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Transportation Research Division

Technical Report 17-3

Experimental Evaluation and Design of Unfilled and Concrete-Filled FRP Composite Piles

Task 5 – Laminate Durability Testing

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16. Abstract (Limit 200 words)

The overall goal of this project is the experimental evaluation and design of unfilled and concrete-filled FRP composite piles for load-bearing in bridges. This report covers Task 5, Laminate Durability Testing.

Mechanical properties of the FRP material were examined using flat witness FRP plates with 2 layers of reinforcing fabric and a nominal thickness of 6.4 mm (0.25 in). The FRP material was tested after exposure to four environmental conditions to verify compliance with the American Association of State Highway and Transportation Officials Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bride Elements (2012) durability requirements. The environmental conditions were: a) Alkali environment exposure; b) Water exposure; c) Freeze-thaw cycles; and d) UV/condensation exposure.

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Technical Report

Durability Evaluation of FRP Pile Material

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Project Task 1199.5

Project: Experimental Evaluation and Design of Unfilled and Concrete-Filled FRP Composite Piles

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SUMMARY

This study was conducted to evaluate the performance of one type of fiber reinforced polymer (FRP) pile in load-bearing applications for the Maine Department of Transportation, with the purpose of assessing pile strength, drivability, and durability. Mechanical properties of the FRP material were examined using flat witness FRP plates with 2 layers of reinforcing fabric and a nominal thickness of 6.4 mm (0.25 in).

The FRP material was tested after exposure to four environmental conditions to verify compliance with the American Association of State Highway and Transportation Officials Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bride Elements (2012) durability requirements. The environmental conditions were: a) Alkali environment exposure; b) Water exposure; c) Freeze-thaw cycles; and d) UV/condensation exposure.

Samples from conditioned plates were tested in tension in the longitudinal and hoop directions. In addition, the glass transition temperature of the material after environmental conditioning was determined. The mechanical properties evaluated were: ultimate tensile strain, ultimate tensile stress, modulus of elasticity and glass transition temperature. The FRP material did not meet minimum property retention requirements for ultimate tensile strain (longitudinal and hoop directions) for three environmental conditions. However, all conditioned samples met the AASHTO guide specification (2012) requirements for retention of glass transition temperature.

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1. LITERATURE REVIEW

Chin et al. (1997) investigated changes in tensile properties and glass transition temperature of vinyl ester and polyester resin castings that were exposed to ultraviolet (UV) radiation, moisture, alkaline, and saline environments. Chin et al. (1997) did not note any significant changes in the loss modulus or storage modulus during glass transition temperature testing of conditioned samples. Tensile testing did not yield any definitive trends either, as the samples with reduced strength had a large scatter of tensile capacities.

Guzman and Brøndsted (2014) researched the effects of salt water immersion on glass FRP samples. Longitudinal tension samples with multi-directional reinforcement lost 24% of their strength and approximately 22% of their strain at failure after being conditioned for 8 years. However, the modulus of the samples was only reduced by 7%.

Hongwang and Huang (2011) tested glass and polyester composite materials exposed to UV radiation. This program examined the flexural deformation and tensile strength of the material after exposure ranging from 30 to 210 days. The flexural deformation under 0.2 N (0.05 lbs) increased 87.4% after 210 days of exposure. The tensile strength decreased 5.3% after 210 days of exposure. Hongwang and Huang (2011) attribute these trends to thermo-oxidation, photo-degradation, and a loss of bond between the fibers and matrix.

Pando et al. (2002) examined the effects of submerging circular FRP shells in fresh water. This test program evaluated properties as a function of time and moisture content. The results of testing were used to create a simplified model of the long-term structural capacity of FRP piles. The model showed a loss of 5% in the axial direction and 24% in flexural.

Shokrieh and Bayat (2007) tested tension, compression, and shear samples exposed to 3, 6, and 12 months of simulated UV exposure using a UV chamber. These samples were constructed with a thickness of 1 mm (0.039 in) for tensile tests and 3 mm (0.12 in) for compressive tests, using glass fibers and an unsaturated polyester resin. Samples lost 38.4% of their tensile strength, 18.8% of their shear strength, and 3.8% of their compressive strength after 100 hours of accelerated UV exposure.

