Results from a five-year research program

Concrete pipes reinforced with polypropylene synthetic macrofibers

Steel fiber reinforced concrete pipes are currently used as an alternative to conventional steel reinforced concrete pipes in some regions of the world, such as Europe and Australia. However, there are concerns with corrosion of the steel fibers as larger cracks develop in the pipes. An extensive five-year research program was carried out at the University of Texas at Arlington (UTA) to evaluate synthetic polypropylene macrofibers as an alternative reinforcement for concrete pipes. The research was performed through collaborations with the American Concrete Pipe Association (ACPA) and its members, and BASF Construction Chemicals. A performance-based ASTM Specification, ASTM C1818 Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe, was developed as a result of the UTA research. The new standard describes a technically strong and durable reinforcement option that can be used for underground piping. Synthetic fiber is required to be prequalified for use in concrete pipes through long-term testing to show that the long-term serviceability factor, α, has a value of 0.90 or higher.

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Concrete pipes have traditionally been designed to have a circumferential steel cage (RCP) as the means of reinforcement, which resists tension in the member resulting from the flexural load exerted on the pipe. Steel cages are placed within pipe walls with at least 1 in. of concrete cover (ASTM C76). In a recent study at UTA, it has been shown that the addition of steel fibers into dry-cast concrete pipes provides an alternative method of reinforcement. In the study, it was determined that steel fibers could be optimized for use in concrete pipes to provide adequate strength, stiffness and the ability to withstand large crack widths. A performance-based ASTM Specification (ASTM C1765) for steel fiber-reinforced concrete pipes was developed based on the study.

A follow up program was carried out to expand fiber-reinforced concrete pipe research by testing polypropylene synthetic macrofiber. Polypropylene macrofibers have a long history of use in concrete applications such as slab-on-ground construction. Their non-corrosive nature makes them an attractive alternative to both steel cage and steel fibers. Concrete pipes reinforced with a commercially available polypropylene macrofiber have been evaluated with respect to the D-load requirements of various classes of pipes, with the D-load as defined in ASTM C76. In addition, the long-term performance of polypropylene fiber-reinforced concrete pipes was evaluated to address any concern about the expected time-dependent behavior of polypropylene fibers. The outcome of the research program has led to the development of a performance-based ASTM Specification (ASTM C1818) for use of synthetic fibers as primary reinforcement in concrete pipes.

Materials

Concrete mixtures

Two types of mixtures are used in precast concrete production: dry cast and wet cast. Dry-cast concrete mixtures, or zero-slump mixtures with water-cementitious materials ratios of about 0.34, are commonly used in concrete pipe production in the United States and were used to produce the pipes for this study. The cementitious content of the mixtures ranged from 500 to 720 lb/yd³ (300 to 430 kg/m³), which represents the typical range for dry-cast mixtures used in the concrete pipe industry. The mixtures were made with Type I/II Portland cement and Class F fly ash and achieved a 28-day compressive strength in the range of 4000 to 5000 psi (28 to 35 MPa).

Polypropylene synthetic macrofiber

Two basic polypropylene fibers are used in the concrete industry; microfibers with diameter less than 0.012 in. (0.30 mm) and macrofibers with diameter equal to or greater than 0.012 in. (0.30 mm). Microfibers are too small in size to effectively reinforce concrete. Macrofibers, on the other hand, have adequate size at an appropriate length to bridge cracks and enhance the post-crack strength of concrete. The synthetic macrofiber used was made of 100% virgin polypropylene. This monofilament macrofiber (shown in Figure 1) is rigid, stick-like, and embossed, and is commercially available as MasterFiber MAC Matrix produced by BASF Construction Chemicals. The fiber conforms to ASTM C1116 and D7508 and has an equivalent diameter of 0.03 in. (0.81 mm), a length of 2.1 in. (54 mm), and a tensile strength of 85 ksi (585 MPa).

Figure 1. MasterFiber MAC Matrix (polypropylene macrofiber).

