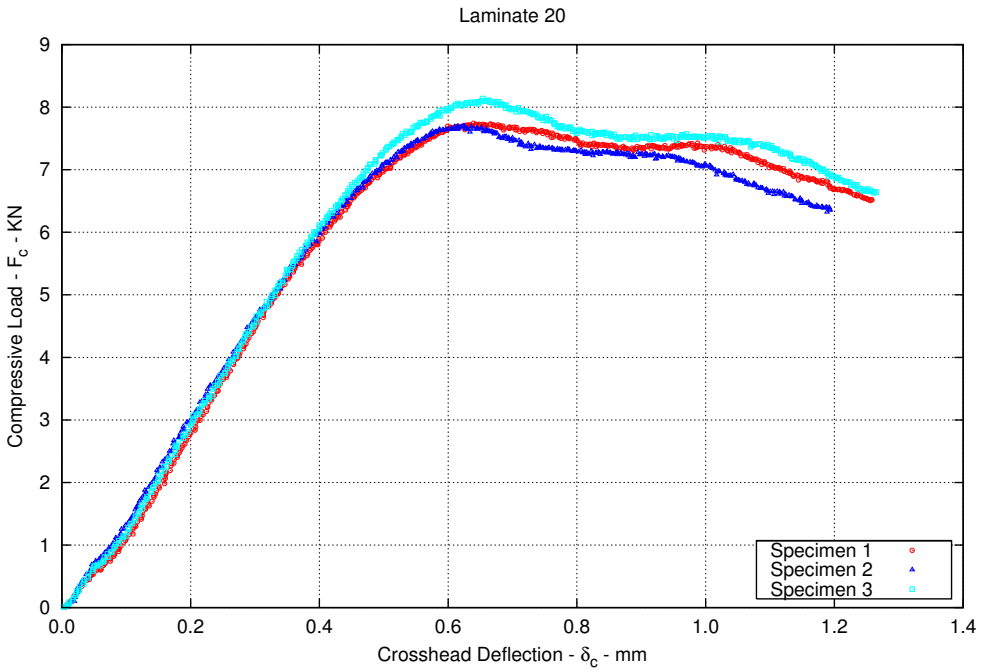


Figure A.206: Response of Laminate 20 to compressive loading.

A.19.4 In-Plane Shear

Table A.369: Laminate 20 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.6	11.3	11.4	22.8	45	null
2	3.1	3.4	11.3	11.3	22.8	45	null
3	3.4	3.7	11.4	11.4	22.8	45	null

Table A.370: Laminate 20 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0359	0.010	11.3	0.0180	0.002	40.0
2	3.3	0.1976	0.060	11.3	0.0359	0.003	37.2
3	3.5	0.1796	0.051	11.4	0.0180	0.002	40.1

Table A.371: Laminate 20 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	13.2	0.9999	0.0009
2	13.9	0.9998	0.0013
3	13.1	0.9999	0.0010

Table A.372: Laminate 20 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	40.0	5,042	1.26	9,318
2	37.2	4,823	1.30	9,418
3	40.1	5,158	1.29	10,390
Average	39.1	5,008	128	9,709
STDEV	1.7	170	1.9	592
CV	0.043	0.034	0.015	0.061

