Fibers-in-Practice

FAQs – Frequently Asked Questions

GENERAL FIBER QUESTIONS

Q. Are fibers an admixture?

A. No. Fibers are defined as **reinforcement**; refer to ACI CT-18, Concrete Terminology. Even though fibers are added to concrete like admixtures, fibers hold concrete together by bridging cracks.

Q. What is the difference between a macrofiber and a microfiber?

A. Differences exist in both the specification and application of macrofibers and microfibers.

Specification: The main difference is in their size, which is typically defined by equivalent diameter or linear density. In the Fiber-Reinforced Concrete (FRC) industry, linear density is typically expressed in units of denier which is the fiber's mass in grams per 9,000 meters of fiber (see Table 1).

Table 1 - Size differences of microfibers and macrofibers

Fiber	Equivalent Diameter	Linear Density
Microfibers	< 0.3 mm (0.012 in)	< 580 denier
Macrofibers	≥ 0.3 mm (0.012 in)	≥ 580 denier

The following ASTM standards can be referenced for further classification:

For synthetic fibers, ASTM D7508/D7508M, "Standard Specification for Polyolefin Chopped Strands for Use in Concrete," details conformance requirements for macrofibers, microfibers, and hybrid fibers, which are a combination of the two. This standard also uses tensile strength and cut length as additional attributes to differentiate synthetic macrofibers from microfibers.

For natural microfibers, ASTM D7357 "Standard Specifications for Cellulose Fibers for Fiber-Reinforced Concrete" details conformance requirements.

For steel fibers, which fall into the category of macrofibers, ASTM A820/A820M, "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete," covers minimum requirements for steel fibers intended for use in fiber-reinforced concrete.

Application: Microfibers are used to control plastic shrinkage cracking of concrete. Other than in the fibrillated version, they do not provide any temperature and shrinkage crack control or add other enhancements to the concrete at typical dosages. Fibrillated microfibers at minimum dosages of 1.5 lb/yd^3 (0.9 kg/m^3) can be used as an alternate to light-gage welded-wire reinforcement (WWR) (generally up to 10-gage), for control of temperature and shrinkage cracking and will add some measure of durability, impact and residual strength, and toughness to the concrete. Macrofibers provide considerable enhancements to the concrete including post-crack residual strength and load transfer across cracks; hold cracks tightly together; improve durability and flexural toughness; and increase fatigue, impact, and shear resistance of the concrete.

Q. Are all synthetic macrofibers the same?

A. No. There are many types of synthetic macrofibers on the market, all with individual benefits and advantages. Aside from differences in physical characteristics such as tensile strength, elastic modulus, material composition, or shape, there are other differences that are not so readily apparent. How well do the fibers mix without balling or clumping? How well do the fibers finish in the concrete? How well do the fibers bond with the concrete? The key to successful use of a synthetic macrofiber is providing the proper dosage for a given application, while meeting the workability and finishability requirements. Stronger fibers or better-bonding fibers will likely require less material than weaker fibers or fibers with less bonding capacity. The manufacturer must support dosage recommendations with testing information. If questions still exist, a trial should be performed to ensure the desired performance is met.

Q. What is a 'structural' synthetic fiber?

A. 'Structural' synthetic fiber is a term that is sometimes used in reference to synthetic macrofibers because of the post-crack residual flexural strength and flexural toughness that they provide to the concrete.

Q. Can high dosage microfibers be used in place of low dosage macrofibers?

A. In general, no. The primary function of a microfiber is the control of plastic shrinkage cracks, and research has shown that at the dosages used these fibers do not have a significant ability to carry load across a crack in hardened concrete. Secondarily, high dosages of microfibers will be more difficult to mix as the fiber counts and surface area of the fibers will be extremely high which can cause problems with mixing and significant loss in slump.

Q. Is fiber length important?

A. Long fibers have more surface area than short fibers of the same type, which means they can anchor in the hardened concrete better and, thereby, provide improved post-crack benefits at the same dosage. There is, however, an optimum length for a particular fiber that depends on the specific fiber shape and stiffness characteristics as well as on the compressive strength of the concrete. Pre-project test pours conducted with the project mixture design and mixing system will provide an indication of the optimum fiber length for a particular fiber application.

