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Specifying Steel Fibers for Concrete Floors

by George Garber

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THIN, SHORT STRANDS OF STEEL FIBER ARE BEING SPECIFIED MORE AND MORE AS REINFORCEMENT IN CONCRETE FLOORS. SOMETIMES, THESE FIBERS ARE USED ON THEIR OWN, AND SOMETIMES THEY ARE USED IN CONJUNCTION WITH CONVENTIONAL REINFORCING STEEL. THEY APPEAR IN GROUND-SUPPORTED SLABS AND IN COMPOSITE STEEL DECK SLABS.

In ground-supported slabs they are used to control cracks, to allow greater joint spacing, and to justify thinner slabs—though the last goal is controversial because it involves properties of fiber-reinforced concrete that experts disagree on. In composite steel deck-slabs, fibers can replace traditional wire mesh to control shrinkage cracks.

Structural engineers are still figuring out how best to design floors with steel fibers. American Concrete Institute (ACI) 360R-10, *Guide to Design of Slabs-on-ground*, offers guidance on their use in ground-supported floors. Steel Deck Institute (SDI) C-2011, *Standard for Composite Steel Floor Deck–Slabs*, gives basic rules for using them in composite steel decks. However, neither document represents the last word on the subject, so the research continues. Meanwhile, specifiers need to think about how to define this material in contract documents.

Whenever people learn a job will include steel fibers, the first question is always some variant of 'how much?' It seems everyone wants to know the fiber dosage, which is usually stated as the mass added to each unit volume of concrete. Typical units are kilograms per cubic meter (kg/m^3) or pounds per cubic yard (lb/cy).

Dosage matters, of course, but it is just a start, because not all fibers are alike. If other key details

[Fiber count is an important factor in the effectiveness of steel fibers as concrete reinforcement. Higher counts result in less distance between fibers and, generally, better performance.]

Figure 1- Equivalent steel-fiber dosage rates

Pounds per cubic yard	Kilograms per cubic meter	Volume
20	12	0.15%
25	15	0.19%
30	18	0.23%
33	20	0.25%
35	21	0.26%
40	24	0.30%
50	30	0.38%
60	36	0.45%
66	39	0.50%
70	42	0.53%
132	78	1.00%

Fibers put into concrete are batched by mass, so volume-based specifications must be converted. This table shows equivalents for specified doses.

Images courtesy George Garber

are not specified, the result is concrete that contains the specified mass of fibers, but does not fulfill the designer's intentions.

Steel fibers in specifications

Since steel fibers can be considered a kind of reinforcement, it is tempting to stick them in *MasterFormat* Division 03 20 00–Concrete Reinforcing, with rebar and wire mesh. However, fibers are better handled in Division 03 30 00–Cast-in-place Concrete or Division 03 24 00–Fibrous Reinforcing. If fibers are put in their own section, it should be referred to in Division 03 30 00–Cast-in-place Concrete as this is where the concrete contractor and ready-mix supplier will look. If the specifications include a special section for the concrete floor, then that would be a good place for the steel fibers.

Every steel-fiber specification should incorporate, by reference, ASTM A820, *Standard Specification for Steel Fibers for Fiber-reinforced Concrete*. This document lays down rules for strength, bendability, dimensional tolerances, and testing that apply to all kinds of steel fibers commonly used in concrete floors. Fibers must have an average tensile strength of at least 345 MPa (50,000 psi). They must be flexible enough to be bent 90 degrees around a 3-mm (⅛-in.) rod without breaking. They cannot vary from specified length or diameter by more than 10 percent. (This does not need to be put in the project specifications, because ASTM A820 does the work for you.)

ASTM C1116, *Standard Specification for Fiber-reinforced Concrete*, can also be incorporated into specifications. This standard regulates how fibers are added to the concrete mix.

Citing ASTM A820 and ASTM C1116 is never enough, however, as these standards explicitly leave important decisions to the designer. A complete specification covers all these points:

- dosage;
- type;
- length;
- effective diameter or aspect ratio; and
- deformations.

