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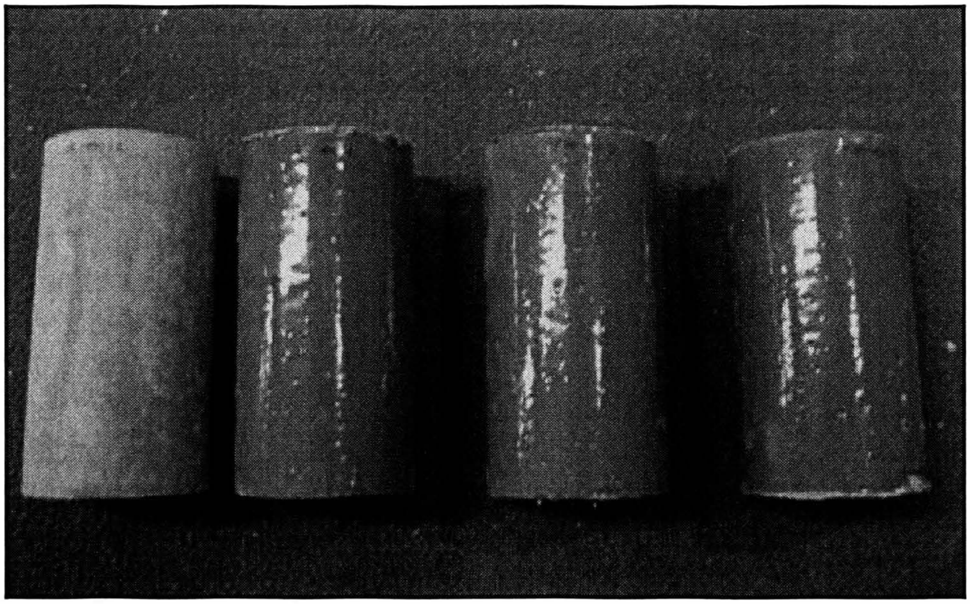
Durability Performance of Polyurea Confined Concrete Cylinders

By: Matthew Beyer
Undergraduate Architectural Engineering Student
at the University of Missouri—Rolla



Advisor: Dr. John J. Myers, P.E.

Department: Civil, Architectural, & Environmental Engineering

Date: May 26th, 2007

Matthew Beyer

Department:	Civil, Architectural, and Environmental Engineering
Major:	Architectural Engineering
Faculty Advisor:	Dr. John J. Myers
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Durability Performance of Polyurea Confined Concrete Cylinders

Over the past decade, polyurea based systems have been researched as a means to retrofit columns and other structural components for increased ductility. During extreme dynamic events such as a seismic or blast event, ductility in these structural components could help minimize damage to the structure and save lives. Including the polyurea is being looked at as a potential alternative to steel jacketing in column repairs. However, little is known about the long-term durability of polyurea systems exposed to environmental conditioning. The following study was designed as preliminary look at the effects of freeze/thaw and deicing on polyurea confined concrete. The study compares the compressive strength and ductility of a sprayed on polyurea system to concrete cylinders subjected to 2-weeks and 4-weeks of environmental conditioning to controlled specimens with and without polyurea confinement in laboratory conditions.

Matthew Beyer is a senior in the Architectural Engineering Program at the University of Missouri-Rolla (UMR). Currently, he is active in Chi Epsilon and the Baptist Student Union at UMR.

INTRODUCTION

With the advent of polymers, researchers have aggressively studied how fiber reinforced polymers (FRP) can replace conventional construction materials or methods. The use of FRP jacketing systems is just one of many applications researchers have studied. In fact, several physically and analytically studies have already been conducted to understand and provide information on the benefits of FRP (Mirmiran[1] et al., 1997 and Pessiki[2] et al., 2001). One application researchers are considering is the revitalization of deteriorating reinforced concrete (RC) members with FRP. Additionally, seismic and explosive blasts have become a major concern, which FRP systems may be able to mitigate. Studies (Carney[3] et al., in 2005, Myers[4] et al., in 2004, Muszynski[5] et al., in 2003 and Porter[6] et al., 2002) have proven how FRP can be used to strengthen walls to improve the ductility of the walls during blasts. In Muszynski's research, a control wall and a wall with an FRP backing was subjected to a blast. The FRP backed masonry wall was successful in holding up to the blast whereas the control wall failed. Muszynski's research is just one of the many research experiments showing the value of FRP material for improved performance. Presently, steel jacketing systems are the major choice for designers when it comes to reinforcing concrete members. FRP jacketing systems are being considered for replacement of steel jacketing systems for several reasons.

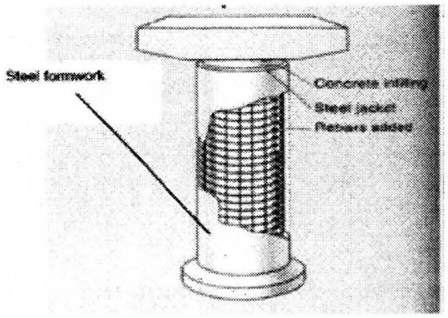


Figure 1: Steel Jacketing System
Graphic Courtesy of Dr. John Myers [8]

Steel is an isotropic material, which diminishes its full potential. A multi-directional material like steel has some fibers running opposite to the load; these fibers are wasted. FPR material can be designed to be uni-direction, which places the full material in the direction of the load. Another concern with steel is its corrosiveness over long-term duration, which FRP materials do not experience. In reference to the methods of construction, FRP systems have several advantages over steel jacketing systems: less labor hours to construct, less skilled labor is needed, and the FRP is a lighter material to transport (Mirmiran[1] et al. 1997). FRP jacketing systems include wrapped, wet lay-up, and epoxy sprayed.

Over the past few decades, polyurea has been heavily researched as a means to retrofit columns and other structural elements for increased ductility in the system. By retrofitting columns, polyurea usage could be essential in saving lives by preventing progressive collapse and reducing structural damage during seismic and blast events. However, little is known about the long-term durability of polyurea in environmental conditions. The following study was designed as preliminary look at the effects of freeze/thaw and deicing on polyurea confined concrete. The study compares the compressive strength and ductility of polyurea sprayed concrete cylinders subjected to 2-week and 4-week environmental conditioning against controlled specimens with and without polyurea confinement in laboratory conditions. The study includes varying concrete design mixes to represent varying concrete types to investigate their effect on the conditioning of the FRP jacketing system. The concrete design mixes that were chosen for this study are: High Strength Lightweight Concrete (LWC), High Strength/High Performance Concrete (HSC), and Normal Weight Concrete (NWC).

