

# Synthetic fibers

Primarily used to reduce shrinkage cracking, polypropylene, nylon, and polyester fibers offer other benefits as well

By Anne Laning

**S**ynthetic fibers are no substitute for structural (primary) reinforcement in concrete because they add little or no strength. But structural reinforcement doesn't provide its benefits until concrete hardens. That's why some contractors add synthetic fibers to concrete as secondary reinforcement. Unlike structural reinforcement, synthetic fibers provide benefits while concrete is still plastic. They also enhance some of the properties of hardened concrete.

Synthetic fibers are most commonly added to concrete for slab-on-grade construction to reduce early plastic shrinkage cracking and increase impact- and abrasion-resistance and toughness. The fibers also can be added to precast concrete to improve resistance to handling stresses, to pumped concrete to improve cohesiveness, and to shotcrete to reduce rebound and material waste.

## How fibers control shrinkage cracking

Shrinkage cracks are short, irregular cracks that can develop in concrete within the first 24 hours after concrete placement. Not to be confused with surface crazing, shrinkage cracks usually pass through the entire depth of the slab. The cracks are generally caused by either plastic or drying shrinkage. Plastic shrinkage occurs before concrete reaches initial set; drying shrinkage occurs after concrete sets.

All concrete shrinks after placement due to a volume change caused by moisture loss. If the shrinkage could take place without any restraint, the concrete would not crack. But slab-on-grade concrete is always subject to at least some restraint by either the foundation, another part of the structure, or by reinforcing steel embedded in the concrete. Restraint also develops during differential shrinkage, when the concrete at the surface shrinks

faster than the underlying concrete. If the tensile stresses caused by restraint exceed the tensile strength of the concrete, the concrete cracks (Ref. 1).

Taking precautions can minimize the possibility of shrinkage cracking. These include keeping the concrete moist during curing and protecting the concrete with temporary coverings or curing compounds to reduce moisture evaporation. But even when you take precautions, shrinkage cracks can occur.

Manufacturers of synthetic fibers say their products can be used to minimize plastic and early drying shrinkage cracking. Mixing the fibers in the concrete at the recommended dosages (usually 1½ pounds per cubic yard) results in millions of fibers dispersed evenly throughout the concrete matrix. This multidimensional reinforcement reportedly gives fresh concrete more tensile capacity to resist typical volume changes. It also helps distribute tensile stresses more evenly. If shrinkage cracks do form, fibers bridge these cracks, helping reduce their length and width.

Various tests have been conducted on synthetic fibers to determine the effects of the fibers on plastic shrinkage cracking. Paul Kraai, a professor at San Jose University, compared early cracking behavior of slab samples made with plain concrete, concrete reinforced with welded-wire fabric, and concrete containing ¾-inch fibrillated polypropylene fibers at a rate of 1½ pounds per cubic yard (Ref. 2). The slabs were 2 feet wide, 3 feet long, and 2 inches thick with edges restrained by panels. Fans blew air at high velocities over the surfaces of the slabs to force rapid drying. The results showed plastic shrinkage crack reductions of 71.5% in the fiber-reinforced sample compared with the plain concrete sample. The sample containing welded-wire fabric showed crack reductions of only 6.5%.

## Other ways fibers enhance concrete performance

The effects of fibers on the behavior of plastic and hardened concrete varies depending on the concrete materials, mix proportions, fiber type and length, and quantity of fiber added. Research from various sources, though, generally agrees that adding synthetic fibers to concrete can improve the following properties:

- Impact resistance (increases of 10% to 50%)
- Abrasion resistance (increases of 20% to 52%)
- Permeability (decreases of 33% to 45%)
- Toughness, or post-crack integrity (increases of 15%)

Most of the research also shows, however, that the fibers provide only slight if any improvement to concrete compressive, tensile, and flexural strengths; modulus of elasticity; and splitting tensile strength.

Recognizing the performance characteristics of synthetic fiber-reinforced concrete, ASTM has established a standard test method for flexural toughness and first-crack strength of fiber-reinforced concrete (ASTM C 1018) and a standard specification for fiber-reinforced concrete and shotcrete (ASTM C 1116).

