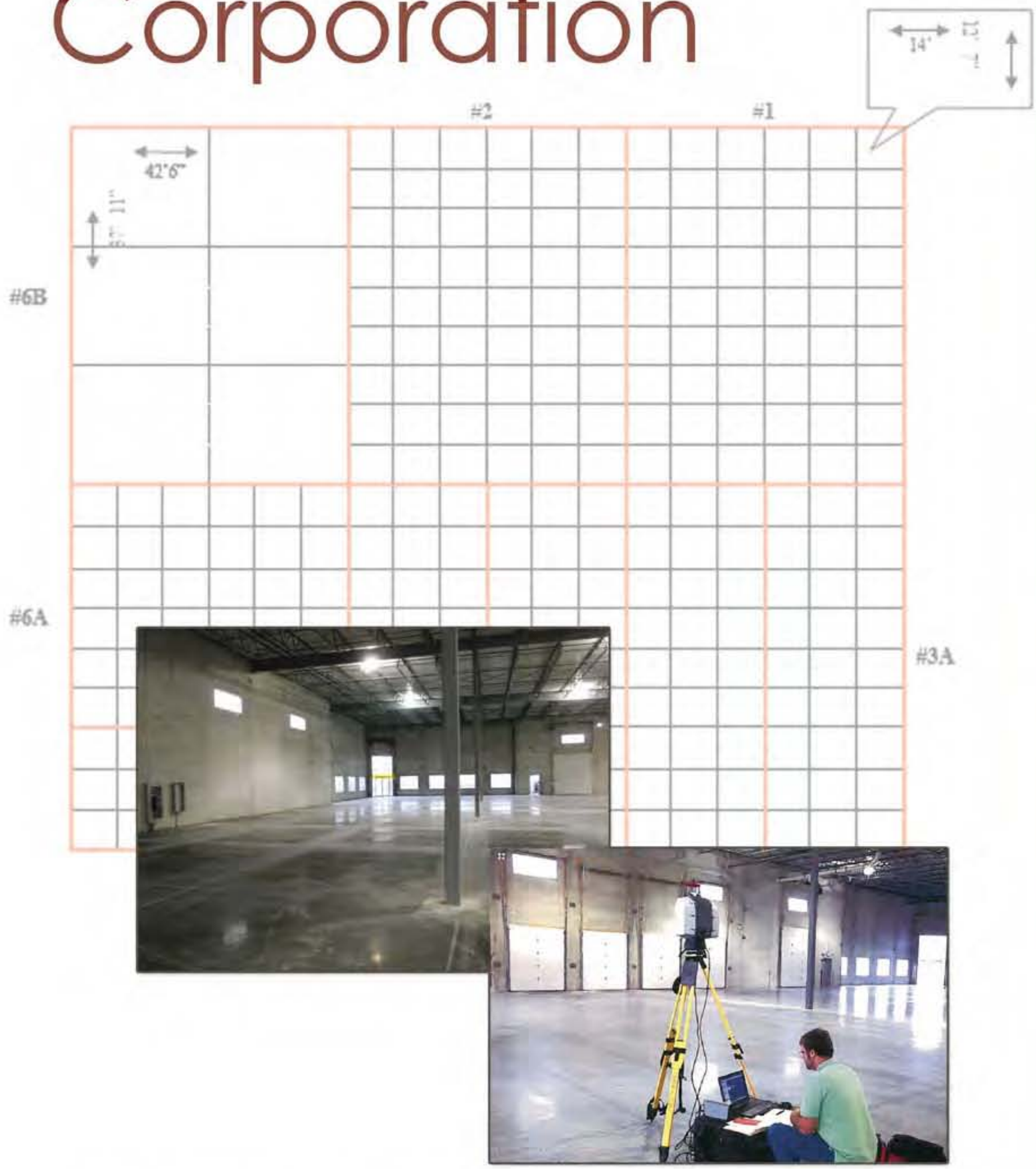
FORTA Corporation

Project Profile White Paper



Chicago Floor Study - Warehouse Floor
Bartlett, IL
February, 2009

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Owner:	Scurto Development Partners, Elgin, IL
Application:	Warehouse floor
Location:	Bartlett, IL
Project Date:	February 10-13, 2009
Concrete Contractor:	Scurto Cement Construction Ltd., Elgin, IL
Ready-Mix Supplier:	Elmhurst-Chicago Stone Co., Elmhurst, IL
Macrosynthetic Fiber:	FORTA-FERRO® macrosynthetic, 2-1/4" long; 3.0 and 7.5 lbs./cu. yd. dosage

Overview

CONCRETE CONSTRUCTION magazine, an internationally respected monthly publication of Hanley Wood LLC, sponsored a real-world study project in February 2009 to investigate and document ways to reduce shrinkage and curling in concrete floors. The project included a variety of variables that potentially affect shrinkage and curling, such as mix design, aggregate size and proportioning, chloride and non-chloride accelerators, rheology admixtures, finishing methods, and synthetic fiber reinforcement. Plans called for dividing the 60,000 sq. ft. warehouse floor into 5,000 and 10,000 sq. ft. sections using 9 different mixes, and monitoring and measuring floor flatness of representative panels over a 2-year period. FORTA Corporation, the pioneer of synthetic fiber reinforcement in the United States, was pleased to participate in the project, offer technical and field support to the steering committee, and donate over 3,000 pounds of macrosynthetic fiber. This white paper concentrates on the fiber-related aspects of the project, and includes the research, project history, ACI background, and general FORTA® fiber-floor philosophy, all of which led up to the Chicago experience. The report then concludes with the Chicago project details, joint practice, and 12-month curling results, along with a list of references used in the paper.

