FIP 9 – Fibers vs. Conventional Steel Reinforcement

What is Reinforcement?

Reinforcement is defined in the American Concrete Institute, Concrete Terminology Document, ACI CT-18, as "bars, wires, strands, fibers, or other slender elements that are embedded in a matrix such that they act together to resist forces." The reinforcement used in concrete can vary greatly depending on the application and type of structure and is typically categorized as either "primary reinforcing" or "shrinkage and temperature reinforcement."

Primary reinforcement is provided to help carry the loads placed on a structure, while shrinkage and temperature reinforcement is mainly provided to minimize cracking due to shrinkage and temperature-induced stresses. Therefore, shrinkage and temperature reinforcement is commonly referred to as secondary reinforcement.

Why use Fibers in lieu of Conventional Reinforcement?

Fiber reinforcement, specifically macrofibers, can easily be used in a wide variety of applications where conventional steel reinforcement is currently accepted as secondary reinforcement. This is recognized in guide reports from the American Concrete Institute (ACI): specifically, ACI 302.1R – "Guide to Concrete Floor and Slab Construction;" ACI 330.2R – "Guide for the Design and Construction of Concrete Site Paving for Industrial and Trucking Facilities;" ACI 332.1R – "Guide to Residential Concrete Construction;" ACI 360R – "Guide to Design of Slabs-on-Ground;" and ACI 544.1R – "Report on Fiber-Reinforced Concrete."

Compared to conventional steel reinforcement, fibers are discrete elements with relatively small cross-sectional area. Consequently, fibers are added to the concrete mixture during batching instead of being placed in the forms before concrete placement. This results in a reinforcement that is evenly dispersed and an integral part of the concrete matrix. Fibrous materials for use in concrete include alkali-resistant glass, organic polymers (such as polyolefins, nylon and carbon), steel and natural fibrous resources. Fibers for use in concrete are classified as either micro or macro, depending on their equivalent diameter. As defined in ACI CT-18, microfibers have an equivalent diameter less than 0.012 in. (0.3 mm) and macrofibers have an equivalent diameter greater than or equal to 0.012 in. (0.3 mm).

The benefits that fibers provide over conventional steel reinforcement when used as secondary reinforcement include: faster construction because concrete placement can start immediately after compaction of the subgrade/base; discharge method of concrete is not limited by the presence of reinforcement; elimination of trip hazards and a safer jobsite; reduced plastic shrinkage; reduced bleeding and elimination of settlement cracking; increased toughness (energy absorption) and ductility resulting in increased impact, fatigue, scour and abrasion resistance; potential for thickness reduction due to increased moment capacity of concrete sections; and economy due to lower in-place costs. In addition, with the exception of steel fibers exposed at the concrete surface, fibers are noncorroding.

Fiber-reinforced concrete sections can possess performance characteristics that match, if not exceed, the performance of steel-reinforced concrete sections, particularly with respect to secondary reinforcement in slabs-on-ground, composite metal deck slabs, and other concrete elements.

How do Fiber Reinforcement Types Compare?

As there are many different fiber types commercially available in the concrete industry, it is important to understand the differences not only between conventional steel reinforcement and fibers, but also the differences amongst fiber types.

Low-volume synthetic microfibers and natural fibers are added to concrete to control and minimize plastic shrinkage cracking, typically at dosages less than 2.0 lb/yd^3 (1.2 kg/m^3). With the exception of fibrillated microfibers, they provide little, if any, benefit in hardened concrete. However, based on historical performance, fibrillated microfibers are also typically used to replace the lightest gage welded-wire reinforcement (WWR) used in concrete slabs-on-ground. Individual fiber manufacturers can provide guidance on the capabilities of their fibrillated microfibers in replacing light-gage WWR.

Macrofibers vary not only in fiber material type, but also in size, geometry, bond characteristics, and physical properties that, in combination with dosage, influence the post-crack strength they provide in hardened concrete. Therefore, to characterize fiber-reinforced concrete (FRC), flexural tests are performed, and the post-crack parameters derived from the tests are used in design. The most common and preferred tests for FRC in North America are ASTM C1609/C1609M for flexural performance using beams and, for shotcrete applications, ASTM C1550 for flexural toughness using a round panel. Using equations provided in ACI 544.4R and in FRCA "FIP 8 – Design and Specification of Fiber-Reinforced Concrete," the flexural residual strength required to replace a specified conventional steel reinforcement can be calculated. An equivalent macrofiber dosage can then be determined from ASTM C1609/C1609M data for a given macrofiber; and, the dosage will increase with increasing steel reinforcing ratio.

Typical synthetic macrofiber dosages can range from 3.0 lb/yd^3 (1.8 kg/m^3) to 20 lb/yd^3 (12 kg/m^3) and steel fiber dosages can range from 15 lb/yd^3 (9 kg/m^3) to 100 lb/yd^3 (60 kg/m^3).

There is a limitation, however, on the amount of steel reinforcement that macrofibers can replace in that increased fiber dosages can result in less workable concrete. Where feasible, a loss in concrete workability may be remedied by modifications in the concrete mixture proportions and the use of mid- or high-range water-reducing admixtures. Extra water should not be used to increase workability.

When Can Fiber-Reinforced Concrete be Used?

In plain concrete elements, in particular, flatwork (such as pavements, ultra-thin white-toppings, topping slabs, concrete parking lots, and residential slabs) where no steel reinforcement is specified, it is always recommended, at a minimum, to use a synthetic microfiber if prevailing ambient conditions may lead to plastic shrinkage cracking. In slabs-on-ground, composite metal deck slabs, and other concrete elements, the use of a macrofiber should always be considered as an option to conventional steel reinforcement.

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Under the current technology of fibers, structural steel designed in accordance with ACI 318 in girders, columns, suspended decking systems and cantilever sections cannot be reduced or replaced. It should be noted, however, that ACI 318 permits the use of steel fibers meeting specific criteria as shear reinforcement. Furthermore, macrofibers can be used in combination with conventional steel reinforcement to supplement load-carrying capabilities and improve other mechanical properties, to reduce congestion to facilitate concrete placement and consolidation, or simply to reduce cost.

References

1. ACI CT-18, "Concrete Terminology," American Concrete Institute, Farmington Hills, MI.
2. ACI 301, "Specifications for Structural Concrete," American Concrete Institute, Farmington Hills, MI.
3. ACI 302.1R, "Guide to Concrete Floor and Slab Construction," American Concrete Institute, Farmington Hills, MI.
4. ACI 318, "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute, Farmington Hills, MI.
5. ACI 330R, "Guide for the Design and Construction of Concrete Parking Lots," American Concrete Institute, Farmington Hills, MI.
6. ACI 332.1R, "Guide to Residential Concrete Construction," American Concrete Institute, Farmington Hills, MI.
7. ACI 360R, "Guide to Design of Slabs-on-Ground," American Concrete Institute, Farmington Hills, MI.
8. ACI 544.1R, "Report on Fiber-Reinforced Concrete," American Concrete Institute, Farmington Hills, MI.
9. ACI 544.4R, "Guide to Design with Fiber-Reinforced Concrete," American Concrete Institute, Farmington Hills, MI.
10. ASTM C1550, "Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)," ASTM International, West Conshohocken, PA.
11. ASTM C1579, "Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)," ASTM International, West Conshohocken, PA.
12. ASTM C1609/C1609M, "Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)," ASTM International, West Conshohocken, PA.

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