POSTPONEMENT OF FAILURE OF CONCRETE BY SURFACE PROTECTION AND DURABILITY ASPECTS

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ABSTRACT

Concrete is the most commonly used construction material in the world with a worldwide consumption of about 12.5 B tonne. It is the most versatile and economical construction material known to humanity. It is used as plain concrete, reinforced concrete and prestressed concrete. In all cases, the failure is initiated by ingress of liquids into concrete. In most cases, the ingress is accelerated by surface cracking induced by shrinkage and creep. In some cases, by stress. The liquids can cause chemical degradation or physical degradation due to freezing and thawing. In plain concrete applications, the failure occurs by surface degradation and spalling. In the case of reinforced concrete, most common failure is due to corrosion of reinforcement. In reinforced concrete, the structural elements are allowed to crack under service loads. The cracking at service loads is not detrimental to these elements as long as there are no intrusions. However, almost all structures are exposed to various types of chemicals and vapors and these foreign elements initiate the degradation. Large amounts of resources are being expended for repair and maintenance concrete structures. Researchers are actively looking for solutions to minimize the problem and identify effective restoration techniques. The results presented in this paper focuses on a coating system that minimizes the liquid intrusion into concrete. This solution is based on the hypothesis that: *most if not all degradation of concrete problems can solved if liquids are not allowed to enter the concrete structural elements and at the same time have an outlet for liquids that are already inside*. In other words, the surface of the concrete structures should have the least permeability, but should be able to release the vapor pressure created by the water that enters into the system at weak locations. Durability and fracture of concrete and other materials including coatings are also discussed.

1 INTRODUCTION

Intrusion of water and other liquids is the primary cause for deterioration of concrete structures. In the case of plain concrete, the failure occurs by spalling and exposure of aggregates. In the case of reinforced concrete, initial deterioration of concrete leads to reinforcement corrosion. Reinforcement corrosion accelerates the degradation process by creating more cracks and further liquid ingress. About two decades ago, a number of transportation structures were coated with polymers. These coating provided a barrier against ingress of liquids but at the same time would not the release of water that is already inside the concrete. Accumulation of water at the interface eventually led to the peeling of the organic coatings. In some cases, deterioration also took place because of ultraviolet radiation. The results presented in this paper deals with a recently developed inorganic coatings.

2 BACKGROUND INFORMATION

A recently developed inorganic matrix, known as Geopolymer, is being evaluated for use in aircrafts and the civil infrastructure [1-7]. This matrix was modified for use as a coating material and adhesive for brick, concrete, wood, and steel. The cementations part is a potassium aluminosilicate, or polysialate-silox with the general chemical structure as shown in Eq. (1),

$$K_n \left\{ -\left(SiO_{2z} - AlO_2 \right)_n \right\} \text{g} w\, H_2O \tag{1}$$

In which $Z >> n$. The resin hardens to an amorphous (glassy) structure at moderate temperatures of 80 to 150°C. Hardeners have been developed to obtain a room temperature cure in about 24 hours. The unique features of the matrix are as follows:

1. The resin is prepared by mixing a liquid component with silica powder. Fillers and hardening agents can be added to the powder component. The two components can be mixed to the consistency of paint. The matrix is water based; consequently, tools and spills can be cleaned with water. All of the components are nontoxic and no fumes are emitted during mixing or curing. The excess material or material removed from the old application can be discarded as general waste.
2. The pot life varies from 30 minutes to 3 hours for compositions that cure at room temperature. Compositions that require heat for curing at 80 to 150°C can be stored at room temperature for weeks.
3. Common application procedures such as brushing and spraying can be used. The product was successfully used to coat bridge substructures by brush and a sprayer in Rhode Island, USA.
4. The matrix bonds well with carbon and glass fibers reinforcements.
5. The matrix can withstand temperatures up to 1000°C, and its mechanical properties are not affected by ultraviolet radiation. Fire tests show that the flame-spread index is zero. The air permeability of the matrix is low; therefore, it can be used to protect the material it covers by reducing the amount of oxygen necessary for combustion.

3 EVALUATION OF INORGANIC POLYMER USING STRENGTH TESTS

Geopolymer-based FRP is compared to the organic polymer-based FRP for strength and stiffness. Both organic and inorganic FRP are reinforced with low cost carbon tows made of 48,000 fibers with an average fiber diameter of 7 μm. Performance of tows and sheets made of 1,000 tows is compared with the performance of carbon sheets made specifically for repair applications. The comparison is made by testing prisms strengthened with 1, 2, and 3 tows, 1 and 2 carbon sheets utilizing both an organic and inorganic matrices.