Afshar et al. (2015) examined the effects of UV radiation and moisture absorption on the flexural properties of carbon fiber and vinyl ester composites used in the marine industry. This study found that vinyl ester composites experience degradation at their exposed surface, with the reduction of flexural properties being most notable in the transverse direction. Afshar et al. (2015) note that the flexural testing of environmentally conditioned gives a larger decrease in mechanical properties because surface damage is aligned with the extreme tension and/or compression fiber. This effect would not be seen in tensile testing. It was found that longitudinal and transverse flexural strength was decreased by 10% and 40% respectively.

2. AASHTO REQUIREMENTS

Fiber reinforced polymer (FRP) samples were tested according to Section 2.2.4.4 of the American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of

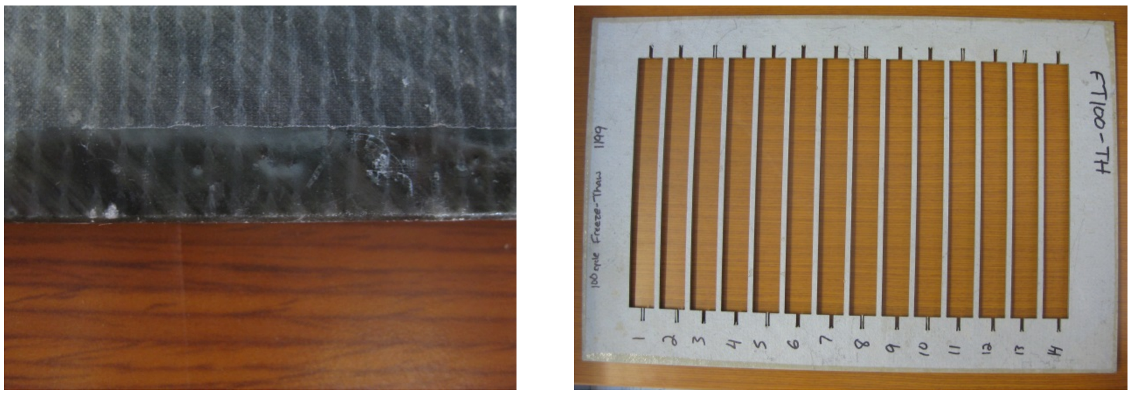
Concrete Bridge Elements (2012). This specifies that samples must retain 85% of the ultimate tensile strain and glass transition temperature after the following environmental conditioning:

- "Water – Samples shall be immersed in distilled water having a temperature of 100 +/- 3°F (38 +/- 2°C) and tested after 1,000, 3,000, and 10,000 hours of exposure.
- Alternating Ultraviolet Light and Condensation Humidity – Samples shall be conditioned in an apparatus under Cycle 1-UV exposure condition according to American Society for Testing and Materials (ASTM) G154 Standard Practice. Samples shall be tested within two hours after removal from the apparatus.
- Alkali – The sample shall be immersed in a saturated solution of calcium hydroxide (pH ~11) at ambient temperature of 73 +/- 3 °F (23 +/- 2°C) for 1,000, 3,000, and 10,000 hours prior to testing. The pH level shall be monitored and the solution shall be maintained as needed.
- Freeze-Thaw – Composite samples shall be exposed to 100 repeated freezing and thawing in an apparatus meeting the requirements of ASTM C666."

3. EXPERIMENTAL PROGRAM

3.1 Environmental Conditioning

FRP panels measuring nominally 533 mm (21 in) by 356 mm (14 in) were cut from the same FRP plates used for mechanical property testing. The edges of these panels were sealed with Derakane 8084, an epoxy vinyl ester resin meeting the durability requirements set by AASHTO (2012), to limit the penetration of moisture at the edges. The dimensions of the panels provided 51 mm (2 in) of extra material at the edge of the panel to further limit the effects of moisture penetration at the edges of the panels. This can be seen in Figure 1.



(a) (b)

Figure 1 Sealed Edges (a) and Edge Distance (b) on FRP Panels for Conditioning (14 samples)

These panels were conditioned according to the environmental exposure conditions set by AASHTO (2012). When duration of the exposure condition was completed, the plates were stored at 23 °C (73 °F) and 50% relative humidity until they could be tested.

3.2 Tension Tests

All tensile testing was conducted in accordance with ASTM D3039. Tensile coupons were cut both in the longitudinal and in the hoop direction of the FRP panels after conditioning. The mechanical properties reported are: ultimate stress, ultimate strain, modulus of elasticity and Poisson’s ratio.

