



FORTA Corporation Technical Report

FRC - SLAB ON METAL DECK



www.forta-ferro.com



FORTA Corporation

TECHNICAL REPORT

FRC Slab on Metal Deck

June 2012

Introduction

In the past, there has been a considerable amount of discussion and dialogue concerning the intent and use of various reinforcement products in concrete placed on metal decks. A portion of the discussion has involved methods of controlling various forms of reinforcement and hence the quality and behavior of the construction. As new reinforcement products, such as fibers, are introduced to the market and understanding of existing products, such as Welded Wire Fabric (WWF) increases, these discussions will continue to evolve regarding the emphasis and direction of quality slab on deck construction.

This product report is intended to convey the current state of the market concerning the use of synthetic fiber reinforcement in concrete placed on metal decks, and is intended for any member of the construction team concerned with quality construction of metal decks. The report is directed to how, why, and where synthetic fibers have been used in metal deck construction, and represents a description of FORTA Corporation's current understanding of the technology and market and how FORTA® products fit into this market. The "FRC Slab on Metal Deck" report is not intended to be considered as engineering, standards, or specifications, but to help clarify the history and practice of Fiber Reinforced Concrete in metal deck construction.

Background

Metal Decks

The construction of slabs on metal deck involves use of a concrete slab with a supporting platform made up of structural steel beams and a metal deck. These deck assemblies are a very common construction method, and represent an economical and valuable way to take advantage of above-ground space for a wide variety of applications, such as office space, inventory storage, or product order fulfillment, each requiring specific structural and loading demands. This deck construction system may be a composite or non-composite design, which is an important distinction and consideration for the project's structural engineering group.

In composite deck design, the concrete slab and the steel beams work together to support the loads placed on the floor, typically achieved by way of shear connectors within the concrete welded to the structural steel beam. A typical composite metal deck consists of a cold formed corrugated steel sheet with a concrete topping, the sheet serving as a permanent form and as the principal slab reinforcement once the composite dynamic has been developed. Historically, welded wire fabric (WWF) has been used as secondary or non-structural reinforcement to control, rather than prevent, concrete cracks caused by restrained shrinkage and temperature changes within the concrete. More recent practice has involved the use of synthetic fibers – primarily macro-synthetic fibers – as an alternate to the WWF, as a more effective way to reduce and control cracking by these causes.

Though in either composite or non-composite design case macro-synthetic fibers are frequently used to control shrinkage and temperature-related cracking, the following report focuses primarily on those decks of composite design. Included are important facets and history of synthetic fiber reinforcement, details concerning crack-width control and other reinforcement objectives, and a summary of the standards and codes that typically impact composite deck construction.

Fiber Synthetic History

FORTA Corporation introduced **micro**-synthetic fibers to the U.S. market in 1978, which were designed to reduce plastic shrinkage cracking and add an element of shrinkage/temperature crack control. These products generally took the form of very fine single-filament polypropylene or nylon fibers (monofilaments) used at a low dosage of 1.0 lb/cu yd (.6 kg/cu m), and deformed net-shaped polypropylene fibers (fibrillated) typically used at 1.5 lb to 3.0 lbs/cu yd (.9 to 1.8 kg/cu m). Though it was well recognized in the laboratory that adding higher dosages would lead to considerably higher levels of shrinkage reduction and significant improvements to post-crack performance, these fine-filament fibers created mixing and placing challenges at elevated dosages due to their high surface-area characteristic.



Micro-monofilament



Micro-fibrillated



Macro-synthetic

Macro-Synthetic Fibers

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 filament shape to accommodate finishability. For over a decade, the result has made FORTA-FERRO® the most user-friendly macro-synthetic fiber in the industry, with scores of successful flatwork projects all over the world. And with these higher fiber dosages came considerable evidence of other important benefits – the dramatic reduction in shrinkage and the notable improvement to post-crack capacity.

Reinforcement Requirements

A wide variety of sources are available regarding standards and codes for the construction of slabs on deck (see section: Standards and Codes, pg. 8). While these standards may establish recommended methods and details, the structural integrity of the deck system and the reinforcement thereof remain firmly within the responsibility of the project structural engineer of record. As such, the engineer must determine the reinforcement requirements and goals based on the deck design and desired capacity. The following non-structural reinforcement topics offer additional guidance to those who specify and construct composite-metal deck assemblies.

Temperature/Shrinkage Reinforcement

Variations in concrete's internal temperature gradient and its tendency to shrink as excess mix water leaves the drying concrete causes cracking generally termed as temperature/shrinkage cracking. This cracking results from the top concrete surface attempting to shrink while the bottom surface is being restrained, as is the case of the mechanical anchorage caused by the deformations of a corrugated metal deck. The reinforcement used to address this temperature/shrinkage dilemma is designed for crack width control, with the intent of minimizing the width of shrinkage cracks between joints and essentially allowing for a larger number of tight cracks rather than a fewer number of wide cracks. Commentary within the most recent SDI – Steel Deck Institute – C-2011 Standard for Composite Steel Floor Deck-Slabs accurately describes this cracking potential: “Even with the best floor design and proper construction, it is unrealistic to expect crack free floors. Every owner should be advised by both the designer and contractor that it is normal to expect some amount of cracking and that such occurrence does not necessarily reflect adversely on either the adequacy of the floor's design or quality of the construction.”¹ This related crack width can be controlled by a nominal amount of distributed reinforcement in the form of bars, welded wire fabric, steel fibers, or macro-synthetic fibers.

