# Reducing the Curing Requirements of Pervious Concrete Using Prewetted Lightweight Aggregate for Internal Curing


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## 1.0 Introduction and Background

Portland Cement Pervious Concrete (PCPC) is a stormwater management tool which can reduce or eliminate detention/retention areas allowing better site utilization. One of the primary concerns about using PCPC in northern portions of the United States is the perceived lack of durability. Since 2004, Dr. Kevern has been evaluating PCPC mixture proportions and testing for durability, including freeze-thaw and surface abrasion. While freeze-thaw durability of pervious concrete is tested in the laboratory using the worst case scenario, completely saturated and rapid freeze-thaw cycling, it should be noted that freeze-thaw deterioration is generally not observed in the field (Delatte et al. 2007, ACI 2010). However, the most common durability related issue for pervious concrete is the surface abrasion and raveling. Surface raveling is often caused by poor curing of the near surface cement paste from insufficient curing under plastic. The low water-to-cement ratio (w/c) and high exposed surface area of pervious concrete causes much greater moisture loss than from conventional concrete. Raveling can be improved by using a curing compound, however durability of pervious concretes cured under plastic is much better (Kevern et al. 2009). Increasing the amount of available water for evaporation and hydration will create a more durable pervious concrete.

Recently testing with super absorbent polymers (SAPs) in pervious concrete has shown improvements to the degree of hydration and durability. An uncured field test has shown equal durability to conventional mixtures cured under plastic (Kevern and Farney 2012). However, SAPs are not available in many markets and the familiarity in the concrete industry is low. Eliminating plastic curing would be a significant cost savings through reduced material and labor, especially with a commonly available material such as prewetted lightweight aggregates.

This testing plan was designed to show the effects prewetted ESCS aggregates have on typical pervious concrete. Key properties for long-term pervious concrete performance were moisture loss, shrinkage, strength development, permeability, and freeze-thaw durability.

## 2.0 Mixture Proportions and Materials

The testing program was designed to determine the effects of including various prewetted fine lightweight aggregates on pervious concrete properties and durability. The experimental plan included a combination of standard concrete verification tests and tests specific to pervious concrete.

The mixture proportions used in the study are shown in Table 1. Testing included one pervious concrete control mixture designed for adequate freeze-thaw durability and strength. The selected baseline pervious concrete mixture was similar to ones currently used around the U.S. The selected mixture contained freeze-thaw durable limestone coarse aggregate, 7% fine aggregate by weight of total aggregate, and a water to cement ratio of 0.34. Chemical admixtures included air entraining agent (BASF Everair Plus) dosed at 1 oz/cwt., water reducing agent (BASF Glenium 7500) dosed at 4 oz/cwt, and a hydration stabilizer (BASF Delvo) dosed at 6 oz/cwt. The design porosity was fixed at 25% for all specimens. For the mixtures containing normal weight coarse aggregate, prewetted fine lightweight aggregate was used to replace the entire volume of the sand used in the control mixture. For the all lightweight aggregate mixture, the volume of normal weight coarse aggregate was replaced with lightweight coarse aggregate.

The three prewetted aggregates used as fine aggregate replacement to the control mixture were selected for a relative low, medium, and high absorption content. Wetted surface dry (WSD) condition was determined after a 72 hr saturation period according to ASTM C1761. The low absorption material was from Buildex at New Market, MO and had a WSD condition of 16%. The medium absorption was from Hydraulic Press Brick Company at Brooklyn, Indiana and arrived prewetted at 19% moisture. The high absorption material was from Big River Industries' at Livingston, Alabama and had a WSD condition of 39%. One additional pervious concrete mixture was included which replaced both coarse and fine aggregate with the medium absorption material from the Hydraulic Press Brick Co, Brooklyn Indiana Plant and arrived prewetted at 11% moisture.

