FORTA® Corporation

Technical Report

FRP:
Fiber Reinforced Pervious

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Overview

Pervious concrete has been used in many countries for many years, and is now becoming more than just an oddity in the United States. The impetus behind this surge in application is a growing need to take full advantage of shrinking building sites, and to accommodate storm-water runoff in the process. Inherent to the air-void nature of pervious, or porous concrete, is the potential for a lack of durability and toughness, which often impacts application choices and project volume. Experts in the art of pervious materials and practice have long sought out ways to improve the material's durability, and to add to the long-term comfort level of owners that choose it and architects that specify it. Synthetic fibers have been tested and used for many years to add an element of crack control, however these fibers have been somewhat limited by shape and dosage, and have not offered a contribution level that could be considered as significant to this long-term durability goal. The advent of second-generation synthetic macro fibers has opened a door of opportunity for this application, one that continues to morph and change with new project experience and laboratory study. Though certainly not all-inclusive nor the final word, this report is intended to at least chronicle what is known to-date, and document existing project and research history to help steer owners, specifiers, and contractors towards best FRP – Fiber Reinforced Pervious - practice going forward.

Pervious concrete comes of age in the U.S.

Pervious Definition, History, and Deficiencies

By definition, the word 'pervious' means permeable, describing a material that has pores or openings that allow liquid to pass through. Therefore, pervious concrete is that which is designed to allow water – primarily storm-water – to pass though its cross-section, and proceed into a drainage bed of some type and then distributed as site conditions allow. Pervious concrete has been described as a material which is first and foremost designed as a stormwater dispersal system, that is cleverly disguised as concrete sidewalks, driveways, and parking lots. The void structure that is necessary to allow for the water movement, is achieved by removing the sand/cement/water paste fraction found in conventional concrete, which essentially results in cement-paste covered aggregates stacked against each other to provide a wearable surface with anywhere from 15% to 30% void space. Since much of conventional concrete's strength comes from that paste fraction that holds the coarse aggregates firmly in place (hardened paste is stronger than air), the constant challenge of pervious concrete designers becomes creating a durable balance between permeability and strength.

Pervious concrete has been utilized in the world scene for over 200 years. In some cases, the construction intent was not permeability focused, but rather stimulated by a simple shortage of concrete building materials during wartime, creating an inadvertent pervious material. Countries like China have pursued the porosity-values of pervious concrete, and have continued to improve and use the technology in millions of cubic yards of in-place applications. Many countries in Europe have expanded the use of pervious in applications that include actual high-traffic roadways and pavements, recognizing the advantages of reduced pavement noise as well as less surface water as contributions to improved driver-friendliness and road safety. Pervious concrete has been used in the United States for approximately 30 years, though has been primarily restricted to low-trafficked applications, such as sidewalks, driveways, curb-and-gutters, and parking lots.

The removal of storm-water has become increasingly important in the U.S. to business property owners, to allow them the latitude of using more available space for commercial enterprise and less area for collection ponds and other treatment methods. The use of pervious concrete for parking lots offers a dual-purpose solution to both storm-water and parking requirements, and offers owners a cost-effective way to optimize their retail space use. However, the challenges have been to specify and place a pervious concrete mix that will not only maintain a porous nature, but remain durable enough to stand the test of time with minimal maintenance and repair. Optimization of aggregates, mixes, and practice has helped extend the expected life of pervious pavements considerably, however the desire for additional toughness and durability in these applications continues to be a priority.

Fiber Reinforcement – History and Background

FORTA Corporation introduced synthetic micro fibers to the U.S. market in 1978, which were designed to reduce plastic shrinkage and offer an element of shrinkage/temperature crack control. These products generally took the form of very fine single-filament polypropylene and nylon fibers, called multi- or mono-filament fibers, normally used at a dosage of 1.0 lb./cu yd, or deformed net-shaped polypropylene fibers, called fibrillated, typically used at 1.5 lbs. to 3.0 lbs./cu yd. Though it was generally acknowledged that higher dosages would lead to considerably higher levels of shrinkage crack reduction, these fine-filament fibers created mixing and placement challenges at these increased dosages due to their high surface-area characteristic. After almost a decade of trials and research, FORTA® introduced the first of its kind synthetic macro fiber in 1999 to solve the user-friendly issues at higher dosages. This ability to add considerably to the fiber volume percentage has allowed for a much higher replacement level of conventional temperature-steel reinforcement in slabs on ground, along with advances in extending joint-spacing practices which have resulted in considerable cost savings and premium floor systems for specifiers and owners for over 10 years.

Micro monofilament

Micro fibrillated

Macro FORTA-FERRO®

As pervious concrete applications began to hit the U.S. construction scene, synthetic micro fibers were quickly considered for their potential to add value to this unique concrete material. As with conventional concrete, micro fiber dosages for pervious were typically in the same range – 1.0 lb./cu yd for short mono-filament fibers and 1.5 lbs./cu yd for fibrillated fibers. The intent for this low-volume fiber usage was primarily to preserve the pervious void-structure stability in the plastic state, and secondarily to add at least a chance for improved crack-control in the hardened state, though low dosages of micro fibers could not be expected to contribute to long-term durability to any major degree based on their history in conventional concrete. The advent of second-generation macro fibers offered the potential for higher possible dosages, and therefore the hope for resulting increases to toughness and durability. Perhaps the larger question was the capacity of macro fibers at high dosages to be user-friendly on real-world pervious projects, and be compatible with the unique air-void mixes involved.

Project Trials and Applications

Over the years, discrete fiber technology has often broken many historic concrete rules associated with conventional single-plane reinforcement, and therefore it is often challenging to prove their worth in advance for a given application. As a result, educated judgment based on previous results and research often plays a large role in expanding the application envelope. Based on this judgment, successful projects are often placed early in development in order to build a collection of job data to help further refine future use and recommendations based on new 'fiber rules'. For FORTA Corporation, the use of synthetic fibers in pervious concrete has followed a similar pattern, progressing from recycled fibrillated micro fibers, to experiments and trial projects with synthetic macro fibers. After study of the 4 important fiber characteristic variables (fiber shape, chemistry, length and dosage) that can be altered to impact a particular application, the focus for pervious began to lean towards longer fiber lengths and higher dosages as the best opportunity to increase pervious concrete toughness and durability. Even fiber shape and chemistry were varied to that end, and a variety of fiber-characteristic projects were placed over the past several years.

Thomas Concrete Pervious Pavement Pad - March 2009

Owner: Thomas Concrete of Georgia, Atlanta, GA
Pervious concrete supplier: Thomas Concrete
Contractor: PCI Systems LLC, Woodstock, GA, Dale Fisher
Fiber: FORTA® Green-Net® recycled fibrillated, 1 ½" long @ 1.5 lbs./cu. yd.

In March 2009, Thomas Concrete of Georgia placed a 6" thick traffic pad outside of their Q.C. office and lab in Atlanta, GA, as a point-to pervious concrete reference for local owners, contractors, and specifiers. Aware of previous history using small dosages of micro-monofilament fibers in pervious applications, their desire was to improve on the reinforcement potential by enhancing the fiber characteristics, and selected a longer, net-shaped fiber, at a higher dosage level – FORTA® Green-Net®. Green-Net® is manufactured from 100% recycled polypropylene materials, providing an additional eco-friendly advantage to green pervious applications. The fiber reinforcement objective was to add early stability to the plastic-pervious void structure, and additional subsequent toughness to the hardened-pervious cross-section, but depended on the fibers' ability to mix quickly and distribute uniformly without adding placement or finishing issues. The 30' x 60' pad was placed at 6" thick, on top of a 6" compacted limestone base to facilitate water percolation and run-off. The 1800 sq. ft. area involved 45 cubic yards of #89 stone pervious concrete, and was placed without control joints to evaluate future performance. The long-length fibrillated fiber mixed extremely well, and was not significantly noticeable on the surface finish, therefore creating no user-friendly issues. After over 4 years in service under relatively low volume traffic yet regular loader and crane conditions, the pervious pad, though not crack-free, continues to maintain a very porous matrix while providing a durable wearing surface for the owner.