The concrete prisms were cast using the following mix proportion. The cement, fine and coarse aggregate contents were: 401, 860, and 720 kg/m^3 of concrete, respectively. The coarse aggregate was limited to 9.5 *mm* in diameter. The water to cement ratio was 0.5. The $50 \times 50 \times 330\, mm$ prisms were cast using steel molds and table vibrators and cured at 100% relative humidity for at least 28 days. The cured samples were prepared for strengthening by sand blasting and then cleaning with a wire brush. Sand blasting was performed using silica quartz sand at a pressure of 60 *KPa*.

Once the surface was cleaned, a thin layer of the inorganic matrix was applied to fill the small air voids and to create a smooth surface. Pre-cut carbon tows and sheets were impregnated with the matrix and placed on the prepared concrete surface and bonded using grooved rollers. A second layer of the matrix was applied as a protective coating. The samples were cured for 24 hours at room temperature followed by 24 hours at 80°C. The elevated temperature was used to ensure adequate curing in a two-day period. One day curing at 80°C is equivalent to about one week of curing at room temperature.

For the organic matrix, the manufacturer's recommendations were followed. The cleaned surface was coated with primer and cured for three days. The matrix and the carbon were placed on the primed surface and bonded using rollers. After applying the topcoat, the samples were left at room temperature for at least seven days before testing. A typical FRP strengthened prism is shown in Figure 1.

3.1 Load set-up and test procedure

The prisms were tested using a center point load over a span of 300 *mm* as shown in Figure 2. An MTS testing machine with computer controls was used to measure load and midspan deflections. The tests were run under displacement control at the rate of 0.1 *mm/min*. The loads and displacements were recorded at intervals of 15 seconds.

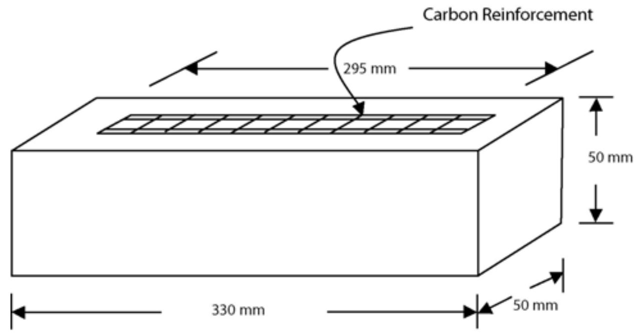

Figure 1. Typical strengthened prism

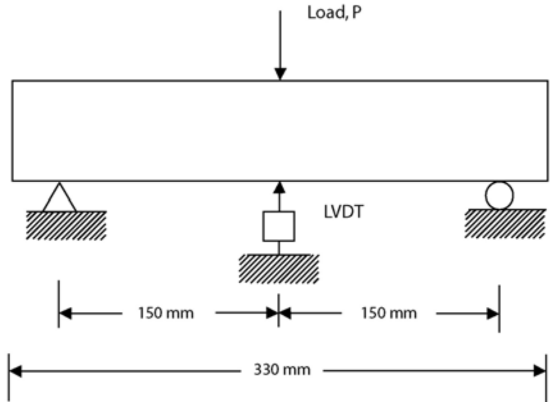

Figure 2. Loading setup

Both of the beams strengthened with organic and inorganic FRP carried considerable load after the development of the crack at the mid span. In both types of FRP-reinforced beam, a single crack developed, it widened until the specimen failed. The crack width at failure increased as the reinforcement increased. The deflection also increased as the crack width increased. In the case of the organic matrix, the crack at midspan extended at the interface towards the supports. In each case, failure was accompanied by debonding of the reinforcement. The authors hypothesize that the debonding is caused by shear failure of the thin layer of concrete near the concrete to FRP interface.

In the beams retrofitted with the inorganic FRP, failure was always caused by fracture of the carbon fibers. This happened in spite of the fact that the inorganic matrix is more brittle than the organic matrix. Failure was initiated by micro cracks that appear within the matrix. The fibers do not act as a single plate as in the case of the organic FRP, thereby reducing the likelihood of delamination. Unlike the organic FRP, inorganic FRP remains bonded to the concrete after the beams failed.

