FORTA Corporation
TECHNICAL REPORT

STEEL-FREE WALL SYSTEMS

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Introduction

In 1978, FORTA Corporation introduced the concept of three-dimensional synthetic fiber reinforcement to the construction market worldwide. One of the major initial product applications was in a wide variety of precast products, such as burial vaults, step units, tanks, 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 actual structural properties of the concrete itself. In 1999, FORTA® introduced FORTA-FERRO® - a structural synthetic fiber that lives up to its name – "Strong As Steel". This fiber has played an important role in the recent changes and development of testing and performance of a wide variety of precast products, and has allowed the industry to realize a valuable goal in producing durable and cost-effective steel-free products.

Problems With Steel

For a 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 N.P.C.A. (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 ± 1/4" per ACI (American Concrete Institute) 318, and the recommended minimum concrete cover over the steel is 1" per A.S.T.M. (American Society for Testing and Materials) C-1227. 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 a 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 in 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 3-1/2 to 7-1/2 lbs./cubic yard depending on reinforcement requirements, and even higher addition rates are possible with reasonable changes to the mix design.

Correct Length

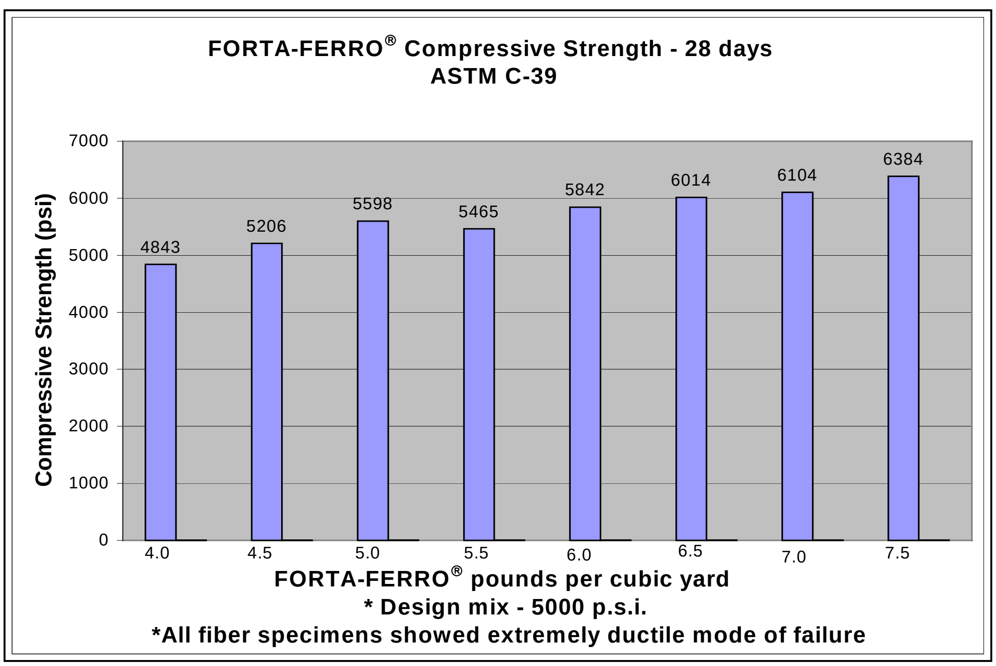
With any fiber, the Critical Bond Length, which is the maximum length of fiber on either side of a potential crack, is an important consideration for long-term performance. Obviously longer fibers are better able to anchor within the concrete than short fibers that tend to lose their grip and pull out.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

FORTA Testing

Since its inception, the FORTA-FERRO® structural fiber has been rigorously tested in a wide variety of both laboratory specimen and actual field 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 program performed at the South Dakota School of Mines and Technology, FORTA-FERRO® was tested in compression using standard 6" x 12" cylinders (ASTM C39) at various dosage levels. At the levels most often considered in precast applications (.25 - .50% by volume, or 4-7.5lbs./ cubic yard, 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 and unique failure mode is naturally a very valuable feature to precast producers.

