Making Pervious Concrete Placement Easy

Using a Novel Admixture System

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Introduction

Though it may be new in some areas of the country, pervious concrete technology has been utilized since the 1970s in various parts of the U.S. as an alternative to complex drainage systems and water retention areas. Its most common applications include parking lots, driveways, sidewalks, streets and other light traffic areas. Recently, there has been renewed interest in pervious concrete due to changes in the U.S. regulatory environment. The EPA recognizes pervious concrete as a Best Management Practice (BMP), and building owners are realizing better land utilization and LEED credits with pervious concrete parking lots (Tennis, Michael & Akers 2004).

Pervious concrete consists of portland cement, coarse aggregate, water and admixtures. The absence of sand in the mix creates voids in the pore structure which allow water and air to pass through the concrete. Through laboratory and field testing, an admixture system (consisting of a polycarboxylate-based water-reducer, cement hydration controlling admixture and viscosity-modifying admixture) has been developed to help in the placement and consolidation of pervious concrete. This paper provides a description of the chemical admixtures used to improve the mixing, handling and performance of pervious concrete. Test data is presented, along with two test methods used to evaluate the hardened performance of pervious concrete. The paper also contains a case study to illustrate the effects of the admixture system on the placement of pervious concrete.

Pervious Concrete Challenges

Across the nation, pervious concrete pavements are gaining in popularity as practical stormwater management systems. Both local and national concrete promotional groups have had successes in projects using pervious concrete. However, there have been instances in which claims and expectations regarding pervious concrete have not been met. For pervious concrete to be successful, it needs to be properly designed according to appropriate specifications for the application, and placed by experienced contractors.

Removing the fine aggregate (sand) from the mix designs of pervious concrete mixtures creates a connected void structure in the hardened mix. However, such a mix is harsh and can create problems on the jobsite through challenges in placement. The open void structure can create rapid and premature moisture loss, resulting in stiffening and a very narrow working window for material placement. The low water-to-cementitious materials ratio and lack of fines make discharging the material difficult and slow, aggravating the already critical placement window. In addition, real world conditions such as hot weather, low humidity, travel delays (as the use of pervious concrete increases in metropolitan areas), project congestion and logistics further complicate the placement of pervious concrete. Concrete producers have reported difficulties in discharging the stiff and rocky mix from the truck, while contractors have battled a short working time window, the need to re-temper, and a labor-intensive effort in placing and compacting pervious concrete. Chemical admixtures can play a key role in overcoming these challenges by controlling workability and set times and by improving the long-term durability of pervious concrete.

Pervious Concrete Admixture System

Through laboratory and field experience, Degussa Admixtures has identified a system of novel admixtures that helps producers and contractors to overcome the mixing, delivery and placement issues typically associated with pervious concrete. The pervious concrete admixture system consists of a combination of a polycarboxylate-based mid-range water-reducing (MRWR) admixture, a hydration controlling admixture (HCA), and a viscosity-modifying admixture (VMA). When pervious concrete is placed in areas exposed to certain conditions of freezing and thawing, an air-entraining admixture should also be used (NRMCA 2004a). Each of the admixtures in the system enhances the performance of the mix in specific ways, leading to a positive overall effect on the handling and placing of pervious concrete. The role of each admixture component in the system is described below.

MRWR: Achieving a desired strength is sometimes a challenge with pervious concrete because of its inherently high void content, in the range of 15 to 25%, which negatively affects strength. Therefore, it is important to create a strong paste to coarse aggregate bond by maximizing cement hydration with the available cement and water. The novel polycarboxylate-based MRWR is a superior cement dispersant that allows pervious concrete to be produced with low water-to-cementitious materials ratios in the range of 0.27 – 0.30. This relatively high level of water reduction and efficient cement dispersion maximizes the strength potential of pervious concrete mixes. Alternatively, a polycarboxylate-based high-range water-reducer or lignin-based MRWR designed for pervious concrete can be used.