Fiber dosage

The amount of fiber is usually specified by mass of fibers per unit volume of concrete—this is measured in kg/m^3 or lb/cy. An alternative is to specify the fiber volume as a percentage of the concrete volume. This makes a lot of sense, especially during the design stage. A volume percentage is easier to visualize, and it stays the same across all measurement systems. However, the workers who actually put the fibers in the concrete have no way to batch by volume. They can only batch by mass, so any volume-based specification will have to be converted along the way. Figure 1 (page 49) shows equivalents for some specified dosages.

Fiber dosages generally range from 12 to 42 kg/m^3 (20 to 70 lb/cy). Dosages below that range are occasionally specified when fibers are used to replace light-gauge wire mesh. Dosages above that range are rare.

Setting fiber dosage is not an exact science, but ACI and SDI offer guidelines. According to ACI's *Guide to Design of Slabs-on-ground*, the fiber dosage in ground-supported slabs should never be less than 20 kg/m^3 (33 lb/cy). When the purpose of the fibers is to allow a wider joint spacing, this guide recommends at least 36 kg/m^3 (60 lb/cy). SDI's *Standard for Composite Steel Floor Deck–Slabs*, has a short, simple recommendation for steel fibers in composite steel deck-slabs: use at least 15 kg/m^3 (25 lb/cy). In the end, though, the decision is up to the floor designer, who may rely on experience or on recommendations from one of the steel-fiber manufacturers.

Types

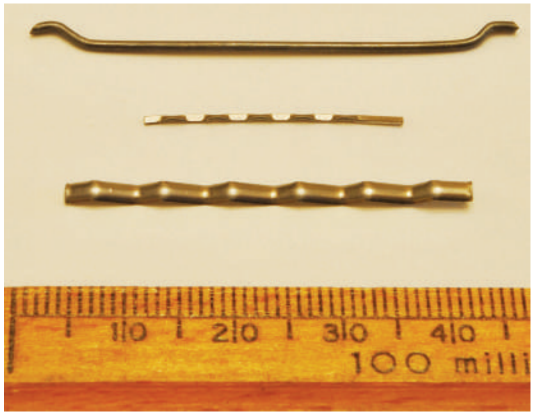
ASTM A820 divides steel fibers into five types, based on how they are made:

- Type I—cold-drawn wire;
- Type II—cut-sheet steel;
- Type III—melt extract;
- Type IV—mill cut; and
- Type V—cold-drawn wire, shaved into fibers.

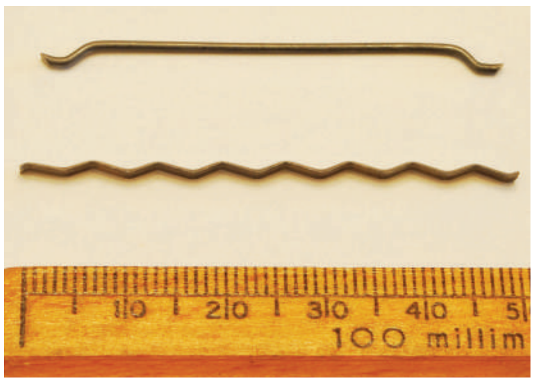
Only Types I, II, and V are currently being used in concrete floors.

Predictably, fiber manufacturers disagree on which type works best. From the user's point of view, the main issue is certain properties may not be available in all types. For example, in the current market the only fibers being made with hooked ends are Type I.

When discussing fiber type, one must watch out for confusion between ASTM A820 and ASTM C1116. ASTM A820, which deals only with steel fibers, divides them into the five types listed above. In contrast, ASTM C1116, which deals with all kinds of fibers, divides fiber-reinforced concretes into four types, depending on what kind of fibers they contain. In ASTM C1116, concrete with steel fibers is called Type I. Types II, III, and IV contain glass, plastic, and cellulose, respectively.



Type I fiber 50 mm (2 in.) long, Type II fiber 25 mm (1 in.) long, and Type V fiber 35 mm (1.3 in.) long.



This photo shows deformations on hooked ends and continuous.

Deformations—including hooked end, flat end, and continuous—are shown here.

Both piles have the same mass, but the 25-mm (1-in.) fibers outnumber the 50-mm (2-in.) fibers almost eight to one.