**Table 1. Summary of Concrete Mixtures**

| Mixture | **Cement** (pcy) | **Coarse Aggregate** SSD (pcy) | **Fine Aggregate** SSD (pcy) | **Water** (pcy) |
|---|---|---|---|---|
| PC (Control) | 573 | 2214 | 164 | 195 |
| PC - BDX (Buildex Fines) | 573 | 2214 | 126 (WSD) | 195 |
| PC - HPB (Hydraulic Press Brick Fines) | 573 | 2214 | 145 (WSD) | 195 |
| PC - BRF (Big River Fines) | 573 | 2214 | 98 (WSD) | 195 |
| PC - LW (All Hydraulic Press Brick) | 573 | 1127 (WSD) | 145 (WSD) | 195 |

All samples were mixed according to ASTM C192. Fresh concrete was weighed for each individual specimen prior to placing. Controlling the unit weight of each specimen ensured consistent density and void content for comparable data analysis. Hardened unit weight, voids, and strength were tested on 4 inch by 8 inch cylinders. Permeability was tested on 4 inch diameter and 6 inch tall cylinders. Permeability cylinders were the samples used for hardened unit weight and void testing with the top and bottom 1 inch removed.

## 3.0 Testing Methods

### *3.1 Unit Weight and Void Content*

Fresh density was determined using ASTM C1688. The void content and hardened unit weight of the pervious concrete was determined using ASTM C1754. All unit weight and void data represents an average of three specimens.

### *3.2 Moisture Loss*

Moisture loss was determined according to ASTM C156 procedure for 9 in. x13 in. samples. The ASTM C156 method determines moisture loss of samples placed in an environmental chamber at 32°C (100°F) and 32% relative humidity for 72 hours.

*3.3 Permeability*

The permeability of mixtures was determined using a falling head permeability test apparatus. The samples were confined PVC shrink wrap and sealed in a rubber sleeve which was surrounded by adjustable hose clamps (Figure 1). The test was performed with an initial water level of 9 inches and a final level of 1 inch (Figure 2). The average coefficient of permeability (k) was determined using Equation 1, which follows Darcy's law and assumes laminar flow. All permeability data represents an average of three specimens.

$$k = \frac{aL}{At} LN\left(\frac{h_1}{h_2}\right) \quad \textbf{(1)}$$

Where:

k = coefficient of permeability, cm/s.

a = cross sectional area of the standpipe, $cm^2$.

L = length of sample, cm.

A = cross sectional area of specimen, $cm^2$.

t = time in seconds from $h_1$ to $h_2$.

$h_1$ = initial water level, cm.

$h_2$ = final water level, cm.

**Fig. 1. Sealing Samples in Heat Shrink Tubing**

**Fig. 2. Permeameter Testing (Green Water Shown for Contrast)**

*3.4 Compressive and Tensile Strength*

Compressive strength tests were performed according to ASTM C39 and splitting tensile tests were performed using ASTM C496. Compressive strength specimens were tested using sulfur caps according to ASTM C617. All strength data represents an average of three specimens.

*3.5 Freeze-Thaw Durability*

Mixtures were investigated for freeze-thaw resistance using ASTM C666, procedure A, in which samples were frozen and thawed in the saturated condition. Specimens were tested for relative dynamic modulus (RDM) according to ASTM C215 and also a less sensitive approach using the aggregate soundness mass loss requirements from ASTM C33. When using a magnesium sulfate solution the allowable aggregate mass loss is 18%, and 12% is allowed for sodium sulfate solutions. By combining the two values, the test was completed when a sample reached 300 cycles or 15% mass loss. Mass loss was tested every 20 to 30 cycles. Figure 7 and Figure 8 show the freeze thaw testing equipment and frozen samples. Durability factor (DF) for the specimens was calculated using equation 2. All freeze-thaw data represents an average of three specimens.

$$DF = \frac{PN}{M} \quad \textbf{(2)}$$

Where:

DF = durability factor of the test specimen

P = relative dynamic modulus (RDM) of elasticity or relative mass, at N cycles, %.

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less, 60% RDM, 85% mass remaining, or 300 cycles.
M = specified number of cycles at which the exposure is to be terminated, 300 cycles.