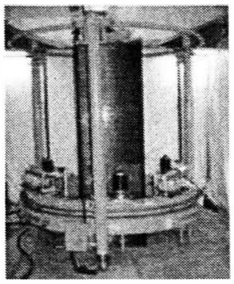


Figure 2: Wrapped FRP Processed
Photo Courtesy of Dr. John Myers [8]

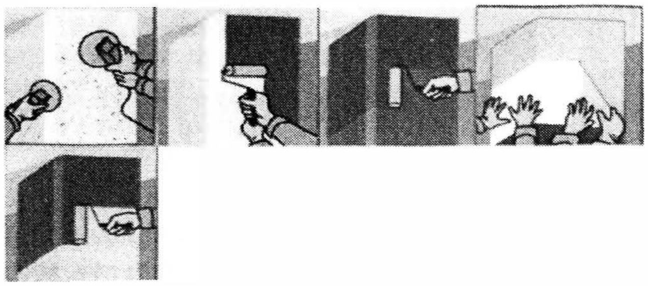
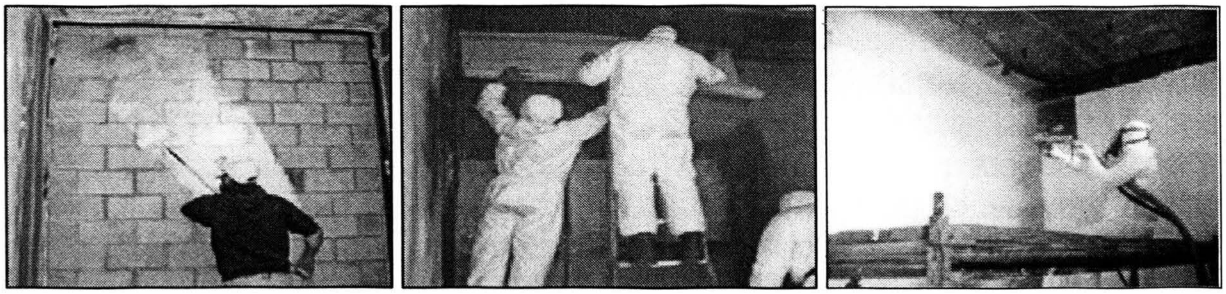


Figure 3: Wet Lay-up FRP Process
Graphic Courtesy of Dr. John Myers [8]



(a) (b) (c)

Figure 4: Sprayed Poly-urea [8]
(a) Priming, (b) Backing (optional process, which increases strength), (c) Epoxy Spraying

EXPERIMENTAL PROGRAM

The experimental program consists of conditioning polyurea jacketed concrete cylinders through freeze-thaw and deicing attacks followed by axial compressive testing to investigate the durability of the conditioned FRP jacketing system based on the compressive strength at failure and the load-deformation response of the specimens. Further, the investigation includes variables of design mix and duration of conditioning. The unconditioned cylinders with and without the jacketing system were tested to evaluate the effectiveness of the jacketing system.

Materials

Three design mixes were evaluated: High Strength Lightweight Concrete (LWC), High Strength/High Performance Concrete (HSC), and Normal Strength Concrete (NSC) with specific densities of 120.54 lb/ft^3 (1,931 kg/m^3), 156.14 lb/ft^3 (2,501 kg/m^3), and 149 lb/ft^3 (2,398 kg/m^3), respectively. The dimensions of the concrete cylinders were 4 in. (10.2 mm) in diameter and 8 in. (20.4 mm) in height. The NSC and the HSC concrete was batched a week before the LWC concrete. During the extra week, NSC and HSC concrete were placed in a moist cure room. LWC concrete did not undergo any moist curing.

Each mix is composed of sixteen specimens, which were divided into four categories: Concrete Control (un-jacketed and unconditioned), Polyurea Jacketed Concrete Control (jacketed and unconditioned), Polyurea Jacketed Concrete (2-week conditioning), and Polyurea Jacketed Concrete (4-week conditioning). Hereon the conditioning will be abbreviated as shown in Table 1. Control specimens were kept at room temperature in laboratory conditions.

Table 1: Program Matrix

Type of Mix Design	Conditioning	Specimen ID Condition–Mix Design–Specimen #	# of Specimens
Conventional Concrete	Control (C)	C–NSC–1 through 4	4
	Control with Poly-urea confinement (PC)	PC–NSC–1 through 4	4
	Poly-urea confinement 2-week Freeze/Thaw Cycle (PSD)	PSD–NSC–1 through 4	4
	Poly-urea confinement 4-week Freeze/Thaw Cycle (PLD)	PLD–NSC–1 through 4	4
High Strength/ High Performance Concrete	Control (C)	C–HSC–1 through 4	4
	Control with Poly-urea Confinement (PC)	PC–HSC–1 through 4	4
	Poly-urea confinement 2-week Freeze/Thaw Cycle (PSD)	PSD–HSC–1 through 4	4
	Poly-urea confinement 4-week Freeze/Thaw Cycle (PLD)	PLD–HSC–1 through 4	4
High Strength Lightweight Concrete	Control (C)	C–LWC–1 through 4	4
	Control with Poly-urea Confinement (PC)	PC–LWC–1 through 4	4
	Poly-urea confinement 2-week Freeze/Thaw Cycle (PSD)	PSD–LWC–1 through 4	4
	Poly-urea confinement 4-week Freeze/Thaw Cycle (PLD)	PLD–LWC–1 through 4	4

The specimens with the jacketing system received a 1/16 in. (1.6 mm) coat of an epoxy-based polyurea. The mechanical property testing of the polyurea was performed by Trevor Hrynyk, a graduate research assistant (GRA) student at the University of Missouri-Rolla. Uni-axial tension testing was preformed on four coupons of polyurea having a gage length of 5 in. (12.7 mm). From these coupons, the stress-strain relationships were determined and are summarized in Table 2.

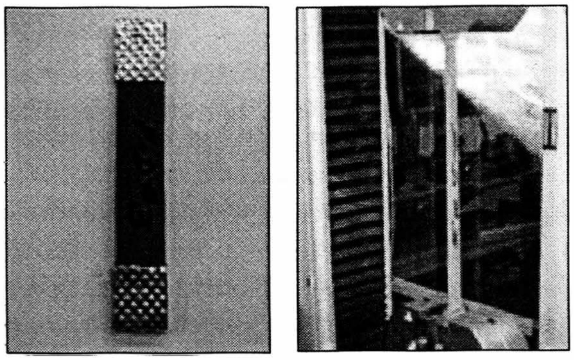


Figure 5: Poly-urea Testing Coupons
Photos Courtesy of Trevor Hrynyk [9]

Table 2 : Polyurea Average Property Values

Stress at Full Yield ksi (MPa)	Modulus of Elasticity ksi (GPa)	Strain at Full Yield	Ultimate Stress ksi (MPa)
0.58 (4.00)	12.1 (0.083)	0.145	> 1.0 (6.89)

Data Courtesy of Trevor Hrynyk [9]

Exposure Programs

The conditioned specimens were subjected to environmental conditions of freeze-thaw cycles and deicing to age-harden the polyurea. These specimens were chosen to either undergo two or four weeks of environmental conditioning as illustrated in Figure 6.