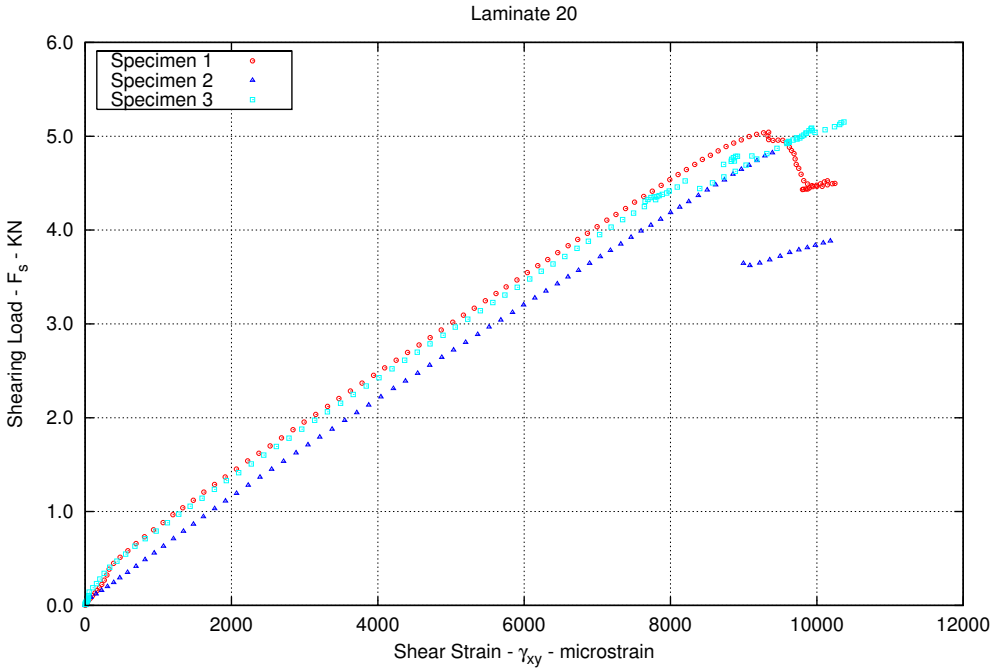


Figure A.207: Laminate 20 shear strain induced with an in-plane shear load.

A.19.5 Interlaminar Shear

Table A.373: Laminate 20 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.5	3.6	6.4	6.4	23.3	60	Interlaminar Shear
2	3.4	3.5	6.4	6.4	23.3	60	Interlaminar Shear
4	3.5	3.4	6.4	6.4	23.3	60	Interlaminar Shear

Table A.374: Laminate 20 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.5	0.0647	0.018	6.4	0.0000	0.000	22.3
2	3.4	0.0395	0.012	6.4	0.0000	0.000	21.8
4	3.5	0.1105	0.032	6.4	0.0000	0.000	21.9

Table A.375: Laminate 20 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
1	22.3	714.4	24.8
2	21.8	652.1	23.3
4	21.9	720.6	25.4

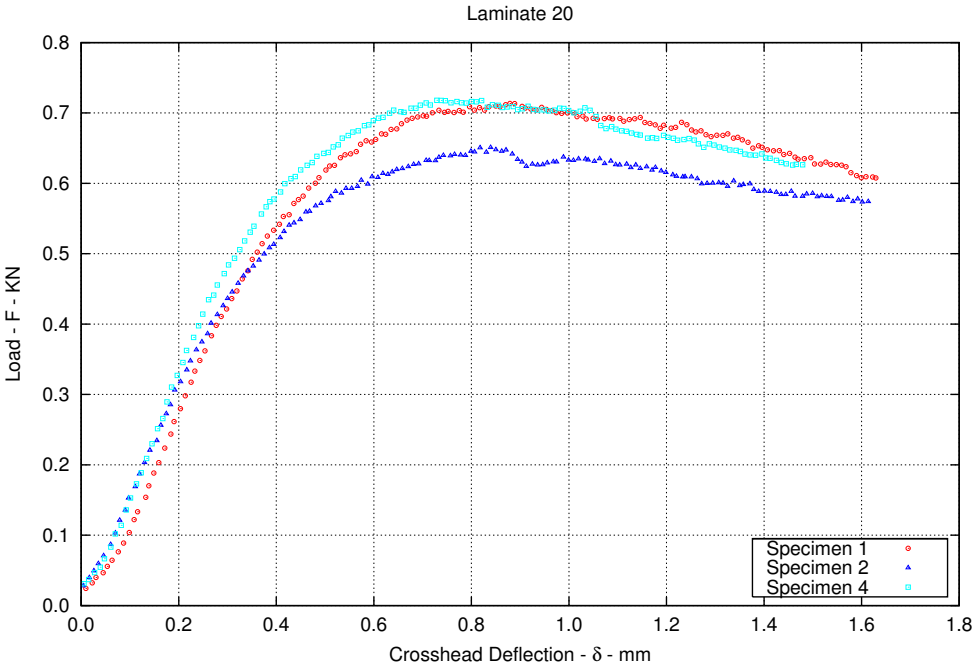


Figure A.208: Laminate 20 interlaminar shear response.