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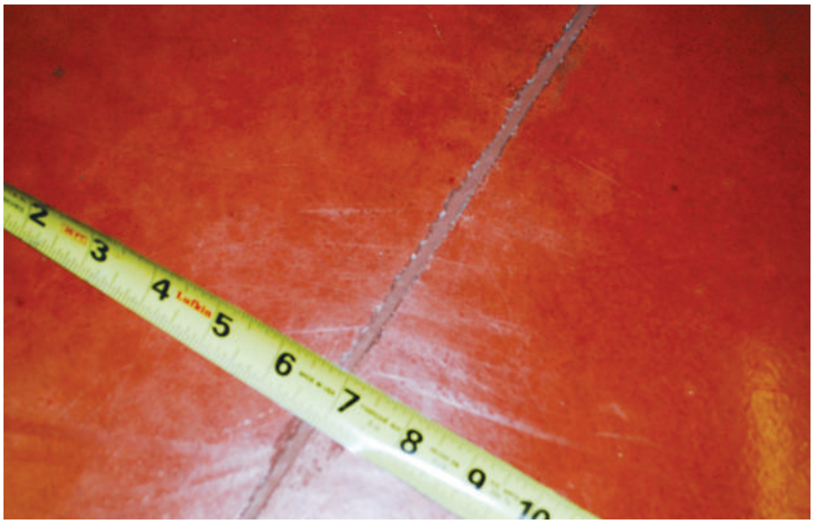
ASTM A820 divides steel fibers into five types, based on how they are made. Predictably, fiber manufacturers disagree on which one works best.



Many people worry steel fibers will show at the floor surface, making the floor look worse. This floor, made with colored concrete and Type II fibers, 25 mm (1 in.) long, shows the steel fibers need not affect appearance.

Thanks to the two different classifications, one can end up with a Type I concrete mix that contains, say, Type II steel fibers. It is important to remember the classification in ASTM A820 covers fibers, while the classification in ASTM C1116 covers concrete mixes.

Fiber length

The steel fibers used in concrete floors range in length from 25 to 65 mm (1 to 2 ½ in.).

While it is usually agreed length matters, there is no consensus as to which length is best. It depends on what the fibers are expected to do. Engineers who rely on fibers' ability to limit the widening of cracks after they have formed—a property called residual strength, ductility, or flexural toughness—tend to prefer longer fibers. Those who rely on fibers' ability to prevent visible cracks tend to prefer shorter ones, because they result in higher fiber counts and less distance between fibers. Concrete workers also like shorter fibers, which are less likely to tangle and stick up above the floor surface.

There are limits in both directions, however. The upper limit seems to be close to 65 mm, and any longer will clump to form balls. Even fibers in the 50 to 65-mm (2 to 2.5-in.) range can tangle, and to prevent that problem are sometimes sold in collated form—stuck together with a weak glue that dissolves as the concrete is mixed. The lower limit has not been well-established, but fibers less than 25 mm long are seldom used in concrete floors today. Researchers are working with even shorter fibers, though, so floor designs that rely on lengths below 25 mm may be seen eventually.

If a design is based on fibers of a particular length, the specification should require that length. Length is specified as a single target value (not a maximum or minimum), with an implied tolerance, according to ASTM A820, of ±10 percent.

Effective diameter or aspect ratio

For a fiber with a circular cross-section, the effective diameter is that of the circular section. For a fiber with a cross-section of any other shape, the effective diameter is that of a circle equal in area to the actual section.

For fibers of Types I to IV, the effective diameter is specified as a single target number, with an implied tolerance of ±10 percent. Type II fibers, which are rectangular in section, can be specified by width and thickness instead of effective diameter.

Type V fibers are supposed to be specified differently. Since the manufacturing process for Type V results in substantial variation in effective diameter, ASTM A820 suggests specifying a range with upper and lower limits, not a target. However, this rule is not universally followed. Some makers quote a single effective diameter for their Type V fibers.