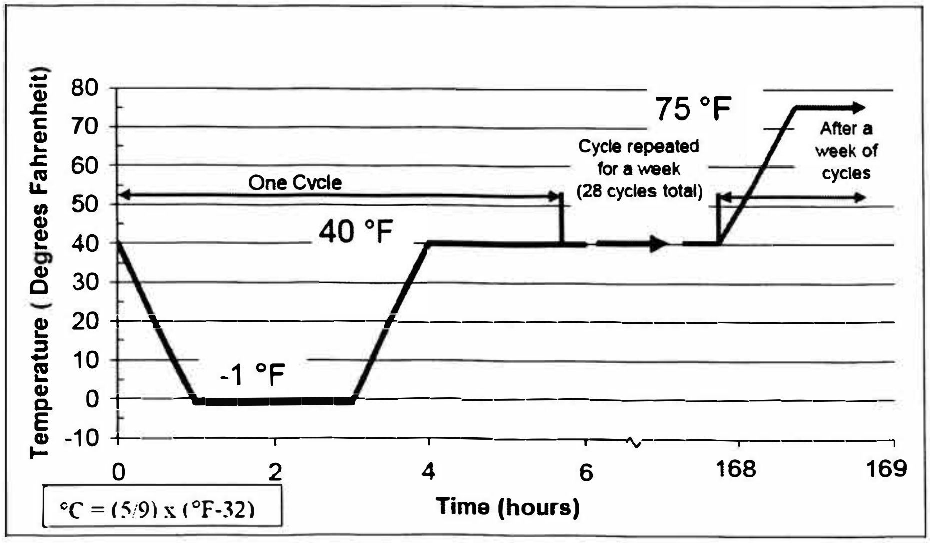


Figure 6: Freeze-Thaw Cycle

Each week the specimens were exposed to several cycles of increasing and decreasing temperature. The maximum temperature reached was 40 °F (4 °C) whereas the minimum temperature of -1 °F (-18 °C) was experienced. At peak temperatures, for both maximum and minimum the chamber was stabilized at those temperatures for a period to ensure the concrete from surface to center reached these values (See Figure 6).

The second environmental mechanism subjected to the conditioned specimens was deicing. A salt solution of ordinary table salt, 7.5% by weight, was sprayed on the specimens three times a week to saturate the surface of the cylinders. The saline solution simulates the effects of deicing on bridges or marine environments. During the freeze-thaw cycles, the salt solution may affect the strength of the concrete as well as the bond between the concrete and polyurea wrap.

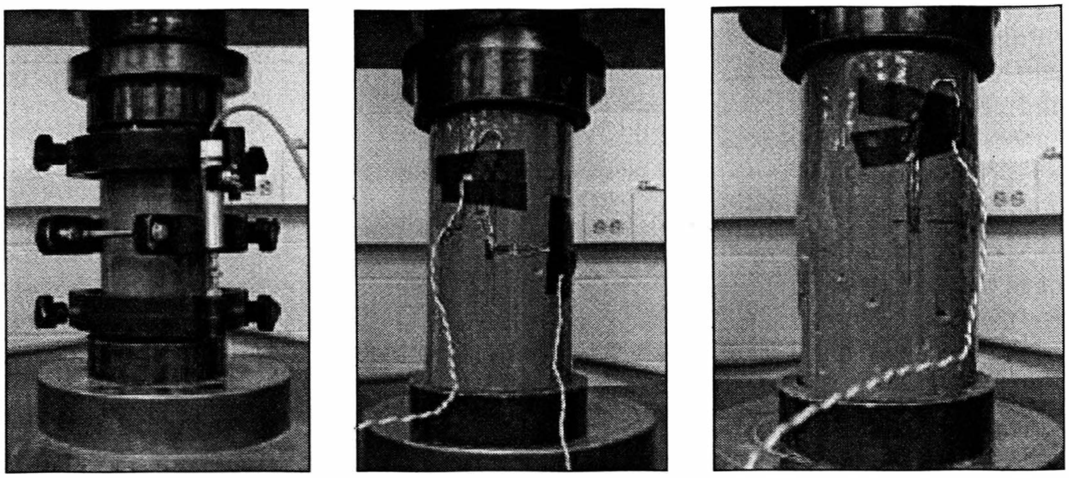
Experimental Test Set-up

Twelve conditions with four specimens representing each condition were constructed (Refer to Table 1). For each condition, the first specimen was axial compressed to failure. Using the data from that first test, 50% of the ultimate compressive strength was calculated. The remaining three specimens were cycled up to 50% of the ultimate compressive strength then back down to zero. Two cycles were preformed with the second cycle being recorded by a compressometer. The compressometer was mounted on these cylinders to measure the axial strain and calculate the modulus of elasticity. The specimens were loaded for a third time and loaded to failure. Due to the frailty of compressometer, the device was taken off during the third loading. Instead, strain gages were used to record the necessary stress-strain values. Two of the three specimens received strain gages. One specimen received a strain gage in axial direction. The second specimen received a strain gage in the axial and the hoop direction on the cylinder. Refer to Table 3 for further information on loading. Placement of strain gages and compressometer are illustrated in Figure 7. The loading rate for all tests was 450 lb/sec (204 kg/sec).

Table 3 : Loading Information for Each Condition

Specimen in each Condition	Type of Loadings	C	A	H
#1	1st Loading- Taken to failure (Max. strength recorded)			
#2	1st Loading- Taken to 50% Max.	X		
	2nd Loading-Taken to 50% Max.	X		
	3rd Loading- Taken to Failure			
#3	1st Loading- Taken to 50% Max.	X	X	
	2nd Loading-Taken to 50% Max.	X	X	
	3rd Loading- Taken to Failure		X	
#4	1st Loading- Taken to 50% Max.	X	X	X
	2nd Loading-Taken to 50% Max.	X	X	X
	3rd Loading- Taken to Failure		X	X

Note: C- Compressometer, A- Axial Strain Gage, and H- Hoop Strain Gage. "X" states which sensors where use for each loading.



