

Fiber-Reinforced Concrete for Long-Term Durable Structures—Case Studies

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Unreinforced concrete has low tensile strength and low strain capacity at fracture. These shortcomings are traditionally overcome by adding reinforcing bars or prestressing steel. Fiber reinforcement can be an alternative to continuous steel reinforcement. As defined by ACI PRC-544.3R-08, Section 1.1,¹ fiber-reinforced concrete (FRC) is a composite material consisting of a concrete/mortar phase and a dispersion of discontinuous fibers which can be randomly distributed, or specifically located in the structure to optimize performance. There are a variety of fiber types available on the market, which address various design requirements and constraints.² Based on their material type, fibers can be classified into four categories: steel, glass, synthetic (nylon, polyester, polypropylene, and carbon), and natural fibers,³ as defined by ASTM C1116/C1116M-23.⁴

Fibers are used to reinforce cementitious materials and to improve their pre- and post-crack behavior. Depending on the fiber type and at appropriate dosages, the addition of fibers can increase flexural strength, enhance ductility, provide increased resistance to plastic and drying shrinkage cracking, reduce crack widths, enhance energy absorption, and improve impact resistance by helping resist concrete tension stresses compared to nonfiber-reinforced concrete. The majority of FRC mixtures use steel, synthetic micro- or macrofiber, glass, or hybrid (or blends of) fibers. The use of FRC improves the safety, economy, sustainability, and functionality of structures.⁵

Rapid advances in fiber materials technology have enabled engineers to incorporate FRC in a variety of applications. Applications for fiber reinforcement include both nonstructural and structural elements. For structural applications, fibers are often used along with conventional reinforcement, where their role is to aid in stress redistribution and in many cases provide additional post-crack flexural strength, thus improving resistance to impact or dynamic loading and material disintegration. The major applications of FRC are slabs-on-ground and pavements, slabs-on-composite metal decks, precast concrete, and shotcrete. Examples of

slab-on-ground and pavement construction include residential, commercial, and industrial floor slabs; airport runways; roadways; and bridge decks. Precast concrete applications include septic tanks, pipes, tunnel linings, burial vaults, fence panels, and bumper blocks. Shotcrete applications often include rock slope stabilization, underground tunnel liners, hydraulic structures, and patch repair.

This article highlights the use of fiber reinforcement to enhance durability of concrete structures, as well as benefits of different types of fibers with projects up to 40 years in service, covering various applications in different geographic locations. Table 1 provides examples of structures where FRC was successfully used for a broad range of applications around the world. It includes details about installation year, location, type of application, project size, and type of fiber, as well as dosage used, where available. Additional applications are available from the various manufacturers of fiber reinforcement products for FRC.

Steel Fibers

Steel fibers for concrete reinforcement are discrete lengths of steel, sufficiently small enough to be randomly dispersed in concrete using common mixing procedures. Typical steel macrofibers diameters range from 0.01 to 0.05 in. (0.3 to 1.3 mm) and lengths from 1.2 to 2.5 in. (30 to 64 mm). ASTM A820/A820M-22, Section 4,⁶ provides classification for five general types of steel fibers, based primarily on the product or process used in their manufacture:

- Type I, cold-drawn wire;
- Type II, cut sheet;
- Type III, melt-extracted;
- Type IV, mill cut; and
- Type V, modified cold-drawn wire.

Steel fibers are available in various geometries including rectangular, flat, cylindrical, and variations or combinations of these. In typical construction, Type I and Type II are most prevalent. The dosage for steel fibers used depends on the