Macro-Fiber History/Background

FORTA Corporation introduced **micro**synthetic 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 (monofilaments) normally used at a dosage of 1.0 lbs./cu.yd., and deformed net-shaped polypropylene fibers (fibrillated) typically used at 1.5 to 3.0 lbs./cu. yd. Though it was well recognized in the laboratory that adding higher dosages would lead to considerably higher levels of shrinkage reduction, these fine-filament fibers created mixing and placing challenges due to their high surface-area characteristic. After years of research and trials, FORTA® introduced the first of its kind **macro**synthetic fiber in 1999 to solve the user-friendly issues at higher dosages. The solution keys became a twisted-bundle shape to eliminate balling, a polypropylene/ copolymer chemistry and long lengths to enhance strength, and a concrete-gray color and special fibril shape to accommodate finishability. For over 10 years, the result has made FORTA-FERRO® the most user-friendly macrosynthetic fiber in the industry, with scores of successful flatwork projects all over the world.

Fiber-Floor Philosophy

For many years, conventional steel mesh and rebar have been used in slabs-on-ground primarily as temperature/shrinkage reinforcement. This practice has been common for projects where requirements call for an unreinforced or lightly-reinforced floor, essentially putting the steel into the category of 'sleeping reinforcement', or that which only begins to work once the concrete cracks. Three-dimensional macrosynthetic fibers have been tested for their post-crack capacity by way of several toughness and residual strength test methods (i.e. ASTM C-1018, C-1399, C-1609), which has allowed design engineers to calculate a steel-to-fiber translation, arriving at a tension and/or bending equivalent. However, the great advantage of three-dimensional macrosynthetic fibers over single-plane steel reinforcement is the capacity to keep the concrete from cracking in the first place, by dramatically reducing concrete shrinkage and the subsequent slab-edge curling that results. As described and explained in the January 1999 CONCRETE INTERNATIONAL article "The First Commandment for Floor Slabs: Thou Shalt Not Curl Nor Crack"[1], slab curling and related joint failure may well be the largest single concrete floor issue encountered by building owners today. Rather than trying to add even more stiffness to an already rigid and brittle floor member, high volumes of macrosynthetic fibers tend to 'relax' the slab by allowing it to behave in a more ductile manner – essentially letting concrete act more like asphalt – while retaining a hard, durable wearing surface and maintaining a strong and tough capacity for loading. In addition to this ductile mode of behavior, the millions of high-tenacity synthetic fibers within the slab cross-section appear to absorb or accommodate the internal stresses caused by plastic and hardened concrete shrinkage. This combination of reduced shrinkage and slab relaxation led FORTA® and others to begin re-considering the conventional joint-space practices for slabs-on-ground.

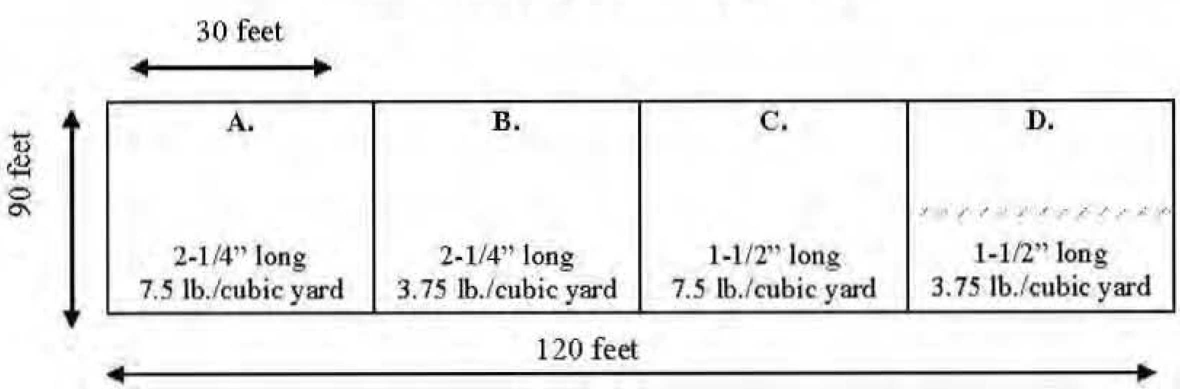
History of Joint-Space Extension

Laboratory research performed in 1999 at the South Dakota School of Mines and Technology confirmed dramatic reductions in plastic shrinkage with the use of the FORTA-FERRO® macrosynthetic fiber.[2] Even at a concentration of 0.5% by volume (7.5 lbs./cu.yd.), reductions of 92% were reported. Though the high-volume synthetic fiber laboratory results were impressive, the implications and potential ramifications to a real-world floor slab had not yet been put into practice.

However, in the spring of 2000, the idea of extending conventional joint-spacing was inadvertently put into play on an industrial floor project in western Pennsylvania.[3] In this case, the FORTA-FERRO® macrosynthetic fiber was accepted as an alternate to the conventional matt-steel reinforcement in a high-load and high-impact manufacturing floor, divided into 4 equal sections of 30' x 90' x 6" thick joined together by 3 key-way construction joints. Each section was to be used as a macro-fiber trial area by varying 2 fiber components: fiber length and fiber dosage. Though original plans had called for contraction-joint sawcuts to

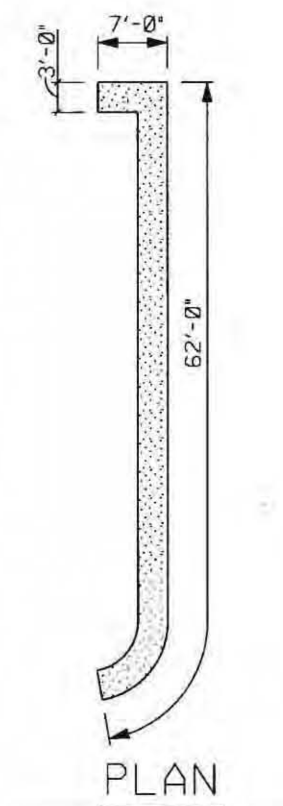
be placed in 15' x 15' sections, contractor delay resulted in the inadvertent decision to leave each 30' x 90' section joint-free and monitor the results. The only contraction joint installed was a 1-1/2" deep sawcut performed at the age of 7 days approximately two feet from slab edge around the perimeter of the entire 90' x 120' floor, to allow for slab movement and to potentially prevent the slabs from being restrained by the perimeter column foundations. At the 2-year mark, only 1 of the 4 floor panels exhibited a surface-visible crack – slab #D which had contained the lowest fiber dosage (3.75 lbs./cu.yd.) and the shortest fiber length (1-1/2") – which was located at approximately 45' of the 90' panel length. The remaining 3 slabs remain crack-free after 10 years in service.