A.20 Laminate 21 - SK/CDB - $[(+45_C/-45_C)_2]_s$

A.20.1 Tension 0

Table A.376: Laminate 21 test log information for tension 0 testing.

	Thickness			Width					
	t1	t2	t3	w1	w2	w3	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	$(^\circ C)$	(%)	Failure
1	3.7	3.9	3.8	25.4	25.4	25.4	25	37	AWB
2	3.9	3.9	4.0	25.4	25.4	25.4	25	37	AGT
3	3.8	4.0	4.0	25.4	25.4	25.4	25	37	AWB

Table A.377: Laminate 21 geometric summary data for tension 0 testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.1057	0.028	25.4	0.0000	0.000	96.6
2	3.9	0.0388	0.010	25.4	0.0000	0.000	99.6
3	3.9	0.0816	0.021	25.4	0.0000	0.000	99.9

Table A.378: Laminate 21 elastic summary data for tension 0 testing.

	Modulus			Poisson's Ratio		
Specimen	(GPa)	r^2	CV	—	r^2	CV
1	14.5	0.998076	0.00732	0.765	0.999906	0.00162
2	13.3	0.998599	0.00578	0.653	0.999794	0.00221
3	13.8	0.998468	0.00627	0.760	0.999758	0.00249

Table A.379: Laminate 21 axial tension failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	96.6	11,586	120	29,957
2	99.6	11,744	118	36,612
3	99.9	11,717	117	29,155
Average	98.7	11,682	118	31,908
STDEV	1.8	84	1.40	4,093
CV	0.019	0.007	0.012	0.128

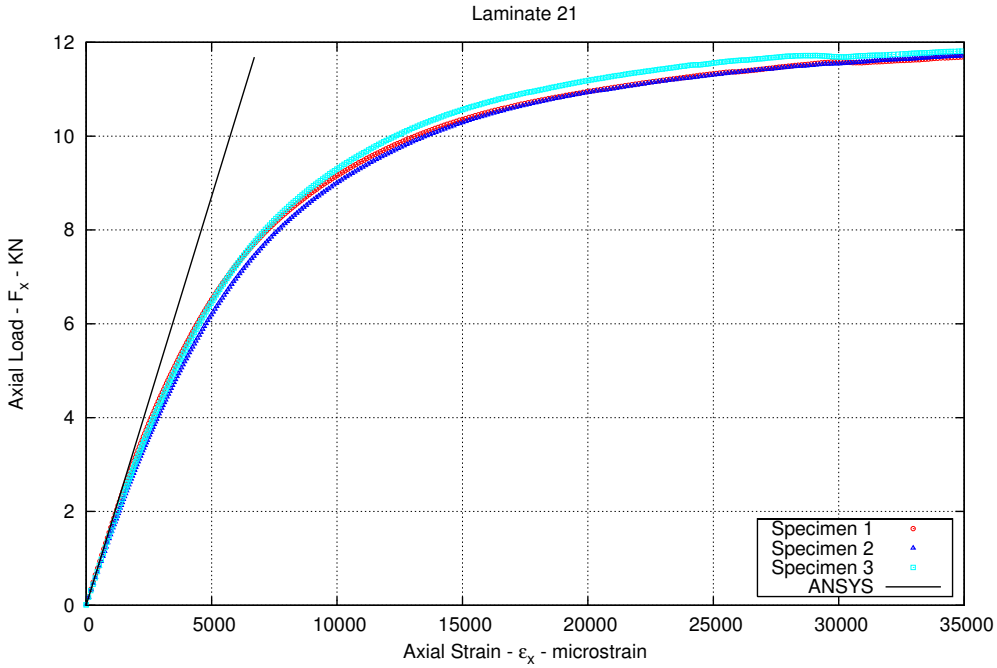


Figure A.209: Laminate 21 axial strain induced with an axial tensile load.