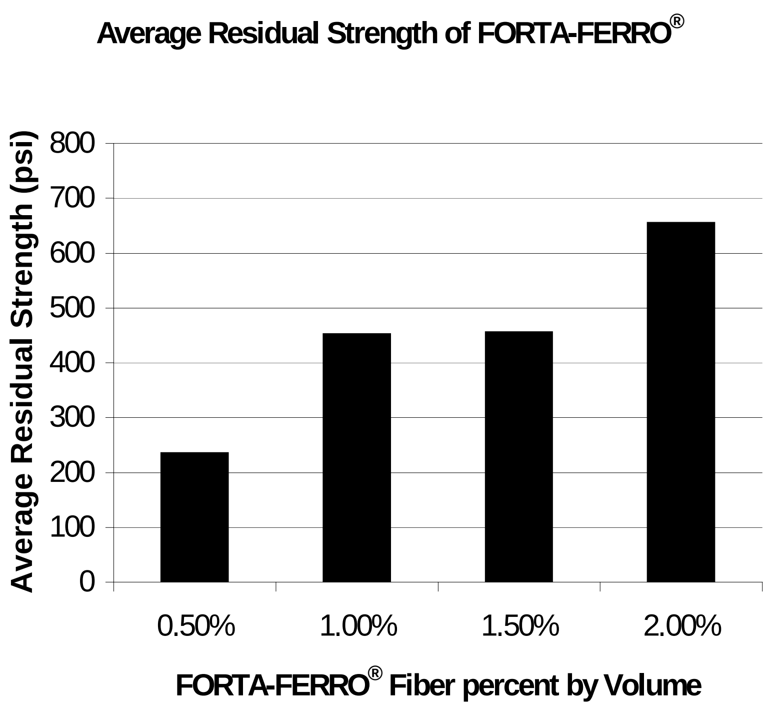


Shrinkage

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 testing at 7.5 lbs. per cubic yard, FORTA-FERRO® showed a remarkable 92% reduction in crack area caused by plastic shrinkage.

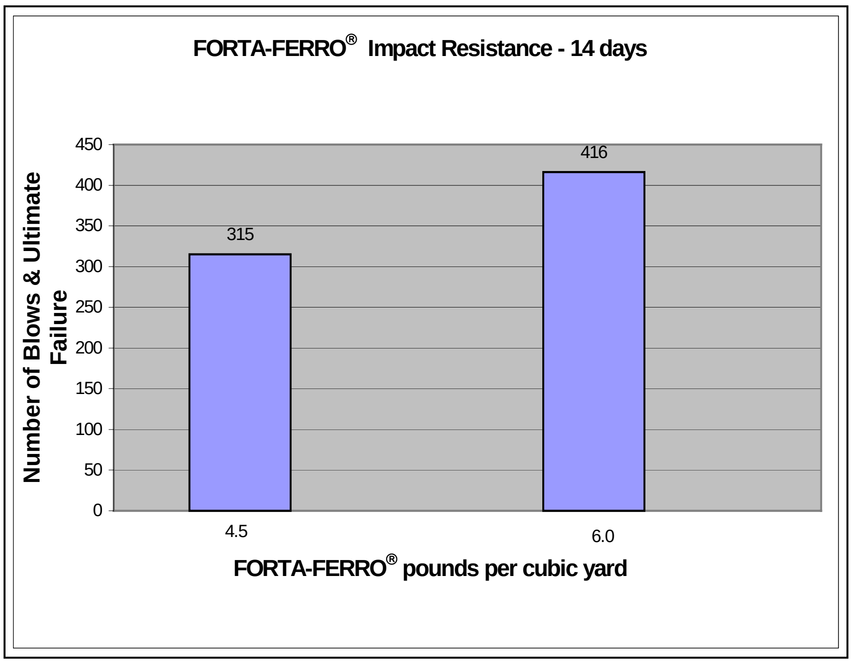
Residual Strength

Residual strength is the amount of load in p.s.i. 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 wall panels. While standard-grade synthetic fibers may offer residual strengths of 25 to 75 p.s.i., the FORTA-FERRO® structural fiber blend offers strengths 150 to almost 300 p.s.i. at dosages normally considered for wall panel production. In the future, this modified beam test (A.S.T.M. C 1399) may also serve as a benchmark test method to compare the post-crack behavior of various fiber types and brands.



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 panels.



Background / Introduction

In the spring of 2007, a producer of architectural wall panels approached FORTA Corporation. This producer was currently using a combination of rebar and wire mesh in both the wall panel and columns. The producer was unhappy with the performance and the result achieved with the steel reinforcement, and was looking for a cost-effective alternative that would achieve desired performance expectations.

FORTA®'s research of this non-load bearing wall application determined that there were many producers trying to achieve the same objective. Most producers were using some type of wire mesh/rebar combination to reinforce the wall panels, columns and footers.