Gilliland Pallet Joint Layout



Based on these somewhat surprising results, cores were taken from a variety of locations for further study using ASTM C856 "Petrographic Examination of Hardened Concrete", performed by world-renowned concrete petrographer Bernard Erlin of the Erlin Company, Latrobe, PA.[4] Of special note were the 2 core samples taken from areas where shrinkage cracks were likely to occur at planned sawcut positions, that showed zero evidence of cracking. The core specimen taken over the sole crack in panel #D showed fibers holding the core halves together, and the crack was described as ".....typical of cracks due to unaccommodated drying shrinkage". Knowing that concrete shrinkage does not typically just magically disappear, it would appear that fibers, given the proper shape, length, chemistry, and dosage, can indeed accommodate a high percentage of normal shrinkage stresses. Along with laboratory shrinkage testing, a historic survey of actual extended joint-space projects and their results can help design engineers develop a comfort level and practice guide for a fiber-floor philosophy.

In early 2003, Mr. Jerry Holland, world-renowned concrete materials, design, and construction engineer, had occasion to personally experiment with the high-volume synthetic fiber, joint-free philosophy. Mr. Holland had studied the benefits of low-volume first-generation synthetic fibers for many years, but was also well aware of the user-friendly limitations involved in attempting to stuff higher dosages of these fine-filament fibers into commonplace concrete floor mixes. As he began his investigation of the next-generation macrosynthetic fibers in early 2003, he had the opportunity to see them first-hand in his own home sidewalk project in Atlanta.[5] In this case, Mr. Holland's crew placed a 3-1/2" thick, 3 ft. wide sidewalk in front of his home stretching 62 total feet with no joints – and reinforced only with 7.5 lbs./cu. yd. of the 2-1/4" long FORTA-FERRO®. The sidewalk – including a 90° re-entrant corner – continues to be crack-free after 7 years of use and Atlanta weather. Based on this personal experience, Mr. Holland placed and observed a wide variety of field trials over the next several years, many of which he documented in a June 2008 article in CONCRETE CONSTRUCTION magazine, "Macro Polymeric Fibers for Slabs On Ground".[6]



Additional Extended-Joint Project Examples

An early expand-the-envelope caliber project was placed in March of 2004 in Marietta, GA.[7] Concrete contractor Teddy Prince used a laser-screed to place a 4" thick topping over a deteriorated roller-skating floor surface, and used 7.5 lbs./cu.yd. of FORTA-FERRO® as an important element to achieve a joint-free 81' x 167' slab. Due to the unique methodology and crack-free results, the Sparkles Roller Rink repair project received the 2004 Award of Excellence in the restoration category by the Georgia Chapter of the American Concrete Institute. Since that time, several additional new Sparkles facilities have been constructed using the same fiber-reinforced, joint-free, polished-floor process.

In May of the same year, FORTA Corporation took advantage of their own FORTA-FERRO® product and experience during construction of their 18,000 sq. ft. plant addition.[8] In an effort to test the joint-space threshold, the L-shaped floor was divided into 2 large joint-free sections, reinforced only with 7.5 lbs./cu.yd. of the 2-1/4" long macro fiber. Though the larger slab (9775 sq. ft., 115' x 85') has developed a tight crack at approximately 60' on the longest side, the more rectangular-shaped slab (7620 sq. ft, 60' x 127') is crack-free after 6 years in service. The F_F (Floor Flatness) measurements for the slabs showed virtually no change at the 6-month mark, indicating a dramatic reduction of shrinkage and curling over the long slab spans. In addition to the savings of the conventional matt-steel reinforcement and placement labor, the FORTA-FERRO® high-dosage process allowed for the elimination of over 2,100 liner feet of sawcut control joints and the costs related to joint-filling and future joint maintenance. And the improved serviceability of the slab after 6 years of fork-truck traffic is immeasurable.

Over the course of the next few years, many additional floor slab projects were added to the growing collection of reduced-joint or joint-free examples using high dosages of the FORTA-FERRO® macrosynthetic fiber. In October of 2006, Tucco Concrete of Cumming, GA, opted for a joint free placement for their 40' x 50' x 6" mechanical building floor slab by using 7.5 lbs./cu.yd. of 2-1/4" long FORTA-FERRO®.[9]

In August of 2007, owner Morrison Custom Welding of Wooster, OH, selected a joint-free design for their 60' x 125' x 6" manufacturing floor slab, also at a 7.5 lbs./cu.yd. fiber dosage[10] to address floor serviceability issues.

Also in August of that year, Attaway Waste Services of Greensboro, GA, chose the FORTA-FERRO® reinforcement as an alternate to conventional matt-steel for cost savings, and used a 7.5 lb. fiber dosage to eliminate sawcut joints for their 80' x 75' x 10" heavy-duty waste-transfer station floor pad.[11] This transfer slab has performed extremely well in over 2 years of constant heavy loader traffic under high impact and abrasion conditions.

A similar sized joint-free manufacturing floor slab (2 – 100' x 90' x 12" panels) has also performed extremely well for Fudpucker Enterprises of Corry, PA, for over 2 years.[12] The finished fiber-reinforced concrete floor surface was extremely compatible with the special epoxy surface coating, which was essential to the Fudpucker dust-free manufacturing process.