Table 1:
Worldwide applications of FRC

Project	Year	Location	Application	Size	Fiber type	Dosage, lb/yd ³	Why used
JFK Airport runway and taxiway	1980	New York, NY, USA	Pavement and overlay	30,000 ft ²	Steel Type I	85	Durability, long-term performance
Pepsi	1990	Cherryville, NC, USA	Pavement	250,000 ft ²	Steel Type I	—	Durability, crack control, load capacity
San Siro Stadium	1990	Milan, Italy	Cladding	77,000 ft ²	Glass	—	Durability, crack control, load capacity
Press Accommodation Building	1992	Barcelona, Spain	Façade cladding	680,000 ft ²	Glass	—	Durability, crack control, load capacity
Clackamas Hwy	1995	Estacada, OR, USA	Shotcrete	~30 yd ³	Synthetic microfiber	4.5	Safety, ease of use, cost
Maersk Container Terminal	1995	Algeciras, Spain	Pavement	3,800,000 ft ²	Steel Type I	—	Durability, crack control, load capacity
Salmon River Bridge	1995	Kemptown, NS, Canada	Bridge deck	8000 ft ²	Synthetic microfiber	8	Crack control, early project for steel-free bridge
SIMAT	1995	France	Precast pipes	—	Steel Type I	51	Ease of construction, long-term durability
Channel Tunnel Rail Link	1996	United Kingdom	Tunnel lining	70 miles	Steel Type I	51	Durability during handling and installation, corrosion resistance
Potsdamer Platz	1997	Germany	Mat foundation, pile supported	754,000 ft ²	Steel Type I	—	Ease of construction, long-term durability
Heathrow Express Station	1998	London, UK	Tunnel lining	150,000 ft ²	Glass	—	Durability, crack control, load capacity
BTS Skytrain	1999	Bangkok, Thailand	Noise barriers	490,000 ft ²	Glass	—	Durability, crack control, load capacity
Hall's Harbour Wharf	1999	Hall's Harbour, NS, Canada	Precast panels, marine environment	~80 yd ³	Synthetic macrofiber	12	Corrosion resistance, durability
Hwy 67 Bridge	1999	Elkhorn, WI, USA	Bridge deck	812 yd ³	Synthetic macrofiber	1.5	Crack control
VJ Rice septic tanks	1999	Bridgetown, NS, Canada	Precast	—	Synthetic macrofiber	11.5	Replacement of welded-wire reinforcement
Aberg Packers Bridge	2000	Madison, WI, USA	Bridge deck	180 yd ³	Steel Type V	80	Reduce transfer cracking
Halawa Quarry Scale House	2000	Honolulu, HI, USA	Pavement	—	Synthetic macrofiber	7.5	Durability, abrasion resistance
IKEA	2001	Sweden	Floor on piles, warehouse	215,000 ft ²	Steel Type I	—	Fiber-only pile-supported slab, ease of construction
Lake Ponchartrain/US-11	2001	New Orleans, LO, USA	Bridge deck overlay	5 miles	Steel Type V	88	Durability, 3D reinforcement
610 Loop overlay	2002	Houston, TX, USA	Pavement	10 miles	Blend	75	Accelerated production, durability
National Air and Space Museum	2002	Chantilly, VA, USA	Slab-on-ground	500,00 ft ²	Steel Type I	50	Durability, crack resistance, load capacity
Port Authority NY and NJ	2002	New York City, NY, USA	Pavement	—	Synthetic macrofiber	5	Rapid repair, less cracking desired
Danish Army/Aalborg Airport	2003	Aalborg, Denmark	Pavement	50,000 ft ²	Steel Type I	51	Ease of use, cost, durability, corrosion resistance
Copper Mine	2005	Los Pelambres, Chile	Shotcrete, underground	22,200 yd ³	Synthetic macrofiber	11.8	Long term durability
Ghent Rd. RTA	2005	Akron, OH, USA	Pavement	25,000 ft ²	Synthetic macrofiber	5.5	Speed of construction, replacement of welded-wire reinforcement, durability
Mason Street Bridge	2005	Green Bay, WI, USA	Bridge deck overlay	—	Synthetic macrofiber	8	Resistance to chloride ingress, corrosion, and general wear

Quartz Hill Water Treatment	2006	Palmdale, CA, USA	Shotcrete	4500 yd ³	Blend	5	Ease of use, corrosion resistance
Belfast Sewer	2007	Belfast, Ireland	Tunnel lining	41,570 yd ³	Steel Type I	51	Durability during handling and installation, corrosion resistance
Route Y and 00 Bridge	2007	Columbia, MO, USA	Bridge deck replacements	900 yd ³	Blend	7.5	Corrosion resistance, durability
USMC Base water channel	2007	29 Palms, CA, USA	Slip-form paving	1800 yd ³	Blend	5	Ease of use, corrosion resistance
1st Street intersection	2008	Abilene, TX, USA	Pavement	2500 ft ²	Blend	36	Durability, cost effectiveness
Abilene Airport parking	2008	Abilene, TX, USA	Pavement	200,000 ft ²	Blend	36	Alternative reinforcement
Interstate 220 Loop	2008	Jackson, MS, USA	Median guard rail base	2000 yd ³	Synthetic macrofiber	3	Accelerated production, durability
NCA Railcar Facility	2008	Tuscumbia, AL, USA	Industrial facility	3,200,000 ft ²	Steel Type I	50	Accelerated production, durability
Commercial warehouse	2012	Polinyà, Spain	Slab-on-ground	15,000 ft ²	Glass	9	Ease of construction, crack control
Private jet hangar	2013	Passo Fundo, Brazil	Slab-on-ground	8600 ft ²	Glass	9	Crack control