Erie Art Museum Pervious Parking and Delivery Pad - July 2010

Owner: Erie Art Museum, Erie, PA
Pervious concrete supplier: Baycrete Ready-Mix, Erie, PA
Contractor: Maya Brothers Inc., Erie, PA
Engineer: Civil and Environmental Consultants, Pittsburgh, PA
Fiber: FORTA® Green-Net® recycled fibrillated, 1 ½" long @ 1.5 lbs./cu.yd.

The July 2010 Erie Art Museum $9 million expansion and renovation project in Erie, PA, involved a variety of interior ground and polished fiber-reinforced floors, as well as 1,300 sq. ft. of exterior pervious parking and delivery areas. As part of the LEED silver-level project, the eco-friendly pervious parking lot area was further enhanced with the recycled FORTA® Green-Net® fibrillated fiber. The use of pervious pavement allowed for manageable storm-water runoff on this slope-challenged project layout, and allowed for a more efficient percentage of interior vs. exterior lot usage. The Green-Net® fiber length was 1 ½", with a dosage of 1.5 lbs./cu. yd. to add additional pervious concrete toughness under loading and abrasive turning-radius delivery areas. Though the fiber length and dosage were greater than conventional fiber usage in pervious applications, placement contractor Maya Brothers Inc. experienced no difficulties in mixing, placing, or finishing the three-dimensional fiber reinforcement. Combined with the sustainable use of polished concrete floors within the museum showroom areas, the Erie Art Museum project was the recipient of the 2010 World of Concrete GreenSite Award for Institutional applications.

GRTA Park & Ride – November 2010

Owner: GRTA – Georgia Regional Transit Authority, Atlanta, GA
Pervious concrete supplier: Walker Concrete LLC, Stockbridge, GA
Contractor: Curb Specialists Inc., Conyers, GA
Pervious concrete consultant: Dale Fisher, Executive Director, National Pervious Concrete Pavement Association, Kennesaw, GA
Fiber: FORTA® Green-Net® recycled fibrillated, 1 ½" long @ 1.5 lbs./cu. yd.

The GRTA rapid transit parking lot represented the first large-scale project application for a more substantial synthetic fiber reinforcement, using 1 ½" Green-Net® at the previously trialed 1.5 lb./cu. yd. dosage. As evidenced in the previous smaller projects, the Green-Net® fiber mixed and distributed very uniformly for pervious concrete supplier Walker Concrete of Stockbridge, GA, and offered minimal visible evidence on the pavement surface finished by Curb Specialists Inc., Conyers, GA. Over 30,000 sq. ft. of 6” thick pervious pavement was placed in late November 2010 for the car-park lot of the Commuter Park & Ride facility in Newnan, GA. The Georgia Regional Transit Authority (GRTA) selected fiber-reinforced pervious concrete as an eco-friendly way to manage storm-water issues on their large site, which is a high-traffic commuter lot connecting Newnan to downtown Atlanta routes, cycling 13 times daily. To-date, GRTA engineers and site staff are pleased that the pervious pavement successfully drains surface-available storm-water, when other surrounding asphalt pavement areas continue to retain rainwater.

Georgia Association of Water Professionals - February 2011

Owner: Georgia Association of Water Professionals, Marietta, GA
Pervious concrete supplier: Thomas Concrete of Georgia, Woodstock, GA
Pervious concrete consultant: Dale Fisher, Executive Director, National Pervious Concrete Pavement Association, Kennesaw, GA
Fiber: FORTA® Green-Net® recycled fibrillated, 1 ½” long @ 1.5 lb./cu. yd., and FORTA-FERRO® synthetic macro fiber, 1 ½” long @ 7.5 lbs./cu. yd.

In March of 2011, the Georgia Concrete and Products Association sponsored a pervious concrete clinic and demonstration at the site of the Georgia Association of Water Professionals headquarters in Marietta, GA. The 6” thick pervious pavement replaced over 1,500 sq. ft. of deteriorated asphalt parking spaces, using two types of synthetic fiber reinforcement to add durability to the light and medium-to-heavy duty pavement areas. Performed with industry-donated materials and volunteer labor, the project was intended to demonstrate the placement and finishing practice of pervious concrete, as well as expose the user-friendly nature of fiber reinforcement. The light-duty parking space areas were reinforced with 1.5 lbs./cu. yd. of 1 ½” Green-Net® recycled fiber, and the medium-to-heavy duty parking and driving areas used 7.5 lbs./cu. yd. of 1 ½” long FORTA-FERRO® macro fiber that contains a majority of a heavy-duty filaments with a small portion of fibrillated fibers. In both cases, the fibers mixed and distributed well, and offered minimal visible evidence on the pavement surface. Of special interest, laboratory work-ups prior to the laydown revealed a surprising 7%

increase in concrete yield with the high-volume macro fiber addition, which allowed for a reduction in cement and aggregate materials and cost in the resulting revised fiber mix. This yield-increase advantage will be an important facet to consider and experiment with on future trial projects.

FORTA Corporation Sidewalk Addition - June 2011

Owner: FORTA Corporation, Grove City, PA
Pervious concrete contractor: Maya Brothers Inc. LLC, Erie, PA
Pervious concrete supplier: Castle Builders Supply, New Castle, PA
Architect: Struxures Inc., Seneca, PA
Fiber: FORTA-FERRO® synthetic macro fiber, 1 ½" long @ 2.5 lbs./cu. yd.

After completion of a $1.5 million office expansion project at FORTA Corporation headquarters, a pervious concrete sidewalk was installed directly in front of the new office wing. The use of pervious concrete over a drainage bed and French drain system allowed designers more latitude for subsequent building and lot landscaping. The 75 ft. long x 5 ft. wide sidewalk was only 4" thick, and continues in front of the building to connect to a pervious concrete pad fronting an exterior elevator access door. The fiber showed little evidence at the surface, though it added considerable early stability to the high-void content concrete. In use, the pervious walk-way and entry pad handles heavy storm-water considerably faster than even the surrounding landscape bark-beds and natural soils.