One of the most challenging joint-free exercises was the more recent North-South bridge deck project in Oahu, Hawaii.[13] A historical issue of extensive shrinkage cracking in Hawaiian bridge decks led researchers and specifiers to use unique synthetic air entrainment and synthetic fiber solutions to solve the problem. Design engineers at KSF Inc., Honolulu, proposed a new high-performance deck mix developed with Island Ready Mix, Ewa Beach, in hopes of dramatically reducing shrinkage and creep. In addition to the unique polymer-air additive, the mix included a special blend of microsynthetic polypropylene monofilament fibers (FORTA® ECONO-MONO®) and macrosynthetic copolymer heavy-duty filament fibers (FORTA-FERRO®) at a combined concentration of 0.5% by volume (7.5 lbs./cu.yd.). Over 1,000 cubic yards of this special 5" thick mix were placed in the summer of 2008 on the North-South Road Separation deck – all without expansion joints. Measurements have shown a 75% reduction in shrinkage and a 60% reduction in creep, and to date, no cracks have been found after almost 2 years in service. KSF is credited with spearheading the unique mix and components, and continues to study variations that may be just as successfully used on future federal D.O.T. projects.

ACI 360 Background

During this time, the American Concrete Institute's Committee 360: Slabs On Ground was in the midst of updating their design-guide document for concrete slabs, and microsynthetic and macrosynthetic fiber developments became an important and relevant topic of discussion. The recently-published completed document – Design of Slabs-on-Ground ACI 360R-10[14] – includes many valuable reference comments and sections regarding the developing application of synthetic fibers, and has become a go-to guide for both specifiers and contractors who are embracing this technology on real world projects. Following are excerpts from ACI 360R-10 and additional commentary that pertains to the use of synthetic fibers in concrete floors.

Chapter 3 – Slab Types
<u>Section 3.2.2 Slabs Reinforced for Crack Width Control</u>
"Slab reinforcement can consist of bars, welded wire reinforcement sheets, steel fibers, or macrosynthetic fibers".

Chapter 11 – Fiber Reinforced Slabs-On-Ground
<u>Section 11.2 Synthetic Fiber Reinforcement</u>
[This section describes and differentiates between the two levels of synthetic fibers: micro synthetic fibers intended for plastic shrinkage crack control used at 0.1% by volume (1.0 – 1.5 lbs./cu.yd), length of 1/4" to 3/4"; and macro synthetic fibers intended for drying shrinkage crack control used at dosages of 0.2 to 1% by volume (3.0 – 15 lbs./cu.yd.), length of 1/2" to 2-1/2".]

<u>Section 11.2.1 Properties of Synthetic Fibers</u>
[In the discussion of macro synthetic fibers at the elevated dosages, this section states that the] "flexural toughness of concrete can be increased significantly with macro synthetic fibers". [The section goes on to suggest that the ASTM C-1399 test method for determining ARS (Average Residual Strength) values provides a quantitative measure that is useful to evaluate the performance of the synthetic FRC.]

<u>Section 11.2.2 Design Principles</u>
[This design section also reiterates the distinction between micro and macro synthetic fibers.] "For <u>micro</u> synthetic FRC, design principles are the same as used for unreinforced concrete. <u>Macro</u> synthetic fibers provide increased post-cracking residual strength to concrete slabs-on-grade, and would use the same design principles as steel FRC".

<u>Section 11.2.3 Joint Details</u>
[Historically, ACI has acknowledged a fairly conservative approach regarding the topic of spacing between contraction joints. In the ACI 360R-06 design document, figure 5.6 in Chapter 5 – Joints, suggests a formula for spacing based on slab thickness: 24 to 36 times the slab thickness in inches. For instance, for a 6" thick slab, normal control-joint spacing would be 144" (12') to 216" (18'). In the newer 360 document, the spacing chart is referenced only from a historical perspective, suggesting that unreinforced slabs should

be jointed even closer together than in the past, such as a maximum spacing of 24 to 30 times the slab thickness, or 12' to 15' for the same 6" thick slab. The consensus arguments for these changes centered around today's more finely ground cements, the prevalence of higher-shrinkage cements, smaller top-size aggregate mixes, and higher cement dosages, all of which contribute to slab shrinkage and curling. It is also important to note that much of the committee discussion regarding the topic of joint-spacing acknowledged the fact that these 24" to 36" (2' to 3') and now 24" to 30" (2' to 2.5') factors were not based on engineering calculations, but instead on years of collected data from both successful and unsuccessful projects. These guidelines have allowed floor designers to arrive at a comfort level for joint-spacing to minimize cracking between joints. In Section 11.2.3, control joint practices are discussed in light of fiber-reinforced slabs-on-ground. With regards to micro synthetic fibers in the normal low dosages for this fiber type, recommended joint-spacing is the same as for unreinforced concrete, which would follow the 2' to 2.5' rule. On the other hand, it is acknowledged that the use of macro synthetic fibers at the elevated dosages increases the post-cracking residual strength of the concrete.] "This material behavior permits wider/longer sawcut contraction joint spacing". While the 360 document acknowledges the possibility of extending joint spacing with macrosynthetic fibers, no multiplier formula is offered to that end.

The Chicago Experience

In the summer of 2008, FORTA Corporation was approached by CONCRETE CONSTRUCTION magazine to be involved in a 60,000 sq. ft. real-world research trial project in Chicago. The project goal was to utilize various concrete mixes and practices to learn more about the common problems caused by shrinkage and curling in floor slabs over the 2-year trial study period. Of the half dozen research variables included in the study, the use of various forms and dosages of synthetic fiber reinforcement became an important aspect of the program, and would hopefully help validate FORTA®'s previous laboratory shrinkage testing and 10 years of field practice success.