3.3 Glass Transition Temperature Tests

Glass transition testing was conducted in accordance with ASTM E1640. A Thermal Analysis Instruments DMA Q800 dynamic mechanical analyzer was used to test samples. The 3-point bend test configuration was used to accommodate the thickness and modulus of the samples. Tests were conducted with a pre-load of 2 N, frequency of 1 Hz, temperature ramp of 3 °C per minute, and amplitude of 10 micrometers. The temperature range was 30 to 140 °C.

Dynamic mechanical analysis determines glass transition temperature (Tg) using 3 properties. Thermal Analysis Instruments describes the 3 different glass transition temperatures as:

- "Onset of the change in slope of storage modulus: Occurs at the lowest temperature and relates to mechanical failure
- Peak of the loss modulus: Occurs at the middle temperature and is more closely related to the physical property changes attributed to the glass transition in plastics. It reflects molecular processes and agrees with the idea of Tg as the temperature at the onset of segmental motion
- Tan Delta Peak: Occurs at the highest temperature and is used historically in literature. It is a good measure of the 'leather like' midpoint between the glassy and rubbery states of a polymer. The height and shape of the tan delta peak change systematically with amorphous content"

For the purpose of this research, the onset of the change in slope of the storage modulus was used as the glass transition temperature in accordance with ASTM E1640.

However, the values corresponding to the peak of the loss modulus and the tan delta curve are also presented for comparison.

3.4 Alkali Environment

Samples were conditioned in containers of an alkali solution comprised of distilled water and calcium hydroxide with a target pH of 11 and temperature of 23 °C (73 °F). Samples were conditioned in a Parameter Generation and Control model 3478-4-W environmental chamber for exposure times of 1,000 hours, 3,000 hours, and 10,000 hours. This can be seen in Figure 2. Temperature, water level, and pH were monitored and adjusted as necessary throughout the exposure time.

Figure 2 Alkali Exposure Test

The results of tension tests on samples conditioned in an alkali solution are presented in Table 1 and Table 2 for longitudinal and hoop directions, respectively.

Table 1 Longitudinal Tensile Properties of Alkali Exposure Samples

Conditioning	**Statistic**	**Ultimate Stress in X (MPa)**	**Ultimate Strain in X (µstrain)**	**Modulus of Elasticity in X (GPa)**	**Poisson's Ratio**
1,000 Hour Alkali Exposure	Mean	497	2.34E+04	23.4	0.37
	Std Dev	35	1.92E+03	0.3	0.01
	COV	7.0%	8.2%	1.4%	3.1%
3,000 Hour Alkali Exposure	Mean	491	2.21E+04	24.0	0.35
	Std Dev	16	1.29E+03	0.3	0.01
	COV	3.2%	5.8%	1.3%	1.4%
10,000 Hour Alkali Exposure	Mean	474	2.13E+04	23.7	0.35
	Std Dev	11	4.68E+02	0.3	0.01
	COV	2.4%	2.2%	1.4%	3.0%

Table 2 Hoop Tensile Properties of Alkali Exposure Samples

Conditioning	**Statistic**	**Ultimate Stress in Y (MPa)**	**Ultimate Strain in Y (µstrain)**	**Modulus of Elasticity in Y (GPa)**	**Poisson's Ratio**
1,000 Hour Alkali Exposure	Mean	159	1.80E+04	16.1	0.33
	Std Dev	7	8.68E+02	0.7	0.05
	COV	4.2%	4.8%	4.2%	13.5%
3,000 Hour Alkali Exposure	Mean	174	1.95E+04	13.7	0.33
	Std Dev	6	6.77E+02	1.4	0.02
	COV	3.5%	3.5%	10.4%	5.8%
10,000 Hour Alkali Exposure	Mean	175	1.99E+04	15.3	0.34
	Std Dev	9	1.04E+03	1.1	0.02
	COV	5.3%	5.2%	7.0%	4.5%

Table 3 Glass Transition Temperature Properties of Alkali Exposure Samples

Conditioning	Onset of Change in Slope of Storage Modulus (°C)	Peak of Loss Modulus (°C)	Peak of Tan Delta (°C)
1,000 Hour Alkali Exposure	84.2	94.2	115.3
3,000 Hour Alkali Exposure	85.4	98.9	114.4
10,000 Hour Alkali Exposure	97.2	106.9	121.6

3.5 Moisture Absorption

Samples were conditioned in a bath of distilled water with a target temperature of 38 °C (100 °F). Containers of water were placed in a VWR Scientific HAFO 1600 Series oven for exposure times of 1,000 hours, 3,000 hours, and 10,000 hours, as shown in Figure 3. Water levels and temperature were monitored and adjusted as necessary throughout the exposure time.