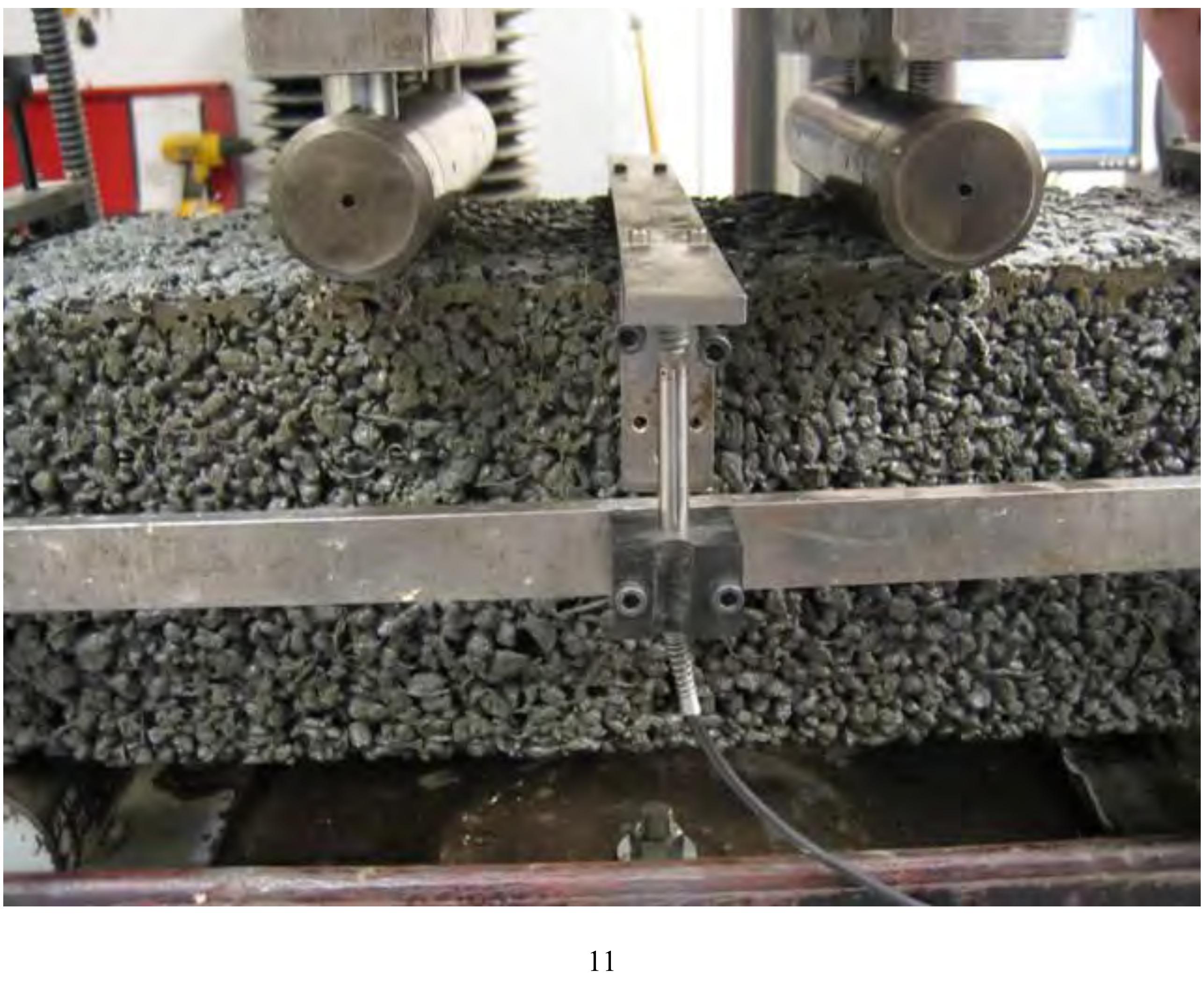
Auburn University Fisheries Center Pad - November 2011

Owner: Auburn University, Auburn, AL
Pervious concrete consultants: Dr. Michael Hein, Professor, Auburn University; Dale Fisher, Executive Director, National Pervious Concrete Pavement Association
Pervious concrete supplier: Couch Ready-Mix USA, Opalaka, AL
Fiber: FERRO-GREEN® synthetic macro fiber, 1 ½" long @ 5.0 lbs./cu. yd

Auburn University Professor Dr. Michael Hein organized a pervious parking lot project at the recently opened E.W. Shell Fisheries Center on campus. Placed on a 12" base of compacted #89 limestone over a geotech filter fabric, this 6" thick pavement was reinforced with a macro fiber blend of the FORTA-FERRO® heavy-duty filaments with the Green-Net® recycled polypropylene fiber, appropriately called FERRO-GREEN®. Due to the medium-duty expected traffic loads, 5 lbs./cu. yd. of the 1 ½" long fiber were used to add early stability to the void structure and ultimately add hardened toughness. This 540 lb. cement mix also contained an internal curing admixture and a hydration stabilizer to aid placement and compaction. Student labor from the College of Architecture and Building Science placed this 24 cu. yd. total pavement area project using a roller-screed/striker.

FRP Laboratory Research

Though considerable research has been performed on pervious concrete with regards to storm-water management, less has been done regarding the material's structural or durability capacity. Several laboratory programs have been performed in the U.S. and abroad with first-generation micro fibers, with the general results offering modest improvements to a variety of areas. These improvements, however, are limited by the inherent limitations of these micro-filament fibers with regards to length, shape, and dosage. The FORTA® goal has been to investigate toughness and durability improvements to pervious concrete with the addition of synthetic macro fibers, and hopefully determine benefit trends with regards to the fiber characteristics to further improve and define future recommendations and use.



An early attempt at testing FRP beams was performed in July 2011, where a small collection of macro fiber specimens were loaded per ASTM 1609-10 standards at TEC Services in Lawrenceville, GA. No control specimens were prepared for the small-scale program, and comparisons were limited as a result. The FRP specimens each contained the FORTA-FERRO® macro fiber at a dosage of 7.5 lbs./cu. yd., 2 ¼" long. The variation range of results was quite high for the specimens tested, which likely had more to do with specimen casting than the fiber contributions or test method deviation. The average peak load for the three tested specimens was 2,848 psi, the average deflection at peak load was 0.0033 in., and the peak stress average was 235 psi. Though the results have minimal value without comparison, the fracture dynamic for the FRP beams was quite interesting. Even after registering first-crack levels, the fiber-reinforced beams showed considerable recovery capacity which is indicative of historic FRC ductile behavior, and certainly creates a desire for additional future testing in this toughness area.

MTSU – CIM Program

As the interest in confirming macro fiber benefits continued, a preliminary directional program was instituted in the summer of 2011 at the CIM – Construction Industry Management laboratories of MTSU – Middle Tennessee State University in Murfreesboro, TN. After considerable discussion with Dr. Heather Brown, CIM Department Chair, the program intent was to focus on macro fiber shapes, lengths, and dosages, with a goal of revealing trends in various test areas that would lead to additional testing with narrower parameters in the future. In general, the test methods selected were intended to help pervious designers gain an understanding of how synthetic macro fibers affect both the pervious permeability capacity and the hardened strength-related areas as well. It was important to determine if fibers would block-off the pervious void channels in the cross-section or add benefit to the void structure, and how those results might impact eventual porosity and infiltration. The program was essentially divided into 2 general aspects, each involving 3 related test areas: 1.) void-related: unit weight, effective air voids, and infiltration, and 2.) strength-related: compression, modulus of rupture, and surface durability. Acknowledging the fact that many of the specimen-preparation methods and actual test procedures for pervious concrete are currently considered to be works-in-progress by a variety of ASTM committees and subcommittees, it was hoped that the preliminary FRP program would still offer direction and indicators of performance values that could be used and adjusted with confidence in the future. Mix design details and fiber parameters are noted below, along with a description of the various test methods utilized and the general results and commentary.

Test Mix Design (per cubic yard)

Cement………………………………… 540 lbs.
Fly ash………………………………… 100 lbs.
3/8" crushed limestone……………… 2600 lbs.
River sand……………………………… 0 lbs.
Water…………………………………… 150 lbs.
Viscosity modifier…………………… 2 oz/cwt
Superplasticizer……………………… 3 oz/cwt
Hydration stabilizer………………… 1 oz/cwt

Fiber Parameters of Focus

Type…………………………………... Synthetic macro fiber blend
Lengths………………………………… 1 ½", 2 ¼"
Dosages……………..……................. 2.5 lb., 5.0 lb., 7.5 lb./cu. yd.

Unit Weight

Per ASTM C 1688 Unit Weight, Density, and Yield of Pervious Concrete and ASTM Work Item 29212 Hardened Density and Voids, unit weights were recorded for the plain and fiber mixes, and the resulting density was determined for each. The unit weight for the control mix was noted at 110 pcf, while the 6 macro fiber mixes varied from a high of 113 pcf to a low of 108 pcf. Though the differences were relatively small, the case could be made that the mixes with lower unit weights would have greater void area as a result, and could lead to possible improvements to porosity and infiltration performance. The lowest of the macro fiber mixes was the 5 lb./cu. yd. dosage of the 2 ¼" long fiber, showing a unit weight of 108 pcf. While there appeared to be no firm trend to unit weight variance due to fiber length, the higher fiber dosages generally recorded lower unit weights than the low dosage mixes. This relationship between unit weight and density to fiber dosage would seem to suggest that increasing macro fiber dosage would not negatively impact porosity, and may, in fact, offer advantages in this void-space area, though additional fiber –to-void research is needed.

