FORTA Corporation

Technical Report

STEEL-FREE MANHOLES

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Introduction

In 1978, FORTA Corporation introduced the concept of synthetic, three-dimensional fiber reinforcement to the concrete construction market worldwide. One of the major initial product applications was in a wide variety of precast products, such as burial vaults, step units, manholes and ornamental products. The FORTA® family of standard synthetic fibers enjoyed widespread use in precast applications as an alternate handling/temperature reinforcement to labor-intensive wire mesh.

During that time, FORTA® continued to study and develop a second generation synthetic fiber that could offer improved performance benefits and affect the structural properties of the concrete itself. In 1999, FORTA® introduced FORTA-FERRO® - a structural synthetic fiber that lives up to it's name – "Strong As Steel." This fiber has played an important role in the recent changes and development of testing and performance of precast manholes, and has allowed the manhole-producing industry to realize a valuable goal in producing durable and cost-effective steel-free products.

Problems With Steel

For lack of a better alternative, steel in various forms, has been used to reinforce precast concrete products for many years. This use, however, has brought with it a complimentary set of problems related to either in-place performance or the actual handling and placement of the steel.

Corrosion of reinforcing steel is a constant concern, and naturally affects the long-term durability and performance of the steel-reinforced concrete product. The "Steel Production Practices" guide of the NPCA (National Precast Concrete Association) specifies that the steel should be free of loose rust and dirt, and should also be free of form release agent. This is often difficult due to the insertion practice of the steel between the thin-wall form sides that have already been coated with form-release agents. Steel reinforcement offers no benefit to impact resistance, and is typically effective only after a crack in the concrete has occurred.

Steel reinforcement must be cut, bent, spliced, and placed within the precast forms, which is very labor-intensive and difficult in thin-wall forms. The handling of steel also adds a common risk for injury and can be extremely dangerous. The tolerance for the proper placement of the steel is only $\pm$1/4" per ACI (American Concrete Institute) 318, and the recommended minimum concrete cover over steel is 3/4" per ASTM (American Society for Testing and Materials) C-478. To prevent the steel from touching a form wall, chairs, wheels and spacers must be used to keep the steel from shifting during concrete pouring. These placement and performance deficiencies of steel reinforcement served as further incentive for FORTA Corporation to develop a level of fiber reinforcement that could serve as a viable alternative.

Development of FORTA-FERRO®

During the development of FORTA-FERRO® structural synthetic fiber, FORTA® utilized their 4-C's Fiber Performance Formula as a basis for improving each important fiber characteristic. By maximizing each of these characteristic areas, the FORTA-FERRO® fiber is able to improve on the level of steel replacement possible.

Configuration

The shape of the fiber is one of the most critical aspects with regards to anchorage and pull-out of the fiber reinforcement. Monofilament fibers that are very fine in diameter and round in shape do not anchor in the concrete as well as heavier, deformed fibers. Normal monofilament fibers would not be expected to act as a replacement for handling or structural steel, but would offer a reduction in shrinkage cracking and provide

protection of corners and edges of the precast product. Fibrillated net-shaped fibers offer a much greater resistance to pull-out, and as a result, have proven their ability to replace non-structural handling steel such as wire mesh in a variety of precast applications. To maximize resistance to pull-out and post-crack behavior, the FORTA-FERRO® fiber involves a blend of two fiber shapes: a fibrillated network configuration, along with an embossed (deformed) configuration in a heavy-duty filament size. This unique blend of shapes gives the FORTA-FERRO® fiber the ability to control temperature-related cracking as well as affect the structural properties of the concrete.

Chemistry

The chemical make-up of the fiber is extremely important if the fiber is expected to hold up in the aggressive alkali environment of Portland cement concrete. The fibrillated-net portion of the FORTA-FERRO® blend is made of 100% virgin polypropylene, which is inert to alkali and chemical attack. The heavy-duty filament portion is comprised of a proprietary blend of two synthetic monomers, resulting is a high density, high modulus copolymer. This copolymer is also inert to chemical and alkali attack, and creates a very high-strength fiber to improve performance and residual strength benefits.