Note: 1 ft² = 0.09 m²; 1 lb/yd³ = 0.6 kg/m³; 1 yd³ = 0.76 m³; 1 mile = 1.6 km

application and the required engineering performance.

The use of steel-fiber reinforcement has been shown to increase durability by limiting crack development and minimizing crack widths, as well as improving fatigue response and impact resistance. Using steel fibers to extend or eliminate saw cut control joints can also help to increase the lifespan of flatwork. It is a common misconception that a steel fiber solution is more prone to cracking and damage from corrosion, but the opposite has been shown in testing and existing projects.

Durable projects with steel fibers

The construction of the Maersk Container Terminal pavement in Algeciras, Spain, began in 1995. This 3.8 million ft² (353,000 m²) project used a Type I steel-fiber solution for anticipated loading and long-term performance requirements (Fig. 1). It remains in use today and is exhibiting excellent performance.

Precast concrete pipes can be challenging to produce at scale with conventional reinforcement. To streamline construction scheduling and improve long-term durability performance, SIMAT in France has been using 50 lb/yd³ (30 kg/m³) of Type I steel fiber-reinforced solutions for their underground elements since 1995 (Fig. 2). This solution has been so successful it continues to be a standard practice for SIMAT today.

In 2002, the National Air and Space Museum in Chantilly, VA, USA, was constructed with a joint-free floor design totaling 500,000 ft² (46,450 m²) using top continuous reinforcement plus 50 lb/yd³ (30 kg/m³) Type I steel fibers. This solution was chosen for heavy long-term loading requirements and to eliminate visible joints in the floor. Among other loads, this slab supports a retired space shuttle and is still in use today.



Fig. 1: Pavement with Type I steel fibers at the Maersk Container Terminal, Algeciras, Spain, constructed in late 1990s



Fig. 2: Precast pipes with steel fibers have been manufactured by SIMAT in France since 1995

The Channel Tunnel Rail Link project in the United Kingdom is one of the largest construction projects in Europe, at approximately 70 miles (113 km) long with an internal diameter of 23.5 ft (7.2 m). Construction began in 1996; the tunnel was constructed with 60 MPa (8700 psi) concrete and 30 kg/m³ (50 lb/yd³) of Type I steel fibers for durability during handling and installation, and long-term corrosion resistance.

A warehouse slab project for IKEA in Sweden was constructed in 2001 on poor soils, where soil remediation was necessary, and the slab had to span between soil support elements. This project included a Type I fiber-only solution for the 215,000 ft² (20,000 m²) area and is still in service.

Synthetic Macrofibers

The inclusion of synthetic macrofibers in concrete structures can lead to maximizing durability and service life and offers potential reduction or elimination of conventional steel reinforcement in certain applications. Synthetic macrofibers have diameters greater than 0.01 in. (0.3 mm) and lengths ranging from 1.5 to 2.5 in. (40 to 65 mm). These products comply with ASTM D7508/D7508M⁷ standard, provide a smaller carbon footprint, and offer a safer, more affordable, and more accessible alternative to conventional steel reinforcement, especially under consideration of time for installation, inspection, and working environment. These service life improvements and material reductions present opportunities for housing and infrastructure construction that contribute to protecting the environment and ensuring public safety, health, security, serviceability, and life-cycle cost effectiveness.

Synthetic macrofibers offer improved chemical, chloride, and alkali resistance; enhanced mechanical properties (toughness; flexural, tensile, and impact strength; ductility); reduced crack width and propagation that inhibits failure modes from carbonation corrosion; chloride-induced corrosion; alkali-silica reaction (ASR); and other deterioration mechanisms, such as thermal spalling.