## Synthetic fiber types

The number of synthetic fiber suppliers has grown in recent years, giving contractors a wide range of fiber products from which to choose. The primary types of synthetic fibers commercially available in the United States are polypropylene, polyester, and nylon. Though the fibers within each type come in various lengths, thicknesses, and geometries, synthetic fibers provide similar benefits when used as secondary concrete reinforcement.

**Table 1. Typical Properties of Synthetic Fibers**

Fiber	Type	Specific gravity	Length (inches)	Tensile strength (psi)	Young's modulus (ksi)
Polypropylene	Fibrillated	0.91	¼-2 ½ (or graded)	80-110	500-700
Polypropylene	Monofilament	0.91	½-¾	40-100	500-700
Polyester	Monofilament	1.34	¾-2	80-170	1450-2500
Nylon	Monofilament	1.16	¾-2	130	750

They also are comparable in cost (about 1.5¢ to 2.5¢ per square foot per inch of concrete depth).

Table 1 shows typical properties of the various synthetic fibers. Most synthetic fibers also have excellent acid, alkali, mildew, and salt resistance, are noncorrosive, and have low thermal conductivity.

**Polypropylene.** Of the synthetic fibers available in the United States, polypropylene is the most widely used in ready mixed concrete (Ref. 3). Polypropylene fibers are hydrophobic, so they don't absorb water and have no effect on concrete mixing water requirements. They come as either fibrillated bundles or monofilaments. To produce fibrillated fibers, manufacturers extrude the polypropylene in sheets that are stretched and slit. The result is a mesh of interconnected fiber strands rectangular in cross section. Manufacturers cut the strands to specified lengths and separate them into bundles. Fiber lengths range from ¼ to 2½ inches. When added to concrete during mixing, the fibrillated fibers open into a network of linked fiber filaments that mechanically anchor to the cement paste (Figure 1). One manufacturer offers a graded fibrillated fiber having various lengths, sizes, and fibrillation patterns. The graded fibers reportedly disperse more thoroughly into all areas of the cement paste during mixing.

Monofilament fibers are fine, cylindrical strands that separate during mixing. Because monofilament fibers are smooth and have a small surface area, they don't anchor into the cement matrix as well as fibrillated fibers. With fibrillated fibers, cement paste penetrates into the network of fiber filaments resulting in better mechanical

anchoring to the concrete. Research shows that lower volumes of fibrillated fibers than of monofilament fibers are needed to improve the post-cracking load-carrying capacity and ductility of concrete (Ref. 4). Some manufacturers recommend using monofilament fibers for relatively short-term benefits, such as plastic shrinkage crack control during the first few hours after concrete placement.

**Polyester.** Though not as widely used as polypropylene fibers, polyester fibers are offered by several manufacturers.

The fiber bundles come only in monofilament form in lengths from ¾ to 2 inches.

Like polypropylene, polyester fibers are hydrophobic. However, they have a tendency to disintegrate in the alkaline environment of portland cement concrete (Ref. 5). To retard this degradation, manufacturers of polyester fibers coat the fibers to resist alkali attack. But the long-term performance of the coated fibers has not been determined.

**Nylon.** Like polyester fibers, nylon fibers come only in monofilament form. What primarily distinguishes them from polypropylene and polyester fibers is their hydrophilic nature. They retain a natural moisture balance of 4.5%. Because of this strong affinity to water, nylon fibers bond chemically to the concrete matrix. The bond of polypropylene and polyester fibers is only mechanical.

Nylon fiber manufacturers also report that their fibers have higher aspect ratios (ratio of length to diameter) than those made of polypropylene. Therefore, they can be added in smaller dosages to produce the same reinforcing effects. Usually

no more than 1 pound per cubic yard is needed.

### Tips on using synthetic fibers

Using synthetic fibers in concrete may require slight modifications to normal concreting procedures. Some fiber manufacturers recommend the following procedures for mixing, placing, and finishing fiber-reinforced concrete.