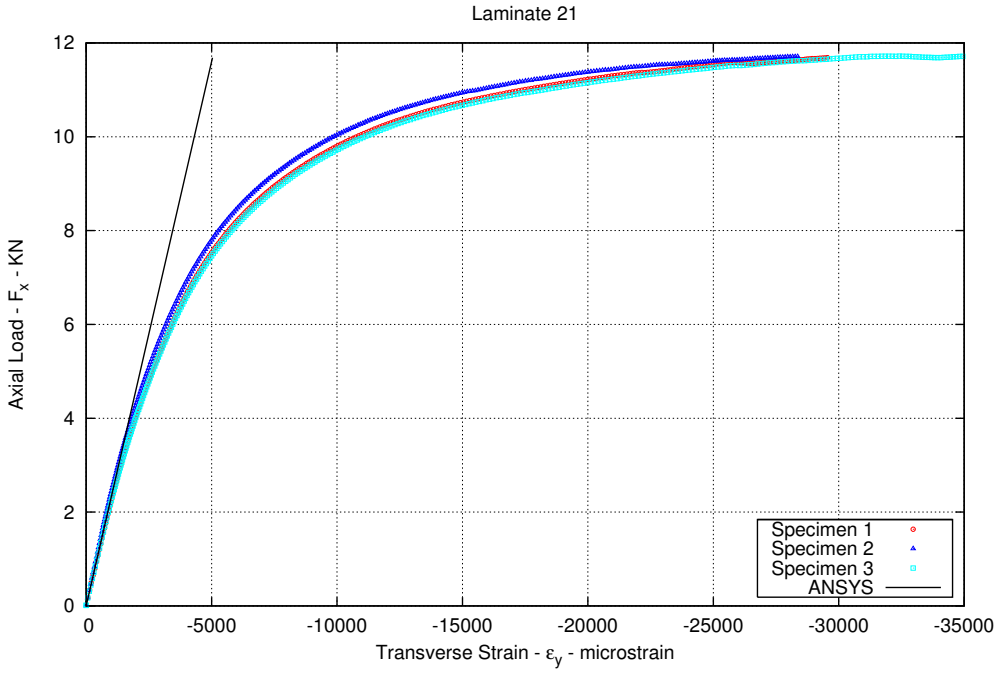


Figure A.210: Laminate 21 transverse strain induced with an axial tensile load.

A.20.2 Compression

Table A.380: Laminate 21 test log information for compression modulus tests.

	Thickness		Width		
	t1	t2	w1	w2	Temperature
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$
1	3.9	3.7	12.6	12.6	23.9
2	3.8	3.8	12.6	12.6	23.9
3	3.7	3.9	12.7	12.7	23.9

Table A.381: Laminate 21 geometric summary data for compression modulus testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.8	0.1616	0.042	12.6	0.0000	0.000	48.3
2	3.8	0.0359	0.009	12.6	0.0000	0.000	48.2
3	3.8	0.1616	0.042	12.7	0.0000	0.000	48.5

Table A.382: Laminate 21 elastic summary data for compression testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	17.2	0.997647	0.00708
2	14.6	0.997604	0.00795
3	16.7	0.999040	0.00457

Table A.383: Laminate 21 test log information for compression strength testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.8	3.7	12.8	12.8	23.9	39	SGV
2	3.8	3.8	12.8	12.8	23.9	39	SGV
3	3.8	3.7	12.8	12.8	23.9	39	SGV
4	3.9	3.9	12.8	12.8	23.9	39	SGV

Table A.384: Laminate 21 geometric summary data for compression strength testing.

	Thickness			Width			
Specimen	Average (mm)	STDEV (mm)	CV —	Average (mm)	STDEV (mm)	CV —	Area (mm^2)
1	3.8	0.0323	0.009	12.8	0.0000	0.000	48.1
2	3.8	0.0458	0.012	12.8	0.0000	0.000	48.5
3	3.7	0.0494	0.013	12.8	0.0000	0.000	47.5
4	3.9	0.0395	0.010	12.8	0.0000	0.000	50.2

Table A.385: Laminate 21 compression failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain $(\mu strain)$
1	48.1	9,031	188	11,613
2	48.5	8,551	176	10,909
3	47.5	8,470	178	11,021
Average	48.0	8,684	181	11,181
STDEV	0.5	303	6.1	378
CV	0.010	0.035	0.034	0.034