The absence of an effective load transferring mechanism among the fibers within the inorganic FRP composite reduces the shear stress at the interface. This lower shear stress implies that debonding failure is unlikely. However, this mechanism does not effectively use the strength of the carbon fibers. The carbon fibers at the micro cracks experience higher stresses, resulting in fiber failure at lower average strains as compared to the fibers in the organic FRP.

3.2 Load-deflection behavior

The load-deflection behavior of beams strengthened with inorganic and organic matrices is presented in Figure 3. In Figure 3, the behavior of beams strengthened with organic FRP reinforced with 1, 2, and 3 tows, 1 and 2 layers of fabric are compared to those using inorganic FRP. A careful review of these curves leads to the following observations.

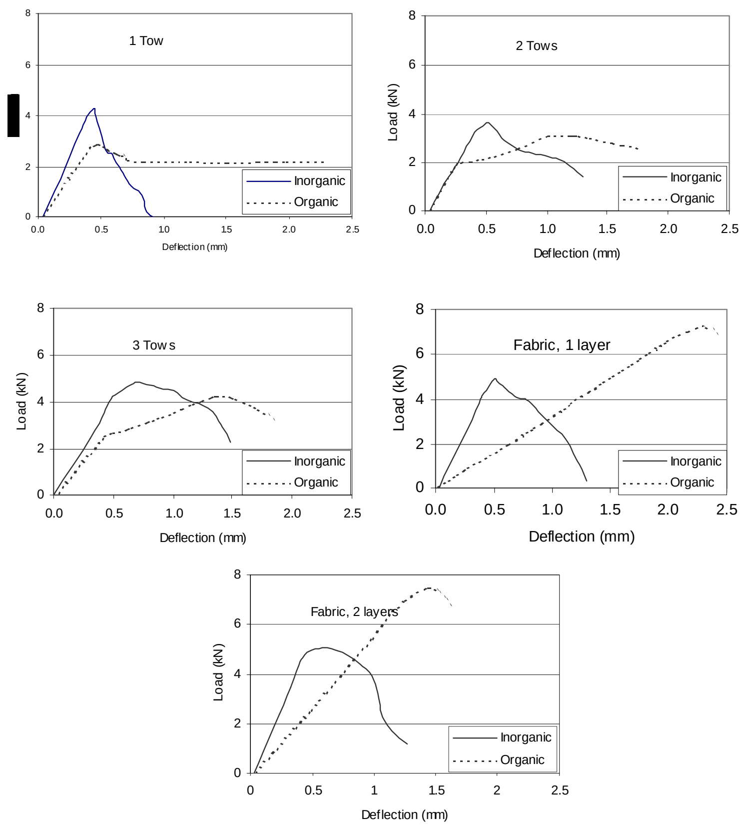

Figure 3. Strength comparison of inorganic and organic FRP

As expected, the beams strengthened with the organic matrix had larger deflections before failure, since the inorganic matrix cracks at strains of about 0.007 *mm/mm* [5]. In addition, the inorganic silicate matrix bonds with the concrete chemically through a transfer of *CaOH* and *KOH* between concrete and the adhesive, resulting in the absence of a well defined inter-laminar layer. Therefore, when the concrete cracks, the cracks go through the repair layer, transferring the forces to the carbon fibers. Consequently, the debonding of the repair plate is much less frequent in the inorganic matrix compared to organic FRP-to-concrete interface, and the average strain in the plate at failure is lower.

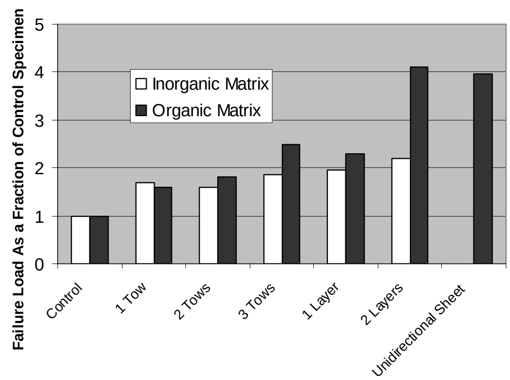

Figure 4. Increase in failure loads

Increase in the failure loads is compared in Figure 4. The increases are presented as a factor of the strength of plain concrete for easy comparison. In beams reinforced with carbon tows, the strength increase for the inorganic and organic matrices is not significantly different. In the case of the inorganic matrix, the beam reinforced with only one tow had a greater strength increase than the beam reinforced with two tows. We observed that in the case of a single tow, the fibers are well spread out and are very close to the bonded surface. As soon as the crack forms in the concrete, it penetrates the FRP. The authors believe that this penetration occurs soon after crack initiation. This process enables the contribution of the carbon fibers at very low crack width and hence the tension force contribution of the concrete is not lost. Strength calculations confirm that, on the onset of cracking, both carbon and tension zone concrete contributes to the strength capacity. The disadvantage in this load-transfer mechanism is the reduction in ductility of the specimen.