(a) (b) (c)

Figure 7: Testing Set-up

(a) Compressometer, (b) Axial and Hoop Strain Gage, (c) Axial Strain Gage

DISCUSSION OF EXPERIMENTAL RESULTS

Modulus of Elasticity

As shown in Table 4, the polyurea wrap actually increases the modulus of elasticity by 2.8% for the NSC. The modulus of elasticity (MOE) for LWC and HSC increased 13.2% and 13.9%, respectively, with the inclusion of the wrap (see Tables 5 and 6). In comparison, the polyurea wrap proves to increase the modulus of elasticity in greater magnitude for higher strength concretes. Interestingly, the preconceived thought was the wrap would not significantly affect the MOE irrespective of concrete type, but rather primarily only increase the ductility of the system. As reported earlier in Table 2, the polyurea material has a tested modulus of elasticity of 12.1 ksi, which is lower than the modulus of elasticity for any of the concrete types used in the experiment. If the polyurea worked as a composite with the concrete, the polyurea wrap would not contribute to the specimen's modulus in any significant fashion. Instead, the wrap created a stiffer specimen by confining concrete and lowering the strain values during compressive testing. To understand why it didn't act as first thought we have to understand polyurea is a plastic material. In some respect the polyurea is like steel, except comparably weaker. Like steel the polyurea has a yield point where the polyurea transforms from a material that has the ability to take on load with little deflection to a material that becomes plastic. During testing, much of the axial force was taken on by the concrete with little deflection in the specimen. Since the concrete didn't deform significantly, the polyurea was not engaged as a composite system. This is the belief why the polyurea only acted to reinforce or make the specimen stiffer. If greater deflections existed the polyurea would have been asked to perform in a plastic nature, as it did when the concrete failed and displaced under the crushing (Refer to Figure 18).

Table 4: Modulus of Elasticity for NSC

Elastic Modulus- Normal Strength Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	8621591	8777709	8398225	5289579
2	8243478	8408523	8726506	8441696
3	8405172	8801258	8623385	8495964
4	---	---	---	---
Max	8621591	8801258	8726506	8495964
Min	8243478	8408523	8398225	5289579
Average	8423414	8662497	8582705	7409080
St. Dev	189715	220263	167879	1835742
Variation	44.40	39.33	51.12	4.04

Table 5: Modulus of Elasticity for LWC

Elastic Modulus- Lightweight/High Strength Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	4383829	5151342	5226021	4818519
2	4839063	5430924	4742651	5203220
3	4669057	5590769	5167302	4604643
4	4723191	4902059	---	4883125
Max	4839063	5590769	5226021	5203220
Min	4383829	4902059	4742651	4604643
Average	4653785	5268774	5045325	4877377
St. Dev	193438	304546	263762	247693
Variation	24.06	17.30	19.13	19.69

Table 6: Modulus of Elasticity for HSC

Elastic Modulus- High Strength/High Performance Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	9765844.4	11521337	10427409	10957753
2	18531868	20964706	9726577.4	10772889
3	10470638	11664339	11356563	10866514
4	---	---	---	---
Max	18531868	20964706	11356563	10957753
Min	9765844	11521337	9726577	10772889
Average	12922784	14716794	10503517	10865718
St. Dev	4870375	5411323	817654	92435
Variation	2.65	2.72	12.85	117.55

Figures 8-10 illustrate the MOE for each concrete type and conditioning. In general prolonged conditioning appeared to reduce the MOE of the concrete. Four weeks of conditioning appeared to be more detrimental than two weeks of conditioning although it must be stated that the variance on testing was high in many grouping and more testing is warranted to confirm this behavior.