The use of conventional steel reinforcement in slab on deck applications brings a host of ease of use and proper placement concerns. For the welded wire fabric to be effective in controlling this shrinkage/temperature cracking, it must be placed within the top-third of the concrete cross-section which can be challenging in actual practice. The simple transport of mesh rolls or sheets to upper-level deck projects can also be difficult and labor-intensive. The time and labor savings provided by a fiber reinforcement system that is simply added to the concrete mix as an ingredient is a considerable advantage, in addition to the uniform three-dimensional reinforcement coverage throughout the concrete deck matrix vs. single-plane steel. Per the SDI Standard, “As a general rule, reduced crack widths can be achieved by increasing the amount of steel reinforcement, or by increasing the fiber dosage and/or minimizing the shrinkage potential of the concrete.”²

Though much of the value of macro-synthetic fibers comes from the ability of the millions of evenly-distributed fiber pieces to accommodate shrinkage/temperature stresses **before** they become visible cracks, the capacity to keep cracks held tightly together becomes the reinforcement focus for slab on deck applications. This post-crack behavior is often determined by a variety of ARS – Average Residual Strength – test methods, such as ASTM C-1399, where fibers are tested at various dosages to determine a relative post-crack strength in terms of psi. In general, macro-synthetic fibers are typically used at dosages ranging from 0.25% by volume (3.75 lbs./cu yd., 2.25 kg/cu m) to 0.50% by volume (7.5 lb/cu yd, 4.5 kg/cu m), depending on the application and requirements. The FORTA-FERRO® macro-synthetic fiber offers top ARS performance for designers to consider based on specific slab on deck requirements.³

Negative Moment Reinforcement

Depending on the design of the composite metal deck and accompanying concrete slab, there may be elements of negative moment over the structural beams. In these cases, the project engineer would require sufficient steel through the joint to accommodate those moments. If the designer desires a continuous slab, then the ACI 318 structural building code would be followed.

Control Joints and Other Details

Control or contraction joints are placed in slabs on ground to create a plane of weakness in hopes of minimizing out-of-joint cracking caused by drying shrinkage and thermal contraction. In these cases, restraint caused by the sub-grade can be reduced to accommodate the control joint goal and practice. However, for slabs on deck, significant mechanical restraint is present due to the deformations of the corrugated metal deck, therefore restricting free concrete movement at the slab bottom at least in one direction, while the top of the slab is subject to movement caused by shrinkage. As a result, the placement of control joints rarely guarantees the desired effect of eliminating between-joint cracks, and is generally not required or recommended, as evidenced in the “Contraction Joints in Elevated Slabs” Position Statement # 23 prepared by the American Society of Concrete Contractors.⁴ As mentioned previously, the intent of the temperature/shrinkage reinforcement is for crack-width control – to hold cracks that may form tightly together – but a certain amount of restrained thermal/shrinkage cracking is to be expected. Based on the use of welded wire fabric or

macro-synthetic fiber reinforcement to that end, control joints are typically avoided due to their relative ineffectiveness for slab on deck applications.

Macro-Fiber Aspects

While micro-synthetic fibers at their typical low dosages (1.0 to 1.5 lbs/cu yd) had little noticeable impact on the concrete or different aspects of placement, higher dosages of macro-synthetic fibers offer various nuances that are best addressed prior to the project start. These areas of fiber addition and mixing, slump, pumping, and finishing are worthy of pre-construction meeting conversation to help maintain a trouble-free project site.

Fiber Addition Point

The correct time and place to add macro fibers to the concrete mixing system varies for different fibers, and therefore it becomes very important to determine the optimum process for the particular fiber being used on the project. Recommendations for one fiber may not apply to another, and therefore the correct addition point and practice should not be assumed as normal, especially with the higher dosages typically required for slab on deck applications. To affect the capacity to hold potential cracks tightly together, it is especially critical to have uniform fiber distribution without clumping or balling. A reasonable litmus test to pre-determine a particular fiber's ability to mix without clumping is to inspect the fiber in its original package – it's safe to assume that if the fiber is tangled in the bag it comes in, it's not likely to un-tangle in 4,000 pounds of wet concrete! If the fibers do not gravity feed well when dry, then special addition tactics will be required, such as feathering them slowly into the mixing system which would require extra time and patience on the part of the ready-mix supplier.



FORTA-FERRO® patented bundles

One of the keys to the mixing success of the FORTA-FERRO® macro fiber is a patented twisted-bundle form, which allows the bundles to remain untangled when dry, and then spring open and separate into individual macro fiber filaments during the wet mixing action. This feature is especially critical in high-volume applications, where 3.0, 4.0 or higher pounds per cubic yard are required. Many fibers will mix and distribute fairly well at low dosages, but will be compromised by balling at dosages over 3.0 pounds per cubic yard. Because of the twisted-bundle form, the correct addition point for FORTA-FERRO® is **during** the mixing process as other ingredients are being added, or **after** the mixing cycle has been completed. For instance, the fibers could be added with the coarse aggregates to a central-batch system, or to the back of the ready-mix truck after the truck has been loaded. In either case, essentially the only **wrong** time and

place to add FORTA-FERRO® is as a first ingredient to the mixing system or alone with a portion of the initial mix water, which would encourage the opportunity for fibers to cling to the sides of the mixing chamber or drum and not get into the actual concrete until the discharge process begins. In general, adding fibers as a first ingredient also raises the likelihood that they may become nose-packed by the cement and other fines, and therefore not become involved in the vigorous mixing action process. For less-than-full loads in a ready-mix truck, i.e. less than 5 cubic yards in a 10 cubic yard capacity drum, it is recommended that the concrete be brought up to the point of discharge and the fibers added directly on top before mixing commences.