Durable projects with synthetic macrofibers

The Mason Street Bridge deck in Green Bay, WI, USA, demonstrates the use of synthetic macrofibers to improve long-term performance and durability. With a synthetic macrofiber dosage of 8 lb/yd³ (5 kg/m³), this bridge deck-wearing course was reconstructed in 2005 for required rehabilitation after a previous overlay had deteriorated due to chloride ingress, corrosion, and general wear. In 2018, after more than 13 years in service, the bridge deck is still performing well (Fig. 3).

VJ Rice Concrete in Bridgetown, NS, Canada, began using synthetic macrofibers in 1997 to replace welded-wire reinforcement in precast concrete septic tanks. Following a load test and waterproofing program to validate a high dosage of 11.5 lb/yd³ (6.8 kg/m³) to replace the conventional steel reinforcement, these tanks have now been in service for over 20 years.

The Port Authority of New York and New Jersey constructed a synthetic macrofiber roadway in 2002 using a dosage of 5 lb/yd³ (3 kg/m³) to improve fatigue resistance and cracking and to allow a rapid repair of a heavily trafficked roadway leading away from the shipping port and terminal. This roadway is still in service today and exhibits excellent performance.

Pavement for the scale house at Hawaii Cement's Halawa Quarry in Honolulu, HI, USA, was constructed in 2000 using 7.5 lb/yd³ (4.5 kg/m³) of synthetic macrofibers to provide abrasion resistance and durability against daily repeated loads from fully loaded aggregate carrying trucks. After more than 20 years in service and withstanding millions of tons of aggregate load, this slab is still in service and continues to exceed expectations.

Synthetic Microfibers

Synthetic microfibers also comply with ASTM D7508/D7508M. They can be in either monofilament, multifilament, or fibrillated form. The addition of synthetic microfibers in concrete pavements is an effective method to control plastic shrinkage cracking by reducing plastic settlement and providing superior microcrack control at the surface. This results in the extension of service life with reduced maintenance. These fibers are relatively fine with a typical diameter of 0.0004 to 0.012 in. (0.01 to 0.3 mm) and are used in relatively small dosages, ranging between 0.5 and 1.5 lb/yd³ (0.3 and 0.9 kg/m³) or 0.03 to 0.1% by volume. Fibrillated synthetic microfibers can be used to replace light gauge welded-wire reinforcement in most cases, typically at a dosage of 1.5 lb/yd³ (0.9 kg/m³).

In addition to the performance benefit of controlling plastic shrinkage cracking, synthetic microfibers are also used in concrete tunnel lining segments to reduce the risk of explosive spalling in the event of fire. When the concrete temperature is substantially increased, the moisture inside the concrete transitions to a vapor state and can lead to increased pressure in the concrete. If there is no way for the pressure to escape, the force inside the concrete can exceed the concrete's tensile capacity and lead to explosive spalling. Synthetic microfibers generally melt under high temperatures and create a capillary void system, which can provide a channel for the steam to escape, thus alleviating the risk of explosive spalling.

Durable project with synthetic microfibers

In 1999, a state highway bridge in Elkhorn, WI, was constructed using 812 yd³ (621 m³) of FRC with 1.5 lb/yd³ (0.9 kg/m³) of fibrillated synthetic microfibers for plastic shrinkage crack control. As shown in Fig. 4, the bridge remains in excellent condition after more than 22 years in service.

Hybrid or Blended Fibers

As defined by ACI PRC-544.3-08, Section 1.4.3, hybrid, or blended, fibers are combinations of fiber sizes, fiber materials,

or both, where in well-designed hybrid composites, there is positive interaction between the fibers, and the resulting hybrid FRC performance exceeds the sum of the individual fiber performances. Categories of fibers known to provide synergies are hybrids based on fiber constitutive response, hybrids based on fiber dimensions, and hybrids based on fiber function. Hybrids based on fiber function include the combination of synthetic microfibers with steel macrofibers, or synthetic microfibers with synthetic macrofibers, where one type of fiber is intended to improve the fresh and early-age properties, such as ease of production and plastic shrinkage crack control, while the second fiber leads to improved mechanical properties. Applications for blended fibers include bridge decks, pavements, overlays, structural mat foundations, and intersections.