Figure 3 Water Exposure Test

The results of tension tests on samples conditioned in a water bath are reported in Table 4 and Table 5 for longitudinal and hoop directions, respectively.

Table 4 Longitudinal Tensile Properties of Water Exposure Samples

Conditioning	**Statistic**	**Ultimate Stress in X (MPa)**	**Ultimate Strain in X (μstrain)**	**Modulus of Elasticity in X (GPa)**	**Poisson's Ratio**
1,000 Hour Water Exposure	Mean	498	2.46E+04	22.1	0.32
	Std Dev	16	1.33E+03	0.4	0.01
	COV	3.3%	5.4%	1.6%	1.7%
3,000 Hour Water Exposure	Mean	461	1.97E+04	24.2	0.34
	Std Dev	25	1.40E+03	0.4	0.01
	COV	5.4%	7.1%	1.5%	2.7%
10,000 Hour Water Exposure	Mean	441	1.96E+04	23.6	0.35
	Std Dev	14	6.89E+02	0.4	0.01
	COV	3.2%	3.5%	1.8%	1.9%

Table 5 Hoop Tensile Properties of Water Exposure Samples

Conditioning	**Statistic**	**Ultimate Stress in Y (MPa)**	**Ultimate Strain in Y (μstrain)**	**Modulus of Elasticity in Y (GPa)**	**Poisson's Ratio**
1,000 Hour Water Exposure	Mean	170	2.20E+04	13.1	0.13
	Std Dev	2	9.53E+02	1.7	0.04
	COV	1.1%	4.3%	13.1%	27.0%
3,000 Hour Water Exposure	Mean	144	1.69E+04	13.4	0.34
	Std Dev	9	1.24E+03	1.3	0.02
	COV	6.1%	7.3%	10.0%	4.5%
10,000 Hour Water Exposure	Mean	173	2.07E+04	14.2	0.14
	Std Dev	6	1.49E+03	0.3	0.01
	COV	3.7%	7.2%	1.9%	10.3%

Table 6 Glass Transition Temperature Properties of Water Exposure Samples

Conditioning	Onset of Change in Slope of Storage Modulus (°C)	Peak of Loss Modulus (°C)	Peak of Tan Delta (°C)
1,000 Hour Water Exposure	85.2	96.4	113.8
3,000 Hour Water Exposure	80.0	90.5	105.5
10,000 Hour Water Exposure	92.9	106.8	121.2

3.6 UV and Condensation Humidity

Ultraviolet (UV)/condensation humidity testing was conducted in accordance with ASTM G154 using a UVA-340 ultraviolet lamp at an irradiance of 0.89 W/m^2/nm. Neither the ASTM standard or AASHTO (2012) specified a duration for this exposure type. Based on prior experience with this type of environmental test in the laboratory, an exposure time of 1,000 hours was selected. A typical cycle for UV/condensation humidity exposure is illustrated in Table 7.

Table 7 Typical UV/Condensation Humidity Test Cycle

Cycle	Step	Duration	Type	Temp. (°C)
1	1	8 hours	UV	60
	2	4 hours	Condensation	50

Samples were placed in a Q-Panel Lab Products QUV/spray test chamber for the specified exposure time, as shown in Figure 4. The FRP panels have a coating to limit degradation due to ultraviolet light. When panels were placed in the conditioning chamber, the coating was placed on the side of the chamber with the UV lamps to mimic the orientation of the coating on the outside of the full scale FRP piles.

Figure 4 UV/Condensation Humidity Test Chamber

The results of tension tests on samples conditioned in the ultraviolet light and condensation humidity chamber are presented in Table 8 and Table 9 for longitudinal and hoop directions, respectively.