HCA: As discussed, pervious concrete has a low water content and a relatively open void structure. Under these conditions, the cement paste tends to hydrate quickly and the mix dries out, thereby shortening the available working time required for placement. The use of a HCA extends the life of fresh pervious concrete mixes by slowing the rate of hydration. By controlling the rate of hydration, the paste fraction of the pervious concrete remains plastic longer. With a longer working window for placement, the tendency to retemper the mix on the job site, which can lead to variability in performance, can be reduced or eliminated. A dosage of 5 fl oz/cwt (325 mL/100 kg) of the HCA provides approximately 60 – 90 minutes of working time at 70˚F (21.1˚C) ambient temperature conditions from the time of batching. The dosage of the HCA can be modified to achieve the desired level of working time for placement.

VMA: Compared to conventional concrete, pervious concrete is a harsh mix because it contains little or no fine aggregate. In the absence of fine aggregate, a unique, commercially available VMA has been developed to add body and help lubricate pervious concrete mixes. The result is better flow, faster discharge time from a truck, and easier placement and compaction of an otherwise dry, harsh mix. In addition, the use of a VMA provides insurance against paste drain down. Paste drain down is a condition in which too fluid a cement paste in pervious concrete migrates to the bottom of the slab, due to gravity, and seals it. This sealing of the bottom surface makes the pervious concrete functionally useless and can be avoided through use of a VMA. The VMA also increases compressive and flexural strength in low compaction pervious concrete mixes by enhancing the paste to aggregate bond.

It should be noted that while all VMAs alter the rheology, or flow behavior, of a concrete mix, each VMA can have a differing effect on the mix based on its specific chemistry. Some VMAs have been used in pervious concrete with less than desirable results. Certain VMAs work by binding water in a concrete mix, thereby changing its viscosity. However, with pervious concrete, this mechanism works against the system by making the concrete even more difficult to place because of increased stiffness characteristics. Therefore, it is important to use an admixture with the appropriate chemistry developed specifically for modifying the rheology of pervious concrete.

The combination of these specific admixtures has significantly improved the mixing and handling of pervious concrete. As with most concrete, admixture dosages can be varied to achieve the desired properties for the application.

Testing Pervious Concrete

Three key performance characteristics have been identified for pervious concrete. These include density (unit weight), compressive strength, and void content. Pervious concrete is not specified or accepted based on strength. Acceptance is usually based on the density (unit weight) of the in-place pavement. The density (unit weight) of pervious concrete typically ranges from 100 to 125 lb/ft^3 (1600 to 2000 kg/m^3). An acceptable tolerance is plus or minus 5 lb/ft^3 (80 kg/m^3) of the design density. The fresh density (unit weight) of pervious concrete is measured using the jigging method described in ASTM C 29 (NRMCA 2004b). The compressive strength of pervious concrete is usually between 500 and 4,000 psi (3.4 and 27.6 MPa), depending on the application, and the void content is typically specified at 15 to 25%. However, because there are currently no standard testing procedures for measuring these parameters, test methods to determine the compressive strength and void content have been developed.

Compressive Strength

In practice, pervious concrete is compacted using different equipment and methods compared to those used for conventional concrete. In general, pervious concrete is either *highly compacted* by using a paving machine or a heavy, weighted hand roller, or *lightly compacted* using a hand roller with no ballast. The method of compaction chosen for a given project is dependent on the actual application as well as the desired strength and void content. Therefore, two methods of consolidation of cylinders have been developed for testing the compressive strength of pervious concrete, based on either high or low compactive effort.

The basic casting method for cylinders to measure the compressive strength of pervious concrete was developed following verbal communications with Dr. Crouch, professor of civil engineering, Tennessee Technological University (TTU) in Cookeville, TN. Using 4 in. x 8 in. (100 mm x 200 mm) steel cylinder molds, pervious concrete test specimens are compacted using a Marshall hammer conforming to specification AASHTO T 245, and shown in Figure 1. The following procedures describe the casting of cylinders for pervious concrete.