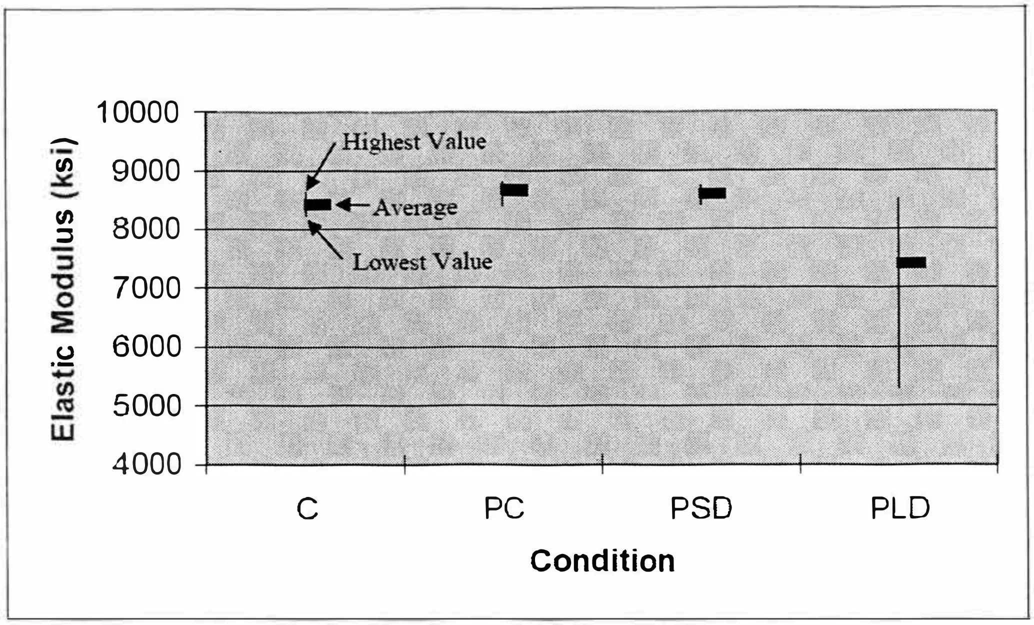


Figure 8: Modulus of Elasticity for NSC

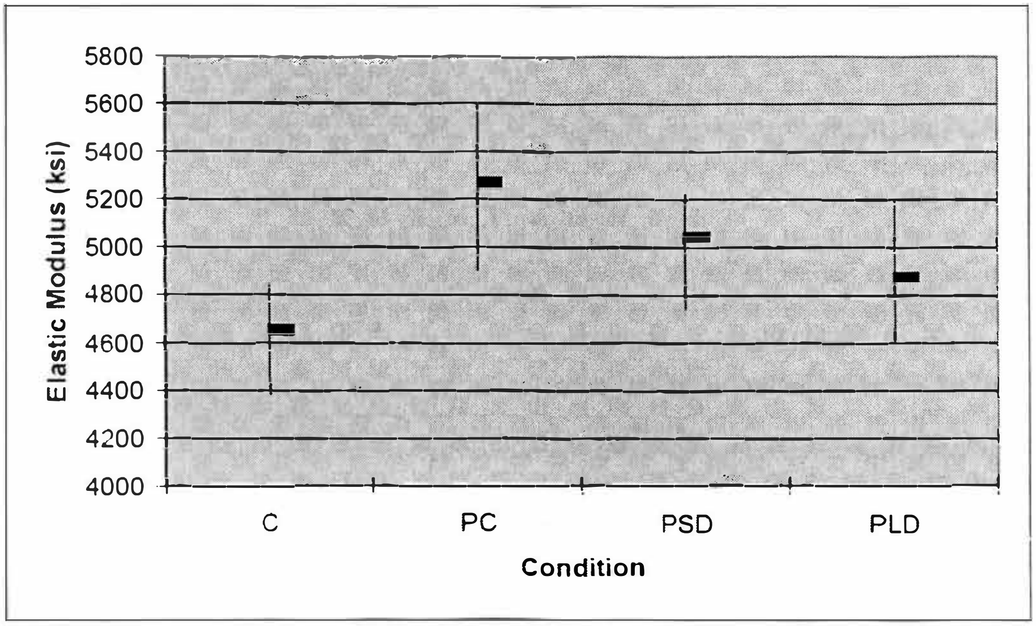


Figure 9: Modulus of Elasticity for LWC

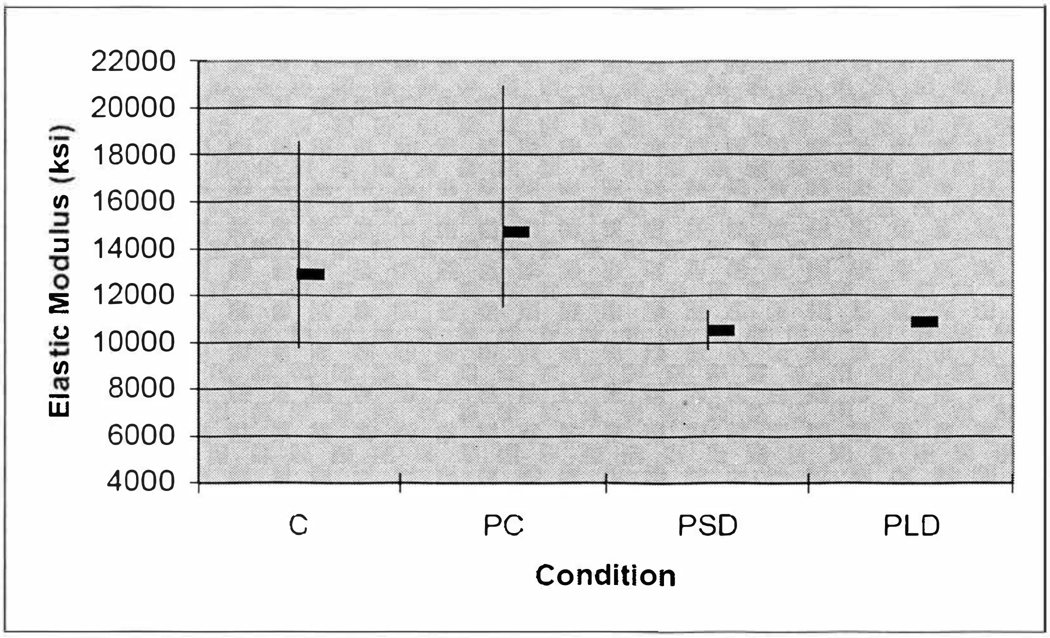


Figure 10: Modulus of Elasticity for HSC

Axial Compressive Strength

The inclusion of the polyurea wrap on the concrete cylinder did not improve the axial compressive strength as illustrated in Tables 7 through 9. In fact, a slight decrease of strength was incurred with the utilization of the wrap. This loss of strength was within the normal variance for concrete, which commonly fluctuates in strength from one test to another. Another possibility for the loss could be accounted by the polyurea's affinity for moisture. Normally, a primer is applied to the application area to restrict the polyurea from absorbing moisture out of the material. In the experimental study, the concrete cylinders were not primed to serve as a worst cases scenario. The cylinders were sprayed with the polyurea before the 28-day period. Though unlikely, the polyurea may have affected the curing of the concrete, which led to lower strength values. More work to examine the interaction of concrete curing and polyurea jacket is warranted.

Table 7: Axial Compressive Strength for NSC

Normal Strength Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	8552	8383	8299	6369
2	8260	8602	8538	7175
3	8515	8327	8234	5939
4	8544	8148	8255	6122
Max	8552	8602	8538	7175
Min	8260	8148	8234	5939
Average f_{ult}	8468	8365	8332	6401
St. Dev.	139.41	187.11	140.31	545.09
Variation	60.74	44.71	59.38	11.74

Table 8: Axial Compressive Strength for LWC

Lightweight/High Strength Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	9732	8129	9426	8511
2	9926	8876	8826	8104
3	9402	9069	8896	7134
4	8579	9011	9467	8498
Max	9926	9069	9467	8511
Min	8579	8129	8826	7134
Average f_{ult}	9410	8771	9154	8062
St. Dev	594.58	435.73	339.66	646.70
Variation	15.83	20.13	26.95	12.47

Table 9: Axial Compressive Strength for HSC

High Strength/High Performance Concrete (psi)				
Specimen	C	PC	PSD	PLD
1	14044	13597	13664	13763
2	14103	14089	14015	13692
3	13808	13566	13991	13982
4	13752	13695	13564	13897
Max	14103	14089	14015	13982
Min	13752	13566	13564	13692
Average f_{ult}	13927	13737	13809	13834
St. Dev	172.68	241.18	228.48	130.48
Variation	80.65	56.96	60.44	106.02

In the long-term conditioned specimens (PLD), a significant loss in strength is shown in Figure 11 and Figure 12. This is due to either the concrete or the polyurea breaking down. Before testing the NSC cylinders with PLD conditioning, it was observed the concrete inside the polyurea started crumbling due to long-term freeze-thaw exposure. Based on that observation, the concrete was concluded as the potential weak link rather than the jacketing material. In support, the compressive strengths found in Figure 13 vary minutely between each condition.