Table 8 Longitudinal Tensile Properties of UV/Condensation Humidity Samples

Conditioning	**Statistic**	**Ultimate Stress in X (MPa)**	**Ultimate Strain in X (μstrain)**	**Modulus of Elasticity in X (GPa)**	**Poisson's Ratio**
1,000 Hour Exposure	Mean	534	2.34E+04	24.0	0.32
	Std Dev	14	1.83E+03	0.5	0.01
	COV	2.6%	7.8%	2.1%	3.0%

Table 9 Hoop Tensile Properties of UV/Condensation Humidity Samples

Conditioning	**Statistic**	**Ultimate Stress in Y (MPa)**	**Ultimate Strain in Y (μstrain)**	**Modulus of Elasticity in Y (GPa)**	**Poisson's Ratio**
1,000 Hour Exposure	Mean	169	2.04E+04	14.0	0.12
	Std Dev	11	1.61E+03	0.5	0.02
	COV	6.4%	7.9%	3.8%	17.9%

Table 10 Glass Transition Temperature Properties of UV/Condensation Humidity Samples

Conditioning	Onset of Change in Slope of Storage Modulus (°C)	Peak of Loss Modulus (°C)	Peak of Tan Delta (°C)
1,000 Hour Exposure	92.6	113.9	128.8

3.7 Freeze-Thaw

Freeze-thaw testing was conducted in general accordance with ASTM C666. Samples were subjected to 100 cycles of freezing at -18°C (0°F) and thawing at 4°C (40°F). The standard specifies that that samples be "surrounded by not less than 1/32 in (1 mm) nor more than 1/8 in (3 mm) of water at all times" or "completely surrounded by air during the freezing phase of the cycle and by water during the thawing phase." The samples in this test were subjected to a target relative humidity of 100% during the thawing phase and 0% during the freezing phase. A typical cycle of freeze-thaw exposure is presented in Table 11.

Table 11 Typical Cycle of Freeze-Thaw Exposure

Cycle	Step	Duration	Initial Temp. (°F)	Final Temp. (°F)	Relative Humidity (%)
1	1	3 Hours	40	40	100
	2	10 Minutes	40	0	0
	3	3 Hours	0	0	0
	4	15 Minutes	0	40	0

Samples were placed on 25.4 mm (1 in) spacers inside an ESPEC ESL-3CA freeze-thaw chamber to allow air to circulate evenly over the plates. The freeze-thaw chamber and sample configuration can be seen in Figure 5.

(a) (b)

Figure 5 Freeze-Thaw Chamber (a) and Sample Configuration (b)

The results of tension tests on samples conditioned in a freeze-thaw chamber are presented in Table 12 and Table 13 for longitudinal and hoop directions, respectively.

Table 12 Longitudinal Tensile Properties of Freeze-Thaw Samples

Conditioning	**Statistic**	**Ultimate Stress in X (MPa)**	**Ultimate Strain in X (µstrain)**	**Modulus of Elasticity in X (GPa)**	**Poisson's Ratio**
100 Freeze-Thaw Cycles	Mean	411	1.88E+04	23.1	0.35
	Std Dev	23	1.72E+03	0.4	0.01
	COV	5.6%	9.1%	1.7%	1.9%

Table 13 Hoop Tensile Properties of Freeze-Thaw Samples

Conditioning	**Statistic**	**Ultimate Stress in Y (MPa)**	**Ultimate Strain in Y (μstrain)**	**Modulus of Elasticity in Y (GPa)**	**Poisson's Ratio**
100 Freeze-Thaw Cycles	Mean	175	2.11E+04	14.4	0.14
	Std Dev	10	1.39E+03	0.5	0.02
	COV	5.6%	6.6%	3.6%	12.0%

Table 14 Glass Transition Temperature Properties of Freeze-Thaw Samples

Conditioning	**Onset of Change in Slope of Storage Modulus (°C)**	**Peak of Loss Modulus (°C)**	**Peak of Tan Delta (°C)**
100 Freeze-Thaw Cycles	92.6	103.5	119.2

4. DISCUSSION ON DURABILITY PROPERTIES OF FRP PLATES

The FRP samples for this test program did not meet the AASHTO (2012) requirement for 85% retention of ultimate tensile strain after conditioning, with tension coupons losing up to 26.4% of their baseline value. The change in properties for ultimate strain, ultimate stress, and modulus of elasticity are presented in Table 15 and Table 16 for longitudinal and hoop directions, respectively. Changes in glass transition temperature properties are reported in Table 17. Values in bold font indicate that less than 85% of the mechanical property was retained after environemntal exposure. Negative percent lost denotes an increase in the material property.