Contents

During FORTA®'s structural fiber research, it became apparent that standard synthetic fibers such as fine monofilaments, and even fibrillated-network fibers, consist of a very high level of surface area on a per pound basis. As a result of this surface area, it becomes difficult to add sufficient quantities of these fiber types to approach structural reinforcement values, without robbing too much of the paste content of the concrete mix. Standard dosage levels for these fibers are generally 1.0 lb/cu yd for fine monofilaments, and 1.5 lbs/cu yd for fibrillated networks with upper dosage levels in the range of 3.0 lbs/cu yd. The unique blend of fiber shapes that make up the FORTA-FERRO® grade of fiber helps minimize the surface area levels, and allows dosage rates to be increased without affecting the rheology of the mix. To date, dosage rates for FORTA-FERRO® in various precast applications have ranged from 3.5 to 7.5 lbs/cu yd depending on reinforcement requirements, and even higher addition rates are possible with reasonable changes to the mix design.

Correct Length

With any fiber, the Critical Bond Length, which is the maximum length of fiber on either side of a potential crack, is an important consideration for long-term performance. Obviously longer fibers are better able to anchor within the concrete than short fibers that tend to lose their grip and pull out. The FORTA-FERRO® length of 2-1/4" (54mm) maximizes the fibers' Critical Bond Length, which allows the residual strength or post-crack performance to also reach their highest levels.

Current National Manhole Specifications and Test Methods

Many precast manhole products are regulated by local code bodies, either on a state or county level. These authorities are typically within various government agencies, such as an On-Site Wastewater Department, a Department of Environment and Natural Resources, and/or a Department of Health and Sanitation.

Two national bodies have also established standards and specifications for precast manholes that include recommendations for the production and testing of manholes. These national-level bodies – ASTM and NPCA – are typically recognized and acknowledged as acceptable sources of applicable and specifiable standards.

ASTM C-478 "Standard Specification for Precast Concrete Manholes" details all aspects of manhole production, such as materials, manufacturing, structural design and concrete strength. ASTM also specifies a form of "Proof Testing" as a method of demonstrating manhole performance: "Vacuum testing-seal the empty manhole and apply a vacuum to ten inches of mercury. The manhole is approved if 90% of vacuum is held for two minutes."

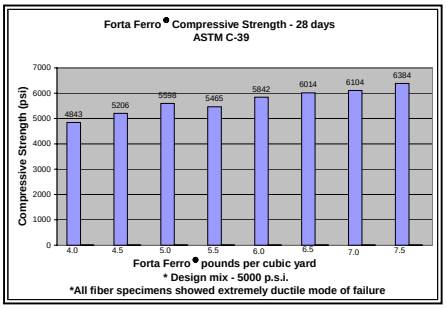
FORTA® Testing

Since its inception, the FORTA-FERRO® structural fiber has been rigorously tested in a wide variety of both laboratory specimen and actual composite manhole test procedures. FORTA-FERRO® fiber has

consistently shown dramatic advantages in the areas of ductility, impact resistance, shrinkage and residual strength, as well as in composite vacuum performance levels.

Compressive

In a recent program performed at the South Dakota School of Mines and Technology, FORTA-FERRO® was tested in compression using standard 6" x 12" cylinders (ASTM C-39) at various dosage levels. At the levels most often considered in precast manhole applications (.25 - .50% by volume, or 4 - 7.5 lbs/cu yd), there was a marked increase in compressive strength performance. More importantly, the mode of failure was reported as an extremely ductile one at all fiber dosages, instead of a conventional brittle and sudden failure. This advantage of enhanced ductility is naturally a very valuable feature to precast manhole producers.



Impact

FORTA-FERRO® has also shown dramatic improvement to impact resistance as tested by the ACI Committee 544 Drop Hammer test. Even at relatively low fiber dosage rates, over 300 blows were required to fail the FORTA-FERRO® reinforced test specimens. Naturally, resistance to shock and impact are important during the handling, delivery and placement of precast manholes.