Mixing Time and Speed

Fibers also differ in their sensitivity to mixing time and mixer speed for proper and uniform distribution. All fibers can be under-mixed, and some fibers can be over-mixed as well. In the case of the FORTA-FERRO® bundles, normal central-batch mixing cycle time is sufficient for proper distribution. In ready-mix truck mixing, the fiber typically requires a minimum of 4 to 5 minutes mixing time at normal mixing revolution speed, at an RPM rate recommended by the mixer manufacturer. If insufficient mixing time is allowed, it will be evidenced during discharge by bundles that have not opened and separated properly. It is important to note that the slow agitation speed used for road travel is not sufficient to properly mix the fibers, and should not be added into the minimum fiber mixing time allotted. This same mixing time and speed recommendation would also apply if fibers are added to the truck on-site rather than at the batch plant, and mixing time should not be shortened even under rushed project conditions. Further, excessive agitation-speed revolution time will not negate or ruin the uniform fiber distribution, in the event of project placement delays. Excessive mixer speed can be just as problematic as slow mixing speed, causing the concrete to hang onto the drum wall rather than be subject to the normal blending and folding action required for uniform mixing of all the ingredients – including fibers. Using an RPM speed that is too high in an attempt to shorten the required mixing time will also result in unopened fiber bundles during discharge. When concrete including FORTA-FERRO® is mixed at the proper time and speed, the extremely uniform fiber distribution is readily evident even to the untrained eye during discharge.

Fiber Slump

A common perception is that most man-made fibers will absorb mix water, and therefore reduce the concrete slump. The FORTA-FERRO® macro fiber chemistry is a blend of polypropylene and copolymer materials, and as such, are hydrophobic and therefore cannot absorb liquids. However, macro fibers **do** act as a cohesive agent in the plastic concrete, binding the ingredients together to some degree, which provides a valuable benefit by reducing mix segregation. This binding characteristic is especially apparent when using high fiber dosages and long fiber lengths. Though high macro-fiber dosages do reduce the visual slump as measured by the slump-cone test, the actual flowability and workability are only effected to a lesser degree (see Pumping section for additional information).



Slump Cone

As an example, a typical concrete mix with 4.0 pounds of fiber per cubic yard (2.4 kg/cu m) may reduce the visual slump by 1 to 2 inches (25.4 to 50.8 mm), however the actual workability will be impacted to a much lesser degree. To regain any loss of workability, the use of superplasticizing admixtures is highly recommended rather than adding additional water. If necessary, pre-project laboratory mixes can be worked up by the ready-mix supplier to help predict the necessary admixture dosage per cubic yard for a given concrete mix and fiber dosage, which can then be adjusted on the job based on ambient temperatures, aggregate absorption, delivery and standing time, etc. It is generally recommended that the fibers be

added and mixed prior to the addition of the superplasticizer to insure that sufficient mixing friction is available to properly distribute and mix the fibers, though mixes will differ in that regard.

Pumping

Fibers also differ greatly in their capacity to be pumped. First-generation **micro**-synthetic fibers at low dosages rarely impact any normal pumping procedures. On the other hand, steel fibers often pose pumping challenges due to their rigidity, especially at high dosages. Some **macro**-synthetic fiber versions, packaged in cylindrically-shaped pucks, offer a high probability of line blockage if the fiber-wrap remains intact. Any fiber that does not mix well will increase the chances for line blockage caused by fiber clumps or balls, even if the pump grate successfully catches a majority of these clumps. Again, due to the advantage of the unique FORTA-FERRO® twisted-bundle form and the resulting uniform fiber distribution, pumping has not been a problem, even at high dosages. In fact, the uniform binding ability of the fiber often results in much more uniform and slightly lower pump pressures that would normally be required for non-fibered mixes, likely due to the reduction in mix segregation courtesy of the fiber. However, issues **will** arise at the pump-hopper **grate**, if pre-project precautions are not taken. The primary high-fiber issue at the grate is quite simply the shape of the grate slats – the narrow, thin, rectangular-shaped slats beg for fiber hang-over and build-up – and essentially, the cohesive tendency of the fibers begins to work too soon and makes fiber-concrete flow-through very difficult and slow. Once the high-fiber concrete passes the protective grate, no actual pumping issues will occur, but the grate slats must be accommodated to avoid project issues and delays.

There are several grate-fix options available – some of which require only a few minutes to prepare – but all deserve forethought before the first ready-mix truck arrives at the pump hopper. The FORTA® Technical Report: “Pumping High-Volume Fibers” 5 provides extensive details regarding all aspects of pumping macro-synthetic fibers, such as chute location and height, critical grate and hopper vibration, and both permanent and temporary grate rehabs. Essentially, the grate change simply involves changing the shape of the slats – from thin and square to thick and round – to allow the high-fiber concrete to easily flow through rather than hang up or drape over. For whatever reason, the pump-grate fiber-flow issue is the most often ignored pre-construction warning, and the most time-consuming and costly when not addressed. Since the concrete on the vast majority of slab-on-deck projects is pumped into place, addressing these pump-grate issues is one of the most important fiber facets that should be included in high-fiber specifications and pre-construction project meetings.