1) The sample of pervious concrete from which test specimens are made shall be representative of the entire batch. It shall be obtained in accordance with Practice C 172.
2) The user has the option of casting test specimens designed to be placed by either *high* or *low* compaction procedures.

a. High Compaction Placement Method: Place the mold on a flat surface. From the sample of concrete obtained in accordance with Practice C 172, immediately fill the mold in 3 lifts. Using the Marshall hammer, deliver 26 blows to each layer to consolidate the concrete as shown in Figure 1. For the third layer, fill the concrete above the top of the mold prior to consolidation to achieve an overall cylinder height of approximately 8 in. (200 mm).

b. Low Compaction Placement Method: Place the mold on a flat surface. From the sample of concrete obtained in accordance with Practice C 172, immediately fill the mold in one lift. Using the Marshall hammer, deliver 5 blows to consolidate the concrete. Fill the concrete above the top of the mold prior to consolidation to achieve an overall cylinder height of approximately 8 in. (200 mm).

3) Complete sample casting within 20 minutes.
4) Demold the samples after 24 hours and wet cure the samples for a minimum of 7 days.
5) Cap and test the cylinders using Practice C 617 and test for compressive strength following Standard Test Method C 39.

Figure 1: A Marshall hammer is used to compact pervious concrete for compressive strength testing.

Void Content

As previously discussed, typical air void content for pervious concrete ranges from 15 to 25%. Effective air voids, however, are those that are accessible from the surface and affect pervious concrete permeability. To measure the effective void content of pervious concrete, the following procedure was developed. The procedure was adapted based on the previously published work by Crouch (Crouch et al. 2003):

1) Cast 4 in. x 8 in. (100 mm x 200 mm) cylindrical specimens following the procedures described for making compressive strength samples for pervious concrete.
2) After 7 days of moist curing, oven dry the sample to a constant mass.
3) Determine the mass of the dry sample to the nearest 0.05 oz. (1 gram). Place the sample into a plastic bag and then insert into a Instrotek Corelok System, as shown in Figure 2, to vacuum the air from the sample and seal the bag. Determine the mass of the sealed sample in the plastic bag to the nearest 0.05 oz. (1 gram).
4) Place the sealed sample in water and determine the mass of the sample submerged in the water to the nearest 0.05 oz. (1 gram).
5) Cut the bag and allow the water to enter the bag and saturate the pervious concrete for a period of 8 minutes. Determine the mass of the submerged, water-saturated sample to the nearest 0.05 oz. (1 gram).
6) Test a minimum of 2 samples for each pervious concrete mix being evaluated.
7) Calculate the bulk specific gravity of the pervious concrete as follows:

$$\text{Bulk specific gravity} = \frac{A}{[B - E - (B - A)/F_t]}$$

where:

A = mass of the dry sample in air before sealing

B = mass of the dry sealed sample

E = mass of the sealed sample in water

F_t = apparent specific gravity of the plastic sealing material at 77 ˚F (25 ˚C), when sealed, (provided by the manufacturer)

Calculate the apparent specific gravity of the pervious concrete as follows:

$$\text{Apparent specific gravity} = \frac{A}{[B - C - (B - A)/F_{t1}]}$$

where:

C= mass of the unsealed sample in water

F_{t1}= apparent specific gravity of plastic sealing material at 77 ˚F (25˚C), when opened underwater, (provided by the manufacturer)

Calculate the effective air void content of the pervious concrete using equation 3:

$$\text{Effective Air Void Content (\%)} = 100 * (1 - G_{mb}/G_{mm})$$

where:

G_{mb} = bulk specific gravity of the pervious concrete

$$G_{mm} = \frac{A}{(A - C)}$$

Figure 2: A Corelok system is used to vacuum air from the pervious concrete sample.