Such trials should consider mixing and finishing, ensuring the length does not cause issues related to balling or surface stubble. See FRCA "FIP 3 – Placing, Pumping & Finishing Fiber-Reinforced Concrete" for additional information.

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Q. Can synthetic macrofibers actually compete "head to head" with steel fibers?

A. Absolutely. In general, synthetic macrofibers (large, coarse, monofilament fibers) are the only synthetic fiber types that can provide equivalent residual strength capacity to steel fibers, depending on the dosage. Other factors such as expected deformations and environmental considerations should also be considered before selecting the appropriate fiber product, whether it is steel or synthetic. There are some structural applications for steel fibers in which synthetic fibers have not yet been used or verified for. See FRCA "FIP 9 - Fibers vs. Conventional Steel Reinforcement" for additional information.

Q. Steel fibers are stronger than synthetic fibers; How can synthetics be considered equal?

A. Synthetic macrofibers generally do have lower tensile strength and modulus of elasticity than steel fibers but will have a much higher fiber count bridging a potential crack. In effect, the total stress transfer capacity across a crack should be equivalent when dosed on a performance basis. The effective section strength is also dependent on the ability of the fibers to bond to the concrete matrix itself. A very high tensile strength fiber without sufficient bond to concrete will not perform as a good fiber candidate. The performance of FRC is determined by the behavior of the composite material rather than that of individual fibers. See FRCA "FIP 9 - Fibers vs. Conventional Steel Reinforcement" for additional information.

Q. Is FRC the same as FRP since they both use fibers?

A. No. FRC uses discrete-length fibers (typically up to 2.5 in (64 mm)) that are encased within hydraulic-cement concrete. Fiber-Reinforced Polymers (FRP) use significantly longer-length fibers that are typically encased within a polymer-type matrix without cement and aggregates.

DOSAGE/APPLICATION QUESTIONS

Q. How is fiber dosage determined?

A. The quantity of fiber required for a given application depends on the specified performance requirement(s) for the fiber-reinforced concrete. For plastic shrinkage crack reduction using microfibers, a crack-reduction ratio (CRR) is typically specified from which the required dosage of microfiber can be determined from ASTM C1579 data. For hardened concrete properties using macrofibers, the fiber dosage is selected to meet either the specified average residual strength (ASTM C1399/C1399M), post-crack equivalent flexural strength (or strength ratio) (ASTM C1609/C1609M), or energy absorption capability (ASTM C1550), and taking into consideration factors including the type and thickness of the concrete element, concrete strength, the specified temperature and shrinkage reinforcement, and loading requirements. Many fiber suppliers offer spreadsheets or other design aids to calculate fiber dosage for different applications, with slabs-on-ground being the most typical. See FRCA "FIP 8 – Design and Specification of Fiber-Reinforced Concrete" for additional information.

Q. What is the minimum dosage?

A. Slab-on-Ground – Minimum dosage rates are typically determined by fiber manufacturers based on standardized product testing and are provided such that any stated minimum requirements or industry standards are met.

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Composite -Metal-Decks – The Steel Deck Institute (SDI) ANSI C-2017 specifies a required minimum dosage of 4.0 lb/yd^3 (2.4 kg/m^3) for synthetic macrofibers, or 25.0 lb/yd^3 (14.8 kg/m^3) for steel fibers, if the fibers are being used for temperature and shrinkage control. In the event the structural assembly falls under UL requirement there is an upper limit of 5.0 lb/yd^3 (3.0 kg/m^3) for synthetic macrofibers, or 66.0 lb/yd^3 (39.2 kg/m^3) for steel fibers. Fiber reinforcement is currently not used to replace negative moment steel in composite deck assemblies.

Q. Can you use less than the minimum?

A. The FRCA does not recommend the use of fibers below the minimum dosage recommended or provided by a supplier, or as required by a specification and/or building code(s). The Engineer of Record (EOR) should consider the overall design and consult the fiber manufacturer when in doubt of the end application and dosage.

Q. How do you design reinforced concrete using macrofibers instead of traditional steel?

A. There are several sources that offer guidance on designing with macrofibers for various structures (slabs-on-ground, slabs-on-piles, residential walls, precast, shotcrete, etc.):

- ACI 544.4R-18: Guide to Design with Fiber-Reinforced Concrete
- ACI 360R-10: Guide to Design of Slabs-on-Ground
- ACI 322-14: Residential Code Requirements for Structural Concrete

In addition, fiber manufacturers are knowledgeable about their specific fibers and can provide guidance.