People sometimes talk about a fiber's aspect ratio instead of, or in addition to, its effective diameter. Aspect ratio is length divided by effective diameter. Since any two of those properties determine the third; all three do not need to be specified. When aspect ratio is specified, be aware ASTM A820 allows the

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Steel fibers are being loaded into a ready-mix truck. Fibers are usually added at the concrete plant, but can also be added onsite.
Photo courtesy Mike McPhee

measured value to vary by ±15 percent from the specified target.

In today's marketplace, effective diameters range from 0.58 to 1.14 mm (20 to 40 mils). As with length, choosing the diameter involves trade-offs. Thicker fibers are less likely to tangle while thinner result in higher fiber counts.

Fiber count

Fiber count—the number of fibers per pound or kilogram—is an important factor in the effectiveness of steel fibers as concrete reinforcement. Higher counts result in less distance between fibers, and that generally means better performance. A floor design based on a particular fiber count may not work as well with a lower count, even if the mass of fibers stays the same.

Though fiber count is never directly specified, it is determined by two properties that are specified: length and effective diameter (or length and aspect ratio, depending on preference). Since shorter fibers are usually thinner, too, reducing the length dramatically raises the fiber count. In this figure, both piles have the same mass. The fibers on the right are 50 mm (2 in.) long and have an effective diameter of 1.14 mm (0.04 in.). The fibers on the left are 25 mm (1 in.) long and have an effective diameter of 0.58 mm (0.02 in.). The shorter fibers outnumber the longer fibers, almost eight to one.

Fiber count can be determined from the following equations:

ADDITIONAL **INFORMATION**

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Abstract
Thin, short strands of steel are being increasingly specified as reinforcement in ground-supported slabs and in composite steel deck-slabs. Structural engineers are still figuring out how best to design with these components, but specifiers need to think about how to define this material in the contract documents. Dosage is critical, for one thing, but not all fibers are alike. Without specifying other key details, one can end up with concrete that contains the specified mass of fibers, but does not fulfill the designer's intentions.

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03 30 00–Cast-in-place Concrete

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B1010.20–Floor Decks, Slabs, and Toppings

Key words
Division 03
ASTM A820
ASTM C1116
Concrete floor
Deck slab
Specifications
Steel fiber

In metric units:

$$c = 1/[(7.9 \times 10-6)L\pi(d/2)2]$$

Where c = fiber count per kilogram
L = length of fiber in millimeters
d = effective diameter of fiber in millimeters

In U.S. customary units:

$$c = 1/[(0.29L\pi(d/2)2]$$

Where c = fiber count per pound
L = length of fiber in inches
d = effective diameter of fiber in inches

Fiber counts range from about 2500 to 20,000 per kilogram (1100 to 9000 per pound).

Deformations

The earliest steel fibers were smooth, straight pins, and ASTM A820 still recognizes that shape as an option. In practice, though, the fibers used today are all deformed so concrete can grip them better. Deformations take one of three forms: continuous, hooked ends, and flat ends.

A continuously deformed fiber has waves or bumps running down its whole length, much like ordinary steel rebar. A hooked-end fiber has a bend—or multiple bends—at each end. A flat-end fiber has its ends squashed flat, somewhat like a kayaker's double-ended paddle.

Conclusion

While dosage, length, effective diameter, and deformation are the essential features every steel-fiber specification should cover, a few other details are worth considering.

Consider requiring fibers be delivered in containers marked to show the mass. Some specifiers go further and demand containers that include the exact quantity going in each cubic meter or cubic yard of concrete. If the specified dosage is 20 kg/m^3 (33 lb/cy), each box or bag would have to contain exactly 20 kg (33 lb). This simplifies batching and reduces the risk of error. Some suppliers may have trouble packaging fibers in anything other than standard quantities.

Fibers should be stored under cover, protected from rain and snow. Left outdoors, boxes can disintegrate and fibers can rust.

Last, it is a good idea to insist all concrete tests, including those needed for approval of the mix design, be made after the addition of fibers. That may seem like common sense, but it will not always happen without a reminder.

Of course, it takes more than the right specification in order to make a successful steel-fiber-reinforced floor—it also takes a smart designer and a careful contractor. Nevertheless, a full, accurate specification is an essential part of the job when the floor is expected to fulfill the designer's intentions. **CS**