**Mixing.** Fibers can be added with the coarse and fine aggregate at the batch plant or to the central or truck mixer at the jobsite. If adding the fibers with other mix ingredients, no extra mixing time is needed. If adding the fibers to mixed concrete, agitate the concrete an additional 3 to 7 minutes as recommended by ASTM C 94 to disperse the fibers thoroughly.

Because synthetic fibers don't affect the chemical hydration of cement, they work with all concrete mixes and admixtures without changing required mix proportions. To eliminate measuring, most fiber suppliers package the fibers in the recommended dosage for a cubic yard quantity of concrete. Some fiber manufacturers package the fibers in cellulose bags that can be added unopened to the mixing drum. These bags disintegrate quickly in concrete, dispersing their contents. The disintegrated bag material has no effect on concrete properties.

Ron Zollo, director of the International Fibrous Concrete Institute, says that uniform distribution of fibers was sometimes a problem years ago because the fibers would clump and form fiber balls in the mix. Manufacturers have eliminated this problem, though, by creating new fiber geometries that prevent fiber balls from forming.

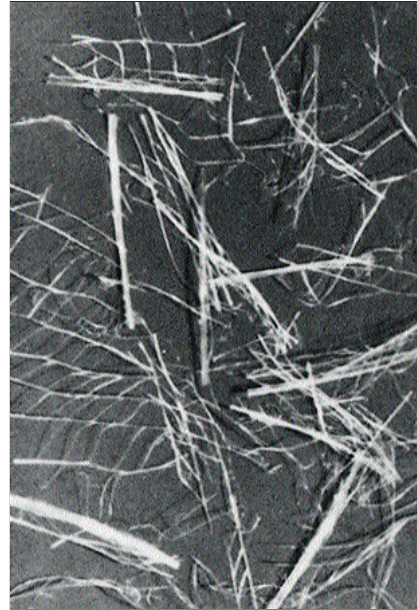
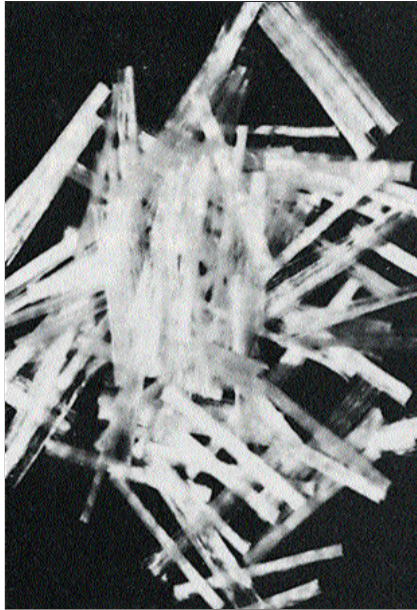
**Placing.** Because synthetic fibers mix into the cement paste, they don't interfere with structural reinforcement systems and they conform to unusually shaped forms, such as those used for curved driveways or some precast products. However, synthetic fibers can increase the stiffness and cohesiveness of the concrete mix. Workers may notice a slight decrease in workability when placing fiber-reinforced concrete. They also may notice a slump loss of up to 1 inch. The extent to which fibers affect slump depends on fiber design, length, and concentration.

Fibers only affect slump by increasing mix cohesion. They do not affect concrete's water-cement ratio. If the mix is too difficult to place, workers should not add extra water, which can weaken the hardened concrete. Instead, a superplasticizer should be used to improve workability. One polypropylene fiber manufacturer even prepackages its fibers with a superplasticizer in water-soluble bags. The superplasticizer reportedly maintains specified slump or increases slump up to 1½ inches.

**Finishing.** Synthetic fibers are compatible with all concrete surface treatments and finishes, such as pattern stamping, exposed aggregate, brooming, and hand or power troweling. The neutral fibers also won't stain or discolor concrete.

However, a fiber-reinforced concrete slab usually bleeds less and more slowly than a plain slab because the fibers hold the concrete together and reduce segregation. So it's especially important when finishing fiber-reinforced concrete not to start too early. Make sure all bleedwater is gone. It's even wise to start floating and troweling closer to final set than normal to help avoid fiber exposure on the slab surface. If any time during finishing, you notice the fibers being pulled up, you may be on the concrete too soon.