A permanent round-bar grate is essentially self-cleansing at high fiber dosages.



Temporary metal pipe lay-over method zip-tied in place



Garden hose slat caps provide an inexpensive last minute solution.

Bleeding

Concrete can obviously bleed in only one direction – upwards – when placed on a non-absorptive metal deck base, a fact that is well known by the finishing team. High dosages of macro-synthetic fibers can also impact bleeding dynamics on deck applications, which must also be a finishing consideration. As mentioned previously, the FORTA-FERRO® fiber is hydrophobic, and therefore will not affect the free water content within the plastic concrete. Further, unlike fiberglass, nylon or some other fiber chemistries, the polypropylene/copolymer fibers will not wick water to the surface. However,

because of their random, three-dimensional location throughout the slab cross-section, these fibers will mechanically block or divert the normal water bleed channels to the surface. As a result, concrete reinforced with high volumes of macro-synthetic fiber will bleed slightly slower and slightly less than non-fibered concrete. This phenomenon should be acknowledged by the concrete finisher to help them properly time the finishing operations. As with plain concrete, the historic finish-timing indicators remain the same for high-volume synthetic fiber reinforced concrete. For example, when a footprint leaves only a slight indentation in the screeded slab surface, timely finishing procedures may commence. Naturally, if the concrete has not finished bleeding of excess or unused mix water, then finishing should be delayed to avoid prematurely sealing the surface which would add to the risk of future delamination and scaling. And obviously at the other extreme, if surface indicators are misread and the slab has gotten away from the finisher, then it will naturally represent a challenge to reopen the surface to allow for a suitable finish. In either case, 'blessing' the young concrete slab with water as a regular practice is just as harmful to fiber-reinforced slabs as it is for unreinforced slabs. Like all slabs, fiber-reinforced slabs must be monitored closely to allow for the correct time – not too early and not too late – for a suitable surface finish.

Finishing

Finishing of slabs-on-deck containing high volumes of macro-synthetic fibers is likely the most feared aspect by contractors not experienced with this high-fiber technology. Because all macro-synthetic fibers are different, this fear is not completely unfounded in some cases. However, great efforts were made in the development of the FORTA-FERRO®-brand fiber to facilitate easy and nearly invisible surface finishing, such as softening agents, a good filament shape, and a concrete-gray color. However, high dosages such as 4.0 to 5.0 pounds per cubic yard (2.4 to 3 kg/cu m) do represent millions of individual fiber pieces and thousands of linear feet of fiber reinforcement throughout the concrete cross-section, some of which will naturally be at or near the slab surface. The key to an acceptable surface finish will be to use techniques that will allow the surface cream to hide and cover those fibers. As mentioned previously, changes in high-fiber concrete bleeding dynamics should be acknowledged and observed by the finishing contractor to avoid premature or late sequencing of the various levels of finishing. And certainly, the type of desired finish will help dictate recommended practices to minimize fiber appearance on the surface.



**Superior high-gloss finish
with high-volume fibers**

As previously mentioned, the characteristics of the FORTA-FERRO® fiber allow it to be a premium finishing fiber for machine hard-trowelled surface finishes. The fibers are easily laid into the surface without creating the 'fuzzies' or rigid-needles of other fiber types. Even at the higher fiber dosages used on deck applications, FORTA-FERRO® allows for a smooth and glossy finish, without negatively impacting flatness and levelness efforts.

Standards and Codes

Various standards and building codes are generally referenced and utilized for slab on metal deck construction, and several impact the proper use of macro-synthetic fibers as an alternate temperature/shrinkage reinforcement. Special references and excerpts from these pertinent codes follow, which will assist engineers to evaluate specific fibers and contractors to submit a fiber system to meet project requirements.

Steel Deck Institute

The Steel Deck Institute (SDI) was formed in 1939 to bring uniformity to the design, manufacture, quality control and construction practices to cold-formed steel decking. Made up of manufacturers of steel floor and roof decks and manufacturers of products used in the production or erection of steel decks, the Institute provides uniform industry standards for the engineering, design, manufacture, and field usage for steel deck applications. Based in Fox River Grove, IL, SDI provides deck-related assistance and information to designers and owners in the form of standards and requirements, and is often the recognized source of the most current materials and practice information for steel deck projects.

One of the SDI standards is “C-2011 Standard for Composite Steel Floor Deck-Slabs”, published on November 30, 2011. This standard is used to determine the nominal resistance and composite stiffness of composite steel deck-slabs, and intended for use with cold-formed composite steel deck construction. Section 2.4 Design, Part 13. Reinforcement for Temperature and Shrinkage, defines this reinforcement as that which is used for crack-control purposes, and allows three reinforcing methods to that end: welded wire fabric, steel fibers, or macro-synthetic fibers. Paragraph a.3 of Section 13. Reinforcement further defines the macro-synthetic option and criteria:

Concrete specified in accordance with ASTM C1116, Type III, containing macrosynthetic fibers meeting the criteria of ASTM D7508 at a dosage rate determined by the manufacturer for the application, but not less than 4 lb/cu yd (2.4 kg/m³). 6

The C-2011 Standard further states that fiber dosage may vary, based on manufacturer’s recommendations, as long as it is not less than the 4.0 lb/cu yd (2.4 kg/cu m) minimum. The FORTA® technical staff is able to provide steel-to-fiber calculations if necessary, or provide a dosage recommendation based on project specifics.