Using the prescriptive method, FORTA® analyzed the existing design of steel reinforcement in a wall. This design called for a #4 bar around the perimeter of the wall, and in addition, 6 x 6 W4.0 x W4.0 wire mesh was called for in the center of the panel. Engineering calculations showed that 7.5 lbs./yd3 of 2-1/4" FORTA-FERRO® in addition to a #3 bar around the perimeter, would achieve the same reinforcement capacity as that of the originally designed steel.

Based on additional discussions with wall producers around the country, it was obvious that a performance-based test method would be necessary to fulfill the needs of many wall producers. The biggest hurdle to overcome would be finding a method to determine the capacity of the wall to withstand extremely high winds. In hurricane-prone regions of the country, building codes require structures to withstand wind loads of up to 150mph.

Objective

With this information in hand, FORTA® set out to accomplish the following:

1. Find an engineering firm that understood synthetic-fiber technology, and could provide engineering services to wall producers around the country.
2. Develop a performance-based test method to prove the capacity of fiber-reinforced wall systems as it related to wind loads.
3. Locate a progressive producer concerned with cost, quality and performance that would be able/willing to cast a variety of panels for testing.
4. Determine a dosage level that would achieve not only the desired wind load capacity, but also allow the producer a safe and cost-effective alternative to conventional steel reinforcement.

Test Method

FORTA Corporation partnered with Delta Engineers in Binghamton, NY. Delta Engineers has been working with synthetic-fiber reinforced precast concrete products for many years, and is licensed in forty of the fifty U. S. states.

The test method that was developed by Delta Engineers would simulate wind loads. The equipment necessary to complete the test consisted of:

- Reaction frame that would support each end of the wall panel similar to that of a column;
- Stable platform to apply a static load from;
- Hydraulic ram to apply the load;
- Pressure gauge to measure the load applied;
- Dial indicator to measure the amount of deflection;
- H-frame to distribute the load applied from the hydraulic ram over the face of the wall panel.

Reaction Frame

Stable Platform/H-Frame

Hydraulic Ram

Pressure Gauge

Dial Indicator

Initial testing was completed at C&M Precast in Kerrville, TX. A variety of different panels were tested. Some panels had a maximum thickness of 5”, while others had a maximum thickness of 4”. Some panels were reinforced with fiber only at a dosage of 6.0 lbs./yd3, others had 6.0 lbs./yd3 of fiber along with a #4 bar around the perimeter, and one panel was reinforced with 6.0 lbs./yd3, a #4 bar around the perimeter and 6 x 6 W4.0 x W4.0 wire mesh in the center of the panel. In addition, the entire wall system was tested as it would be installed in the field.

The test was conducted by the following method:

1. The wall panel was placed in the reaction frame.
2. The H-frame was hung and centered in the middle of the wall panel.
3. The hydraulic ram was positioned between the stable platform and the center of the H-frame.
4. The dial indicator was zeroed out and placed in the center of the wall panel on the opposite side of the hydraulic ram.
5. Force was applied via the hydraulic ram in increments of 200 psi as determined by the pressure gauge.
6. Deflection was measured at each 200 psi increment.
7. The applied force continued to increase until the wall panel cracked.

Pressure Gauge

Cracked Panel

Test Results

Panel #1 – Containing 6.0 lbs./cy of FORTA-FERRO® and (1) #4 perimeter bar. This panel was tested as it would be installed in the field with precast posts. Deflection was not measured.

Panel #1			
Gauge (psi)	Force (lbs)	W (psf)	Deflect. (in)
1200	3046	113	**
1400	3553	132	**
1600	4061	150	**
1800	4569	169	**
2000	5076	188	**
2200	5584	207	**
2400	6091	226	**
2600	6599	244	**
2800	7107	263	**
3000	7614	282	**
3200	8122	301	**
3400	8629	320	**
3600	9137	338	**
3800	9645	357	**
4000	10152	376	**

246 mph

Panel #2 – Containing 6.0 lbs./cy of FORTA-FERRO® fiber with no reinforcing steel and a stone face finish with a maximum thickness of 5”.

Panel #2			
Gauge (psi)	Force (lbs)	W (psf)	Deflect. (in)
1600	4061	150	0
1800	4569	169	0.01
2000	5076	188	0.024
2200	5584	207	0.039
2400	6091	226	0.055
2600	6599	244	0.078
2800	7107	263	0.086
3000	7614	282	0.098
3200	8122	301	0.11
3400	8629	320	0.138
3600	9137	338	Cracked

233 mph

Panel #3 – Containing 6.0 lbs./cy of FORTA-FERRO® fiber with no reinforcing steel and a stucco finish with a maximum thickness of 4”.