Durable project with blended fibers

A durable project featuring blended fibers is the 1st Street intersection in downtown Abilene, TX, USA, that has been in service since 2008. This 2500 ft² (230 m²) intersection, shown in Fig. 5, was reinforced with 34.5 lb/yd³ (20.4 kg/m³) of Type V steel fibers and 1.5 lb/yd³ (0.9 kg/m³) of synthetic microfibers. The blend was chosen for durability and cost effectiveness. When evaluated 14 years later, there were no signs of damage or needed repairs.

Glass Fibers

Glass fiber-reinforced concrete (GFR) contains alkali-resistant (AR) glass fibers conforming to ASTM C1666/C1666M-08(2023),⁸ which covers minimum requirements for AR glass fibers intended for use in GFR by spray-up, GFR premix, FRC, and other cement-based products to ensure their long-term durability in cement-based composites. AR glass fibers for concrete reinforcement are typically chopped strands of glass fibers randomly dispersed in concrete using common mixing procedures. Glass fibers may be either integral strands built from a bundle of

glass filaments or dispersible filaments. Fibers can be up to 1.4 in. (36 mm) long with a range of aspect ratios to match different applications. Dosages range from 1 lb/yd³ (0.6 kg/m³) for simple applications up to 5% by volume (200 lb/yd³ or 120 kg/m³) for highly

technical applications. The dosage of glass fibers depends on the application and the required engineering performance.

The use of glass fibers has been shown to increase durability by limiting crack development and minimizing crack widths.



Fig. 3: Views of the deck of the Mason Street Bridge in Green Bay, WI, USA, which was constructed with synthetic macrofibers: (a) during construction in 2005; and (b) after more than 13 years of service

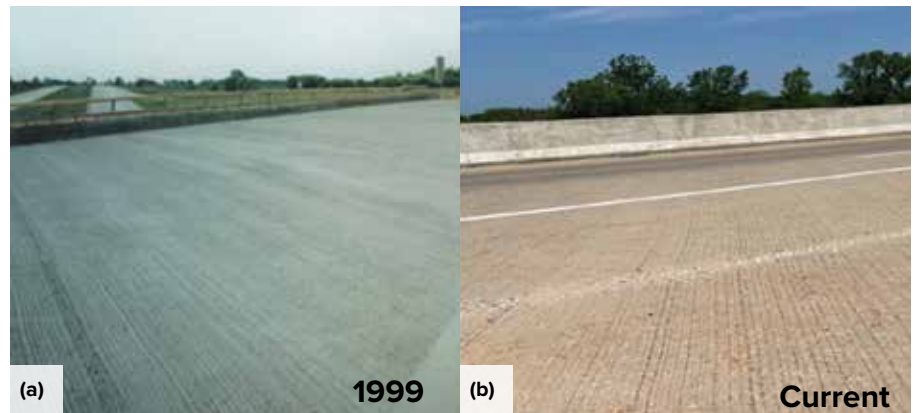


Fig. 4: Views of the deck of a state highway bridge in Elkhorn, WI, which was constructed with fibrillated synthetic microfibers: (a) during construction in 1999; and (b) after more than 22 years in service

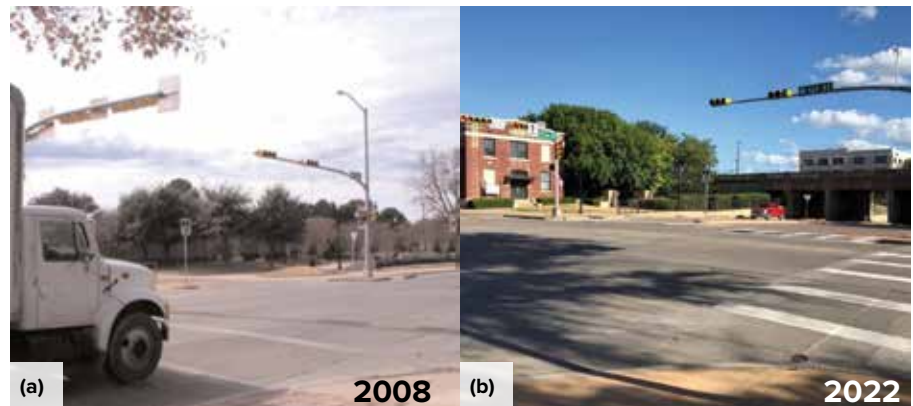


Fig. 5: Views of pavement in Abilene, TX, USA, which was constructed with a blend of steel and synthetic fibers: (a) shortly after construction in 2008; and (b) after 15 years in service

Durable projects with glass fibers

A 15,000 ft² (1400 m²) commercial warehouse was built in Polinyà, Spain, in 2012 with 8.5 lb/yd³ (5 kg/m³) of AR glass macrofibers for anticipated loading and long-term performance requirements and 1 lb/yd³ (0.6 kg/m³) of dispersible AR glass microfibers to reduce plastic shrinkage cracking.