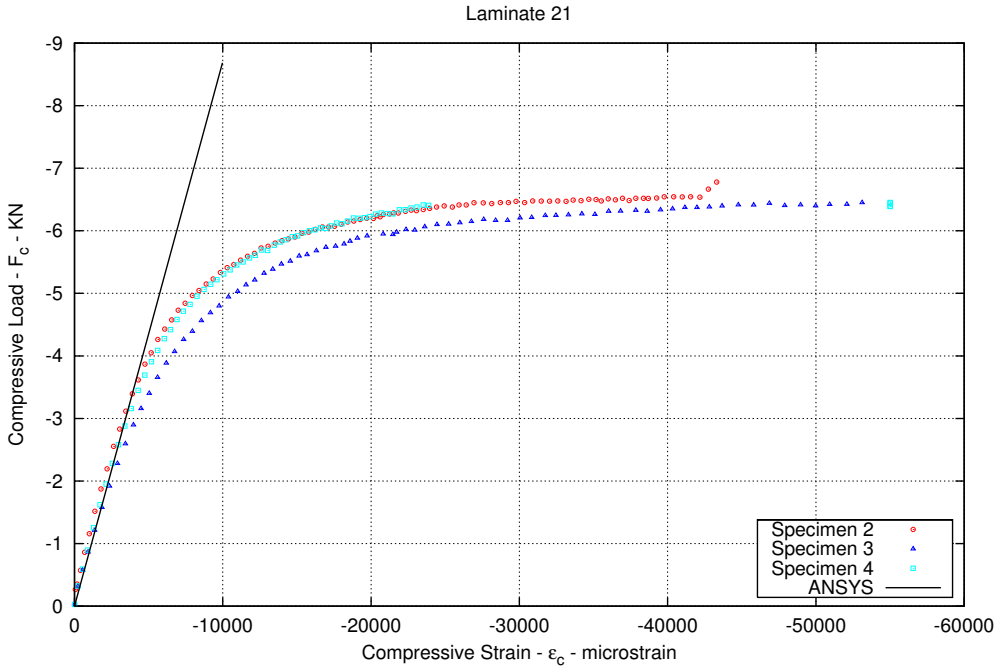


Figure A.211: Laminate 21 axial strain induced with an axial compressive load.

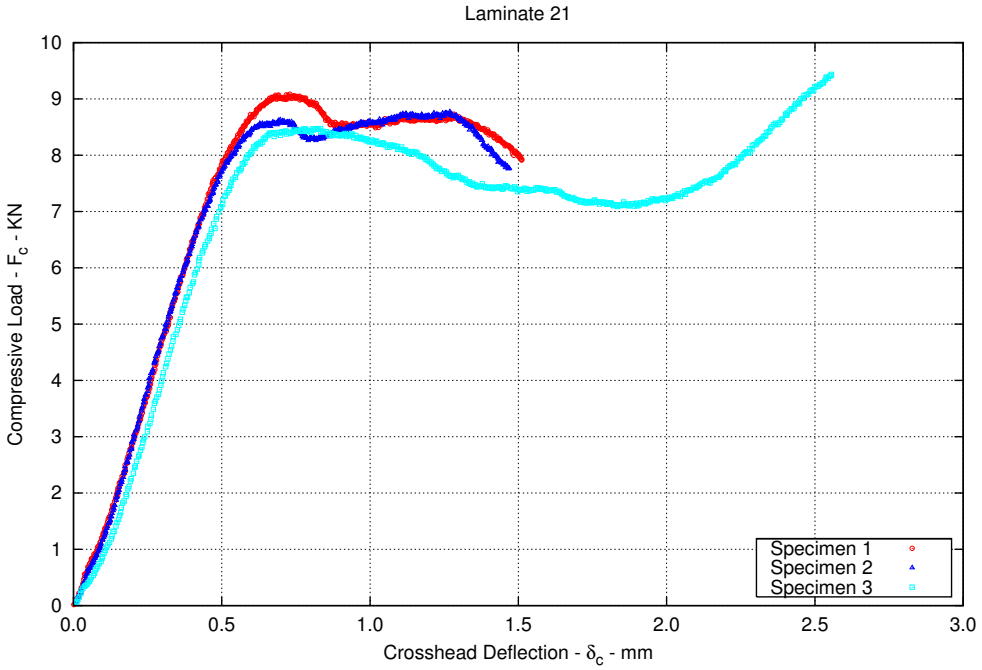


Figure A.212: Response of Laminate 21 to compressive loading.