Shrinkage

The unique fiber blend of heavy-duty filaments and fibrillated networks allows the FORTA-FERRO® fiber to offer structural performance as well as reductions to plastic shrinkage cracking. Conventional steel reinforcement, such as mesh, rebar or steel fibers, has no ability to control shrinkage-related cracking, and are typically effective only after the concrete has cracked. In recent testing at 7.5 lbs/cu yd, FORTA-FERRO® showed a remarkable 92% reduction in crack area caused by plastic shrinkage.

Residual Strength

Residual strength is the amount of load in psi that can be carried by the fiber reinforcement after the concrete has cracked. Fibers' ability to hold cracks tightly together is a necessary feature in a wide variety of precast products such as manholes. While standard-grade synthetic fibers may offer residual strengths of 25 to 75psi the FORTA-FERRO® structural fiber blend offers strengths of 150 to almost 300psi at dosages normally considered for manhole production. In the future, this modified beam test (ASTM C-1399) may also serve as a benchmark test method to compare the post-crack behavior of various fiber types and brands. FORTA Corporation has recently proposed revisions to manhole standards that include a minimum residual strength of 150psi for any fiber that is proposed as a steel reinforcement alternate.

Vacuum

In the past, it has been difficult, if not impossible, to determine the composite strength and performance of manholes. Tests could be run on laboratory concrete specimens, however these small specimens were not conducive to testing of the conventional steel reinforcement, and did not provide overall performance of the entire manhole.

The introduction of a standardized vacuum test procedure has given code bodies and manhole producers alike the ability to test the entire manhole product, and to compare alternative methods of reinforcement. The vacuum results, in inches of mercury, can also be translated into pounds per square foot of load on the manholes. These translations can then be applied to real-world, field load requirements, to help establish manhole design criteria. This relatively easy and inexpensive test method has afforded FORTA® the opportunity to show conclusive evidence that the FORTA-FERRO® structural synthetic fiber is a viable alternative to the expensive and labor-intensive process of conventional steel reinforcement.

FORTA® FIVE-POINT REINFORCEMENT PROGRAM

Precast Manholes

The following procedure formula has been prepared to assist your efforts when proposing the FORTA-FERRO® structural synthetic fiber as an alternate reinforcement to precast manhole producers. Our experience to date with this product and application has suggested that this 5-point program will not only increase the probability of success during initial testing, but will also insure us of continued reinforcement performance with each producer.

1. Hold A Pre-Trial Meeting
- Review local codes.
- Determine acceptable test methods and results by local authorities.
- Choose comparison reinforcements options for tests.
- Review mix design.

2. Initiate FORTA® Engineering Services Support
- Review manhole design and dimensions.
- Choose fiber options.
- Determine necessary FORTA-FERRO® fiber dosage based on engineering review.

3. Initiate Pilot Test Program
- Involve local code approval authority to witness casting.
- Prepare mixes and carefully record all data.
- Cast manholes as pre-determined.
- Store and cure manholes for 28 days.

4. Perform Composite Manhole Testing
- Again involve local code approval authority to witness testing.
- Pull vacuum on manhole submittal options.
- Verify and record all resulting data.
- Submit written results to code authority.

5. Complete Program Education and Training Program
- Provide instructional seminar for batching and production staff.
- Recommend and review options for periodic performance testing, such as annual vacuum tests, periodic beams/cylinders, etc.
- Recommend frequency for FORTA® technical update sessions for producer's administrative and production staff.

Opelika, Alabama

Structural synthetic fibers have gained alternate reinforcement approval in several areas of the United States, using the vacuum test process as a method to show compliance with ASTM and NPCA standards. As a starting point, the FORTA-FERRO® fiber was tested in Opelika, Alabama at 4.0 lbs/cu yd dosage in July, 2002, as an alternate to the normal wire mesh and rebar reinforcement. The manhole was a standard manhole produced by Alabama Precast & Pipe Supply LLC. The FORTA-FERRO® reinforced concrete reported a minimum compressive strength of 4,000psi at 28 days. The ASTM C-1244 "Standard Test Method for Concrete Sewer Manholes by Negative Air Pressure" was used to investigate performance levels of fiber reinforced manholes. With no visible cracks during the test, the FORTA-FERRO® reinforced manholes held 10 inches of mercury for two minutes with no loss in vacuum, thereby exceeding any local and national code performance levels. (See test-result confirmation letter below.)