**Fig. 3. Freeze-thaw apparatus**

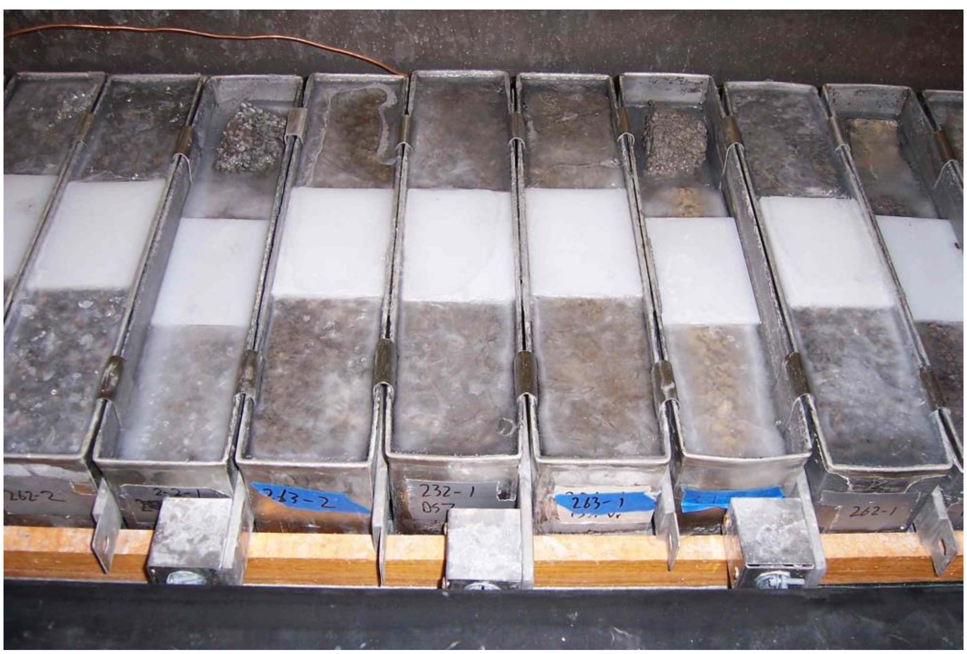

**Fig. 4. Samples during freeze-thaw testing**

*3.6 Shrinkage*

Restrained ring shrinkage was tested according to ASTM C1581. Time to cracking, strength at initial crack, and residual strength is reported for averages of sample pairs.

**Fig. 5. Ring Shrinkage Testing on Pervious Concrete**

*3.7 Degree of Hydration*

Degree of hydration testing was performed using the ignition oven technique for measuring non-evaporable water on four specimens from each mixture at 7, 28, and 90 days (Fagerlund 2009). Paste was obtained from 6 mm (1/4 in.) of the surface, where raveling is likely to occur. Curing of degree of hydration samples was determined for sealed conditions. Degree of hydration data represents an average of 4 samples.

## 4.0 Results

*4.1 Fresh and Hardened Properties*

Fresh and hardened properties are shown in Table 2. When compaction energy is fixed and density is allowed to vary, ASTM C1688 unit weight is a good indicator of workability with denser mixtures being more workable. However, since the density of the lightweight aggregates is less than the control sand, even at equal workability, the mixtures containing lightweight aggregates should have lower hardened density. All of the mixtures which contained fine lightweight aggregate had greater fresh density than the control, indicating increased workability. The hardened density was similar for all of the lightweight aggregate mixtures. Figure 6 shows the relationship between fresh and hardened unit weight for the samples. The measured void content generally rose with the inclusion of the lightweight aggregate. Since void content measurement includes both connected and interconnected void space, the increase in observed voids resulted from the inclusion of voids within the lightweight aggregates. The permeability generally decreased for all of the fine lightweight aggregate mixtures, also indicating increased compaction from increased workability. Permeability was similar between the fine lightweight aggregate mixtures.