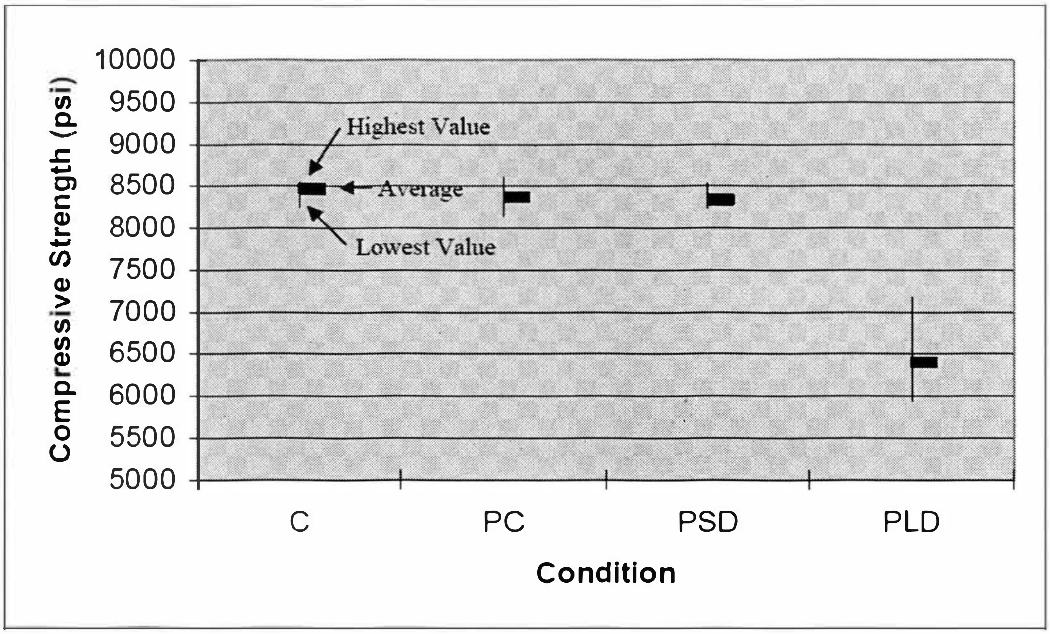


Figure 11: Axial Compressive Strength for NSC

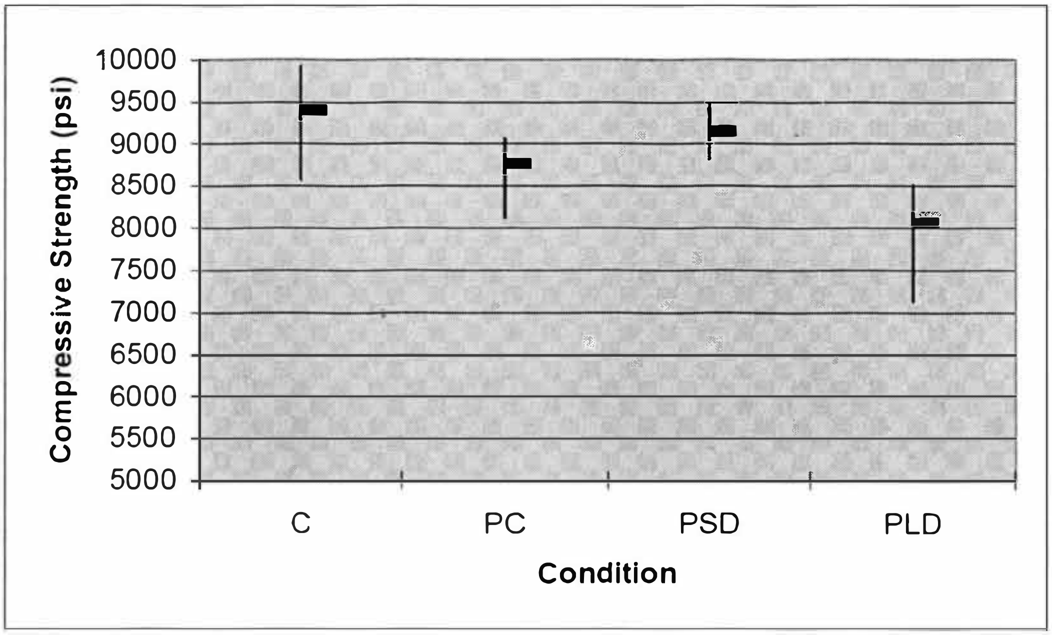


Figure 12: Axial Compressive Strength for LWC

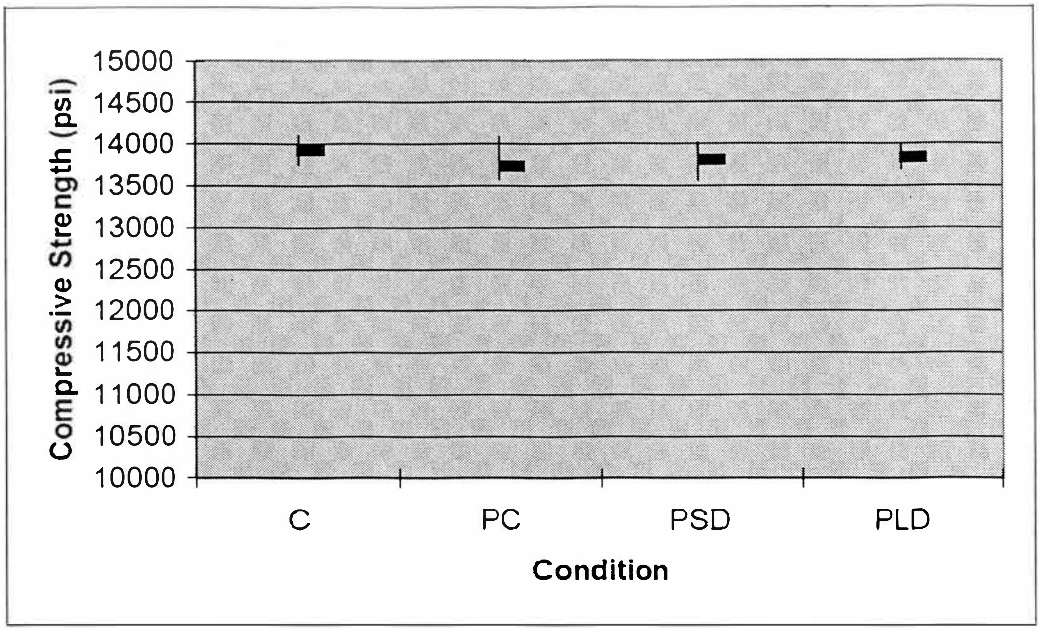


Figure 13: Axial Compressive Strength for HSC

Hoop Strain

A strain gage parallel to the circumference was placed on one cylinder for PC, PSD, and PLD conditions for each mix design. In Figures 14, 15, & 16, the ductility in the hoop direction decreases a little with duration under environmental exposure. In Figure 14, a significant loss in hoop ductility for the PLD condition is due to the poor freeze-thaw resistance of the NSC mix.