Q. How should macrofibers be specified?

A. The specification of fiber-reinforced concrete (FRC) made with macrofibers should be performance-based and dependent on the application. Approved methodologies such as those provided in ACI 544.4R must be used to calculate the characteristic parameter to be specified. The characteristic parameter can be: average residual strength, ARS (psi or MPa) as defined in ASTM C1399/C1399M; residual strength, f_{150}^{D} (psi or MPa) or equivalent flexural strength, $f_{e,3}$ (psi or MPa) or equivalent flexural strength ratio, $R_{T,150}^{D}$ [also $R_{e,3}$] (%), which are defined in ASTM C1609/C1609M. For example, "fiber dosage shall provide a minimum residual strength, f_{150}^{150}, of 200 psi (1.4 MPa) in a 4,000 psi (28 MPa) concrete mixture." These specified values are translated into a dosage based upon the manufacturer's testing performed in accordance with the associated ASTM Standard Test Method. It is also recommended that specifications be written to include submittal of manufacturer's data demonstrating compliance.

For shotcrete applications, the performance of fiber-reinforced shotcrete (FRS) is determined by means of energy absorption capacity in panel tests following ASTM C1550 or EN 14488-5. Energy is defined as the area under the load-displacement curve and is expressed in Joules (J). The specification of FRS should read, for example, "fiber dosage shall provide a minimum energy absorption capacity of 280 J in a 4,000 psi (28 MPa) shotcrete mixture at seven days of age."

See FRCA "FIP 8 – Design and Specification of Fiber-Reinforced Concrete" for additional information.

Q. For macrofibers, what residual strength should be specified?

A. Residual strength or post-crack performance of fiber-reinforced concrete can be determined by either ASTM C1609/C1609M, C1399/C1399M, and even C1550 *(energy absorption).* The engineer of record (EOR) shall determine values based on the overall design intent and desired performance level. See ACI 544.4R for more information related to design criteria and performance selection.

Q. Can fibers be used in exterior applications?

A. Yes. However, some fibers, such as steel, may exhibit corrosion issues if they appear at or just beneath the concrete surface on projects with environmental exposure. Although this type of localized surface corrosion is not visually appealing, it does not affect the integrity of the concrete. The possible ramifications for a particular application should be evaluated prior to the project and acknowledged by all parties. Synthetic and natural fibers are non-corrosive and chemically inert, and therefore are not affected by environmental exposure conditions.

Q. Can fibers be used to reduce the thickness of concrete slabs and pavements?

A. While fibers typically do not add to the first-crack flexural strength (modulus of rupture, ASTM C78/C78M) of the concrete, they do add to the flexural capacity and fatigue strength of slabs-on-ground. As a result, the flexural toughness values provided by a particular fiber and dosage can be used in flexural design calculations, thereby often reducing the concrete thickness needed to support the project design loads. Given the proper toughness or residual strength values for a particular fiber at a specific dosage, design engineers can calculate the appropriate slab thickness for the fiber-reinforced concrete. See FRCA "FIP 8 – Design and Specification of Fiber-Reinforced Concrete" for additional information.

Q. Can fibers be used in composite steel deck slabs in lieu of welded-wire reinforcement?

A. Yes. Section 2.4.B.15, Reinforcement for Temperature and Shrinkage, of the ANSI/SDI C-2017 Standard for Composite Steel Deck Floor-Slabs permits the use of either steel fibers or synthetic macrofibers at dosages determined by the manufacturer for the application in lieu of welded wire reinforcement (WWR), subject to minimum dosages of 25 lb/yd^3 (14.8 kg/m^3) and 4.0 lb/yd^3 (2.4 kg/m^3), respectively. The following summarizes the provisions in ANSI/SDI C-2017. In addition, Underwriters Laboratories (UL) and the International Code Council Evaluations Service (ICC-ES), under some well-defined circumstances in fiber specific reports, recognize some microfibers as alternatives to welded wire fabric in concrete and steel floor units of listed fire-resistant-rated floor/ceiling and floor-design assemblies.