In 1990, GFRC was selected to provide durability and crack control for the exterior panels of the renovation for the San Siro Stadium in Milan, Italy. Over 1000 panels totaling about 77,000 ft² (7150 m²) were produced to provide curtain walls and cladding to the four towers supporting the beams of the roof. GFRC architectural panels typically contain a minimum of 4% AR glass fibers by mass of total mixture.

Concluding Remarks

Evidence of the long-term durability associated with fiber reinforcement can be found not just herein, but in structures constructed throughout history. Since ancient times, for example, straw has been used to reinforce sunbaked bricks, and horsehair has been used to reinforce masonry mortar and plaster.³ Monuments to the benefits of fiber reinforcement

include the Roman Colosseum in Italy and the walls of the Alamo in Texas. With continued advancements in fiber technology and design, FRC offers the long-term durability that is an essential component in the industry's quest to lower the embodied carbon associated with the built environment and can help ensure that today's constructions are tomorrow's monuments.

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Selected for reader interest by the editors.



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Estas mejoras en la vida útil y reducciones de materiales presentan oportunidades para la construcción de viviendas e infraestructura que contribuyen a proteger el medio ambiente y garantizar la seguridad pública, la salud, la capacidad de servicio y la rentabilidad durante todo el ciclo de vida.

Las macrofibras sintéticas ofrecen resistencia mejorada a químicos, cloruros y álcalis; propiedades mecánicas mejoradas (dureza; resistencia a la flexión, a la tracción y al impacto; ductilidad); reducción del ancho y la propagación de las grietas que inhiben los modos de falla debidos a la corrosión por carbonatación; corrosión inducida por cloruro; reacción álcali-sílice (RAS); y otros mecanismos de deterioro, como el desconchado térmico.

Proyectos duraderos con macrofibras sintéticas

El tablero del puente Mason Street en Green Bay, WI, EE. UU., demuestra el uso de macrofibras sintéticas para mejorar el rendimiento y la durabilidad a largo plazo. Con una dosis de macrofibra sintética de 8 lb/yd³ (5 kg/m³), esta capa de rodadura del tablero del puente fue reconstruida en 2005 para la rehabilitación requerida después de que una sobrecarpeta anterior se hubiera deteriorado debido al ingreso de cloruro, la corrosión y el desgaste general. En 2018, después de más de 13 años en servicio, el tablero del puente sigue funcionando bien (Fig. 3).

VJ Rice Concrete en Bridgetown, NS, Canadá, comenzó a utilizar macrofibras sintéticas en 1997 para reemplazar la malla electrosoldada en fosas sépticas de concreto prefabricado. Luego de una prueba de carga y un programa de impermeabilización para validar una dosis alta de 11.5 lb/yd³ (6.8 kg/m³) para reemplazar el refuerzo de acero convencional, estos tanques han estado en servicio durante más de 20 años.

La Autoridad Portuaria de Nueva York y Nueva Jersey construyó una carretera de macrofibra sintética en 2002 utilizando una dosis de 5 lb/yd³ (3 kg/m³) para mejorar la resistencia a la fatiga y al agrietamiento y permitir una reparación rápida de una carretera muy transitada que se aleja del puerto y la terminal de embarque. Esta vía todavía está en servicio hoy y exhibe un excelente desempeño.

El pavimento para la casa de báscula en la cantera Halawa de Hawaii Cement en Honolulu, Hawaii, EE. UU., se construyó en el año 2000 utilizando 7.5 lb/yd³ (4.5 kg/m³) de macrofibras sintéticas para proporcionar resistencia a la abrasión y durabilidad frente a cargas repetidas diarias provenientes del transporte de agregados en camiones completamente cargados. Después de más de 20 años en servicio y soportando millones de toneladas de carga de agregados, esta losa sigue en servicio y continúa superando las expectativas.