Underwriters Laboratories

Underwriters Laboratories (UL) is a global institution for product testing in all phases of the building and construction industry, having certified over 21 billion products covered by the UL certified trademark. As such, UL maintains state of the art testing facilities, including the 20,000 sq. ft. large-scale fire-testing unit in Northbrook, IL. In order to be considered as an alternate to conventional temperature steel reinforcement in fire-rated metal deck assemblies, a complete fire testing regimen is required of a representative concrete deck panel reinforced with the macro-synthetic fiber being utilized.

In April of 2009, deck panels were tested for FORTA Corporation at the UL fire resistance laboratory reinforced with FORTA-FERRO® macro-synthetic fiber. Based on the successful results regarding thermal transmission and load capacity, it was determined that the use of FORTA-FERRO® is permitted as an alternate to welded wire fabric in all D700, D800, and D900 series designs when used at a maximum dosage rate of 5.0 lbs/cu yd (3.0 kg/cu m) for up to 3-hour assembly ratings (see FORTA® USA Test Report Summary # 20-097). Neither the average limiting temperature nor the individual limiting temperature of the unexposed deck surface were breached during the 3 hour 23 minute test duration, and the assembly was able to maintain the full design load for the entire 3 hour 23 minute test. Pursuant to the successful conclusion of the test program, FORTA® was issued UL certification # R18522 8 and is permitted to bear the UL classified trademark.

American Society of Testing and Materials

ASTM International, formerly known as the American Society of Testing and Materials, is a global association formed to develop and deliver international voluntary consensus standards. These standards are developed by an exhaustive debate system by over 30,000 society members from over 135 countries. Two of these standards involve synthetic fiber reinforcement, and are often referred to in slab on metal deck project specifications.

ASTM D7508/D7508M-10 is the Standard Specification for Polyolefin Chopped Strands for Use in Concrete, which essentially covers the pertinent fiber characteristics for both micro- and macro-synthetic fibers. Polyolefin is defined as any long-chain synthetic polymer that is comprised by at least 85% by weight of ethylene, propylene, or other olefin monomers, and a macro polyolefin fiber is one that has a linear density greater than or equal to 580 denier, an equivalent diameter greater than 0.012 in. (0.3 mm). To comply with the D7508 standard, a fiber must meet the macro-fiber definition and minimum denier requirement, have less than a 1% finish on the fiber, have a tensile strength greater than 50,000 psi (344.4 MPa), and be of cut length between 0.5 in. (12 mm) and 2.5 in. (65 mm).

ASTM C1116/C1116M-10 is the Standard Specification for Fiber-Reinforced Concrete, which covers all forms of fiber-reinforced concrete that are delivered to a purchaser with the ingredients uniformly mixed and that can be sampled and tested at the point of delivery. Of special importance to the use of macro-synthetic fibers in slabs on deck application is the fiber classification as defined in C1116 4.1.3 Type III Synthetic Fiber-Reinforced Concrete, which essentially requires testing or historic proof that the synthetic material is inert to deterioration due to alkali attack found in Portland cement for the life of the structure, with the polyolefins polypropylene and polyethylene confirmed as durable in that regard.

The FORTA-FERRO® macro-synthetic fiber meets the requirements and standards of both ASTM D7508 and C1116, and is therefore suitable for use in slab on metal deck project applications that require this compliance. 9

American Concrete Institute

The American Concrete Institute (ACI) was founded in 1904, and has since become the world-wide acknowledged source for technical knowledge and support for concrete and its many applications. With over 20,000 members and representing 120 countries, ACI continues to develop, share, and disseminate the knowledge and technical information necessary to utilize concrete in a wide variety of ways. Several ACI committees and respective publications are dedicated to the construction and reinforcement of slab on metal decks:

- ACI 302.1R-04 Guide for Concrete Floor and Slab Construction, Chapter 3.3 Suspended Slabs; ACI Committee 302 Construction of Concrete Floors develops and reports pertinent information on the materials and procedures to construct concrete floors. The 302.1R-04 Guide provides valuable information for those concrete floors placed on metal deck construction, and is referenced in most slab on deck standards and specifications.
- ACI 318-11 Building Code Requirements for Structural Concrete; ACI Committee 318 Structural Building Code develops and maintains building code requirements for structural concrete. For slab on composite metal deck construction, the 318-11 Building Code Requirements for Structural Concrete document would be referenced when the concrete slab is designed for negative moments, and the designer would follow the ACI 318 code for reinforcement requirements in the negative moment regions.
- ACI 544 3R-08 Guide for the Specification, Proportioning and Production of Fiber Reinforced Concrete; ACI Committee 544 Fiber-Reinforced Concrete develops and reports information on concrete reinforced with short, discontinuous, randomly-dispersed fibers. The 544 3R-08 Guide is often referenced on slab on deck applications to provide specifiers, producers, and contractors guidance for proper proportioning and production when fibers are utilized.

Project References

Synthetic fibers produced by FORTA Corporation have been used successfully in slab on metal deck projects for many years. The FORTA® technical and engineering staff is available to assist deck designers by providing the necessary fiber characteristic information and dosage recommendations to meet specific project requirements. Following are several representative project examples where the FORTA-FERRO® macro-synthetic fiber was specified and utilized.