Laboratory Test Data

An informal industry survey has indicated that about 80 to 90% of pervious concrete is placed by hand and uses low compaction methods during installation. The use of the unique VMA is designed to facilitate the ease of pervious concrete placement by adding body and lubricating the mix, thus increasing flow, workability and assisting in the compaction process. To evaluate the dosage effect of the VMA on compressive strength and effective void content of pervious concrete produced with low compaction, several mixes were made in the laboratory. The strength and void contents were measured by using the test methods described earlier. For this study, the MRWR and HCA dosages were held constant. These dosages were determined by trial mixes which showed excellent cement dispersion and working time. Both the concrete and ambient temperatures were held constant at 70 ˚F (21.1 ˚C) during this evaluation. The material properties for this study are shown in Table 1.

Table 1 Material Properties

Material	Properties
Cement	Type I
	Specific Gravity: 3.15
Coarse Aggregate	
	Particle Shape: Rounded Gravel
	Bulk Specific Gravity: 2.61
	Dry Rodded Unit Weight: 99.20 lb/ft?
	Void Content (ASTM C29): 39%

1 lb/ft^3 = 16.02 kg/m^3

The design mixture proportions consisted of a cement content of 600 lb/yd^3 (356 kg/m^3), 2,600 lb/yd^3 (1,543 kg/m^3) of coarse aggregate, a water content of 162 lb/yd^3 (96 kg/m^3), and an air content of 23%.

The yielded mixture proportions for this study are shown in Table 2.

Visually, the mixes containing the VMA appeared to have more body and were more workable than the reference mix without the VMA present.

Table 2 Mixture Proportions

Material	Mix 1	Mix 2	Mix 3	Mix 4
Cement (lb/yd^3)	600	606	600	616
Coarse Aggregate, #89 (lb/yd^3)	2608	2630	2608	2675
Water (lb/yd^3)	162	163	162	171
w/cm	0.27	0.27	0.27	0.28
Admixtures				
MRWR (fl oz/cwt)	5.0	5.0	5.0	5.0
HCA (fl oz/cwt)	5.0	5.0	5.0	5.0
VMA (fl oz/cwt)	0	2.0	5.0	10.0

1 lb/yd^3 = 0.5933 kg/m^3

1 fl oz/cwt = 65.2 mL/100 kg

The test results from this study, shown in Table 3, indicate that the density and effective voids of the four mixes were typical of pervious concrete. The data also indicates that as the dosage of VMA increases, there is a corresponding increase in both compressive and flexural strength of the pervious concrete.

Table 3 Test Data

Plastic Properties	Mix 1	Mix 2	Mix 3	Mix 4
Density (Unit Weight) (lb/ft^3)	125.0	125.0	125.0	127.0
Effective Voids (%)	24.8	26.4	25.5	28.1
Hardened Properties				
Compressive Strength (psi)				
7 day	1,340	1,730	1,600	2,200
28 day	1,670	2,120	1,950	2,200
Flexural Strength (psi)				
28 day	300	430	500	490

1 lb/ft^3 = 16.02 kg/m^3

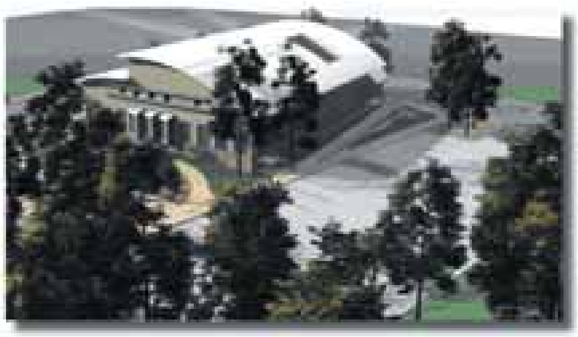
145 psi = 1 MPa

Case Study

Project:	East Atlanta Library
Location:	Atlanta, GA
Date:	June, 2005
Contractor:	PCI Systems, LLC
Producer:	Thomas Concrete
Details:	10,000 ft^2 (929 m^2) / 185 yd^3 (141 m^3) @ 6 in. (150 mm) pervious concrete
Base:	6 to 24 in. (150 to 610 mm) of #57 stone with non-woven geo-textile
Soil Type:	Clay

Figure 3: Artist's rendition of the East Atlanta Library *(see above next column)*

Figure 3:



For this project, shown in Figures 3, 4, and 5, the Fulton County government worked collaboratively with the construction management team to specify pervious concrete because of the material's environmental benefits and to facilitate LEED (Leadership in Energy & Environmental Design) Green Building Rating System™ certification. LEED certification recognizes building projects that demonstrate a commitment to sustainability and meet the highest performance standards.