CONCRETE CONSTRUCTION Senior Editor Joe Nasvik first reported an overview of the project in the February 2009 issue – "Researching Warehouse Floors: Are there ways to reduce curling and shrinkage in floors?"[15] Of the 9 planned mixes, all contained some form of synthetic fiber reinforcement:

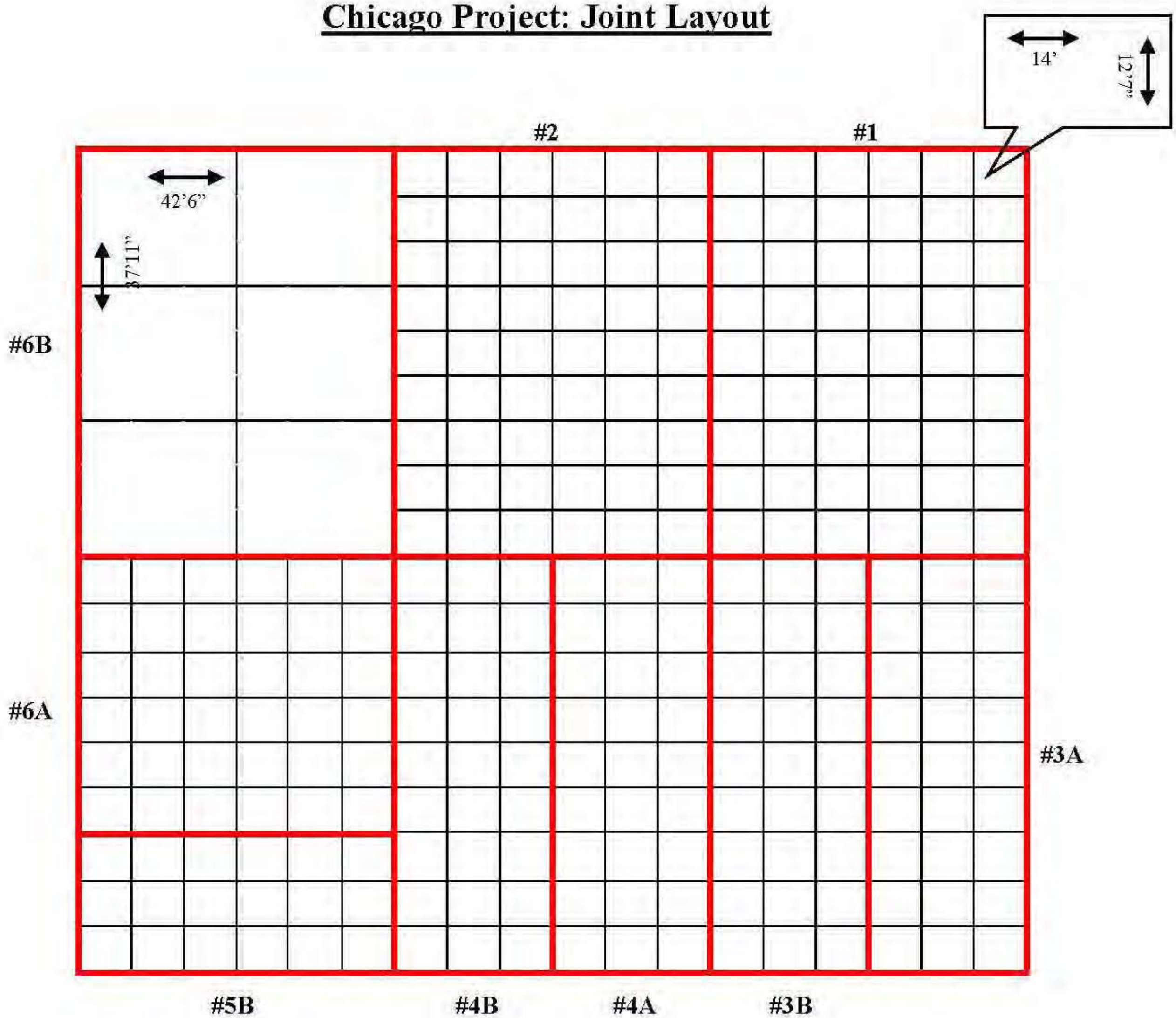
1. 1.5 lbs./cu.yd. of microsynthetic (fibrillated polypropylene);
2. 3.0 lbs./cu.yd. of macrosynthetic (FORTA-FERRO® 2-1/4") or
3. 7.5 lbs./cu.yd of macrosynthetic (FORTA-FERRO® 2-1/4").

Mix Design Chart

Concrete Mix	Area Placed (sq. ft)	3/4" AGG	1-1/2" AGG	NCA	Calcium Chloride	Midrange H20	Poly C	Macro Fiber	Micro Fiber
Mix #1	10,000	X		14		6			1.5#
Mix #2	10,000		700#		1%	6			1.5#
Mix 3a	5,000		700#	14			2	3#	
Mix #3b	5,000		700#	21			2.5		1.5#
Mix #4a	5,000		300#		2%		2.5	3#	
Mix #4b	5,000		700#		2%		2.5	3#	
Mix #5b	5,000		700#	21			2.5	3#	
Mix #6a	5,000		700#		2%		2	3#	
Mix #6b	10,000		700#		1%		5.5	7.5#	

The various mixes were placed on February 10-12, 2009, and were divided into 5,000 or 10,000 sq. ft. sections to enable comparisons of the mix and placement variables. Of special note, all of the 1.5 lb. and 3.0 lb. fiber-dosage areas were sawcut into 14' x 13' panels, following the conservative 2x (in./ft.) ACI 360 historical joint-space formula. However the 7.5 lb. fiber dosage area covering 10,000 sq. ft. was cut into much larger 38' x 42.5' panels, resulting in a 6-1/2x (in./ft.) formula. This process resulted in a dramatic reduction in the amount of sawcutting and related costs (cutting, filling, and future joint maintenance) per 10,000 sq. ft. area: 6 large panels instead of 54 small panels; 966 liner ft. less per 10,000 sq. ft.; 80% reduction in sawcuts. Had the higher-dosage macrosynthetic fiber been utilized on the entire 60,000 sq. ft. warehouse, almost 6,000 feet of sawcuts could have been eliminated.