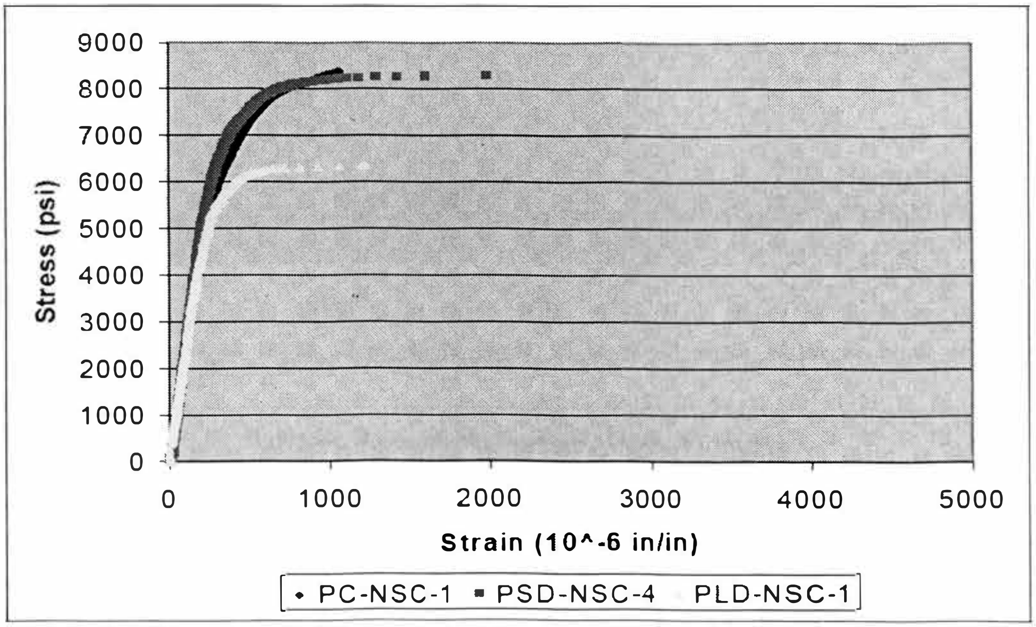


Figure 14: Compressive Strength vs. Hoop Strain for NSC

For the high strength mixtures (see Figs. 15 and 16), it would be expected for the concrete to exhibit excellent freeze-thaw resistance due to the disconnected capillary structure with the concrete pore structure and this is exhibited in their behavior. Since only one specimen per grouping had a strain gauge in the hoop direction, it is believed that specimen PSD-LWC shown in Figure 15 was likely a non-representative test result.

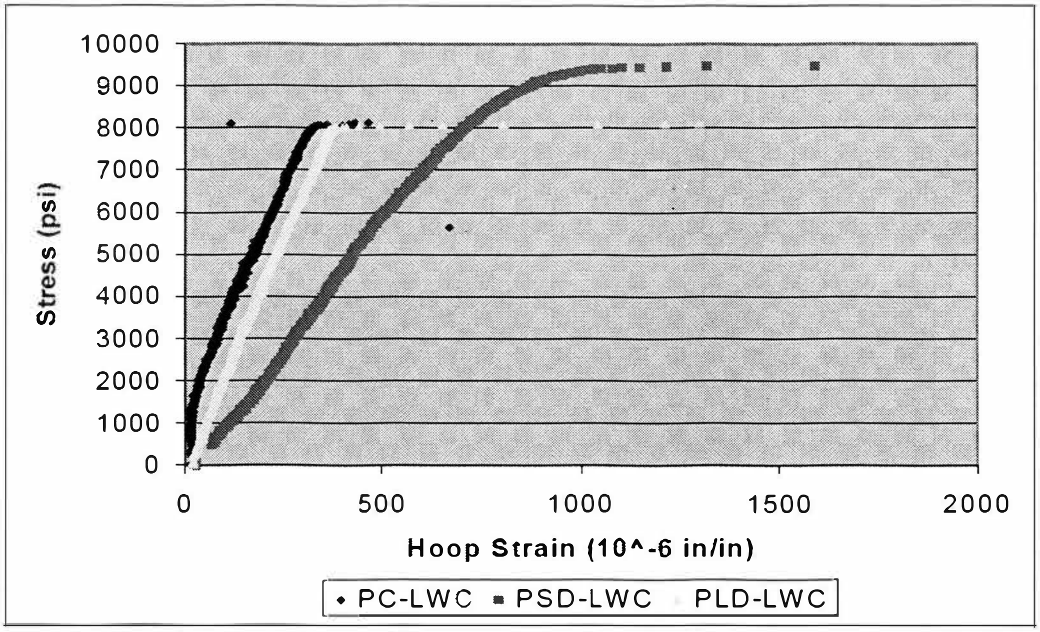


Figure 15: Compressive Strength vs. Hoop Strain for LWC

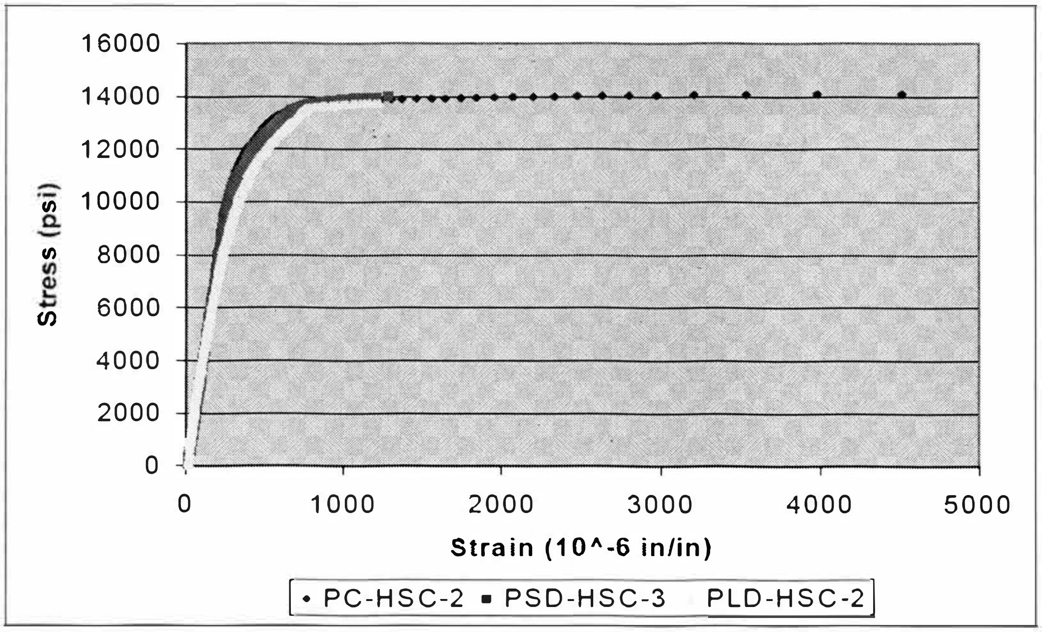


Figure 16: Compressive Strength vs. Hoop Strain for HSC

Bond

The polyurea wrap was cut down the length of a representative cylinder, removed for core concrete and laid out. The polyurea wrap proved to have good bond adherence to the concrete, even after testing as represented in Figure 17. The bond of the polyurea wrap appeared unaffected by the environmental conditioning.