Testing of concrete pipes

Full size concrete pipes with internal diameters of 15 to 48 in. (380 to 1200 mm) were used in the study. The wall thickness of the pipes was per ASTM C76 for each pipe size and pipe class. The fiber dosage needed to meet the ultimate strength requirement of a particular pipe class was determined through D-load testing.

The equipment used in manufacturing the pipes was either Packerhead or Hawkeye. The difference between the two types of equipment is the mode of compaction of the dry-cast concrete mixture, with the Hawkeye equipment being less sensitive to the water content of the mixture than the Packerhead equipment. The manufacturing equipment are shown in Figure 2.

Figure 3 shows a picture of a 36-in. diameter pipe immediately after production,

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along with pictures of the dry-cast mixture and a close-up of the finished surface of the pipe.

The D-load test setup is shown in Figure 4(a). For the long-term performance evaluation, the laboratory testing procedure followed the requirements in the ASTM C1818 Specification. This testing is required to prequalify a synthetic fiber for use in concrete pipes by determining a long-term servicea-

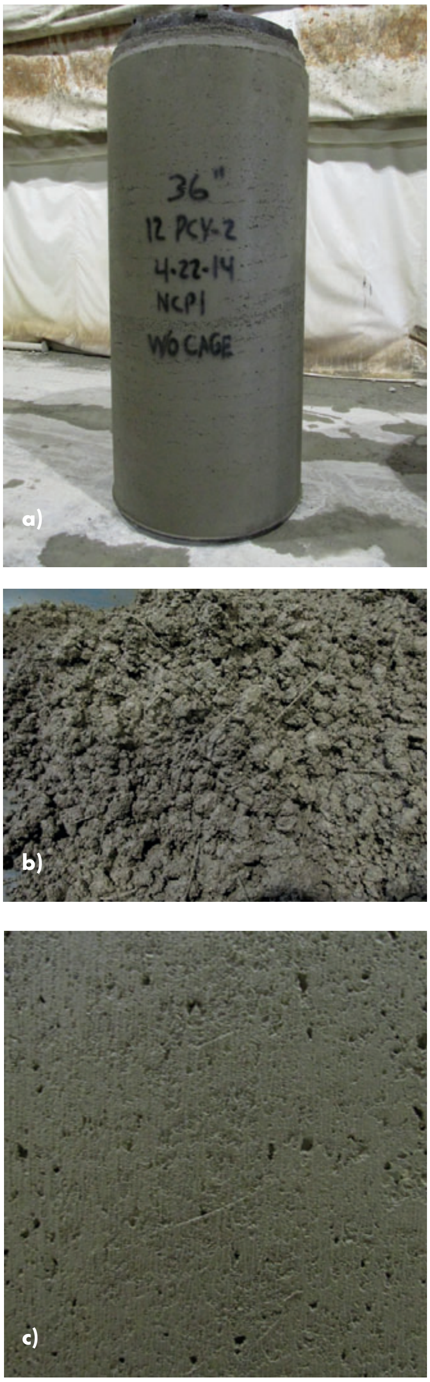

Figure 3. (a) Polypropylene fiber-reinforced concrete pipe immediately after jacket removal; (b) dry-cast concrete mixture (zero-slump mixture); (c) finished surface of the pipe.

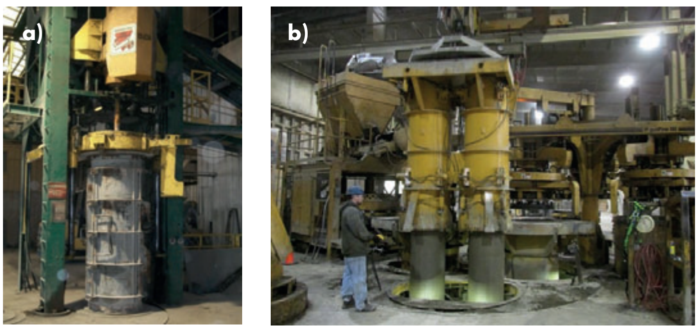

Figure 2. Manufacturing equipment: (a) Packerhead production; (b) Hawkeye production.