Effective Air Void Content

Per ASTM D 7063 Effective Air Voids Determination, the air void content for the control mix was rated at 24.4%, which is reasonable for, and representative of, a well-designed pervious concrete mix. Though common thought might suggest that fibers would actually reduce void content, this may only be the case for low dosages of synthetic micro fibers, and just the opposite for higher dosages of synthetic macro fibers. In fact, the trend that surfaced in the density testing continued in the void content phase, showing generally that higher fiber dosages resulted in the highest void content. The highest effective air void recorded was for the 7.5 lb./cu. yd. fiber dosage at 31.9%, an increase of 7.5% void content vs. the control. Again, this addition to void space due to increasing macro-fiber dosage would support the previous density evidence, and suggest ultimate contributions to porosity. This additional void-space dynamic also leads to discussions regarding increases to yield, with implications involving how to best use those changes. For instance, with a predictable void and yield response, designers could choose to anticipate higher yields with high-volume fiber use, or adjust the mix accordingly in order to save material costs in the mix, however it is important to consider the potential impact of higher void areas in other strength-related concrete areas.

Infiltration

Per ASTM C 1701 Infiltration of Pervious Concrete, the water infiltration rate in inches per hour was determined for the control and 6 macro fiber mixes. As the void-related results suggested, improvements to infiltration rates tended to be manifested by adding fiber dosage. In most cases, the longer fiber length per given dosage also recorded the higher infiltration rate. In fact, the highest recorded infiltration rate of 2,074 inches/hour was recorded for the long 2 ¼" fiber at the highest dosage of 7.5 lbs./cu. yd., which was considerably higher than the 1,384 inches/hour for the control, representing a noticeable 50% improvement.

Compressive

Per guidelines established in ASTM Work Item 29213 Compressive Strength, cylinders were cast and tested at both 7 and 28 days. Historically, pervious concrete has shown a high level of variability in compressive strength testing, some reports showing variability higher than 30%, which would indicate that a higher number of specimens should be tested than the 3 each of each mix in the MTSU program. The fiber results were equally inconclusive in this program, though some general trends may possibly be gleaned. In almost all cases, the control values at 7 days (1525 psi) and 28 days (2000 psi) were higher than the macro fiber mixes, though after review of the void-space data, this may be quite understandable. When the air void results are related to the compressive results, there is a general trend that appears to be quite logical regarding pervious concrete: the higher the voids, the lower the compressive strength. This pattern was also revealed in the macro fiber mixes, where the higher void mixes showed lower compressive strength results. However, the highest comparable fiber mix was the 7.5 lb dosage of the 1 ½" long fiber at 1,750 psi at 28 days, even though this mix reported the highest air void content of almost 32%. Additional future testing in this area is needed to develop fiber dosage and length trends, and should include consideration of mix adjustments to accommodate comparable void/compression relationships. Further, future compressive testing might include at least visual comparisons of 1st-crack vs. ultimate failure dynamics with high-fiber mixes, which would be a valuable concept for designers and owners.

Modulus of Rupture

Per ASTM C 78 Flexural Strength standards, modulus of rupture results were also recorded for the control and 6 macro fiber mixes. Again, future MOR research might include a higher number of specimens to reduce deviation levels. In all but one fiber case, the macro fiber mixes broke at levels notably higher than the control. The control average was 115 psi, and the highest macro fiber result was 215 psi. In all cases, MOR benefited from a longer length fiber. As with compression, future research showing post-crack behavior in an MOR dynamic would be very helpful to predict additional long-term durability benefits afforded by fibers.

Surface Durability

Per ASTM Work Item 23667 Surface Durability under the jurisdiction of ASTM subcommittee C 09.49 Pervious Concrete, pervious concrete pucks were tested to determine the percentage of material loss as dictated by this work-item method. In coordination with the MTSU-CIM program, this testing was completed by the AMEC Geotechnical and Construction Materials Laboratory in Nashville, TN. Commonly known as the L.A. Abrasion Test, the presumption is that a lower percentage of material loss indicates improvements to pervious toughness, based on a combination of impact, abrasion and fatigue conditions. The control specimen resulted in losses of 37%, and all fiber mixes showed equal or considerably less percentage losses. Both of the 5.0 lb. dosage fiber mixes reported the lowest losses, at 30% and 29% for the 2 ¼" and 1 ½" lengths respectively.

MTSU and Future Research Summary

Based on the preliminary and directional MTSU test program, several trends and tendencies became apparent that bear additional consideration and testing. The potential concern that the use of synthetic macro fibers would deter benefits to pervious concrete's permeability and flow-rates appeared to be in question, at least for mixes that are not adjusted for density. In this light, a void-structure study would offer rationale for certain hardened-concrete test parameters, such as compression, to be re-considered in future testing, to adjust the mixes to allow for a comparison of true and equal material densities. Of special importance were the macro fiber enhancements to both flexural strength and surface durability, which bodes well for the opportunity of synthetic macro fibers to make good on the premise of adding toughness and durability to all sorts of pervious concrete applications. Though optimum fiber trends were somewhat challenging to detect, the MTSU program showed clear indication that longer fibers improved durability, modulus of rupture, and infiltration, and in general, higher fiber dosages offered improved results in most test areas. Future research will hopefully be able to narrow the possible fiber and mix variables, and reduce the testing variability to add to the confidence level of pervious specifiers and owners. In addition, future testing may consider additional hardened-concrete test methods and specimens, such as a rotating-wheel or rotating-ball abrasion type test, to further define and reveal additional toughness benefits along with improvements afforded to post-crack and ductile-failure dynamics offered by high dosages of synthetic macro fiber reinforcement. Another desirable test area would be comparisons of freeze/thaw results at various fiber concentrations and lengths, which would hopefully reveal fiber contributions to both post-crack behavior and cohesiveness in hardened pervious concrete under these conditions.

University of Missouri @ Kansas City Program

Based on the results and direction garnered from the MTSU research program, a more focused and extensive testing program was needed to further investigate the effect of synthetic macro fibers on a variety of pervious concrete characteristics. This program – "Investigating the Durability of Pervious Concrete Reinforced with FORTA® FERRO-GREEN® Macro Fibers" was conducted in 2012 by John T. Kevern Ph.D., PE, LEED AP, Assistant Professor of Civil Engineering at the University of Missouri – Kansas City. Dr. Kevern has been evaluating pervious concrete mixtures and allied test methods for over a decade, and is considered a national expert and source for pervious concrete knowledge and engineering for a variety of U.S. code and standard bodies. The program included a wide variety of plastic and hardened pervious concrete parameters, including fresh workability, unit weight, fresh density, void content, hardened unit weight, permeability, infiltration, compressive and tensile strengths, surface abrasion, raveling, and freeze-thaw durability. The testing regimen was designed to determine an optimum combination of fiber dosage and length of the FERRO-GREEN® synthetic macro fiber that would improve pervious concrete durability. Unlike the previous MTSU program, this testing carefully considered the void content of all plain and fiber mixes, keeping it fixed and tightly controlled through sample production in order to evaluate only those effects caused by the fibers. The design void content of all mixes was 25%, and allowed for relative comparisons of the fibers' impact on strength and related properties.

Test Mix Design (per cubic yard)

Concrete mixture proportions were selected to determine the effects of the 6 fiber combinations of length and dosage on pervious concrete material properties, with the baseline mixture similar to ones currently used throughout the United States. The porosity was fixed at 25% for all specimens, with a W/C ratio of 0.34.

Cement……………………………………………………………..573 lbs.
3/8" crushed limestone…………………………………………………..2175 lbs.