> "Reinforcement for Temperature and Shrinkage:
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> Reinforcement for crack control purposes other than to resist stresses from quantifiable structural loadings shall be permitted to be provided by one of the following methods:
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> 1. Welded wire reinforcement or reinforcing bars with a minimum area of 0.00075 times the area of the concrete above the deck (per foot or meter width), but not less than the area provided by 6 x 6 - W1.4 x W1.4 (152 x 152 - MW9 x MW9) welded wire reinforcement.
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> 2. Concrete specified in accordance with ASTM C1116, Type I, containing steel fibers meeting the criteria of ASTM A820, Type I, Type II or Type V, at a dosage rate determined by the fiber manufacturer for the application, but not less than 25 lb/yd^3 (14.8 kg/m^3).
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> 3. 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 4.0 lb/yd^3 (2.4 kg/m^3)."

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Q. Will the concrete be hairy?

A. This was a historically older occurrence that was most often experienced when using synthetic microfibers. The extremely high fiber count of synthetic microfibers would produce hairy slabs when practices for finishing FRC were not followed. Today, most monofilament microfibers are limited to 1.0 to 1.5 lb/yd^3 (0.6 to 0.9 kg/m^3).

The use of synthetic macrofibers, as well as some natural microfibers, greatly reduces the occurrence of hairy concrete slabs. FRC should not be hairy; proper addition, mixing, placing, and finishing will yield an excellent floor finish. Keep in mind if a hairy slab is experienced, the integrity of the slab is still maintained. Though aesthetically displeasing, a simple remedy of using a rosebud torch to melt away any exposed fiber at the surface resolves the issue in an efficient manner. Pre-project trials are recommended to ensure that the owner's expectations are met regarding the surface appearance of a particular fiber and dosage.

MIXTURE DESIGN QUESTIONS

Q. Do synthetic fibers absorb water?

A. While some synthetics, such as nylon, can absorb a small amount of batch water, the most commonly used fibers made of polypropylene or polyethylene are hydrophobic and cannot absorb water. The normal reduction in visual slump with these synthetic fibers, particularly at higher dosages, is a result of the fibers acting as a binder or cohesive agent in the mixture, rather than a function of water absorption. See FRCA "FIP 3 – Placing, Pumping & Finishing Fiber-Reinforced Concrete" for additional information.

Q. Do fibers require additional water for placement?

A. No. Adding additional water to the designed mixture will reduce the strength of the concrete. When workability is affected due to high fiber content, use of chemical admixtures is advised, not additional water. See FRCA "FIP 3 – Placing, Pumping & Finishing Fiber-Reinforced Concrete" for additional information.

Q. Where should fibers be added to the mixing system?

A. The optimum fiber addition point will vary depending on the shape, stiffness, and dosage of a particular fiber. Some fiber types perform best as a first ingredient, while other types require addition during or after all other mix ingredients have been charged. Typically, fiber manufacturers can give guidance on when their fibers should be added to the mixing system. In some cases, it is advisable to perform your own pre-project test pour with a given fiber to determine the optimum addition point as well as optimum mixing time. See FRCA "FIP 2 – Batching Fiber-Reinforced Concrete" for additional information.

Q. How long should the fibers be mixed in the concrete?

A. It is generally recommended to mix any type of fiber for 4 to 5 minutes for normal concrete mixtures in ready-mix operation after all other mixture constituents have been added.

Q. Why do fibers "ball up" in concrete mixes?

A. All fiber types (steel, micro- and macro-synthetic) have the potential to "ball up" in concrete. This phenomenon can be caused by insufficient mixing time, wrong sequencing, addition of fibers into concrete mixtures that are too dry (slump decreases to zero) or into mixtures that do not have enough fine particles (cement, sand, supplemental materials, etc.) to coat the fibers, which in turn "paste starves" the system and again causes the slump to decrease to zero. Loose fibers in an empty drum may clump together and fiber types that are too long or have varying geometries may also cause problems. As always, a pre-project test pour should be performed to ensure that the mixture will support the fiber type and dosage, and that the batching sequence will not cause any problems. See FRCA "FIP 2 – Batching Fiber-Reinforced Concrete" and "FIP 3 – Placing, Pumping & Finishing Fiber-Reinforced Concrete" for additional information.