When more fibers are added, the load transfer becomes much less localized and an increased crack width opening occurs before failure. This results in an increased ductility but less utilization of the carbon fibers. The average stress and strain of carbon at failure reduces as the amount of fibers is increased. Ductility can also be improved by adding short fibers to the matrix [3]. The stress and strain also decrease at failures with an increase in fiber content in organic matrices, but the decrease in failure strains is more gradual. Inorganic FRP provides strength increases up to 216 percent whereas equal reinforced organic FRP provides up to 411 percent increase.

4 EVALUATION OF INORGANIC POLYMER USING DURABILITY TESTS

Concrete strengthened or coated with composite were evaluated under wetting, drying, and scaling conditions. The effectiveness of a strengthening system consisting of an inorganic matrix used in conjunction with several commercially available forms of carbon was studied. The matrices were applied to high strength concrete specimens and subjected to wet-dry and scaling conditions. The effectiveness of the matrix was studied using the results of flexure tests obtained before and after exposure to wet-dry and scaling conditions. The specimens consisted of plain high-strength concrete and high strength prisms reinforced with discrete carbon fibers, carbon tows, and fabrics.

4.1 Preparation and Testing of Samples

The concrete mix and preparation of the samples are as described for the bonding tests. The dimensions of the prisms were $50 \times 50 \times 330\,mm$. Sand blasting was performed using silica quartz sand at a pressure of 550 *KPa* (80 *psi*). The set-up built to expose the samples to wetting and drying cycles consists of a $1350 \times 685 \times 152\,mm$ stainless steel basin elevated to a height of 1.2 *m*. The specimens were placed in this basin. A reservoir containing 75 liters of a 3% saline solution was installed beneath the basin. A heater and a temperature gage were attached to the saltwater reservoir to ensure that the water remained at a constant temperature of 50°C. Elevated temperature was used to accelerate the deterioration process. The salt water was transported from the reservoir to the basin containing the samples by a pump. A timing valve attached to the drain of the basin controlled the flow of the water back into the reservoir. A 450 ^{mm} fan was installed 600 *mm* above the basin to help circulate air during dry cycles.

After the test specimens were placed in the stainless steel basin, the timers were set to allow for a three-hour wet and three-hour dry cycle. At the beginning of each wet cycle, the pump filled the basin to a level that totally submerged the samples with salt water from the reservoir. After three hours, the basin's drain valve opened allowing water from the basin to drain back into the reservoir and the fan began to circulate air above the basin. At the conclusion of the three-hour dry cycle, the wet portion of the next cycle began. Visual inspection confirmed that the samples' surfaces were dried.

The set-up built to expose the samples to scaling conditions consisted of rectangular plastic dams fit atop the coated surface of the specimens. The height of the dams was 25 *mm*. The dams were attached to the coated surface of the samples with a bead of waterproof caulk. The dams were filled with three percent saline solution to a depth of 6 mm. The scaling test described in ASTM C672 was designed to allow the completion of one scaling cycle in a 24-hour period. The samples with the dams containing the saline solution were placed in a freezing chamber. They were kept at -5°C for sixteen hours. At the end of this freezing cycle, the samples were removed from the freezing chamber and kept at room conditions. After eight hours in this environment, the thaw cycle was completed and a new scaling cycle began as the samples were returned to the freezing chamber. The samples were tested in flexure using three-point bending test after 50 wet-dry and scaling cycles.

4.2 Durability Test Results and Discussions

The test samples consisted of two plain concrete samples for control, two samples strengthened with both two and four percent discrete carbon fibers, two samples strengthened with one, two, and three carbon tows, and two samples strengthened with one and two layers of carbon fabric. Two specimens were tested at 0, 50, and 100 cycles of exposure. The objective was to determine whether discrete fibers would add strength and toughness to plain concrete and whether it is possible to add continuous reinforcement to plain concrete.