River sand……………………………………………………………….165 lbs.
Water……………………………………………………………………195 lbs.
High-range water reducer…………………………………………………4 oz/cwt
Air entrainer……………………………………………………………..2 oz/cwt
Hydration stabilizer……………………………………………………...6 oz/cwt

Fiber Parameters of Focus

Type…………………………………………………………………synthetic macro
Lengths…………………………………………………………………..1 ½", 2 ¼"
Dosages……………………………………………………………….2.5 lbs, 5.0 lbs, and 7.5 lbs/cy

Fresh Workability

Fresh concrete workability was determined using low-pressure gyratory compaction to quantify initial workability and the required compaction energy. Two gyratory indices were generated to help indicate workability and compaction energies: WEI – Workability Energy Index, and CDI – Compaction Densification Index. For workability, 3 of the fiber mixes (1 ½" long at 2.5 and 5.0 lbs/cy and 2 ¼" long at 2.5 lbs/cy) showed higher WEI levels than the control, meaning they were slightly more fluid and flowable than the control mix, while the remaining fiber mixes (1 ½" long at 7.5 lbs/cy and 2 ¼" long at 5.0 and 7.5 lbs/cy) showed lower WEI levels and were slightly less fluid than the control. For compaction, the fiber mixes resulted in higher CDI levels, meaning they had a higher resistance to compaction. The mixtures became slightly stiffer and had a slightly higher resistance to compaction with increased fiber dosage. These workability indices would appear to be quite logical, based on the uniform three-dimensional distribution of the long-length fibers throughout the matrix, and would indicate the potential hardened concrete value of the fibers' cohesive properties. Regardless, all mixtures had excellent workability and were classified as self-consolidating.

Fresh and Hardened Unit Weight

The fresh unit weight as determined by ASTM C1688 is often a good indicator of workability, and the fiber unit weight changes followed the workability results quite closely. For instance, the fresh unit weight for the shorter 1 ½" fibers did not vary significantly from the 121.8 pcf of the control mix at any dosage, while the longer 2 ¼" fibers resulted in slightly higher unit weights as dosage increased (124.4, 125.1, and 125.8 pcf). Interestingly, all of the fiber mixes of any length and dosage showed the same or lower hardened unit weights than the control of 116.8 pcf.

Hardened Void Content

As measured by ASTM C1754, the hardened void content of the control mix was 25.9%. Each of the 1 ½" fiber dosages showed slightly higher void percentages, while the 5.0 lb and 7.5 lb dosages of the 2 ¼" fiber showed slightly lower void percentages, such as the 7.5 lb/cy dosage at 23.1%. In general, the void content and hardened unit weight of all samples were similar and within the variability of the test methods.

Permeability and Infiltration

The permeability of mixtures was determined using a falling-head permeability test apparatus on 4” diameter x 6” tall cylinders, and infiltration was determined per ASTM C1701 on 14” x 14” x 6” slabs, which is a combination constant and falling head test.

Permeameter Testing (Green Water Shown for Contrast)

Infiltration Testing

Both permeability and infiltration were reduced in the fiber mixes compared to the control mix, however no statistical trends were observed with respect to fiber dosage rate. On average, the 1 ½” fiber mixes reduced permeability by approximately 30% from the control, and the 2 ¼” fiber mixes showed a reduction of 45%. For infiltration, both fiber lengths showed an average reduction of approximately 40% for the 3 dosages, and results were again quite varied, likely due to the random orientation of the fibers. The fiber mix average permeability of almost 1,000 in./hour and average infiltration rate of almost 200 in./hour are very high, and well above what is actually needed in the field. Though these water-penetration results should be acknowledged by pervious designers when considering fiber reinforcement, it is important to note that the vast majority of pervious pavements do not fail as a result of insufficient permeability - most pavement failures are attributed to lack of toughness and durability - and the hardened-property benefits afforded by macro fibers far outweigh any disadvantages.

Compressive Strength

Compressive strength testing was performed by averaging 3 specimens using 4” x 8” cylinders per ASTM C39. For the most part, there was no difference in compressive strength between the control and fiber mixes at either 7 or 28 days, though the higher fiber dosages and long length showed noticeable increases. It is generally accepted that macro fibers would not be expected to change the compressive strength of plain or pervious concretes.

Compressive Strength PSI

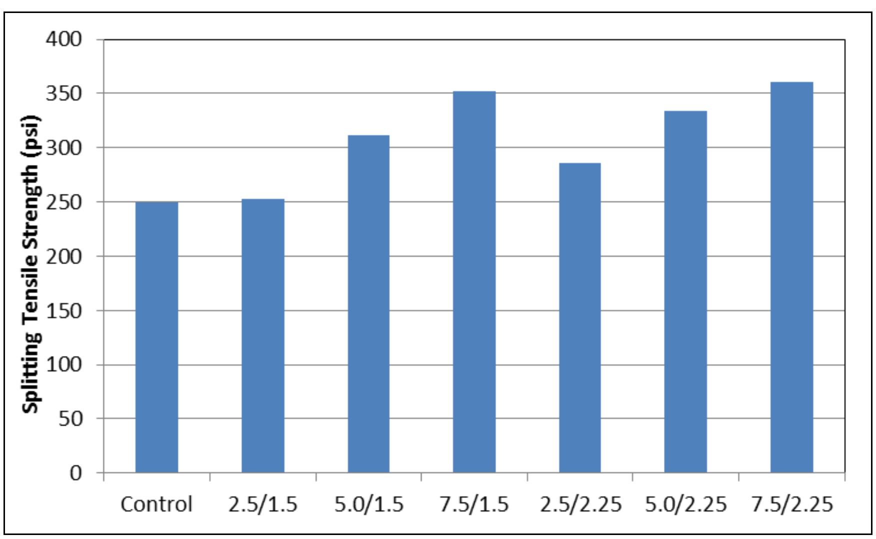
Mix	7-day	28-day
Control	2188	2423
2.5 lb/1.5”	2095	2265
5.0 lb/1.5”	2099	2635
7.5 lb/1.5”	2390	2501
2.5 lb/2.25”	1947	2257
5.0 lb/2.25”	2434	2858
7.5 lb/2.25”	2478	2457

Splitting Tensile Strength

Splitting tensile strength testing was performed by averaging 3 specimens using 4” x 8” cylinders per ASTM C496. All fiber mixes – both fiber lengths at all dosages – showed an increase in tensile strength over the control, and strength increased for each fiber length as dosage increased. Given the same fiber dosage, the longer lengths offered slightly higher tensile strengths ranging from + 3% to + 13 % vs. the shorter fiber. The greatest improvement to 28-day tensile strength over the control was the 7.5 lb/cy dosage of the 2 ¼” fiber, resulting in an increase of 44%. These improvements to tensile strength offer considerable weight to the claim of improved pervious concrete durability afforded by synthetic macro fibers.

Tensile Strength PSI, 28 day

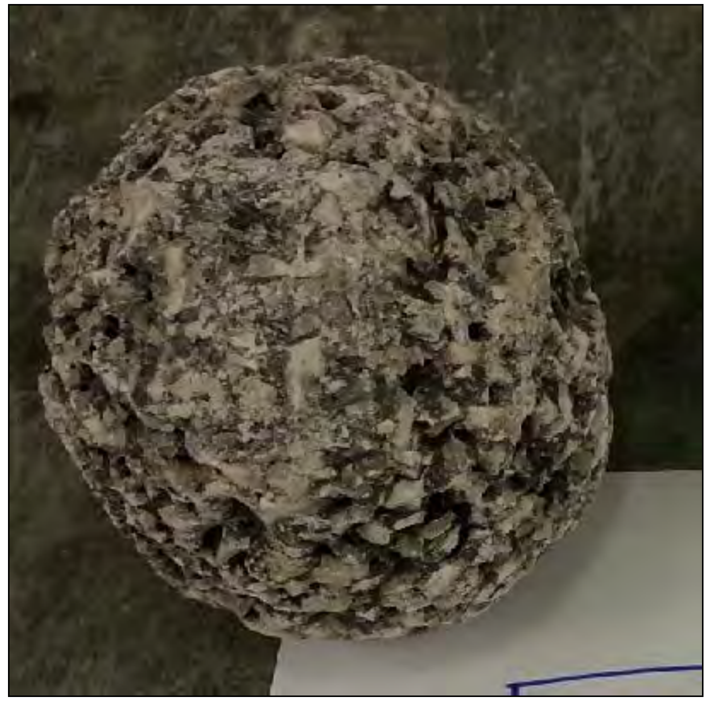
Mix	
Control	250
2.5 lb/1.5”	253
5.0 lb/1.5”	311
7.5 lb/1.5”	352
2.5 lb/2.25”	286
5.0 lb/2.25”	334
7.5 lb/2.25”	361



Average splitting tensile strength results for the various mixture

Raveling Resistance

The potential for early-age raveling was determined according to ASTM C1747. Three 4” diameter x 4” high specimens were cast per mix and then cured in sealed conditions for 7 days prior to the test. The hardened specimens were then placed in a standard LA abrasion revolving-drum device without the steel-ball surcharge, and mass loss measured after 500 revolutions. Durable mixes generally result in rounded spheres, where less durable mixes completely degrade into loose aggregate.