Chicago Project: Joint Layout



Macrosynthetic fiber mix #6B offered 80% reduction in sawcuts.

42.5' x 38' x 6" vs. 14' x 13' x 6"

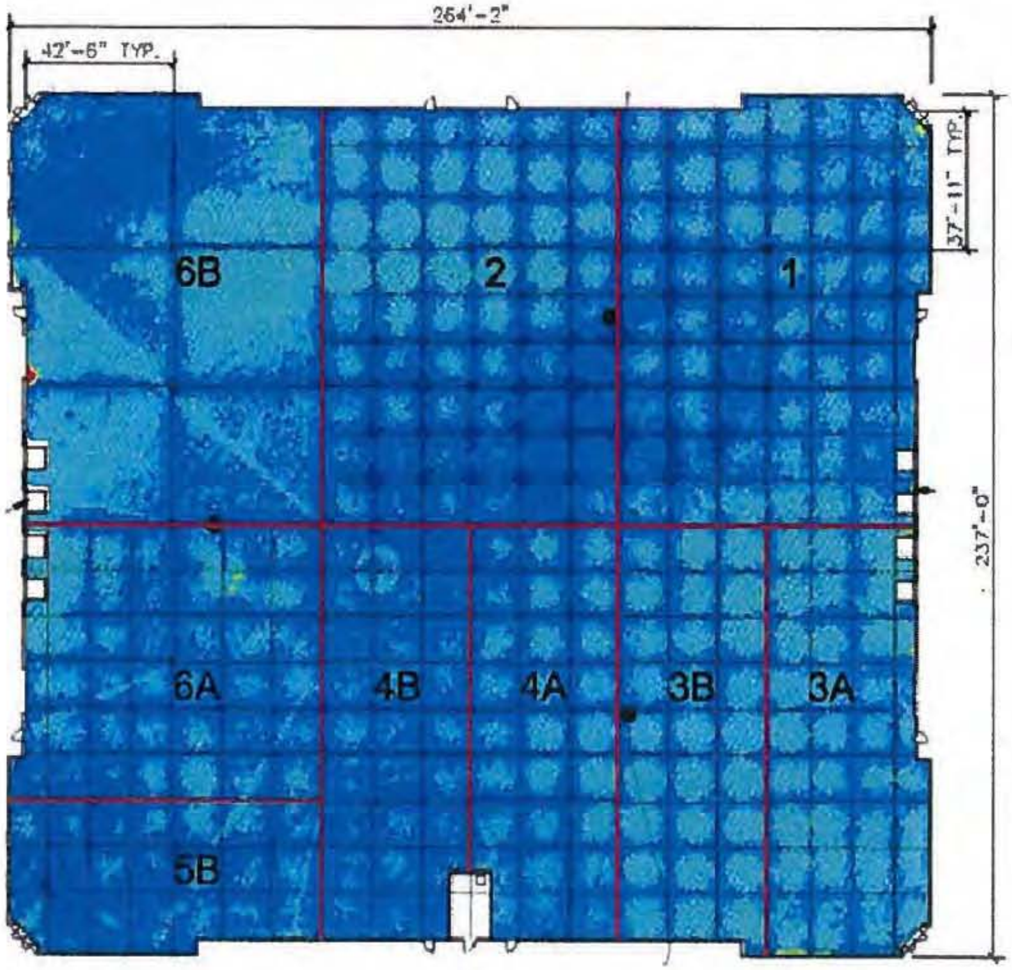
Small 14' x 13' sawcut panels

Chicago Results

The macro-fiber results to date have been quite compelling from both a user and performance standpoint. From a use standpoint, uniform fiber distribution and surface finish can sometimes present problems at these relatively high dosage rates if the particular fiber's chemistry, color, length, and shape are not optimized. In the case of the FORTA-FERRO®, both the 3.0 lb. and 7.5 lb. concentrations were added by the Elmhurst-Chicago Stone staff directly into the ready-mix trucks as a next-to-last ingredient, just prior to the addition of the superplasticizer admixture, and mixed at mixing speed for 4-5 minutes. ECS Quality Control Director Pete Stamatopoulos reported no fiber mixing or balling issues during the run of the project, and the FORTA-FERRO® twisted-bundle configuration allowed for a very uniform fiber distribution throughout the mixes. The 7.5 lb. dosed mixes increased the polycarboxylate superplasticizer concentration to 5.5 oz./cwt from 2.5 oz./cwt of the other fiber mixes to maintain proper flowability and accommodate for the additional fiber surface area. Due to the elimination of conventional matt-steel reinforcement in the floor, all loads were tailgated into place, negating a possible pumping operation.

None of the fiber mixes offered any negative issues with regards to the laser screed slab placement, and the color, chemistry, and shape of the FORTA-FERRO® fiber helped offer an excellent surface finish. Nationally acclaimed concrete contractor Scurto Cement Construction was able to deliver a high burnished surface, even at the 7.5 lb. fiber dosage.