**Table 2. Hardened Concrete Results**

| Mixture | Fresh Unit Weight ASTM C1688 | Hardened Unit Weight ASTM C1754 | | Voids ASTM C1754 | | Permeability ASTM C1754 | |
|---|---|---|---|---|---|---|---|
| | Avg. (pcf) | Avg. (pcf) | COV (%) | Avg. (%) | COV (%) | Avg. (in./hr) | COV (%) |
| PC (Control) | 121.8 | 116.8 | 0.4 | 25.9 | 2.7 | 1680 | 7.8 |
| PC - BDX (Buildex Fines) | 127.8 | 113.5 | 0.1 | 23.3 | 3.4 | 1080 | 31.1 |
| PC - HPB (Hydraulic Press Brick Fines) | 128.8 | 112.9 | 0.1 | 27.6 | 1.0 | 1200 | 18.0 |
| PC - BRF (Big River Fines) | 124.6 | 113.7 | 0.1 | 30.3 | 5.0 | 1320 | 49.4 |
| PC - LW (All Hydraulic Press Brick) | 76.4 | 63.3 | 0.3 | 42.8 | 0.9 | 4600 | 5.5 |

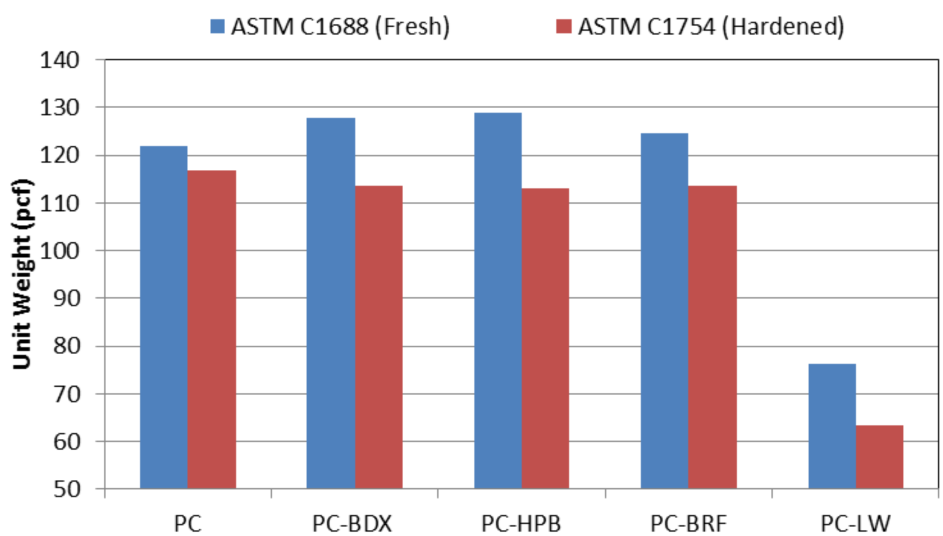


**Fig. 6. Relationships between fresh and hardened unit weight**

Moisture loss data is shown in Table 3 and Figure 7. Intuitively, adding additional water to the mixture contained within the lightweight aggregate should result in greater moisture loss. However, the control sample had similar moisture loss to all the samples containing the fine lightweight aggregate. The mixture containing all lightweight aggregate did have substantially higher moisture loss than the conventional pervious concrete mixtures.

**Table 3. Hardened Concrete Results.**

| Mixture | ASTM C156 Moisture Loss 24 hrs | 36 hrs | 72 hrs |
|---|---|---|---|
| | | kg/m$^2$ | |
| PC (Control) | 2.4 | 2.5 | 2.6 |
| PC - BDX (Buildex Fines) | 2.1 | 2.4 | 2.6 |
| PC - HPB (Hydraulic Press Brick Fines) | 2.1 | 2.4 | 2.6 |
| PC - BRF (Big River Fines) | 2.1 | 2.5 | 3.1 |
| PC - LW (All Hydraulic Press Brick) | 3.3 | 3.8 | 4.1 |