Raveling specimens before and after testing

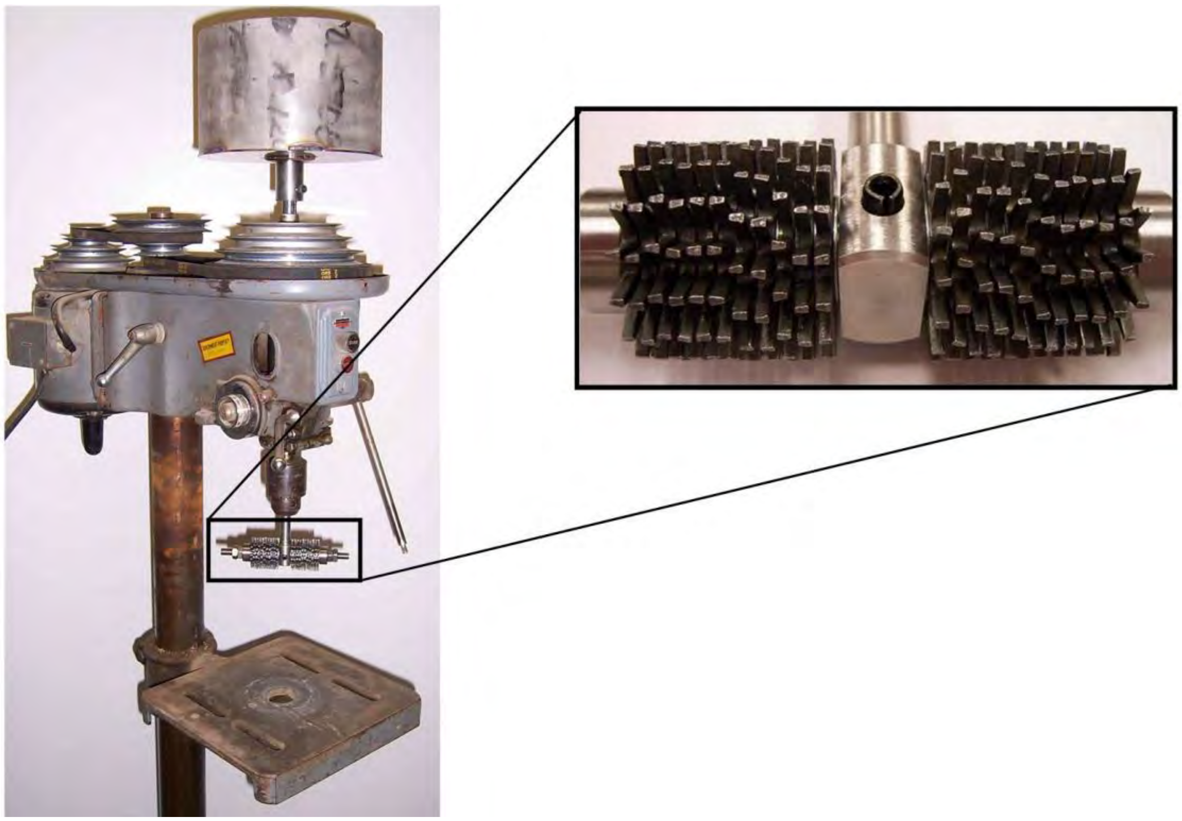
Fiber addition decreased the material lost in the LA abrasion test anywhere from 5% to 15%, though no trends were observed for fiber dosage or fiber length.

Raveling % Losses, ASTM C1747

Mix	
Control	28.6%
2.5 lb/1.5”	24.2%
5.0 lb/1.5”	26.5%
7.5 lb/1.5”	27.1%
2.5 lb/2.25”	26.0%
5.0 lb/2.25”	24.5%
7.5 lb/2.25”	26.2%

Surface Wearing

Surface wearing abrasion was determined according to ASTM C944, where a constant load of 22 lbs. is applied through rotary-cutter dressing wheels in direct contact with the sample surface. The diameter of the circular abraded area is 3.25”. The specimen beams were first cleaned with a stiff-bristled brush and vacuumed on all sides to remove any loose materials. After the 2-minute abrasion, the beams were brushed clean again and vacuumed. The mass loss between trials was recorded and averaged for the 6 specimens per mix.



Surface abrasion device

All fiber dosages and lengths resulted in significant abrasion improvement, ranging from 30% to 65% reduction in abraded losses vs. the control. Similar to the raveling results, there was no clear trend with regards to fiber length or dosage. The most common durability-related issues for pervious pavements in cold-weather climates are surface abrasion and raveling caused by snow-plowing exercises, and the contributions by the macro fiber in these areas are significant to the long-term durability in this regard.

Surface Abrasion Losses, grams ASTM C944

Mix	
Control	11.0 g
2.5 lb/1.5”	3.8 g
5.0 lb/1.5”	4.8 g
7.5 lb/1.5”	4.8 g
2.5 lb/2.25”	5.7 g
5.0 lb/2.25”	4.7 g
7.5 lb/2.25”	7.7 g

Freeze-Thaw Resistance

One of the primary concerns about using pervious concrete in northern portions of the United States and other cold-weather climates is the perceived lack of freeze-thaw durability. Though freeze-thaw deterioration of properly-draining pervious pavements is generally not observed in the field, the aggressive laboratory test regimen under worst-case scenario, completely-saturated, and rapid freeze-thaw cycling conditions, helps satisfy those concerns of specifiers and owners. Mixtures were investigated for freeze-thaw resistance using ASTM C666 procedure A where samples are frozen and thawed in saturated condition.

Freeze-thaw apparatus

The tests were completed when the specimen reached 300 cycles or a 15% mass loss, which was measured every 20 to 30 cycles. Also, a durability factor was calculated using both mass and relative dynamic modulus (RDM) criteria for each specimen.

Freeze-Thaw Durability

Mix	Mass Durability Factor	RDM Durability Factor
Control	53	14
2.5 lb/1.5”	38	12
5.0 lb/1.5”	53	7
7.5 lb/1.5”	85	21
2.5 lb/2.25”	89	40
5.0 lb/2.25”	91	41
7.5 lb/2.25”	96	44

The control specimens all failed suddenly between 180 and 210 cycles, for a cycle average of 187. The mix with the lowest fiber dosage (2.5 lb/cy) and the shorter length (1 ½”) failed at 133 cycles, generally failing via a single crack bisecting the specimens vs. the complete disintegration of the control failure. The fiber mix at 5.0 lbs/cy of the 1 ½” length also failed to complete the test, losing sufficient mass to end the test at 188 cycles. The remaining fiber mixes all completed the 300-cycle program easily, as reflected by the remaining-mass values considerably higher than the control. The RDM durability factors for those same fiber mixes were also considerably higher than the control – almost 3 times as high for the long-fiber mixes.

Even more compelling than the measurable mass losses and durability factor levels were the actual photographs of representative specimens for each mix. The non-fibered control mix lost complete integrity at a failure of 187 cycles. The 2.5 lb/cy dosage of 1 ½” fiber did not complete the 300-cycle program, but failed in a single-crack mode at 133 cycles. The higher 5.0 lb/cu yd dosage of 1 ½” failed at almost the identical 188 cycle mark as the control, but still retained remarkable integrity compared to the control. All of the remaining fiber mixes (7.5 lb/cy of 1 ½”, 2.5 lb/cy of 2 ¼”, 5.0 lb/cy of 2 ¼”, and 7.5 lb/cy of 2 ¼”) all completed the 300-cycle program, with the shape and condition of the specimens improving dramatically with increased fiber dosage.