Table 1 presents a summary of all pertinent information obtained from the load-displacement response of the strengthened samples exposed to wet-dry conditions. The peak load for each of the samples is included in this table. The flexural stiffness of each sample was estimated using the following equation,

$$EI = \frac{Pl^3}{48\delta} \tag{2}$$

Where *EI* is the flexural stiffness in $N{\cdot}m^2$, *P* is the peak load on the specimen in *kN*, *l* is the length of the specimen in millimeters, and δ is the deflection at peak load in millimeters. Ductility is one of the major benefits that resulted from the FRP strengthening. The area under the load displacement curve was used as a measure of ductility. The values listed in Table 1 are the average values obtained from the two samples for each reinforcement type.

Table 1. Summary of flexural test results obtained using specimens exposed to wet-dry cycles

Designation	No. of Wet/Dry Cycles	Peak Load	Flexural stiffness	Toughness
		(kN)	($N-m^2$)	(N-m)
CON00	None	2.25	3501	0.72
CON50	50	3.2	6113	0.597
CON100	100	3.58	5338	0.751
2FIB00	None	3.49	4104	0.942
2FIB50	50	3.49	3846	1.041
2FIB100	100	3.36	3444	1
4FIB00	None	3.9	5051	0.992
4FIB50	50	3.98	4506	1.088
4FIB100	100	3.95	5137	1.046
1TOW00	None	3.99	3530	2.103
1TOW50	50	3.79	6084	1.57
1TOW100	100	4.01	5137	1.598
2TOW00	None	3.26	4621	2.788
2TOW50	50	4.19	5023	3.091
2TOW100	100	3.78	4563	2.744
3TOW00	None	4.15	4449	4.175
3TOW50	50	4.55	5740	3.898
3TOW100	100	4.56	4047	4.277
1LAY00	None	4.28	5969	3.459
1LAY50	50	4.83	5252	4.505
1LAY100	100	4.11	5338	4.621
2LAY00	None	4.7	6630	4.218
2LAY50	50	3.76	3616	2.894
2LAY100	100	5.65	5884	4.714

In Table 1, CON00, CON50, and CON100 are the control samples exposed to wet-dry conditions. The load-displacement relationship was linearly elastic up to the peak load. The peak loads of the control samples increased with exposure to wet-dry conditions. After exposure to 100 cycles of wet-dry, the peak load of the control samples had increased by over 50%. Samples 2FIB and 4FIB were strengthened with two and four percent discrete carbon fibers, respectively. The load-displacement behavior was identical to the control samples exposed to wet-dry conditions. Linearly elastic behavior was observed until the point of brittle failure. The peak loads of the samples were unchanged by exposure to wet-dry conditions.

The second type of reinforcement that was studied utilized carbon tows. As seen in Table 1, the area of the carbon reinforcement could be increased by bunching the carbon tows in groups of two or three. The load-displacement relationship of these samples is shown in Figure 5. As in the control samples, behavior was linearly elastic prior to cracking of the concrete. The addition of the carbon tows, however, greatly improved the ability of the sample to sustain load after cracking. Increased carbon area provided increase in the sustained load. Additionally, load was sustained through a greater displacement as the number of carbon tows was increased. In each case, the peak load of the samples exposed to 100 cycles of wet-dry was greater than the unexposed samples. Comparable values were observed in the toughness of the exposed and unexposed samples.