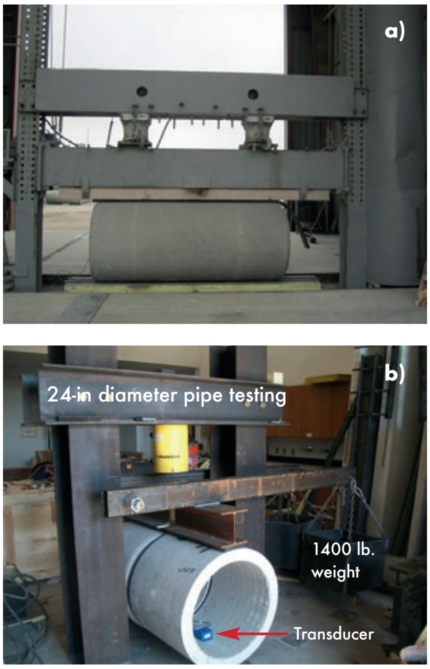

Figure 4. (a) Three-Edge Bearing Test or D-load test; (b) Long-term test setup. 24-in diameter pipe testing with 1400 lb weight. Transducer placed inside the pipe

bility factor, α, for the concrete-fiber composite. The value of α is required to be equal to or greater than 0.90 for a given synthetic fiber to be acceptable as reinforcement in concrete pipes. A loading system was designed to apply a constant load to the test pipe. A dead weight was hung at the free end of a cantilevered rod to apply the required constant service load over the pipe. Two 2-ft. (600-mm) length sections of pre-cracked pipe of the same diameter and pipe class were tested at a time. The test setup is shown in Figure 4(b) with a transducer on the inside of the pipe for vertical deformation measurements. In addition to the laboratory testing, field testing of buried pipes was performed to simulate the concrete pipe under sustained loading from soil pressure. Both un-cracked and pre-cracked Class III pipes of 24-in (600-mm) and 36-in. (900-mm) diameter were subjected to sustained service loads.

Test results

The level of load at which hairline cracks occur in the synthetic fiber reinforced concrete pipe is roughly equivalent to its ultimate load. That is, unlike RCP, SYN-FRCP is crack-free under service loads. Typical load-displacement curves for SYN-FRCP and RCP are shown in Figure 5, in which the fiber dosage (12 lb/yd³ or 12 pcy) is such that the ultimate load levels for both pipes are the same.

The measured vertical deformations for pipes with internal diameter of 36 in. (900 mm) in the sustained loading tests are presented in Figure 6. The long-term serviceability factor, α, is calculated from the vertical deformation using the following equation which is given in the ASTM C1818 Specification.

$$\alpha = ID_f / ID_o$$

where ID_o is the initial inside vertical dimension of the pipe and ID_f is the final extrapolated inside vertical dimension of the pipe. The figure shows that by 10,000 hours the deformations have levelled off at very small values, indicating excellent performance of the pre-cracked pipes in supporting the service loads. If the deformation has not levelled by 10,000 hours, the pre-cracked pipe must be evaluated based on extrapolating the deformation-time data to the target design life (e.g., 100 years). The deformation for the 36-in. (900-mm) diameter Class IV pipe was smaller than that for the Class III pipe as a result of the higher fiber dosage required to achieve the Class IV performance level in the same concrete mixture. However, the α values of 0.984 and 0.987, respectively, for the Class III and Class IV pipes are practically equal. A similar result was obtained for the 48-in. (1200-mm) diameter Class III and Class IV pipes which were manufactured with the same concrete mixture as the 36-in. (900-mm) diameter pipes. The α values for both the 36-in. (900-mm) and 48-in. (1200-mm) diameter pipes range from 0.982 to 0.987, indicating practically the same values. Hence, for a given fiber and concrete mixture, α has a constant value independent of size and class of pipe.