Control mixture failed at 187 cycles with complete loss of integrity

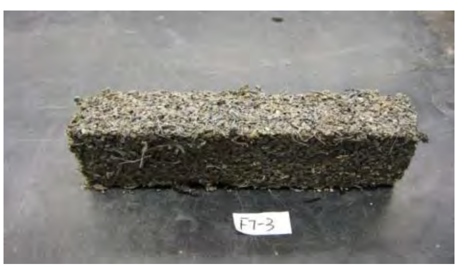
1 ½” fiber at 2.5 lb/cy failed at 133 cycles in single-crack mode

1 ½” fiber at 5.0 lb/cy failed at 188 cycles yet retained integrity

1 ½” fiber at 7.5 lb/cy at 300 cycles

2 ¼” fiber at 2.5 lb/cy at 300 cycles

2 ¼” fiber at 5.0 lb/cy at 300 cycles



2 ¼” fiber at 7.5 lb/cy at 300 cycles retained almost complete integrity

UMKC Summary

The UMKC test program was designed to show the effects of the FERRO-GREEN® synthetic macro fiber on typical fresh and hardened pervious concrete properties, with an emphasis on those properties that would impact long-term durability, namely tensile strength, surface abrasion, and freeze-thaw durability. Considering only these 3 performance areas, Dr. Kevern suggested that an optimum fiber selection might be a 5.0 lb. dosage of the long 2 ¼" fibers, however other job-specific conditions might lead the user or specifier towards higher dosages of shorter fibers depending on the circumstances. The void content and hardened unit weight of all fiber and non-fiber samples were similar and within the test method variability. The addition of fibers increased the tensile strength for all mixes, and increases in dosage offered commensurate increases in strength. Raveling and abrasion were reduced for both fiber lengths and all fiber dosages. Freeze-thaw durability was substantially improved, especially with the long 2 ¼" fiber mixes. And the unique twisted-bundle, long-length FERRO-GREEN® macro fibers were user-friendly with regards to mixing and uniform distribution – the fibers were added initially to the mixing system with the coarse aggregates, and were fully dispersed and uniformly distributed in the final concrete. Based on the wide variety of test parameters in this program, a strong case can be made that the FERRO-GREEN® macro fiber can dramatically improve the long-term durability performance of pervious concrete pavements.

Standards and Industry Resources

As the use of pervious concrete becomes more commonplace in the United States, many national, state, and local organizations have become involved in the documentation, specification, and training efforts for this material and practice. Almost all of the state ready-mix concrete associations provide information and services promoting the use of pervious concrete to their members, many of which are seasoned veterans of the technology. Four national/international organizations have become the major voices for pervious concrete in the U.S., and supply a wealth of knowledge and information for all partners involved in a pervious concrete application.

ASTM

The American Society for Testing and Materials (www.astm.org) general committee for concrete-related aspects is Committee C09 Concrete and Concrete Aggregates, which currently maintains membership of over 1,100 concrete industry experts. C09 entails 46 subcommittees as well, focused on specific concrete materials and topics, including Subcommittee C09.49 on Pervious Concrete. This subcommittee has been a major force in developing standard test methods for pervious applications, such as C1688/C1688M-10a for Density and Void Content of Freshly Mixed Pervious Concrete and C1701/C1701M-09 for Infiltration Rate of In Place Pervious Concrete. In addition, a variety of new pending methods are constantly in process, such as work items WK29212 for Hardened Density of Pervious Concrete, WK29213 for Compressive Strength of Pervious Concrete, and WK23367 for Evaluating the Surface Durability Potential of a Pervious Concrete Mixture.

NRMCA

The National Ready Mixed Concrete Association (www.nrmca.org) has become a major clearing house for a wide variety of resources related to the materials and use of pervious concrete in 5 general areas: certification, instructional webinars, video resources, design assistance, and related publications. NRMCA developed and manages the "Pervious Concrete Certification" program, which allows specifiers to require only contractors experienced in the placement of pervious concrete to participate in these projects by demanding the successful completion of the pervious certification program. NRMCA also offers hundreds of webinar topics, including a

2-part program on "Understanding Pervious Concrete: Hydrological Design and Resources Software". A dramatic video proof of the storm-water capacity of pervious concrete is available via a NRMCA sister website at www.GreenConcrete.info, which also lists a variety of available NRMCA publications on the topic, including "Pervious Concrete Pavement". One of the most valuable tools NRMCA offers to designers is "Project Planning Assistance", which puts the association's worthy technical staff at the disposal of architects and engineers that need advice and direction with regards to pervious concrete applications.

ACI

As would be expected, the American Concrete Institute (www.concrete.org) has placed considerable emphasis on this developing technology by forming a committee specific to the application in 2001, Committee 522 Pervious Concrete. With a very simple mission to 'develop and report information on pervious concrete', the committee has grown to almost 90 voting and associate members involved with the material and application. This committee has been instrumental in creating a variety of reports and specifications on pervious concrete and its practice, including ACI 522R-10 Report on Pervious Concrete and ACI 522.1-08 Specification for Pervious Concrete Pavements. In addition, Committee 522 has sponsored educational sessions at conventions and other events, such as the two-part program "The Leading Edge of Pervious Concrete". Naturally, pervious concrete plays an important role within ACI's current emphasis on sustainability in concrete applications.

NPCPA

A more recent organization for the pervious cause is the National Pervious Concrete Pavement Association (www.npcpa.org) . This association's mission is "To expand and improve the use of pervious concrete as a preferred paving method by providing education and resources that enhance quality and performance", with a future goal of becoming the recognized and authoritative voice for pervious concrete. The NPCPA is formed of a 10-member Board of Directors with considerable expertise and background in the concrete and pervious concrete industries, and ably led by Executive Director, Dale Fisher, who has 26 years of pervious concrete construction experience and is one of the nation's foremost authorities on pervious concrete. NPCPA has become a valuable resource to the three general facets of the growing pervious community – designers, contractors and producers, and regulators. For designers, the association can supply specifications, plan details, and lunch & learn programs, as well as mix calculators and product and tool sources to contractors and producers. Regulators of storm-water systems are able to use NPCPA to acquire pavement maintenance programs as well as a valuable source of current available literature and research on pervious concrete. NPCPA also administers a popular seminar and workshop program to interested groups and owners – "Design for Pervious Concrete". FORTA Corporation was fortunate to be one of the founding members of this organization, and continues to play an important guiding role within the organization with regards to the potential for fiber reinforcement benefits to this growing application.

FORTA® Product Development for Pervious Concrete

As the company that initiated the synthetic fiber reinforcement industry in the U.S., FORTA® has continued to develop a wide variety of fiber characteristics to accommodate many types of application demands. As a producer of a full line of synthetic micro and macro fibers, FORTA® is able to offer any of the standard fiber types previously used in pervious concrete, and is uniquely positioned to develop and recommend fiber characteristics that will further enhance toughness and durability properties of the material. A study of these fiber characteristics can assist the designer, user, and owner in predicting the effects and performance in a particular application, and help increase the opportunity for a successful and more durable result.

Fiber Characteristics

Concrete reinforcing fibers are available in many shapes, chemistries, and lengths, each offering different benefits and results. In conventional concrete where fibers are encapsulated within the matrix, fibers are available in steel, fiberglass, cellulose, and a wide variety of synthetics. In pervious concrete, the fibers would be much more exposed to the elements, which limits the fiber choices that are appropriate. To-date, the fibers most often considered for pervious applications have been synthetic and cellulose. The following fiber characteristics focus on these fiber types, and allow the designer and user a basic fiber formula to help them anticipate what to expect from their use. This characteristic formula generally places these fibers into one of three performance categories or levels: Level 1 – monofilament micro fibers to reduce plastic shrinkage cracking prior to initial set; Level 2 – fibrillated or net-shaped micro fibers to reduce plastic and hardened shrinkage and control temperature-related cracking; and Level 3 – macro fibers to control temperature-related cracking and offer an additional measure of post-crack performance. Determining the proper fiber characteristics will help define and ensure the expected fiber performance results.