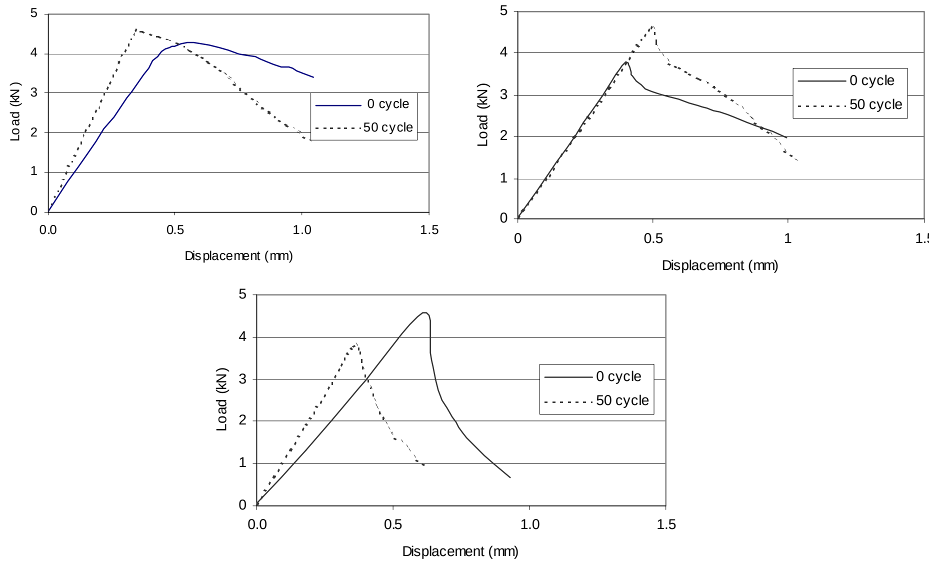

Figure 5. Comparison of load-deflection response of inorganic FRP reinforced with 1, 2, and 3 carbon tows before and after wet-dry cycles

Samples were also strengthened with unidirectional carbon sheets and exposed to wet-dry conditions. Either a single or a double layer of carbon was bonded to the tension face of the samples before exposure to wet-dry conditions. The load-displacement behavior was identical to the behavior of samples strengthened with carbon tows. Comparable peak load values and increases in toughness were observed after wet-dry exposure.

Table 2. Summary of flexural test results obtained using specimens exposed to scaling

Designation	No. of Scaling Cycles	Peak Load (kN)	Flexural stiffness ($N\text{-}m^2$)	Toughness (N-m)
CON00	None	2.25	3501.4	0.72
CON50	50	3.44	6055.7	0.63
2FIB00	None	3.49	4104.1	0.94
2FIB50	50	3.75	6514.9	0.77
4FIB00	None	3.9	5022.5	0.99
4FIB50	50	4.11	6687.1	0.85
1TOW00	None	3.99	3271.8	2.11
1TOW50	50	3.77	5166	1.51
2TOW00	None	3.47	4592	2.79
2TOW50	50	3.77	2123.8	4.3
3TOW00	None	4.15	3415.3	4.18
3TOW50	50	4.48	6687.1	3.62
1LAY00	None	4.28	5051.2	3.46
1LAY50	50	4.19	5137.3	3.04
2LAY00	None	4.7	5166	4.22
2LAY50	50	4.58	3788.4	3.66

The samples exposed to scaling conditions were strengthened with the same amount of fibers as those exposed to the wet-dry cycles. Peak load, flexural stiffness, and toughness were used to evaluate samples after 50 cycles of scaling. The results obtained from the flexural testing of the samples are shown in Table 2.

In samples strengthened with two and four percent discrete carbon fiber, the load-displacement relationship was linearly elastic until the peak load for both unexposed samples and samples exposed to scaling. The strength increases were less than ten percent when two or four percent carbon was used. An insignificant drop in the toughness was observed for each of the samples after exposure to scaling conditions. The flexural stiffness increased by at least 50 percent after scaling cycles. As in the wet-dry experiment, carbon tows were used to strengthen the samples. The tows were externally bonded to the tension face of the samples with the inorganic matrix. The load-displacement relationship of these samples before and after scaling exposure is shown in Figure 6.

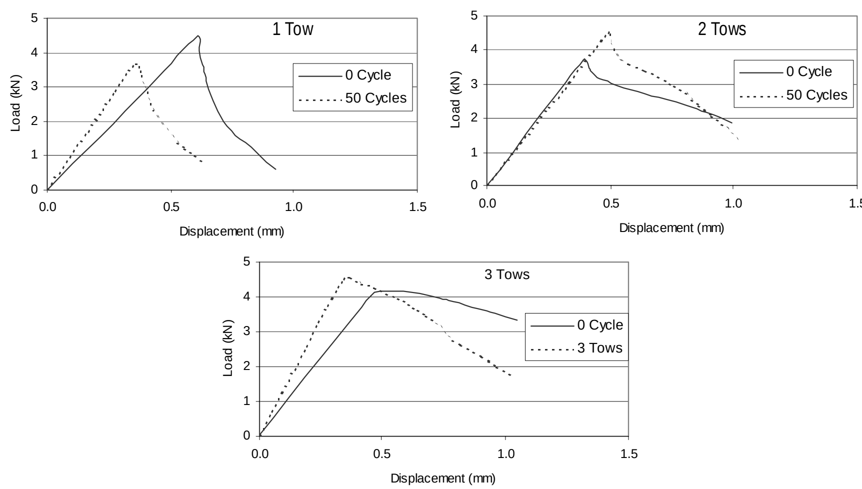

Figure 6. Comparison of load-deflection response of inorganic FRP reinforced with 1, 2 and 3 carbon tows subjected to scaling exposure