A

2005

B

2018

Fig. 3: Vistas del tablero del puente Mason Street en Green Bay, WI, EE. UU., que fue construido con macrofibras sintéticas: (a) durante la construcción en 2005; y (b) después de más de 13 años de servicio.

Microfibras Sintéticas

Las microfibras sintéticas también cumplen con ASTM D7508/D7508M. Pueden estar en forma de monofilamento, multifilamento o fibrilada. La adición de microfibras sintéticas en pavimentos de concreto es un método eficaz para controlar el agrietamiento por contracción plástica al reducir el asentamiento plástico y proporcionar un control superior de las microfisuras en la superficie. Esto da como resultado una extensión de la vida útil con un mantenimiento reducido. Estas fibras son relativamente finas con un diámetro típico de 0.0004 a 0.012 pulgadas (0.01 a 0.3 mm) y se usan en dosis relativamente pequeñas, que oscilan entre 0.5 y 1.5 lb/yd³ (0.3 y 0.9 kg/m³) o 0.03 a 0.1% por volumen. En la mayoría de los casos, se pueden utilizar microfibras sintéticas fibriladas para reemplazar la malla electrosoldada de calibre ligero, generalmente en una dosis de 1.5 lb/yd³ (0.9 kg/m³).

Además del beneficio de desempeño que supone controlar el agrietamiento por contracción plástica, las microfibras sintéticas también se utilizan en segmentos de revestimiento de túneles de concreto para reducir el riesgo de desconchado explosivo en caso de incendio. Cuando la temperatura del concreto aumenta sustancialmente, la humedad dentro del concreto pasa a un estado de vapor y puede provocar un aumento de presión en el concreto. Si no hay forma de que escape la presión, la fuerza dentro del concreto puede exceder la capacidad de tracción del concreto y provocar un desconchado explosivo. Las microfibras sintéticas generalmente se derriten a altas temperaturas y crean un sistema de huecos capilares, que puede proporcionar un canal para que escape el vapor, aliviando así el riesgo de desconchado explosivo.

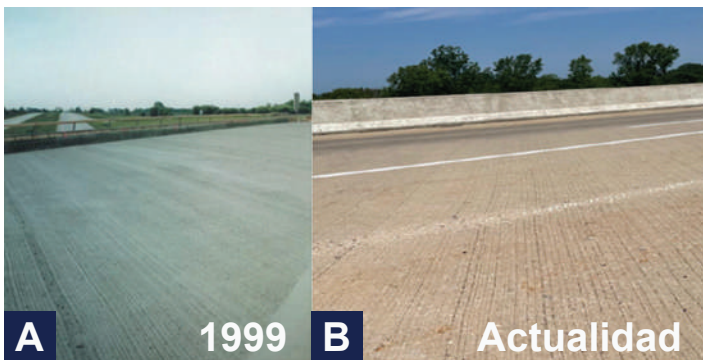


Fig. 4: Vistas del tablero de un puente de una carretera estatal en Elkhorn, WI, que se construyó con microfibras sintéticas fibriladas: (a) durante la construcción en 1999; y (b) después de más de 22 años en servicio.

fibra o ambos, donde en compuestos híbridos bien diseñados, existe una interacción positiva entre las fibras y el desempeño resultante del CRF híbrido excede la suma de los rendimientos de las fibras individuales. Las categorías de fibras que se sabe que proporcionan sinergias son los híbridos basados en la respuesta constitutiva de la fibra, los híbridos basados en las dimensiones de la fibra y los híbridos basados en la función de la fibra. Los híbridos basados en la función de la fibra incluyen la combinación de microfibras sintéticas con macrofibras de acero, o microfibras sintéticas con macrofibras sintéticas, donde un tipo de fibra está destinado a mejorar las propiedades frescas y de edad temprana, como la facilidad de producción y el control de grietas por contracción plástica, mientras que la segunda fibra conduce a una mejora en las propiedades mecánicas. Las aplicaciones de fibras mezcladas incluyen tableros de puentes, pavimentos, sobrecarpetas, cimientos de losas estructurales e intersecciones.

Proyecto duradero con microfibras sintéticas

En 1999, se construyó un puente de una carretera estatal en Elkhorn, WI, utilizando 812 yd³ (621 m³) de CRF con 1.5 lb/yd³ (0.9 kg/m³) de microfibras sintéticas fibriladas para el control de grietas por contracción plástica. Como se muestra en la Fig. 4, el puente permanece en excelentes condiciones después de más de 22 años en servicio.