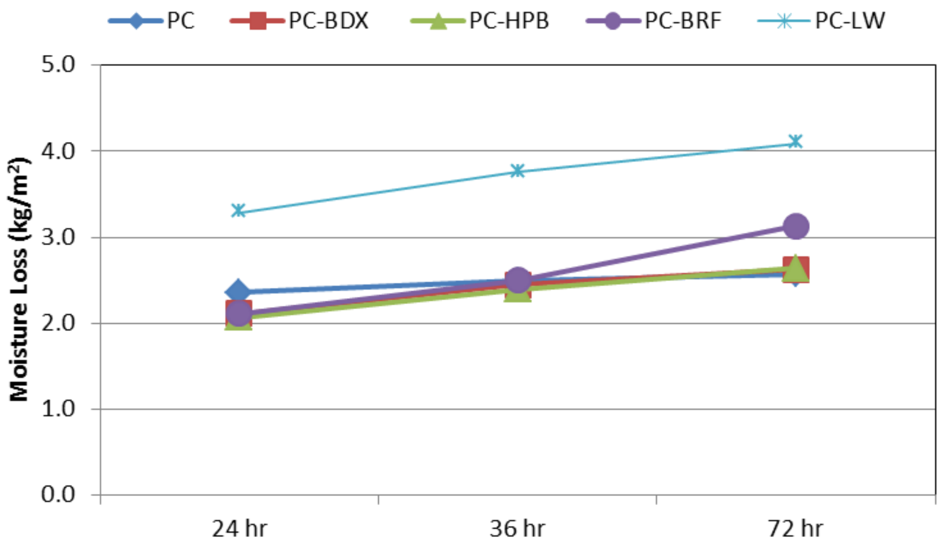


**Fig. 7. Moisture loss results per ASTM C156**

The degree of hydration results are shown in Figure 8 for all ages. All samples containing prewetted fine lightweight aggregate had significantly greater hydration than the control, except PC-HPB at 7-days. The degree of hydration testing was performed on sealed specimens to represent field conditions when pervious concrete is cured covered under plastic. At 28 days and 90 days there was no difference between any of the internally-cured specimens.

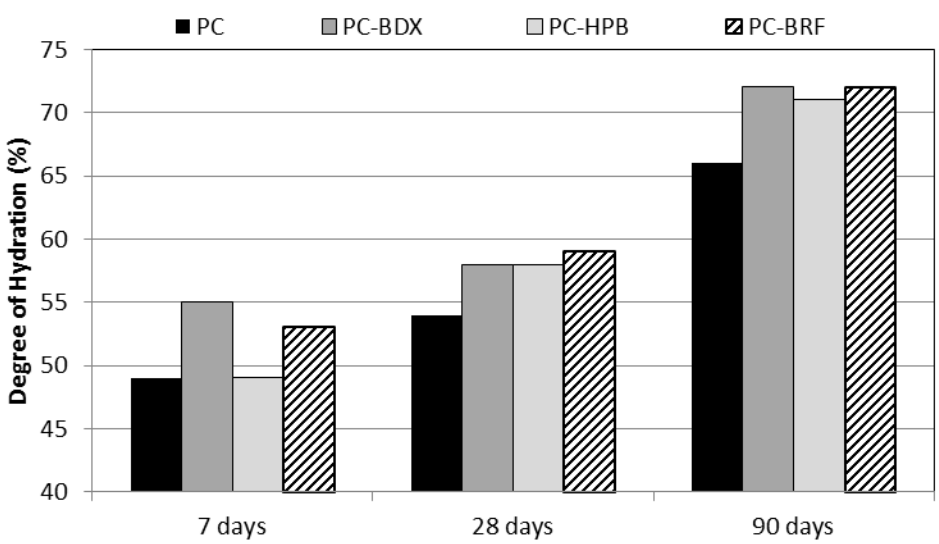


**Fig. 8. Degree of hydration results.**

The compressive and tensile strength testing results are shown in Table 4. There was no difference in compressive strength between the control and any of the fine aggregate replacement mixtures at 7 days. At 28 days all of the fine lightweight aggregate mixtures were stronger (both compressive and tensile strength) than the control. Pervious concrete mixtures containing only portland cement generally exhibit the strength gain behavior shown in Fig. 9, with little additional strength gain after 7 days. The control mixture only had a 4% gain in strength between 7 and 28 days, while all of the fine lightweight aggregate mixtures gained between 16% and 29% additional strength as shown in Figure 9.