A.20.3 In-Plane Shear

Table A.386: Laminate 21 test log information for in-plane shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
1	3.9	3.9	11.5	11.5	23.3	66	null
2	3.8	3.9	11.4	11.4	23.3	66	null
3	3.8	4.0	11.5	11.5	23.3	66	null

Table A.387: Laminate 21 geometric summary data for in-plane shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
1	3.9	0.0180	0.005	11.5	0.0180	0.002	44.7
2	3.8	0.0539	0.014	11.4	0.0359	0.003	43.9
3	3.9	0.1257	0.032	11.5	0.0000	0.000	44.7

Table A.388: Laminate 21 elastic summary data for in-plane shear testing.

	Modulus		
Specimen	(GPa)	r^2	CV
1	17.6	0.9815	0.0053
2	20.1	0.9973	0.0034
3	16.1	0.8260	0.0170

Table A.389: Laminate 21 in-plane shear failure allowables.

Specimen	Area (mm^2)	Load (N)	Stress (MPa)	Strain ($\mu strain$)
1	44.7	6,227	139	5,298
2	43.9	6,227	142	6,072
3	44.7	5,865	131	4,999
Average	44.4	6,106	137	5,456
STDEV	0.5	209	5.5	554
CV	0.010	0.034	0.040	0.101

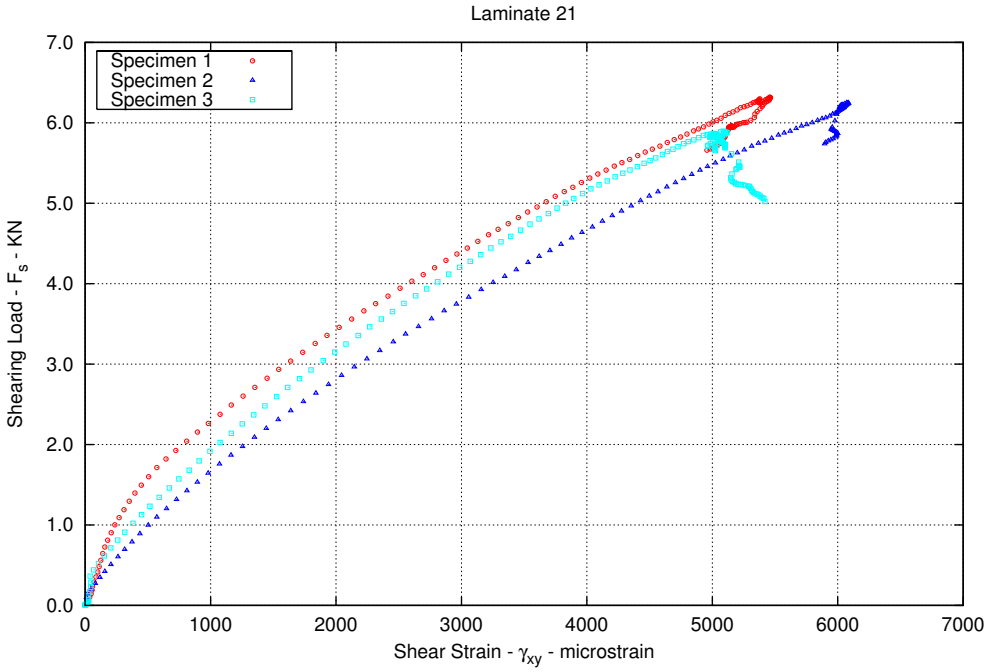


Figure A.213: Laminate 21 shear strain induced with an in-plane shear load.

A.20.4 Interlaminar Shear

Table A.390: Laminate 21 test log information for interlaminar shear testing.

	Thickness		Width				
	t1	t2	w1	w2	Temperature	Humidity	
Specimen	(mm)	(mm)	(mm)	(mm)	$(°C)$	(%)	Failure
2	3.9	3.9	6.4	6.4	23.3	60	Interlaminar Shear
3	3.8	3.9	6.4	6.4	23.3	60	Interlaminar Shear
5	3.7	4.0	6.3	6.4	23.3	60	Interlaminar Shear

Table A.391: Laminate 21 geometric summary data for interlaminar shear testing.