Fibras Híbridas o Mixtas

Según lo definido por ACI PRC-544.3-08, Sección 1.4.3, las fibras híbridas o mezcladas son combinaciones de tamaños de fibra, materiales de



Fig. 5: Vistas del pavimento en Abilene, TX, EE. UU., que fue construido con una mezcla de acero y fibras sintéticas: (a) poco después de la construcción en 2008; y (b) después de 15 años de servicio.

Proyecto duradero con fibra mezclada

Un proyecto duradero que incluye fibras mezcladas es el de la intersección de 1st Street en el centro de Abilene, TX, EE.UU., que ha estado en servicio desde el 2008. Esta intersección de 2,500 pies² (230 m²), mostrada en la Fig. 5, fue reforzada con 34.5 lb/yd³ (20.4 kg/m³) de fibras de acero Tipo V y 1.5 lb/yd³ (0.9 kg/m³) de microfibras sintéticas. La mezcla fue elegida por durabilidad y efectividad de costo. Cuando fue evaluada 14 años después, no existían signos de daño o reparaciones necesarias.

Fibras de Vidrio

El concreto reforzado con fibras de vidrio (CRFV) contiene fibras de vidrio resistentes a los álcali (RA) de acuerdo a la ASTM C1666/ C1666M-08(2023)⁸, que cubre los requerimientos mínimos para que las fibras de vidrio RA destinadas a ser utilizadas en CRFV por pulverización, premezcla de CRFV, CRF y otros productos a base de cemento para garantizar su durabilidad a largo plazo en compuestos basados en cemento. Las fibras de vidrio RA para concreto reforzado suelen ser hebras de fibras de vidrio cortadas y dispersas aleatoriamente en el concreto usando procedimientos de mezcla común. Las fibras de vidrio pueden ser hilos integrales contruidos a partir de una hebra de filamentos de vidrio o filamentos dispersables. Las fibras pueden tener hasta 36 mm (1.4 pulg.) de largo con una variedad de relaciones de aspecto para combinarse con diferentes aplicaciones. El rango de dosis va desde 1 lb/ yd³ (0.6 kg/m³) para fácil aplicación, hasta 5% por volumen (200 lb/ yd³ o 120 kg/m³) para aplicaciones altamente técnicas. La dosis de las fibras de vidrio depende de la aplicación y el desempeño ingenieril requerido.

El uso de fibras de vidrio ha demostrado incrementar la durabilidad al limitar desarrollo de grietas y minimizar anchos de grietas.

Proyectos durables con fibras de vidrio

A En 2012 se construyó un almacén comercial de 15,000 pies² (1,400 m²) en Polinyà, España, con 8.5 lb/ yd³ (5 kg/m³) de macrofibras de vidrio RA para carga anticipada y requisitos de rendimiento a largo plazo y 1 lb/ yd³ (0,6 kg /m³) de microfibras de vidrio dispersables RA para reducir el agrietamiento por contracción plástica.

En 1990, el CRFV fue seleccionado para proporcionar durabilidad y control de grietas para los paneles exteriores de la renovación del Estadio San Siro en Milán, Italia. Se produjeron más de 1,000 paneles con un total de aproximadamente 77,000 pies² (7,150 m²) para proporcionar muros cortina y revestimiento a las cuatro torres que sostienen las vigas del techo. Los paneles arquitectónicos de CRFV normalmente contienen un mínimo de 4% de fibras de vidrio AR por masa de la mezcla total.

Observaciones Finales

La evidencia de la durabilidad a largo plazo asociada con el refuerzo de fibra se puede encontrar no sólo aquí, sino también en estructuras construidas a lo largo de la historia. Desde la antigüedad, por ejemplo, se ha utilizado paja para reforzar ladrillos cocidos al sol y crin de caballo para reforzar morteros de mampostería y yesos³. Monumentos a los beneficios del refuerzo con fibras incluyen el Coliseo Romano en Italia y los muros del Álamo en Texas. Con avances continuos en la tecnología y el diseño de la fibra, el CRF ofrece la durabilidad a largo plazo que es un componente esencial en la búsqueda de la industria para reducir el carbono incorporado asociado con el entorno construido y puede ayudar a garantizar que las construcciones de hoy sean los monumentos del mañana.

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