**Table 4. Strength Testing Results.**

| Mixture | Compressive Strength 7-day ASTM C39 | | Compressive Strength 28-day ASTM C39 | | Tensile Strength 28-day ASTM C497 | |
|---|---|---|---|---|---|---|
| | Avg. (psi) | COV (%) | Avg. (psi) | COV (%) | Avg. (psi) | COV (%) |
| PC (Control) | 2188 | 6.7 | 2281 | 10.8 | 281 | 19.5 |
| PC - BDX (Buildex Fines) | 2295 | 2.2 | 2955 | 19.4 | 353 | 9.0 |
| PC - HPB (Hydraulic Press Brick Fines) | 2199 | 12.0 | 2554 | 20.7 | 358 | 8.7 |
| PC - BRF (Big River Fines) | 1962 | 8.0 | 2402 | 9.8 | 327 | 25.5 |
| PC - LW (All Hydraulic Press Brick) | 817 | 39.2 | 897 | 4.0 | 213 | 4.7 |

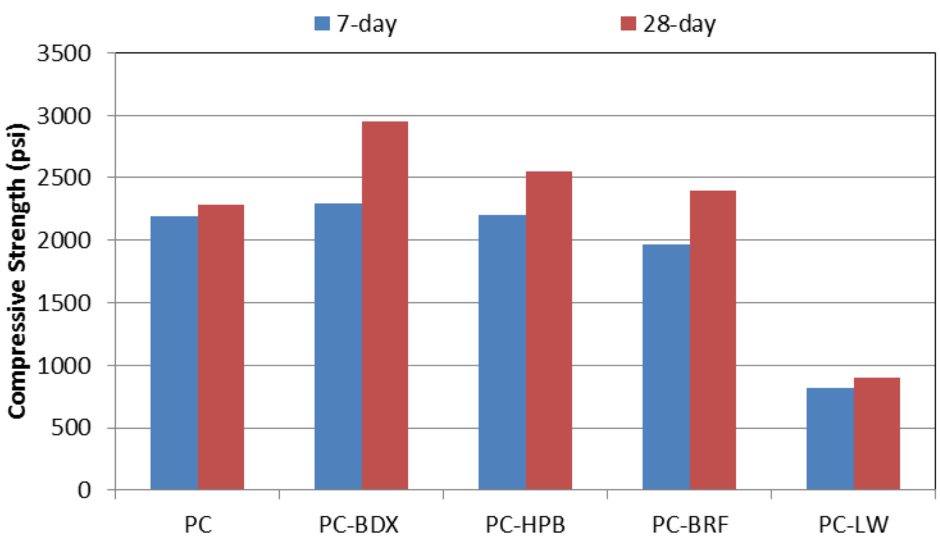


**Fig. 9. Average Compressive Strength Results for the Various Mixtures.**

### *4.2 Freeze-Thaw Durability Evaluation*

The inclusion of all types of prewetted fine lightweight aggregate improved the durability of the control mixture. The control mixture failed at 187 cycles using the mass loss criteria for a durability factor of 53. The control mixture failed at 69 cycles using the relative dynamic modulus criteria for a durability factor of 14. The results using the mass loss criteria are shown in Figure 10 and relative dynamic modulus results shown in Figure 11. Complete freeze-thaw results are provided in Table 5. The mixture containing both the fine and coarse lightweight aggregate had the best relative performance using either criterion. Performance shown in Fig. 11 directly corresponds to the absorption of the lightweight aggregates contained within the mixture with higher absorption producing better freeze-thaw durability.