Bon Tool Company Warehouse/Office

FORTA-FERRO® macro-synthetic fiber was utilized in two phases of the warehouse and office expansion project in October of 2002 for the Bon Tool Company in Gibsonia, PA. The 2 ¼ in (54 mm) long macro fiber was used at a dosage of 5 lbs/cu yd (3 kg/cu m) as an alternate to the temperature/shrinkage steel reinforcement in the 6 in (152 mm) thick warehouse floor covering 55,000 sq ft (5,110 sq m) as well as in 15,000 sq ft (1394 sq m) of 3 in (76.2 mm) slab on deck office area at a dosage of 3 lbs/cu yd (1.8 kg/cu m). The use of macro fibers as a simple ingredient to the concrete mix alleviated the challenges and cost associated with hoisting rolls of conventional welded wire fabric to the second-floor deck location as well as the proper placement within the concrete cross-section. The pumping, placing, and finishing of the macro fiber-reinforced concrete offered no issues on the deck segment of the project, and provided a user-friendly and cost-effective method of crack control.



Owner: Bon Tool Company, Gibsonia, Pennsylvania

Engineer: Brace Engineering, Pittsburgh, Pennsylvania

Concrete Supplier: DuBrook Ready Mix, Butler, Pennsylvania

Concrete Contractor: Hohman Cement Contractors, Pittsburgh, Pennsylvania

Fiber: FORTA-FERRO® 2-1/4" structural synthetic

Fiber Dosage: 5.0 lbs./cubic yard (floor slab) and 3.0 lbs./cubic yard (office deck)

Taco Mac Deck Topping

In October of 2009, FORTA-FERRO® macro-synthetic fiber reinforcement was selected as an alternate temperature/shrinkage reinforcement to welded wire fabric for the 3 in (76 mm) thick slab on deck project for the Taco Mac Restaurant in Atlanta, GA. The 2 1/4 in (54 mm) long fiber was used at a dosage of 4 lbs/cu yd (2.4 kg/cu m), and pumped easily over 150 ft (45.7 m) to the upper-level deck location in a 3 in (76.2 mm) line pump. In this project case, the fibers were compatible with a light brown integral color and a light broom textured finish for the exterior customer-service area.



Owner: Taco Mac Restaurant Group, Prado Complex, Atlanta, GA

Concrete Contractor: Catamount Contractors, Atlanta, GA

Concrete Supplier: Thomas Concrete, Atlanta, GA

Atlanta Botanical Gardens

FORTA-FERRO® was specified and utilized on the high-profile suspended concrete deck walkway project at Atlanta Botanical Gardens in December of 2009. In conjunction with primary steel reinforcement tied into the metal deck frame and support system, the 2 1/4 in (54 mm) macro-synthetic fiber was used at a dosage of 7.5 lbs/cu yd (4.5 kg/cu m) to minimize shrinkage-related cracking and eliminate construction and control joints over the length of the structure. This unique concrete pathway or “Canopy Walk” is the longest suspension walkway through a wooded area in the United States. Over 500 ft (152 m) in length, the elevated sidewalk was 10 to 12 ft (3 to 3.7 m) wide and placed at 5 in (127 mm) thick on the special metal deck and suspension system.



Owner: Atlanta Botanical Gardens

Location: Atlanta, GA

Application: Suspended concrete walkway

Architect: Jova, Daniels, Busby, Inc., Atlanta, GA

Engineering: Halvorson and Partners Engineers, Atlanta, GA; Thornton Tomasetti, Atlanta, GA

General Contractor: Hardin Construction, Atlanta, GA

Ready-Mix Supplier: Ready Mix USA, Atlanta, GA

Fiber: FORTA-FERRO® macrosynthetic, 2-1/4" long, 7.5 lbs./cu. yd. dosage

Special Note: The Atlanta Botanical Gardens project was the FORTA Corporation United States Project of the Year Award winner for 2010, awarded to Tom Baggett, Territory Sales Manager.

Sigma Thermal

The new manufacturing and office facility for the Sigma Thermal Corporation in Marietta, GA, provided the opportunity to take advantage of a variety of FRC – Fiber Reinforced Concrete – applications and performance levels. Long-time specifier and user of FRC, Stan D. Lindsey and Associates took advantage of two fiber types and three fiber dosages to accomplish their reinforcement goals in various portions of the project. For over 800 cubic yards of concrete used for interior office slabs, exterior sidewalks and parking area, and loading docks, the micro-fibrillated FORTA® Econo-Net® 1 ½” fiber was used at dosage of 3.0 lbs/cu yd to control cracking. For 30,000 sq. ft. of heavy-duty 8” thick manufacturing floor slab on ground, Lindsey specified the macrosynthetic FORTA-FERRO® 2 ¼” fiber at a high dosage of 7.5 lbs/cu yd and followed a regimen of low-shrinkage concrete and practices to push joint-spacing out to 50’ x 60’ column lines. And for 21,000 sq. ft. of 6 1/4” thick lightweight slab on composite metal deck, FORTA-FERRO® macrosynthetic fiber was used as an alternate to welded wire fabric at a dosage of 5.0 lbs/cu yd. The macro fiber was added and mixed uniformly by the experienced team at Thomas Concrete, pumped easily by Brundage-Bone Concrete Pumping, and placed and finished efficiently by Wheeler Services of Atlanta, who has used fiber reinforced concrete in a wide variety of previous project applications. In all, fiber reinforcement was used successfully to control cracking and add toughness in over 2,000 cubic yards of concrete.