The response was linearly elastic prior to cracking of the concrete. The ability of the samples to sustain load after cracking, however, was greatly improved by the carbon tows. As the area of the carbon was increased, a larger percentage of the cracking load was sustained by the sample. Exposure to scaling conditions had minimal effect on the strength capacity of these samples. When a single tow was used, weakening occurred but samples with two or three tows had higher strength after exposure. In each case, the variation was less than ten percent. An inverse relationship was noted between the toughness and flexural stiffness of the samples. When an increase in toughness was observed, the flexural stiffness of the sample decreased.

The next set of samples was strengthened using unidirectional carbon sheets. Either a single or a double layer of the carbon was bonded to the tension face of the specimens. The behavior was identical to that of the samples strengthened with carbon tows. Insignificant changes in the flexural strength of the samples were found after exposure to the scaling cycles. Exposed samples maintained at least 97 percent of their flexural strength. Any changes in the toughness or flexural stiffness of the samples are consistent with the slight decrease in failure load and do not indicate significant weakening of the samples.

5 DURABILITY AND DETERIORATION CONSIDERATIONS

Much of the deterioration of concern is due to environmental effects and/or exposure to loads, speeds and other operating conditions that are not fully anticipated in the original design. There are many forms of deterioration to consider, such as fatigue, overload, ultraviolet damage for composites, corrosion, and wear. The loss due to corrosion alone amounts to $100 billions per year in the U. S. Materials of interest include the full spectrum of construction materials, metals, ceramics, polymers, composites, and coatings. Application areas include, but are not limited to, units of the constructed infrastructure such as machines, structures (above and below ground), transportation systems and units, and manufacturing machinery. Some possible research topics could be,

- Multiple interactive effects and deterioration mechanisms
- Accelerated techniques, related instrumentation and model validation to long-term field data
- Determination of service life from wear tests and modeling
- Deterioration of structural materials and protective coatings (e.g. polymeric coatings on bridges) as a function of environment
- Failure mechanisms of composite materials
- Corrosion protection systems
- Size effects in testing, instrumentation and modeling
- Relevant statistical methods and reliability
- Comparison of models with long term field data

Figure 7 is a very unique Integrating Sphere, 2 *m* in diameter with multiple channels [exit ports] of uniform ultra-violet [UV] exposure for polymeric materials, including coatings, textiles, vinyl siding, bulk plastics, asphalt, roofing membranes/shingles, sealants, geo-textiles, and fiber-reinforced composites. In addition to UV exposure, load application, moisture, temperature, and possibly salt in the future, can be applied to simulate environmental conditions under accelerated conditions.

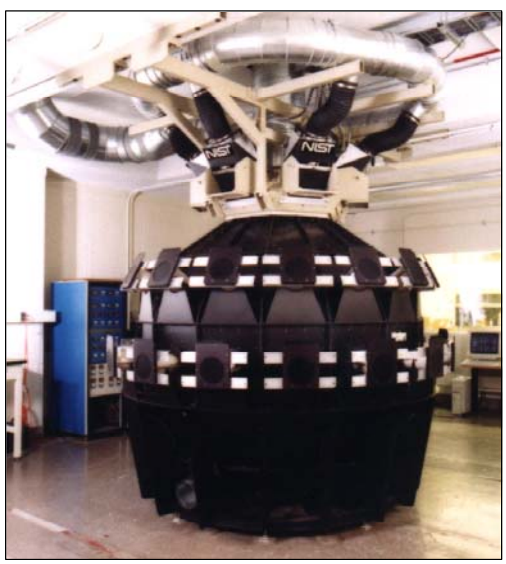

Figure 7. Photodegradation apparatus [Courtesy of J. Chin, NIST]

5.1 The Chong Cycle

Chong [Ref. 12] of the Federal Highway Administration created a variation of ASTM D5894 and added a low temperature cycle for testing the durability of bridge coatings; this test was called as "The Chong Cycle" by Aragon and Frizzi [13]. This 500-hour (h) cycle alternates 70-h cold at -23°C with 215-h UV/condensation (4-h UVA lamp at 60°C followed by 4-h condensation at 40°C) and 215-h alternating 1-h salt fog at 35°C and 1-h drying at ambient temperature (Figure 8).