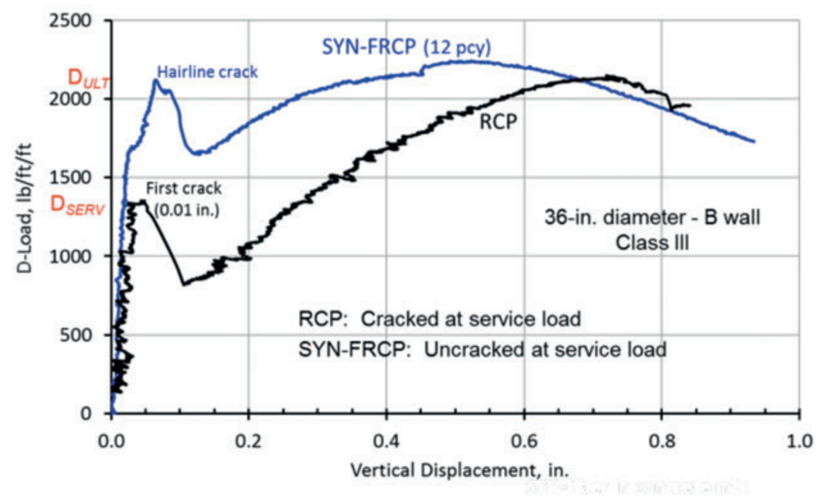

Figure 5. Load-displacement curves from D-load testing.

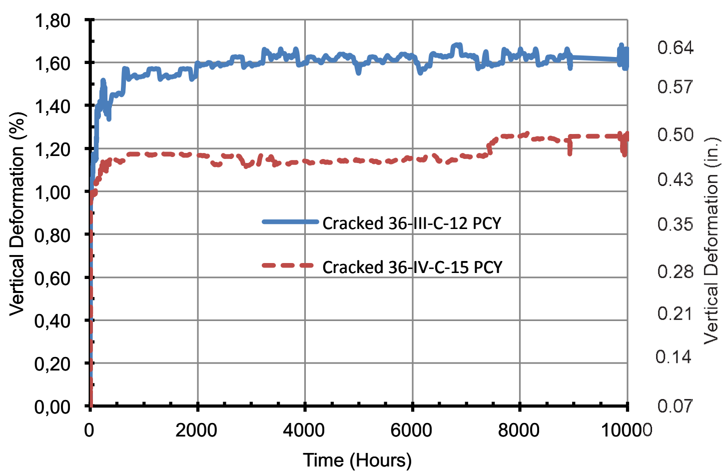

Figure 6. Deformation vs. time for 36-in. (900-mm) diameter pipes under sustained loading.

The values of the serviceability factor α range from 0.969 to 0.987 for the laboratory testing. The corresponding field data for the buried pipes range from 0.972 to 0.985, which are practically the same as the values for the laboratory testing. This narrow range of values was obtained for the concrete mixtures used in the study. Hence, conservatively, the average long-term serviceability factor α obtained with the polypropylene synthetic macrofiber used in the research program (MasterFiber MAC Matrix) is 0.97, which would cover the typical concrete mixtures used in dry-cast pipe production in the United States. For other synthetic fibers, the values of α must be obtained using the variety of concrete mixtures available for pipe production; this will determine if a single value can be used for the fiber in all the mixtures.

The excellent long-term performance of the pre-cracked pipes reinforced with the polypropylene synthetic macrofiber used in the research program shows that a synthetic fiber-reinforced concrete pipe that is cracked due to an accidental overload would have sufficient long-term post-crack strength in service if the creep deformations in the concrete-fiber composite are very low ($\alpha \geq 0.90$). If the pipe is designed appropriately, in accordance with current design methods for standard reinforced concrete pipe, the creep deformations will remain low, and there will be no problems.

FURTHER INFORMATION

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