There were many constructability concerns on the project, including ambient temperatures exceeding 90˚F (32.2˚C), a small congested site, and potential travel delays. However, the issue of most concern was the slope of the parking lot. The parking lot was approximately 60 ft x 170 ft (18 m x 52 m) at a slope of 3-5% along its length. It consisted of a single travel lane with parking on both sides. Because there was only a single entry to the parking lot, the strategy was to place the 20 ft (6.1 m) wide parking stalls from the bottom of the slope to the top on two different days. On day 3, placement of the travel lane would be accomplished by backing the ready-mix trucks up the slope and pouring from the top of the slope down. Though the positive slope would speed placement of the parking stalls, the negative slope would hinder the placement of the travel lane.

For the uphill placements, concrete discharge times of 30 minutes or less and little re-tempering were expected, but the downhill placement of the travel lane was of concern. It was anticipated that the pervious concrete would not discharge due to the negative slope of the travel lane and the relatively flat chute position. Two options were considered for the downhill placement of the travel lane: use of either a conveyor or a VMA in the pervious concrete mix. Because conveyers may have a tendency to separate the stone from the cement and produce an inconsistent finish, the option of using a VMA in the pervious concrete was chosen.

The placement of the pervious concrete parking lot occurred over three days. On the first day, 60 yd^3 (46 m^3) were placed on the first row of parking stalls with a slope of 3-5%, with placement occurring from the bottom to the top of the incline. On average, each truck was re-tempered using 4 to 8 gal (15 to 30 L) of water and discharged in approximately 20 to 25 minutes.

The following day, 60 yd^3 (46 m^3) were placed on the second row of parking stalls with a slope of 3%, again being placed from the bottom to the top of the incline. On average, each truck was re-tempered using 8 to 10 gal (30 to 38 L) of water and discharged in approximately 25 to 30 minutes.

On the third day, 5 yd^3 (4 m^3) were placed on the travel lane with a slope of 4%, with placement occurring downhill. However, because of the negative slope, the pervious concrete would not discharge easily and the remainder of the placement was cancelled.

On the final day, VMA was introduced into the mix and 63 yd^3 (48 m^3) were placed on the travel lane with a slope of 4%, pouring downhill. On average, each truck was discharged in 20 to 25 min with no re-tempering.

For each day's pour, a Bunyan Striker® was used to screed and compact the pervious concrete to 18% voids. A hydration stabilizer and water reducer were used to facilitate placement and improve workability.

The combined use of a high quality MRWR, HCA, and VMA was instrumental to the success of this project.

Figure 4: Close up view of pervious concrete

Figure 5: Finished pervious concrete parking lot
(see top picture next column)

Observations

Based on the lab and field data presented in this paper, the following observations can be made.

1. Test methods for determining the compressive strength and effective voids of pervious concrete have been developed.
2. The use of a novel admixture system provides extended working time and facilitates the ease with which pervious concrete can be placed.
3. In low compaction placement procedures, the use of the unique VMA provides an increase in both compressive and flexural strength of pervious concrete.
4. The case study has shown that in the field, the novel admixture system helps in the placement and consolidation of pervious concrete.

Future Work:

The authors believe that additional research is necessary to further develop the compressive strength and effective void test methods discussed in this paper. Testing is currently underway to examine the effect of several variables on the test results and to develop a precision statement for the methods.

Additional work is also underway to further research the effects of admixtures on the resulting properties of pervious concrete.

References:

Codes and Standards:

ASTM C 29 Standard Test Method for Bulk Density ("Unit Weight")
ASTM C 39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C 172 Practice for Sampling Freshly Mixed Concrete
ASTM C 617 Practice for Capping Cylindrical Concrete Specimens
AASHTO T 245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

Citations:

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