	Thickness			Width			
	Average	STDEV	CV	Average	STDEV	CV	Area
Specimen	(mm)	(mm)	—	(mm)	(mm)	—	(mm^2)
2	3.9	0.0368	0.009	6.4	0.0000	0.000	24.7
3	3.8	0.0467	0.012	6.4	0.0000	0.000	24.3
5	3.8	0.2452	0.064	6.3	0.0090	0.001	24.3

Table A.392: Laminate 21 interlaminar shear summary.

		Max	Apparent
	Area	Load	Shear Stress
Specimen	(mm^2)	(N)	(MPa)
2	24.7	941.6	29.3
3	24.3	854.7	27.1
5	24.3	940.2	29.7

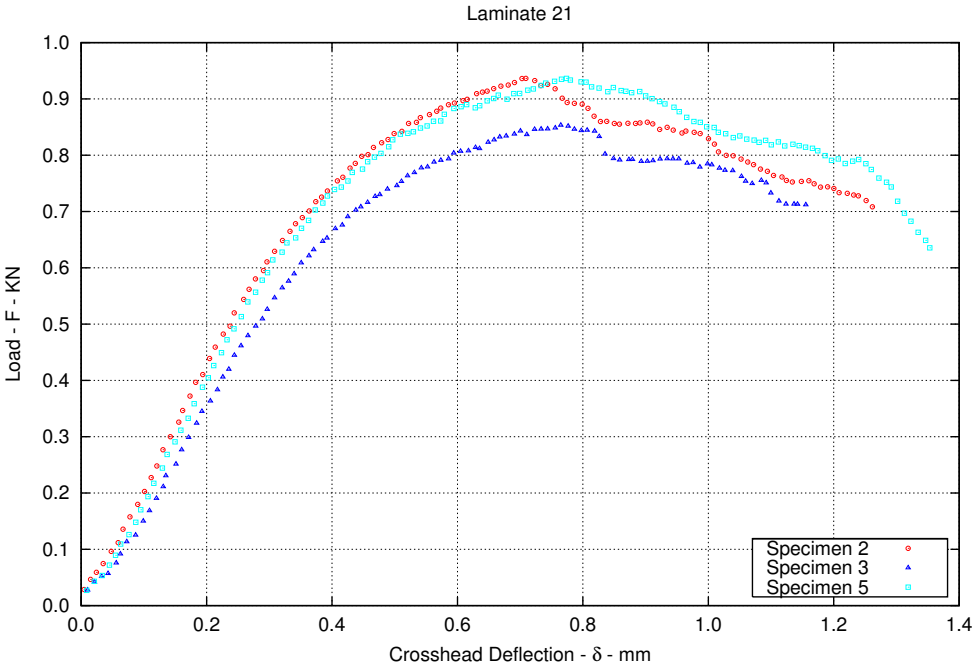


Figure A.214: Laminate 21 interlaminar shear response.

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14. ABSTRACT
Twenty anisotropic carbon/glass hybrid composite laminates have been fabricated, tested, and analyzed. Coupons have been subjected to mechanical testing to measure elastic properties and strength of the laminates using tensile, compressive, transverse tensile, and in-plane shear tests. The tensile moduli generally correlate well with experiment without correction for end constraints imposed by the test fixtures. The results suggest that shear moduli of the anisotropic materials are affected by end constraints. The results indicate that extension/shear coupling is maximized with the least loss in axial tensile stiffness by using carbon fibers oriented 15° from the long axis for approximately two-thirds of the laminate volume (discounting skin layers), with reinforcing carbon fibers oriented axially comprising the remaining one-third of the volume. First-ply failure predicted by three common criteria -- max stress, max strain, and Tsai-Wu -- proves generally conservative, with the stress-based criteria the most conservative.

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composites, anisotropic, carbon composites, glass composites, hybrid composites, mechanical testing, failure criteria

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U	U	U	UU	300	19b. TELEPHONE NUMBER *(Include area code)* (785) 838-3771

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