Q. Do fibers affect slump?

A. Sometimes. The effect on slump depends upon several attributes:

1. The starting slump of the mixture. There is less effect when the starting slump is high, but more effect when the starting slump is low.
2. The fiber count and fiber dosage. The higher the dosage (and thus the fiber count), the greater the effect on slump.
3. The total surface area (or size) of the fiber being used. The greater the surface area, the greater the effect on slump.

It should be noted that slump as measured by the slump cone test is only a measure of consistency from batch to batch, and therefore not necessarily indicative of the actual workability of a particular mixture. Though the visual slump of a fiber mixture may appear to be reduced, the actual workability may be impacted to a much lesser degree. Pre-project trials of FRC mixes are recommended to determine appropriate corrective measures if additional workability is required.

Q. How much slump loss can I expect with the use of fibers?

A. Depending upon the applied dosage, slump loss can be expected with the use of just about any fiber type on the market. The higher the fiber dosage in the concrete mix, the higher the potential loss of slump of concrete. (Note that for a given aspect ratio and dosage, microfibers may have a greater effect on slump than macrofibers. This is due to the higher fiber count of some microfibers per pound of fiber. In other words, the impact on slump will be greater when using 2.0 lb/yd^3 (1.2 kg/m^3) of a microfiber than if using 3.0 lb/yd^3 (1.8 kg/m^3) of a macrofiber.)

Similar to aggregates, fibers in the concrete mixture require paste to coat the individual strands. The more surface area to cover, the higher the paste demand within the mix. The more paste covering the fibers, the less available to act like a lubricant within the mixture, and thus loss of slump will occur.

Concrete mixtures that have low cement contents may sometimes not support the use of higher dosages of fiber and mixing problems will result, usually in the form of "fiber balls" or "stony" mixtures. At all times, ensure that the slump of the concrete does not fall to zero (no slump or workability).

In general, synthetic microfibers at a dosage range of 1.0 to 3.0 lb/yd^3 (0.6 to 1.8 kg/m^3) will typically produce a slump loss of 1 to 3 in (25 to 75 mm), synthetic macrofibers at a dosage range of 3.0 to 10.0 lb/yd^3 (1.8 to 6.0 kg/m^3) or steel fibers at a dosage range of 15 to 50 lb/yd^3 (9 to 29.6 kg/m^3) will typically produce a slump loss of 1 to 5 in (25 to 125 mm). Slump loss should be countered by the use of plasticizing agents such as mid- and/or high-range water reducers. It may even be necessary with high fiber dosages to adjust the mixture proportions to assure adequate paste content for the fibers used; consult your fiber manufacturer. The use of excess water will impact the compressive strength and possibly cause segregation of the concrete mixture and should be avoided. See FRCA "FIP 2 – Batching Fiber-Reinforced Concrete" and "FIP 3 – Placing, Pumping & Finishing Fiber-Reinforced Concrete" for additional information.

Q. Will the use of fibers impact the air content or compressive strength?

A. Generally, the use of macrofibers does not adversely impact the air content or compressive strength of concrete. It may sometimes be perceived that strength or air is altered, but this is usually caused by excessive mixing, addition of water, higher temperatures and/or incorrect measurement of moisture in aggregate stockpiles. Air fluctuations can also be attributed to changes in actual slump of concrete – note that the fibers only alter the visible slump and that fiber-reinforced mixtures should have slump flow measured under vibration such as using an inverted slump cone. Historically, some fiber surfactants or glues have been known to add air or interact with other chemical admixtures causing unwanted additional air, however this is a rare occasion with today's production practices.

Q. Do fibers affect unit weight of the concrete?

A. It depends on fiber type and mixture design adjustments. Unit weight is based on exact proportioning of the mixture and the air content. For synthetic fibers, if the air content does not change with the addition of fibers, then the unit weight does not change either. For steel fibers, which have a higher density, it is possible that the unit weight will increase depending on the volume fraction used and mixture design adjustments to accommodate that volume fraction.

Q. Do fibers float or sink in concrete?

A. In normal weight concrete, well mixed fibers in correctly proportioned concrete will normally not float nor sink due to the specific gravity of the materials and viscosity of the mixed concrete. In fact, fibers will typically help suspend the larger aggregate and prevent mix segregation.

Q. Can fibers have an impact on other chemicals added to the mix?

A. Typically, no. However, some fibers are manufactured with a processing aid or spin finish that can impact other chemicals added to the concrete mix. It is always best to verify with the fiber manufacturer.

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