Panel #3			
Gauge (psi)	Force (lbs)	W (psf)	Deflect. (in)
1200	3046	113	0.008
1400	3553	132	0.044
1600	4061	150	0.068
1800	4569	169	0.086
2000	5076	188	0.108
2200	5584	207	0.13
2400	6091	226	0.155
2600	6599	244	0.173
2800	7107	263	0.195
3000	7614	282	Cracked

212 mph

Panel #4 – Containing 6.0 lbs./cy of FORTA-FERRO® with WWR 6x6 W4/W4 located in the center of the wall.

Panel #4			
Gauge (psi)	Force (lbs)	W (psf)	Deflect. (in)
1200	3046	150	0
1400	3553	169	0.011
1600	4061	188	0.037
1800	4569	207	0.047
2000	5076	226	0.061
2200	5584	244	0.078
2400	6091	263	0.094
2600	6599	282	0.107
2800	7107	301	0.122
3000	7614	320	0.138
3200	8122	301	0.152
3400	8629	320	Cracked

227 mph

Notes:

- cylinders were cast during the production of the wall panels; the average compressive strength of the test specimens was 6293 psi at 33 days.
- the pressure gauge was provided and calibrated by PSI Engineering; a chart was provided showing load (lbs.) versus pressure (psi).
- uniform loads (W psf) were calculated by setting the bending moment produced by a point load to an equivalent bending moment produced by a uniform load and dividing by the panel height (6’).

Determining Wind Loads:

Per American Society of Civil Engineers (CASE) guidelines, the following assumptions were made:

- Exposure Category: C
- ASCE Building Classification: II, (ASCE, Table 1-1)
- Gust Factor, G=1.3
- Structure is rigid and at grade.

Based on these assumptions, analytical procedure method #2 will be used to calculate basic wind speed. (ASCE Section 6.5)

Step 1 – Calculate velocity pressure (qz)

F = uniform load (W) / Gust factor (G)
Cf = force coefficient = 2.00 (ASCE Figure 6-21)
Af = projected area normal to the wind = 1.0 sf

qz = F / (G * Cf * Af)

Step 2 – Determine basic wind speed (V)

Kz = velocity pressure exposure coefficient = 0.85 (ASCE Table 6-3)
Kzt = topographic factor = 1.0 (ASCE Section 6.5.7.2)
Kd = wind directionality factor = 0.85 (ASCE Table 6-4)
I = importance factor = 1.0 (ASCE Table 6-1)

V = SQRT((qz / (0.00256 Kz Kzt Kd I))

Results

The minimum performance level achieved during the testing process was on panel #3, which contained 6.0 lbs./cy of FORTA-FERRO® fiber with no reinforcing steel and a stucco finish with a maximum wall thickness of 4”. The resulting basic wind speed was 212 mph.

The first panel tested was on an installed section. The only steel reinforcement was the #4 bar around the perimeter of the wall panel – the columns and the footer contained no steel reinforcing. The wall panel was not cracked in this set-up because it was believed the entire system would tip over before a crack occurred.

It is clear from the performance testing that wall panels reinforced with FORTA-FERRO® at sufficient dosage will exceed any building code requirements that exist in the United States, including those in hurricane-prone regions of the country.

There are many other benefits that FORTA-FERRO® can provide compared to conventional steel reinforcement:

1. Improved profit for the producer.
   -FORTA-FERRO® is less expensive than steel reinforcement.
   -There is virtually no labor with FORTA-FERRO®
   -FORTA-FERRO® is safer than wire mesh.
2. Improved performance.

COMPARE THE PERFORMANCE:	SYNTHETIC FIBER	VS.	REBAR/ WIRE MESH
* Reduces plastic shrinkage cracking?	Yes		No
* Increases impact resistance?	Yes		No
* Provides three-dimensional reinforcement?	Yes		No
* Reduces bleed water?	Yes		No
* Increases abrasion resistance?	Yes		No
* Arrives at job-site in place?	Yes		No
* Has ability to hold cracks together?	Yes		Yes
* Involves safety problems during placement?	No		Yes
* Involves corrosion problems?	No		Yes

<u>Sources</u>

Delta Engineering
2000 International Building Code
7-05 ASCE – Minimum Design Loads for Buildings and Other Structures
2008 Means CostWorks