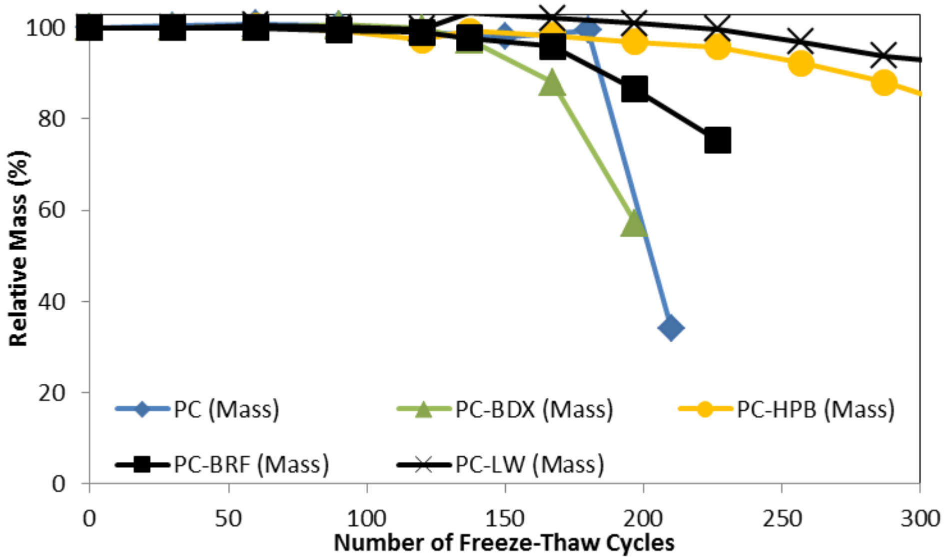


**Fig. 10. Freeze Thaw Testing Results Using Mass Criteria**

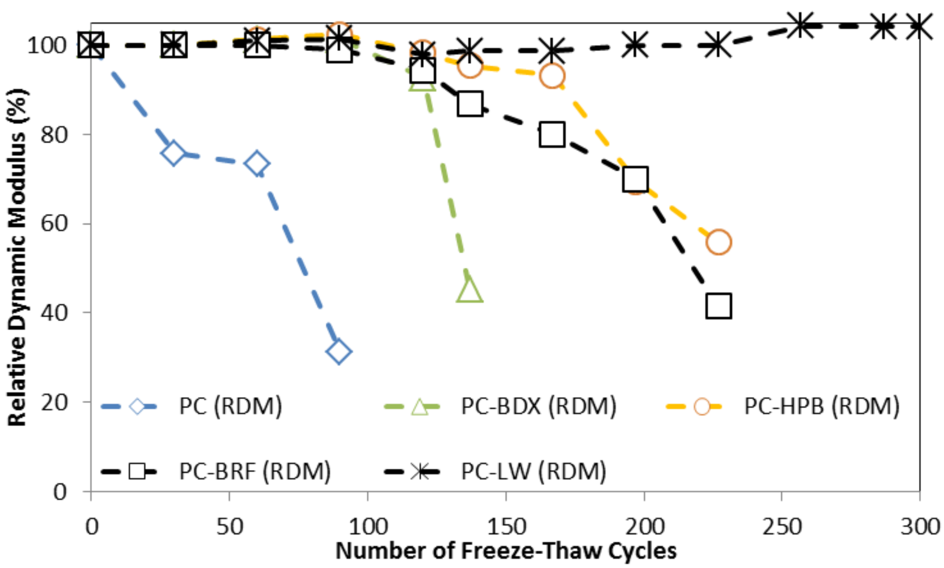


**Fig. 11. Freeze Thaw Testing Results Using Relative Dynamic Modulus Criteria**

**Table 5. Freeze Thaw Testing Results**

| Mixture | Durability Factor Mass | Durability Factor RDM |
|---|---|---|
| PC (Control) | 53 | 14 |
| PC - BDX (Buildex Fines) | 48 | 26 |
| PC - HPB (Hydraulic Press Brick Fines) | 85 | 44 |
| PC - BRF (Big River Fines) | 57 | 42 |
| PC - LW (All Hydraulic Press Brick) | 92 | 100 |

*4.3 Ring Shrinkage*

Restrained ring shrinkage testing results are shown in Figure 12. The results showed a large reduction in shrinkage compared to the control samples. Considering the only difference between mixtures was a small portion of sand (except for the all lightweight mixture), the reduction in shrinkage is remarkable. Also, between 5 and 7 days the mixtures containing lightweight aggregate started experiencing some strain relaxation. At the end of testing there was no difference in strain between any of the mixtures containing lightweight aggregate.