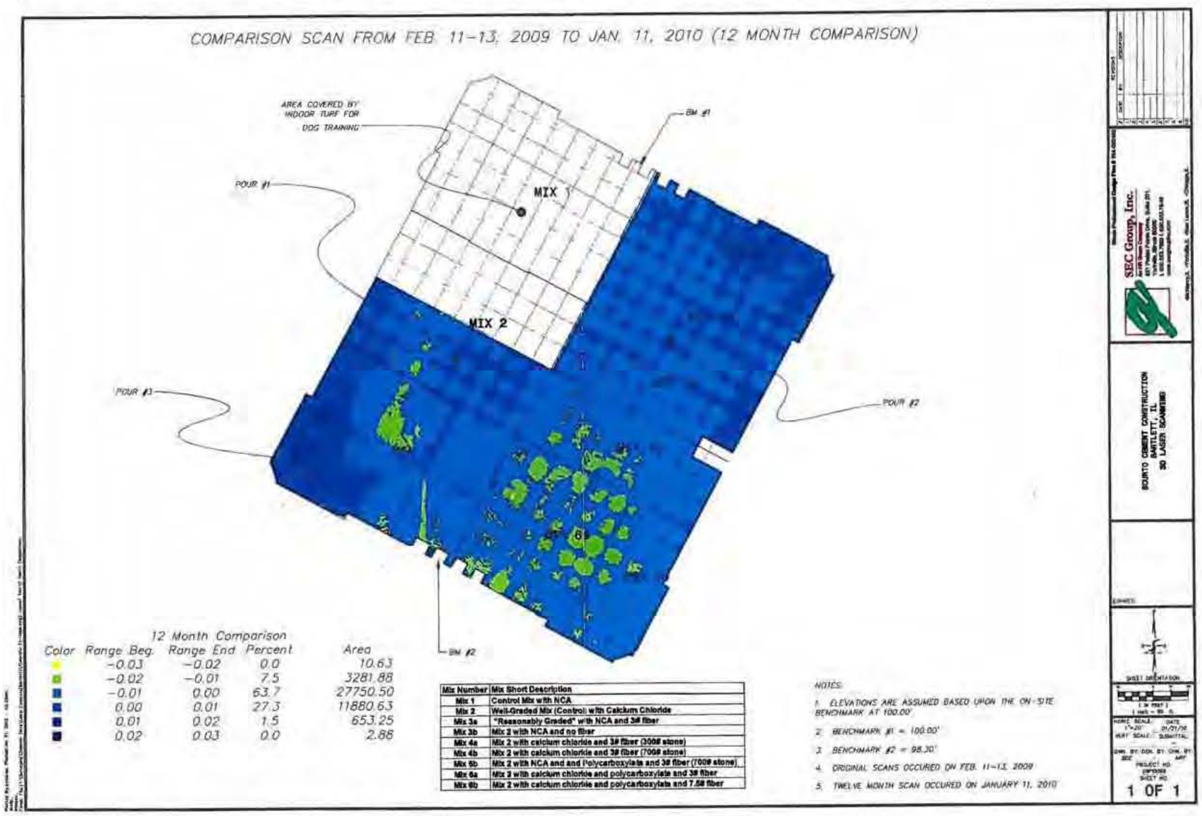
Though the user-friendly fiber aspects were admirable on the project, the most compelling results were the curling numbers and scans delivered at various points in the project's life. The floor surface profiles were measured in two ways – a conventional D-meter and a 3-D laser scanner. In both cases, measurements were taken the morning after each section's placement as a baseline, and then at the 30-day anniversary. As reported in the second project article update, "Warehouse Floor Field Test", May 2009,[16] editor Joe Nasvik reported that ".....at the 30-day mark, the floor begins to show signs of curling" as evidenced by the 3-D laser scan profile.



Due to the fact that the warehouse had no early business occupants, the building maintained an even temperature of approximately 50°F with a relative humidity of 60 to 75%. As might be expected under these almost laboratory-like curing conditions, slab changes were relatively small as base elevations of slab centers generally dropped approximately 1/8", while slab edges generally raised approximately 1/8", which is typical behavior as a slab begins to curl. Though early panel comparisons were difficult to determine, the 30-day colored scan revealed noticeable differences in the center and edge elevations between the small 14' x 13' panels (1.5 – 3.0 lbs. of fiber) and the larger 38' x 42.5' panels (7.5 lbs. of macro-fiber), indicating a possible trend for future measurements.

In the third project article report "Curling and Shrinkage in Floors", September 2009[17], Nasvik admitted that considerable curling and elevation changes had yet to materialize, which he attributed to the building remaining idle due to the down economy. Warehouse temperatures reached 68°F and the relative humidity was a constant 75% – ideal conditions for curing concrete. As warehouse activity and use began to increase, it was anticipated that shrinkage and curling would also increase, and would be considerably more noticeable at the 1-year anniversary mark. The article took the opportunity to highlight the use in most mixes of the next-generation polycarboxylate superplasticizers that can extend slump life and reduce mix water requirements by 10 to 15%. These features have indicated a high level of "fiber-friendliness" in previous FORTA® project experiences, especially when fiber dosage is 5 lbs./cu. yd. or higher. Nasvik also commented on several important mix design aspects that are critical to creating low-shrinkage mixes. For instance, though a control mix used a conventional 3/4" aggregate, all other mixes were comprised of larger, reasonably graded 1-1/2" to 3/8" aggregates. The value of this large aggregate gradation also spills over into mix-water requirements, creating more of a dependence on total water than on w/c (water/cement) ratios. As a result, the project mixes had between 28 and 33 gallons of water per cubic yard, for a w/c ratio range of .48 to .53, which is also fiber-friendly. And the relatively low cement contents (517 lbs.) were able to reach or exceed design strengths, while not encouraging a shrinkage-prone result.

As predicted, the 12-month results began to highlight the curling differences in the various mixes and began to show the benefits in that regard of the 3.0 lb. and 7.5 lb. macro-fiber sections. Though parts of Mix 1 and Mix 2 had been subsequently covered, the colored 3-D laser scan showed dramatic differences between the low-fiber and high-fiber sections, most notably with regards to 7.5 lb. fiber, stretched-joint area.



While the dark blue coloring indicates considerable curling in many of the small 14' x 13' panels, many of the 3 lb. and 7.5 lb. fiber sections showed little, if any, slab-edge curling. To further quantify the visual scan, Allen Face, an internationally regarded floor flatness expert and a member of the project's steering committee, submitted the curling radii and corner lift data for 7 of the project mixes. The curling results are quite linear with regards to fiber dosage, with the first two mixes (#1, #2, 1.5 lbs./cu.yd.) showing the most curling, and the last mix (#6B, 7.5 lbs./cu.yd.) showing the least curling. In fact, the #6B results showed a slight 'negative curl' or warping effect, which is especially impressive because of the much larger 38' x 42.5' panels in that section. The combination of no steel, 80% less joints, and no mid-panel cracking to date at the 1-year anniversary creates a compelling story and practice for the future of the concrete flooring industry.