Owner: Sigma Thermal Corporation, Marietta, GA

General Contractor: Garrard Construction Group, Duluth, GA

Concrete Contractor: Wheeler Services Inc., Atlanta, GA

Pumping Contractor: Brundage-Bone Concrete Pumping, Atlanta, GA

Structural Engineer: Stan D. Lindsey and Associates, Atlanta, GA

Ready-Mix Supplier: Thomas Concrete, Atlanta, GA

Fiber: FORTA-FERRO® macrosynthetic 2 ¼” @ 5.0 lbs/cu yd for lightweight slabs on metal deck

FORTA-FERRO® macrosynthetic 2 ¼” @ 7.5 lbs/cu yd for manufacturing slab on ground

FORTA® Econo-Net® microfibrillated 1 1/2” @ 3.0 lbs/cu yd for office slab on ground

St. Luke's Hospital

In May of 2011, concrete supplier Arrowhead Concrete Works of Duluth, MN, suggested synthetic fibers as a potential reinforcement alternate to conventional WWF – Welded Wire Fabric – for the St. Luke's Hospital and Regional Trauma Center new addition project. The 5-story facility involved a simple slab on ground along with a variety of slab on composite metal deck configurations that required a range of steel deck gauges, steel reinforcement, and concrete thicknesses. Estimators for Kelleher Construction of Burnsville, MN, worked closely with the FORTA® Technical Department to perform the required steel-to-fiber calculations and reach a macrosynthetic fiber dosage that would meet or exceed the reinforcement requirements for the deck construction. The fiber-alternate calculation report was reviewed and approved by the Cogdell Spencer and Erdman design/build firm, a 2012 acquisition of Lillibridge Healthcare Services Inc., Chicago, IL, which maintains over 400 medical facility properties covering 21 million square feet.

As a result, the FORTA® Econo-Mono® micromonofilament fiber was used to reduce plastic shrinkage cracking in 600 cubic yards of concrete for the first-floor slab on ground, and the FORTA-FERRO® macrosynthetic fiber was used at a dosage of 3.0 pounds per cubic yard of concrete as an alternative to conventional WWF reinforcement for the slabs on metal deck. Saving delivery, upper-level transport, and placement costs of the steel, macro fibers represented a considerable time and cost savings to the project as a three-dimensional reinforcement that was simply added to the concrete mix and pumped easily into place. The fiber offered no difficulties to the concrete placement and finishing process, and resulted in a smooth and fiber-free surface finish suitable for the final floor treatment. In all, FORTA-FERRO® was used to reinforce over 85,000 square feet of metal deck construction for the new St. Luke's Hospital project.



Owner: Lillibridge Healthcare Services Inc., Chicago, IL – a Ventas Inc. company

Tenant: St. Luke's Hospital and Regional Trauma Center, Duluth, MN

Application: Slab on composite metal deck

Design/Build Firm: Cogdell Spencer and Erdman, Duluth, MN

Concrete Contractor: Kelleher Constuction, Burnsville, MN

Pumping Contractor: R and S Pumping, Richmond, WI

Ready-Mix Supplier: Arrowhead Concrete Works, Duluth, MN

Fiber: FORTA-FERRO® macrosynthetic, 2 ¼" long @ 3.0 lbs/cu yd for slabs on deck

FORTA® Econo-Mono® micromonofilament, ¾" long @ 1.0 lb/cu yd for slab on grade

Amazon.com

In May 2012, the FORTA-FERRO® macrosynthetic fiber was used in a very large slab on metal deck project that provided a working surface for the 2nd-level order fulfillment operations for the Amazon.com division of Amazon Corporation. Previous mezzanine projects had resulted in an unacceptable level of cosmetic cracking, and a high volume dosage of macrosynthetic fiber was selected as a cost-effective potential corrective measure. The fiber was 2 ¼" long at a concentration of 0.5% by volume (7.5 lbs/cu yd), and used in over 237,000 square feet of 3 ½" composite metal deck. The fiber-reinforced concrete was pumped over 300 feet in some areas in a 4 in. line, and pumped easily after minor pump-grate corrections were performed. To-date, only very few short, tight cracks have been reported from re-entrant corner stairwell openings, and cracking on the open deck has essentially been eliminated.



Owner: Duke Realty Corporation, Indianapolis, IN

Location: Fairfield Commons, Middleton, DE

Occupant: Amazon.com

Concrete Consultant: CRT Concrete Consulting LLC, Fishers, IN

Concrete Contractor: Lithko Contracting Inc., Nashville, TN

Concrete Supplier: Heritage Concrete, Wilmington, DE

Pumping Contractor: Heritage Concrete, Wilmington, DE

Fiber: FORTA-FERRO® macrosynthetic, 2 ¼" long @ 7.5 lbs/cu yd dosage

Conclusion

Research, practice, and dialogue will continue regarding the reinforcement materials used in the concrete for slab on metal deck applications. Based on a wide variety of standards, and a multitude of industry reference projects, macrosynthetic fibers have become a well-recognized, cost effective, and acceptable reinforcement for these applications. An increase in the number of fiber reinforced slab on deck projects provides clear evidence of the growing acceptance and sufficient performance of fiber reinforced concrete.