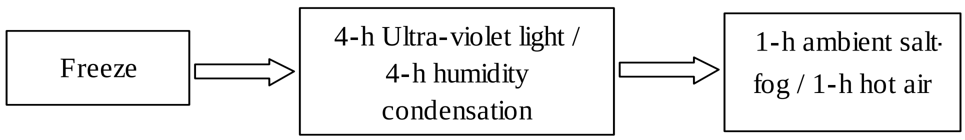

Figure 8. The Chong cycle

The total duration of the typical test is 3,000 hours. The results obtained with the Chong cycle have been compared to those obtained from salt-fog test (ASTM B117) and to a natural marine exposure of 28 months. Twelve coating systems, including waterborne system, were tested and this cycle produced a very good representation of natural weathering (Table 3). Chong justifies the importance of exposure to low temperature with the idea that volume of cold water absorbed by the coating leads to a mechanical stress representative of certain natural stress. Due to the importance of low temperature stress, a new cycle is being developed for the Method ISO/ (WD.9) 20340. A freezing phase at -20°C for 24 hours is replacing the dry cycle in the original method.

Table 3. The correlation coefficient for developed scribe creepage between laboratory tests and 28-month salt-accelerated outdoor exposure

	ASTM B117	Modified ASTM D5894[1]	The Chong Cycle
12 Coating systems[2]	-	0.67	0.87
8 coating Systems[3]	0.3	0.81	0.89

[1]The Chong Cycle minus freeze phase.
[2]Tests were performed for 3,000 hours.
[3]Tests were performed for 2,000 hours.

5.2 Semi-circular fracture specimens

The semi-circular bend (SCB) specimen was proposed by Chong [14] to investigate brittle fracture. The core-based SCB test specimen shown in Figure 9 along with other ISRM standard specimens, has certain inherent favorable properties such as simplicity, minimal requirement of machining and the convenience of three-point loading that can be easily accomplished with a standard load frame. After the beam is broken, the remaining specimen can be used as SCB specimens to determine the fracture toughness of layered (transversely isotropic) materials using a single core, yielding fracture toughness in all three orientations.

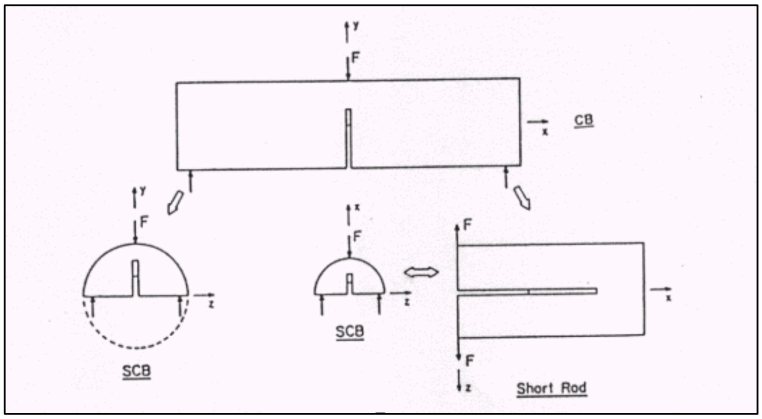

Figure 9. Core-based fracture toughness test specimens

6 CONCLUSIONS

Based on the experimental and analytical results presented in this paper and observations made during the testing, the following conclusions can be drawn:

- Both inorganic and organic matrices can be effectively used for strengthening unreinforced concrete. The organic matrix provides higher deformations at failure. The inorganic matrix is fire and UV resistant.
- The load transfer mechanisms are different for inorganic and organic matrices: The inorganic matrix composite develops micro cracks and failure occurs by fracture of the carbon. The load transfer from fiber to fiber within the composite plate is not very efficient, especially when fiber areas are large. The organic matrix plates fail by delamination.
- For both organic and inorganic matrices, the average fiber strain at failure reduces with an increase in fiber area.
- When carbon composites are used to strengthen unreinforced systems, load redistribution through a crack plays a major role in the failure mechanism. This aspect should be considered in repair design.
- Both the matrix and the interface are durable under wetting and drying and scaling conditions. There is no decrease in the maximum load capacity after 100 cycles of wetting and drying or 50 cycles of scaling
- There is an insignificant decrease in toughness (area under the load-deflection curve) after scaling exposure.
- Fundamental research in deterioration and durability of structures and materials have shown great potential for enhancing the functionality, serviceability and increased life span of our civil infrastructure systems.

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