When finishing fiber-reinforced concrete, use only steel or magnesium trowels and floats. Wood trowels and tools are more abrasive to the surface and may reveal more fibers. Also, don't use tined garden rakes to move or place the concrete. The tines can disrupt fiber distribution. For textured or broom finishes, use a broom with stiff bristles and broom in only one direction. This will cause the fibers at or near the concrete surface to align within the ridges so they are not apparent.



**Figure 1.** Fibrillated polypropylene fibers (left) consist of interconnected fiber strands that open during mixing (right).

If mixed into concrete thoroughly, fibers should not float to the concrete surface nor sink to the bottom. Still, fibers may appear on or near the surface because they are distributed throughout the concrete. Any surface fibers that do appear will wear off quickly under light traffic. If a surface coating is specified, burn off exposed fibers with a propane torch before applying the coating.

### Fibers vs. wire mesh

Both synthetic fibers and wire mesh used as secondary reinforcement can help control cracking in cast-in-place and precast concrete. The primary differences are when and how they work. Fibers are most beneficial soon after concrete placement by controlling the formation of plastic shrinkage cracks. Wire mesh, on the other hand, does not prevent crack formation.

Instead, the mesh holds cracks together *after* they have formed.

From an economic standpoint, using fibers eliminates the costs of handling and placing wire mesh. Also, wire mesh must be placed properly to be effective. This is not a concern with fibers, which disperse evenly throughout the concrete during mixing. And unlike wire mesh, synthetic fibers are noncorrosive and won't rust.

An ideal secondary reinforcement system would use both fibers and properly placed wire mesh. But this approach is not always practical or cost-effective. If you must choose between fibers and wire mesh, base the decision on the benefits and limitations of each product.

### Fibers in shotcrete and precast concrete

Though synthetic fibers are most commonly used in cast-in-place concrete, their use in shotcrete and precast products is growing. Adding synthetic fibers to shotcrete can reduce rebound and material waste, permit thicker layers per pass, reduce sagging, and inhibit plastic shrinkage cracking. Shotcrete reinforced with a high volume of fibrillated polypropylene fibers was first used successfully in 1988 for a tunnel lining project in Alberta, Canada (Ref. 6). The shotcrete contained 1½-inch-long fibers at a minimum content of 10.1 pounds per cubic yard. Even with these high fiber volumes, the shotcrete was easy to mix with standard equipment. It also pumped easily and there was no rebound during application.

Precasters use synthetic fibers in their products to add early strength, help reduce concrete breakage during handling, and save on labor. They also report fewer shrinkage cracks when using the fibers (Ref. 7). Some precasters use synthetic fibers in unusually shaped precast products, such as planters and urns, instead of wire reinforcing. If not carefully placed,

wire reinforcing in these products is sometimes exposed when the products are removed from the forms. <sup>5</sup>

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## Dos and Don'ts For Using Synthetic Fibers

Fibers can significantly enhance concrete performance, but they don't guarantee crack-free concrete. The guidelines below can help you decide when and when *not* to use fibers for a particular application.

### Do specify synthetic fibers for:

- Reducing concrete cracking due to plastic shrinkage
- Replacing or supplementing wire mesh as secondary reinforcement when inhibiting early shrinkage cracking is important
- Reducing concrete permeability
- Greater impact and abrasion resistance of concrete
- Areas requiring nonmetallic secondary reinforcement
- Cohesive mix designs for shotcrete
- Areas requiring secondary reinforcement that resists alkalis, chemicals, and chlorides

### Don't specify synthetic fibers for:

- Controlling cracking resulting from external stresses
- Replacing any structural steel reinforcement
- Higher structural strength
- Eliminating or reducing curling or creep
- Increasing the structural number of portland cement concrete pavements or slabs on grade
- Increasing the distance between control joints
- Decreasing the specified thickness of overlays, pavements, or slabs on grade