Upon failure the wrap would instantaneously stretch to contain the fragmented concrete inside (See Figure 18). The wraps ability to hold in or contain the concrete fragments/debris when it fails in a very brittle fashion under high compressive stress exhibits the positive attributes that the wrap can contain the debris and fragmentation under high sudden stress levels. However, the polyurea wrap at times would fracture with the HSC mix (see Figure 19). This only occurred with the HSC, due to the more violent failures that HSC specimens experienced. The amount of cases the polyurea fractured was evenly distributed among all conditions: PC, PSD, and PLD.

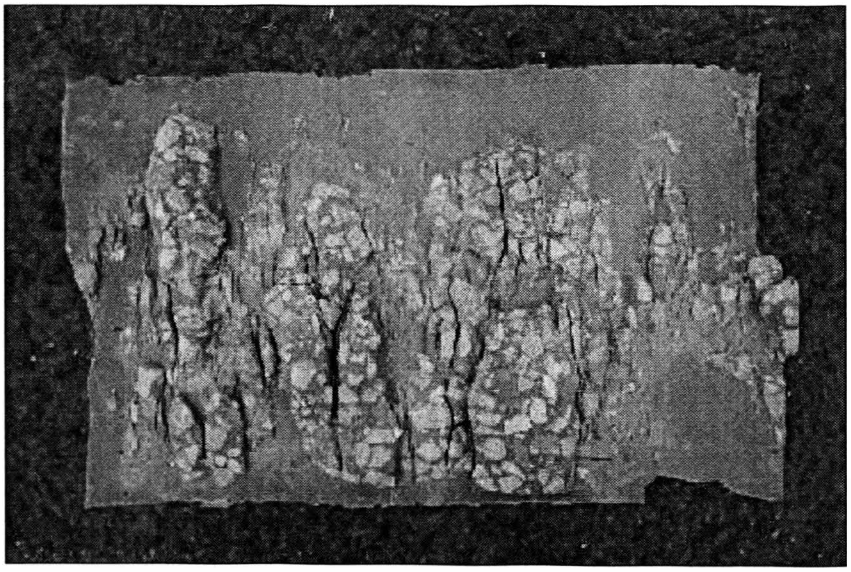


Figure 17: Polyurea Bond to Concrete After Failure

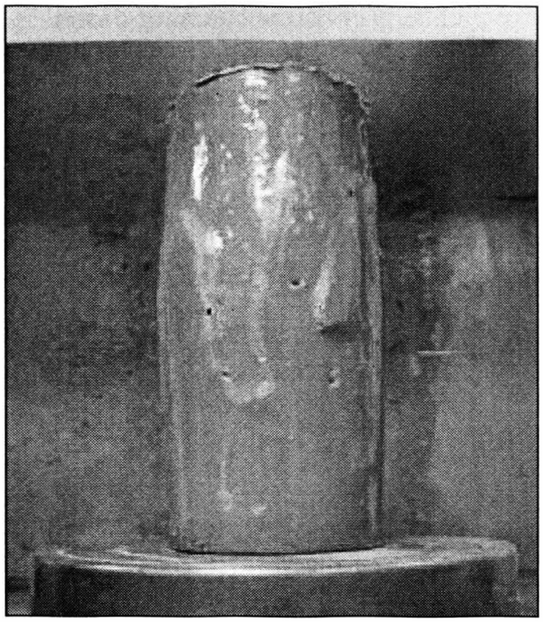


Figure 18: Ductility of Poly-urea Wrap Confining Concrete

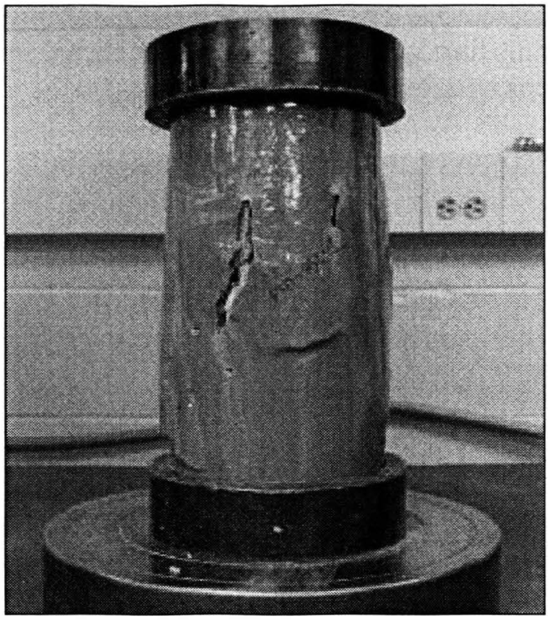


Figure 19: Failure of Poly-urea Wrap

CONCLUSIONS

The purpose of this study was to observe the effects of aggressive environmental agents and freeze-thaw cycles on the performance of polyurea wrapped concrete. The data resulting from this study shows polyurea to have good durability to both freeze-thaw and deicing. The polyurea wrap created an elastic confinement on the concrete which made the cylinder stiffer. That increase in stiffness enabled the polyurea cylinders to take on load with lower deflection than the control cylinders. On observation during testing, the polyurea wrap did not engage or rupture until after failure of the concrete; it performed well containing and confining the concrete as it failed in a brittle fashion under high stress levels. As represented in the polyurea wraps ability to contain the concrete, a more ductile member could be constructed to take on extra loads during seismic and blast events.

Further research should be done on full-scale columns to more accurately understand exactly how the wrap affects the ductility of the concrete member. The 4-in. x 8-in. cylinders used in the experimental study was not subjected to realistic deflections normally found on full-scale columns. The smaller deflections experienced with 4-in. x 8-in. cylinder used little of the ductility performance the polyurea wrap could have delivered in a full-scale column.

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