1. Shape

As in conventional concrete, the shape of the fiber affects not only several important ease-of-use aspects in pervious concrete, but also impacts the fibers' ultimate performance in the plastic and hardened concrete. To achieve a goal of reducing plastic shrinkage cracking during the early life of the concrete, i.e. the first 24-hours, a very fine, mono- or single-filament fiber shape is sufficient. To enhance the fibers' ability to reduce additional temperature related cracking, a deformed or net-shaped fiber should be considered. To accomplish a goal of temperature-crack control and added post-crack load capacity, a heavy-duty macro fiber filament shape should be used. Each of these shapes will have different degrees of effect on the fibers' mixability, uniform distribution, slump, and finishability.

2. Chemistry

Generally, glass and steel fibers are not considered appropriate in open-void pervious applications, since alkali and weather elements would be detrimental to the fiber performance, and pedestrian and vehicular traffic safety would be compromised. Short, fine fibers made of cellulose (paper) have been used in pervious applications to help reduce early cracking, and perhaps provide some level of internal curing by holding initial mix moisture. The most commonly used fiber in pervious has been polypropylene and various copolymer blends, which are non-absorptive, chemically inert, and non-corrosive. These synthetics can be produced in a variety of shapes and lengths, depending on the desired performance goals. Polypropylene fiber can also be made of recycled materials, which may add to the eco-friendly concept of pervious pavement applications.

3. Dosage

Fiber dosage is dictated, again, by the desired performance results, but may also be limited by the fiber shape. If Level 1 early-age crack control is the sole requirement, dosages of 1.0 to 1.5 pounds per cubic yard are typical. For enhanced Level 2 temperature-crack control performance, dosages of 1.5 to 3.0 pounds per cubic yard have become the norm. For Level 3 post-crack benefits, macro fiber dosages have ranged from 2.5 to 7.5 pounds per cubic yard, depending on the level of toughness desired. The fiber shape, chemistry, and length may all effect the optimum dosage levels for a specific fiber type.

4. Length

In conventional concrete, longer fiber lengths have proven to have improved hardened and post-crack values than shorter fibers, however fiber length will also affect mixability and distribution. Fine micro fibers are typically limited to relatively short lengths of ¼” to ¾”, while deformed net fibers range from ¾” to 1 ½” lengths. Synthetic macro fibers have been used in the small-aggregate pervious mixes in lengths of ¾”, 1 ½”, and longer 2 ¼”, though pre- project practice is typically recommended to determine the optimum length for a specific mix and aggregate.

Fiber Use Considerations

Many of the early considerations regarding the use of fiber reinforcement in pervious applications have been based on their compatibility to the actual mixing, placement, and compaction/finishing of the concrete. For instance, it is imperative that the variety of fiber shapes, chemistries, dosages, and lengths be tested to make sure they will allow for easy addition and mixing without fiber balling, and also allow for reasonable placement and compaction without creating major issues. Both laboratory mix mock-ups and real-world lay-down trials are highly recommended when changing the 4 most important fiber characteristic combinations. In general, early trial and project observations suggest that each fiber type must be optimized to facilitate the use of fiber in pervious applications, and each type may differ in suggested practice for best addition point and mixing time. Pervious concrete producers should rely on their fiber supplier for best-practice recommendations, as the same practices may not apply for all fiber types. The same principle applies for placement and compaction as well, and pervious contractors are encouraged to perform trials with the various fiber types to help them become familiar with possible nuances during placement.

Performance Levels and Fiber Type Recommendations

Current industry knowledge and research regarding fiber-reinforced pervious concrete would suggest the following fiber characteristics to accommodate three general performance expectations:

Level 1. Early shrinkage crack control and limited early stability – very fine filaments of polypropylene, used at a dosage of 1 pound per cubic yard of short ½” to ¾” length (FORTA® Mighty-Mono® monofilament fiber, packaged in 1.0 lb. bags)

Level 2. Shrinkage and temperature crack control with additional pervious stability contributions – deformed/fibrillated-net fibers of virgin or preferably recycled polypropylene, used at a dosage of 1.5 pounds per cubic yard of ¾” to 1 ½” lengths (FORTA® Green-Net® recycled fiber, packaged in 1.5 lb. bags)

Level 3. Shrinkage/temperature crack control, considerable stability enhancements, and improved post-crack performance, toughness, and durability - heavy-duty macro filaments of polypropylene and copolymers blended with recycled polypropylene network fibers, used at dosages of 2.5, 5.0, or 7.5 pounds per cubic yard of 1 ½” to 2 ¼” lengths (FORTA® FERRO-GREEN® synthetic macro fiber, packaged in 2.5 lb. bags)

As is the case in fiber-reinforced conventional concrete, it would be expected that maximizing each of the important fiber characteristics will also maximize the ultimate performance in pervious concrete applications. For instance, improvements to the fiber shape will allow for improved anchorage within the pervious matrix, therefore adding to the toughness. Using long fiber lengths will enhance the fibers’ ability to anchor and deflect load over a wider area, and minimize the potential for fiber pull-out. And as the fiber volume or dosage increases, improvements to toughness, durability, and abrasion resistance would be expected, and positive changes to concrete yield offers the possibility of additional mix economies. In all cases, mixes and materials should be tested with a particular fiber to ensure compatibility, and to properly balance the ultimate performance with the user-friendly demands for trouble-free placement. Based on the requirements and expectations of each FRP performance level, FORTA® altered existing fiber products or developed completely new application-specific fiber grades. The FORTA® Mighty-Mono® fiber represents a traditional Level 1 fiber for pervious concrete, and is typically used in ½” lengths at a 1 pound dosage per cubic yard. FORTA® Green-Net®, a Level 2 fiber, was designed specifically to address the eco-friendly aura of pervious concrete applications, and is produced using 100% recycled polypropylene materials. And FORTA® FERRO-GREEN® was developed to combine macro fiber technology with eco-friendly materials, to provide the best opportunity to improve pervious concrete as a Level 3 reinforcement.

Summary

Like any add-on material or new application method, fiber reinforcement must prove its merit value by balancing the cost vs. performance benefit equation. Depending on the reinforcement level selected by the specifier or project owner, synthetic fibers might add $0.015 per square foot/inch of thickness for low-dosage micro-fibers, or up to $0.115 per square foot/inch of thickness for high-dosage macro fibers. These related costs would then need to be evaluated from a benefit-over-time perspective to determine the value for short-term or long-term benefits afforded by the selected fiber type and dosage.

Though pervious concrete has proven to be a valuable construction material and technique for a wide range of storm-water related issues, the historic soft spot has been a question of long-term durability, which often limits the potential for more and heavier pavement applications. Project use and early laboratory research has already proven that an opportunity exists for macro fibers to answer this durability question, and future trials and testing will help quantify more closely the exact values that could be expected. There are many performance areas where fiber improvements could enhance the integrity of pervious applications, for instance improved early stability, improved preservation of void space and therefore permeability, possible reduction or elimination of control joints, less deterioration of existing joints, reduction of surface raveling, increased freeze/thaw resistance, the potential for improvements to fatigue or load capacity, and basic overall improvements to pervious pavement durability. Aside from changes in aggregates, cement, proportioning, and practice, synthetic fibers, as an integral reinforcement, represent the best opportunity to enhance the performance of pervious concrete and therefore improve its use with confidence in the future.

FORTA® personnel are available to assist with fiber selection and use, as well as the explanation of reasonable expectations of the fiber. FORTA® representatives do not engage in the practice of engineering or architecture as licensed by government agencies, nor are they licensed to act in a role of overall project supervision where FORTA® products are used. FORTA® personnel are available solely for the support of our customers - those that purchase and specify our products.

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