As mentioned previously, this report was prepared simply to relay current industry standards with regard to fiber reinforcement on metal deck projects, and is not intended as engineering practice. FORTA Corporation continues to lead the synthetic fiber industry in research and new application technology, and will update the report and data as new standards, testing and project references become available.

References

1. Steel Deck Institute "C-2011 Standard for Composite Steel Floor Deck-Slabs", November 30, 2011, pg. 17.
2. Steel Deck Institute "C-2011 Standard for Composite Steel Floor Deck-Slabs", November 30, 2011, pg. 18.
3. FORTA® U.S.A. Report Summary # 20-08 "Residual Strength for FORTA-FERRO® at Two Dosages, January 2009.
4. "Contraction Joints in Elevated Concrete Slabs", Position Statement # 23, American Society of Concrete Contractors.
5. Technical Report: "Pumping High-Volume Fibers", FORTA Corporation, December 2011.
6. Steel Deck Institute "C-2011 Standard for Composite Steel Floor Deck-Slabs", November 30, 2011, pg. 17.
7. FORTA® U.S.A. Report Summary # 20-09 "U.L. Fire Resistance Testing – FORTA-FERRO®", January 2010.
8. U.L. Certification Directory, CBXQ.R18552 Fiber Reinforcement and Concrete Additives, 2009.
9. Certification Synthetic Fiber Reinforcement, FORTA Corporation, October 19, 2011

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.



FORTA Corporation

100 FORTA Drive, Grove City, PA 16127-6399 U.S.A.

1-800-245-0306 or 1-724-458-5221

Fax: 1-724-458-8331

www.forta-ferro.com



FORTA®, FORTA-FERRO®, and  are registered trademarks of FORTA Corporation. © June 12, 2012

Details Regarding Submittals and Supporting Documents

A variety of submittals with supporting documents may be required for slab on metal deck projects where macro-synthetic fibers are considered as the temperature/shrinkage reinforcement in the concrete slab. For the most part, project specifications may require compliance with the Steel Deck Institute C-2011 Standard, as well as compliance with the ASTM Standards regarding synthetic fibers. In addition, some projects may require UL fire-rating certification for the deck structure. This Technical Report includes the data and documentation for the FORTA-FERRO® macro-synthetic fiber reinforcement required for submittals for each of these three standards:

1. SDI “C-2011 Standard for Composite Steel Floor Deck-Slabs”; The submittal must include the FORTA-FERRO® fiber aspect ratio (79.5), length (2 ¼ in, 54 mm), equivalent diameter (0.0283 in, 0.72 mm), and dosage (minimum 4.0 lbs/cu yd, 2.4 kg/cu m).
2. ASTM D7508 and C1116; FORTA-FERRO® meets the required minimums of denier, equivalent diameter, tensile strength, and length for D7508, and meets the chemical make-up requirements as inert to deterioration from alkali attack per C1116 4.1.3 Type III
3. UL Rating; For projects that require a UL fire-rated deck structure, UL Certification # R18522 confirms compliance of FORTA-FERRO® macro-synthetic fiber for up to and including a 3-hour assembly rating.

Attached Documents

- FORTA-FERRO® Fact-Data Sheet
- FORTA® U.S.A. Test Report Summary # 20-08
- ASCC Position Statement # 23, “Contraction Joints in Elevated Concrete Slabs”
- FORTA® U.S.A. Test Report Summary # 20-09
- U.L. Certification Directory, CBXQ.R18552 Fiber Reinforcement and Concrete Additives
- Certification Synthetic Fiber Reinforcement, FORTA Corporation, October 19, 2011

Certification

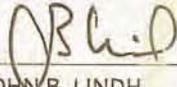
SYNTHETIC FIBER REINFORCEMENT

MATERIAL CERTIFICATION

FORTA Corporation hereby certifies that each grade of our fiber reinforcement is manufactured of 100% virgin synthetic materials containing no reprocessed materials. In addition, the FORTA® product grades are fully-oriented fibers, and are designed and manufactured specifically for use in concrete.

SPECIFICATION AND CODE COMPLIANCE

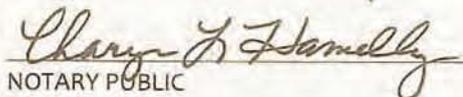
The FORTA® grades of fiber reinforcement comply with the material specifications of ASTM-C-1116 "Standard Specification of Fiber Reinforced Concrete and Shotcrete", Section 4.1.3 and ASTM D-7508 "Standard Specification for Polyolefin Chopped Strands for Use in Concrete." The FORTA® products also comply with the national building codes, including the International Building Code, International Residential Code, BOCA National Building Code, Standard Building Code, and Uniform Building Code. (ICC-ES Report #ESR-2720. FORTA® products are also classified by Underwriters Laboratory #R18552(N).



JOHN B. LINDH
President

Commonwealth of Pennsylvania
County of Mercer

Subscribed and sworn to before me
This 26th day of July, 2012



NOTARY PUBLIC



Notarial Seal
Charyn L. Hamelly, Notary Public
Jackson Twp., Mercer County
My Commission Expires Feb. 24, 2015

FORTA CORPORATION

100 FORTA Drive
Grove City, PA 16127-6399 USA
1-800-245-0306
1-724-458-5221
FAX: 1-724-458-8331
www.fortacorp.com