Table 15 Changes in Tensile Properties in the Longitudinal Direction after Environmental Conditioning

Conditioning	**Ultimate Strain in X (µstrain)**	**Percent Lost**	**Ultimate Stress in X (MPa)**	**Percent Lost**	**Modulus of Elasticity (GPa)**	**Percent Lost**
Baseline	2.56E+04	—	530	—	22.5	—
1,000 Hour Alkali	2.34E+04	8.5	497	6.3	23.4	-4.0
3,000 Hour Alkali	2.21E+04	13.6	491	7.4	24.0	-6.8
10,000 Hour Alkali	2.13E+04	**16.9**	474	10.5	23.7	-5.1
1,000 Hour Water	2.46E+04	4.0	498	6.1	22.1	2.0
3,000 Hour Water	1.97E+04	**23.2**	461	13.1	24.2	-7.5
10,000 Hour Water	1.96E+04	**23.5**	441	**16.8**	23.6	-4.9
100 Freeze-Thaw Cycles	1.88E+04	**26.4**	411	**22.5**	23.1	-2.6
1,000 Hour UV and Condensation	2.34E+04	8.3	534	-0.6	24.0	-6.7

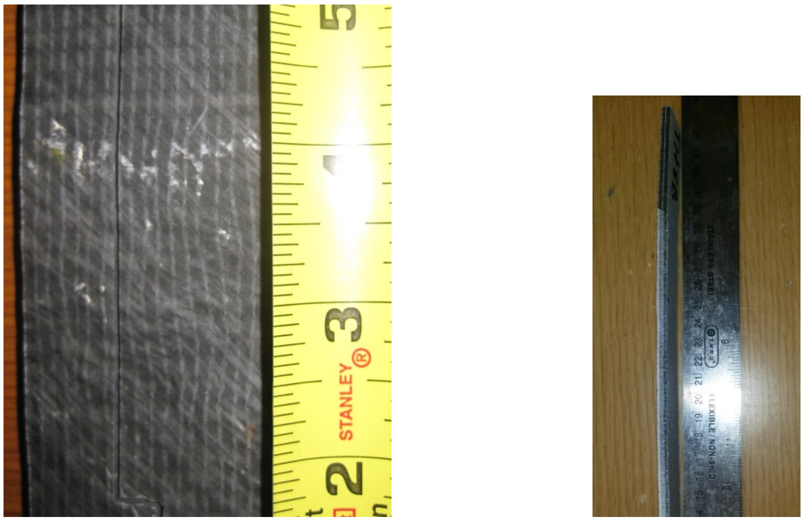
Table 16 Changes in Tensile Properties in the Hoop Direction after Environmental Conditioning

Conditioning	**Ultimate Strain in Y (µstrain)**	**Percent Lost**	**Ultimate Stress in Y (MPa)**	**Percent Lost**	**Modulus of Elasticity (GPa)**	**Percent Lost**
Baseline	2.27E+04	—	174	—	13.7	—
1,000 Hour Alkali	1.80E+04	**20.7**	159	9.0	16.1	-18.1
3,000 Hour Alkali	1.95E+04	14.3	174	0.3	13.7	-0.6
10,000 Hour Alkali	1.99E+04	12.5	175	-0.6	15.3	-12.2
1,000 Hour Water	2.20E+04	3.1	170	2.7	13.1	3.8
3,000 Hour Water	1.69E+04	**25.6**	144	**17.4**	13.4	1.8
10,000 Hour Water	2.07E+04	8.7	173	0.5	14.2	-3.9
100 Freeze-Thaw Cycles	2.11E+04	7.1	175	-0.5	14.4	-5.8
1,000 Hour UV and Condensation	2.04E+04	10.2	169	2.7	14.0	-2.6

Table 17 Changes in Glass Transition Temperature after Environmental Conditioning

Conditioning	Onset of Change in Slope of Storage Modulus (°C)	Percent Lost	Peak of Loss Modulus (°C)	Percent Lost	Peak of Tan Delta (°C)	Percent Lost
Baseline	86.8	—	93.2	—	118.5	—
1,000 Hour Alkali	84.2	3.0	94.2	-1.1	115.3	2.7
3,000 Hour Alkali	85.4	1.6	98.9	-6.2	114.4	3.4
10,000 Hour Alkali	97.2	-12.0	106.9	-14.8	121.6	-2.6
1,000 Hour Water	85.2	1.8	96.4	-3.5	113.8	4.0
3,000 Hour Water	80.0	7.9	90.5	2.9	105.5	11.0
10,000 Hour Water	92.9	-7.1	106.8	-14.6	121.2	-2.2
100 Freeze-Thaw Cycles	92.6	-6.7	103.5	-11.1	119.2	-0.6
1,000 Hour UV and Condensation	96.9	-11.6	113.9	-22.3	128.8	-8.7