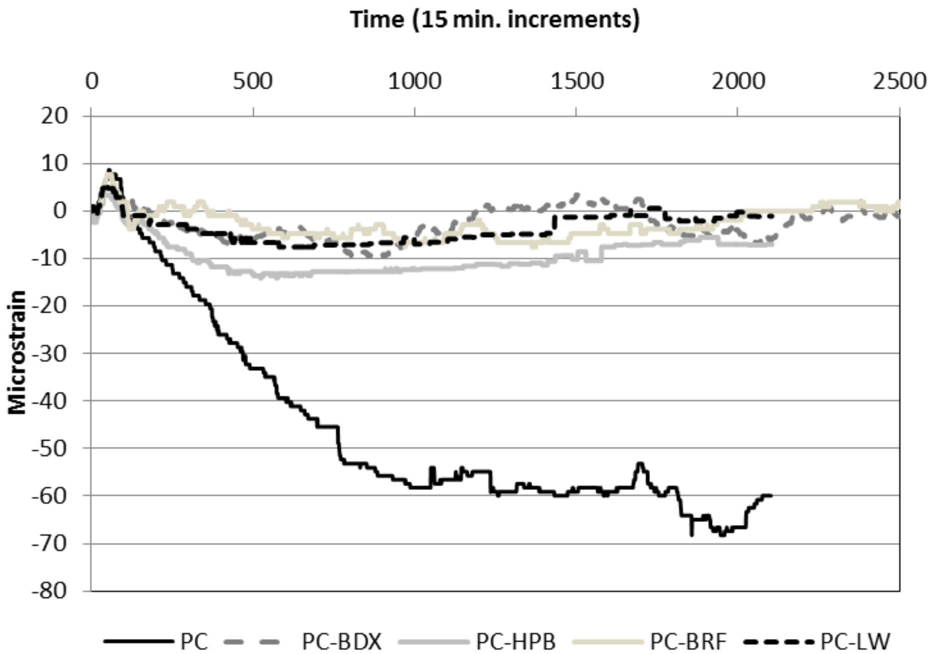


**Fig. 12. Ring Shrinkage Testing Results**

## 5.0 Observations

The testing plan presented herein was designed to evaluate the affects prewetted lightweight aggregates had on pervious concrete properties and durability. A baseline mixture was selected which represented a common mixture used in the US with adequate strength and durability. Three fine lightweight aggregate materials from Buildex, Hydraulic Press Brick, and Big River Industries were used as complete replacement for sand in a pervious concrete mixture. The fine aggregates were selected to represent low, medium, and high absorption materials. One additional mixture was included which also utilized lightweight coarse aggregate, provided by Big River Industries. The void content of all mixtures was fixed and tightly controlled through sample production to allow evaluation of only the effects caused by the prewetted aggregates. Based on results of the testing performed, the following observations can be made:

- Mixture containing prewetted fine lightweight aggregate had better workability than the control as indicated by greater fresh density.
- Moisture loss from mixtures containing prewetted fine lightweight aggregate was similar to the control samples.
- All lightweight aggregate tested produced significant increases in the degree of hydration over the control mixture. Performance was similar between the aggregate types at 28 and 90 days.
- Samples containing fine prewetted lightweight aggregate as a replacement for conventional sand had similar compressive strengths to the control mixture at 7 days. At 28 days the fine aggregate samples all were stronger than the control.
- Prewetted lightweight aggregate improved freeze-thaw durability. Performance was directly related to the amount of additional pore space provided within the lightweight particles.
- All samples containing lightweight aggregate had significantly less shrinkage than the control mixture in ring shrinkage testing.

The results indicate that when prewetted fine lightweight aggregate should be used to replace the small portion of conventional sand used in pervious concrete mixtures, all important properties were improved.

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