From: Allen Face [mailto:af@allenface.com]
Sent: Thursday, February 18, 2010 6:17 PM
To: Daniel Biddle
Subject: Fw: Curling Study Results

Dan -

Note that the listed values are the averages for all the test runs made in an area.

Here are the curling radii (in feet) and the corner lifts (in inches) for the different mixes given in order of most curled to least curled:

Mix 2 : 2636' .184"

Mix 1 : 3660' .133"

Mix 4A : 4491' .108"

Mix 6A : 5369' .091"

Mix 3B : 6034' .081"

Mix 4B : 7255' .067"

Mix 6B : -14752' -.033"

The negative values for 6B mean that rather than curling, it warped very slightly (i.e. the corners went down rather than up).

All the panel diagonal test lengths associated with the above values = 18 ft.

Therefore, for these data, the following formula converts any positive radius of curvature, R (in feet), into a positive corner lift, Y (in inches):

Y = 12 * (R - SQRT[R^2 - 81])

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Project Updates

CONCRETE CONSTRUCTION magazine will continue to monitor and report on future results and developments on the Chicago/Scurto study project, with the next floor profiles planned for July 2010 and February 2011. Additional job details can be attained by visiting their website at www.concreteconstruction.net, and typing "C.C. Field Study" into the search engine, or visit the FORTA® website at www.forta-ferro.com and click on "Latest News: 2009". In the latest field study article in CONCRETE CONSTRUCTION's March 2010 issue, editor Nasvik describes the unique curing scenario of the varied test slabs "One Year Later."[18] Most of the panels showed some amount of early curling at the 3-month mark, yet seemed to 'relax' to some degree at the 6-month point due to the constant and near-perfect temperature and humidity conditions in the unoccupied facility. However, now that the building has been opened up for use, slab curling has become more prominent, and future curling and edge-elevations are expected to continue. In the article, Nasvik describes this phenomenon he calls "curl relaxation" of slabs, which he accurately depicts as a cyclic floor occurrence, noting that "Floor surface elevations aren't static and probably go through this cycle countless times due to changing ambient conditions." FORTA®'s research and practice history would suggest that the fiber's ability to add ductility to inherently brittle floor plates encourages this curl relaxation, and therefore accommodates these cyclic curing and temperature changes. In the article section entitled "How to build floors with less curling", Nasvik states "….the study has shown mix 6B – with the dosage rate of 7.5# macrofibers per cubic yard of concrete….has demonstrated no significant elevation changes over the past year". Interestingly, the column line sawcuts within the high-fiber 10,000 sq. ft. section have yet to activate, however, the overall section dimension (85' x 114") has shrunk, as evidenced by the increased construction-joint width of 1/2" around the perimeter. This combination of non-activated sawcuts and no mid-panel cracking leads Nasvik to conclude "Warehouse maintenance issues start along control joints because forklift traffic causes crumbling and cracking – where curling is the highest and the least support for a panel exists. So high-volume macro fiber slabs offer the possibility of flatter slabs with less maintenance over time".

Summary

As the first and oldest synthetic fiber reinforcement producer in the United States, FORTA Corporation has had a long history and tradition of promoting good concrete, good concrete practices, and proven technology in conjunction with their family of fiber reinforcements. FORTA® has promoted first-generation synthetic fibers at relatively low dosages (1.0 to 3.0 lbs./cu.yd.) as a tremendous construction material to reduce cracking due to plastic shrinkage and temperature-related causes. In this function, FORTA® strongly recommended strict adherence to conventional wisdom regarding acceptable joint-spacing for slabs-on-ground, such as the 2x historical guidelines noted in various ACI publications.

With the advent and development of FORTA®'s next generation structural or macrosynthetic fiber, higher dosages became very possible, thus encouraging additional testing in areas of toughness and post-crack behavior. As a result of the positive post-crack research and engineering conversions, the use of macrosynthetic fibers as a viable alternate to conventional steel reinforcing in floors, slabs, and pavements, became commonplace in successful projects all over the world. And based on the dramatic laboratory-proven reductions in plastic and hardened shrinkage, it seemed only a natural progression to translate those benefits with regards to curling to slabs-on-ground, and determine if joint space considerations could indeed be affected.

Over the past 10+ years, FORTA® has participated in scores of representative joint-free or joint-stretching projects all over the United States. This collection of successful project data has helped create a comfort level with the technology, and helped compliment FORTA®'s "Fiber-Floor Philosophy". The Chicago Floor-Study Warehouse project is helping to validate the shrinkage and curling aspects of this philosophy, and will play an important role in assisting owners, specifiers, and contractors who strive to build better and more serviceable floors in the future.

Safeguards

Despite the successes and project history over the past decade, it is also very clear that macrosynthetic fibers are only a part, albeit an important part, of a complete recipe to control shrinkage and curling in slabs on ground. Many additional facets of this recipe should be carefully considered when embarking on a joint-stretching path, such as subgrade friction, various modes of restraint, proper curing, and a host of other shrinkage-reducing techniques. The FORTA® Technical Department has developed a pre-project checklist to alert producers and contractors to important and sometimes special aspects of high-volume fiber usage, such as fiber addition and mixing, slump, pumping, and finishing. In addition, the FORTA® field staff is trained and willing to assist project participants to identify and implement the additional recipe ingredients when changes to conventional joint-spacing are being considered.

Acknowledgements: Thanks to Pete Stamatopoulos and his team at Elmhurst-Chicago Stone for their help and hospitality at the batch plant during the project. Thanks also to Greg Scurto and Scurto Cement Construction for their positive feedback and willingness to work with FORTA®. And a special thanks to Jerry Holland, Wayne Walker, and the Structural Services Inc. team for their help and guidance on this and many other similar projects.

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