Tensile properties may have also been influenced by variations in the material and manufacturing defects. This is especially noticeable for the change in ultimate stress of longitudinal and hoop direction samples that were exposed to freeze-thaw cycles. Longitudinal tension samples lost 22.5% of their baseline ultimate stress, while hoop tension samples increased by 0.5% despite being exposed to the same conditions. Some manufacturing defects that were observed in durability samples were misaligned reinforcing fabric and warping of the FRP panels. An example of misaligned fibers is shown in Figure 6. It was only possible to see misaligned fibers in one of the two layers of reinforcement, because the opposite side of the panels was covered with a blue coating.



(b)

Figure 6 Misaligned Fibers (a) and Warping (b) in Durability Samples

Sets of unconditioned tension and glass transition temperature coupons were tested over the duration of environmental conditioning to evaluate the changes in the material properties over time. These samples were stored indoors in a heated and cooled facility, but temperature and humidity were not monitored or maintained at a constant value. Results of these tests are presented in Table 18, Table 19, and Table 20. There is no data reported for Baseline Set C of longitudinal tension samples because 6 out of 12 samples failed in the grips of the Instron test machine and 2 additional samples experienced an error in data acquisition.

Table 18 Changes in Tensile Properties in the Longitudinal Direction of Unconditioned Samples

Conditioning	**Ultimate Strain in X (µstrain)**	**Percent Lost**	**Ultimate Stress in X (MPa)**	**Percent Lost**	**Modulus of Elasticity (GPa)**	**Percent Lost**
Baseline (June 2013)	2.56E+04	—	530	—	22.5	—
Baseline Set B (May 2014)	2.39E+04	6.7	516	2.7	23.7	-5.5
Baseline Set C (November 2014)	No Data		No Data		No Data	
Baseline Set D (February 2014)	2.45E+04	4.2	545	-2.7	24.0	-6.6

Table 19 Changes in Tensile Properties in the Hoop Direction of Unconditioned Samples

Conditioning	**Ultimate Strain in Y (µstrain)**	**Percent Lost**	**Ultimate Stress in Y (MPa)**	**Percent Lost**	**Modulus of Elasticity (GPa)**	**Percent Lost**
Baseline (June 2013)	2.27E+04	—	174	—	13.7	—
Baseline Set B (May 2014)	2.02E+04	11.1	184	-5.4	13.3	2.8
Baseline Set C (November 2014)	1.71E+04	**24.6**	156	10.2	12.2	10.9
Baseline Set D (February 2014)	1.77E+04	**21.9**	166	4.6	15.0	-10.2

Table 20 Changes in Glass Transition Temperature of Unconditioned Samples

Conditioning	**Onset of Change in Slope of Storage Modulus (°C)**	**Percent Lost**	**Peak of Loss Modulus (°C)**	**Percent Lost**	**Peak of Tan Delta (°C)**	**Percent Lost**
Baseline (June 2013)	86.8	–	93.2	–	118.5	–
Baseline Set B (May 2014)	No Data		No Data		No Data	
Baseline Set C (November 2014)	94.6	-9.0	107.5	-15.4	112.0	-1.2
Baseline Set D (February 2014)	99.0	-14.0	106.6	-14.4	122.3	-3.2

Unconditioned sets of tensile samples also showed variations in ultimate stress and strain for the longitudinal and hoop directions. Two sets of baseline hoop tension tests did not retain 85% of the baseline value found in the first set of tests (June 2013), even though they were not exposed to environmental conditioning. Variability was also observed in the glass transition temperature of the unconditioned samples at different times. This further illustrates the influence of defects and material variability on the material property retention after environmental exposure.

5. CONCLUSIONS AND RECOMMENDATIONS

Witness FRP plates were exposed to the four environmental conditions outlined in the AASHTO guide specification (2012). The FRP material did not meet minimum property retention requirements for ultimate tensile strain (longitudinal and hoop directions) for three environmental conditions. However, all conditioned samples met the

AASHTO guide specification (2012) requirements for retention of glass transition temperature for all the environmental conditions. Tensile properties may have been influenced by variations in the material and manufacturing defects. In order to satisfy the requirements of the AASHTO guide specification (2012), a polymer resin with greater environmental resistance (for example, formulated for exterior use) should be selected and verified through material testing after environmental conditioning.

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