A Survey of Fiber Options

A GUIDE TO CHOOSING THE CORRECT FIBER OPTION FOR YOUR APPLICATIONS

By Mac Young

In today's concrete industry, while we are fortunate to have options, the wide variety can also create a paradox of choice: With dozens of commercially available fiber types and countless variations, how do you choose the right fiber for your application, performance requirements, and project goals?

This article provides a practical overview of fiber technology by explaining the primary role of fibers in concrete, the five key characteristics that differentiate them (including chemistry, length, shape, dosage, and delivery method [aspect ratio]), as well as the major fiber categories defined by these characteristics (macro and micro). By the end of this article, readers will have a stronger understanding of fiber technology and the difference in many unique fiber options on the market, as well as more confidence in selecting the right fiber for their specific project needs.

WHAT IS THE JOB OF FIBERS?

In the fiber industry, there's an old hyperbole about concrete: "You can guarantee three things about concrete — it's fireproof, it's theft-proof, and it's guaranteed to crack." While the first two are certainly debatable, the last one is an accepted reality of concrete. This brings us to the two primary jobs of fiber-reinforced concrete: The first is to extend the service life of concrete by delaying the formation of cracks, and the second is to help control and mitigate crack growth once cracking occurs.

WHAT TYPES OF CRACKING DO FIBERS HELP MITIGATE?

There are two main types of cracking that fibers can help reduce: Early-age plastic shrinkage cracking and hardened concrete cracking.

- **Plastic shrinkage cracking** occurs within the first few hours after placement, while the concrete is still in its plastic state. It develops when moisture evaporates from the concrete surface faster than bleed water can replace it, causing the surface to shrink and crack (Fig. 1).
- **Hardened concrete cracking** occurs after the concrete has cured and can result from a number of factors, including thermal movement, drying shrinkage, structural loading, and other external forces the concrete is exposed to throughout its service life (Fig. 2).

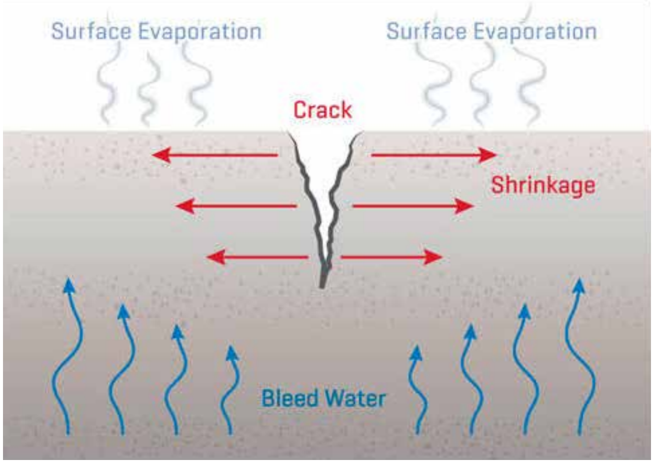

Fig. 1: Visual depiction of how plastic shrinkage cracks form

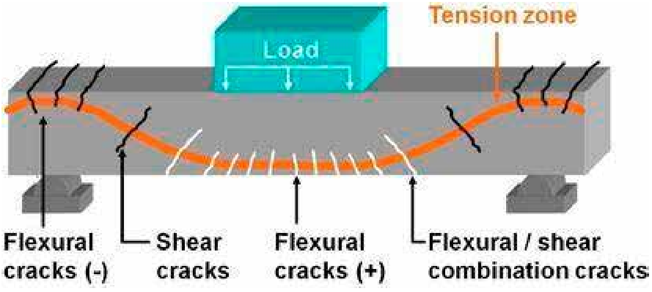

Fig. 2: Visual depiction of how structural hardened cracks can form

While fibers cannot always prevent these cracks from forming, they help bridge developing cracks, improving toughness and durability while limiting crack widths and extending the service life of the concrete.

UNDERSTANDING THE 5 KEY CHARACTERISTICS OF FIBER FOR YOUR APPLICATION

There's a lighthearted story I like to tell when explaining the importance of the five key characteristics of fiber. My grandmother wanted a lightweight, easy-to-walk dog, so she went to the local animal shelter looking for a beagle puppy. She picked out the cutest one she could find, took him home, and named him Thor. Well, Thor certainly lived up to his name — instead of growing into a beagle, he grew into a 120 lb (54 kg) rottweiler.

I use this story as an example because, just as my grandmother should have understood the key characteristics of the type of dog she wanted, specifiers, engineers, contractors, and producers should understand the key characteristics of the fibers they are selecting. Knowing these characteristics helps ensure the fiber chosen will deliver the performance required for a specific application or project.

Fortunately, identifying the right fiber doesn't have to be complicated. Nearly every fiber can be evaluated by five key characteristics: Chemistry, length, shape, delivery method (aspect ratio), and dosage.

CHEMISTRY

The chemistry of a fiber is determined by what it is made of. In fact, most fibers, regardless of their brand name, are identified by their chemistry because it largely determines how they will perform and behave within the concrete matrix. For example, steel fibers behave differently than the more common polypropylene fibers, and polypropylene fibers behave differently than glass, basalt, acrylic, or cellulose fibers. As you can see, there are many different fiber chemistries available, each with its own unique characteristics (Fig. 3).

While each chemistry offers different performance benefits, there are three key characteristics that should be common among them all:

1. The fiber should be chemically stable, meaning it will not degrade or deteriorate over time.
2. It should be alkali resistant, so it can withstand the highly alkaline environment of concrete without breaking down.
3. The fiber should have low water absorption, so it does not significantly affect the available water needed for proper cement hydration. Unlike hydrophobic fibers (steel, polypropylene, carbon, etc.), natural hydrophilic fibers, like cellulose, will absorb water: They may help provide some internal curing benefits, but the concrete mixture design must account for the water demand of the fibers.

Fig. 3: An example of different microfiber chemistry: A) Polypropylene; B) Acrylic; C) Recycled Carbon Fiber; D) Basalt

LENGTH

Fibers are manufactured in a wide range of lengths to meet the performance requirements of specific applications (Fig. 4). In general, fiber length influences two primary performance characteristics:

1. The shorter the fiber, the more effective it is at controlling plastic shrinkage and early-age cracking.
2. The longer the fiber, the more effective it is at intersecting and bridging larger cracks that develop after the concrete has hardened.

Fibers ranging from approximately 3 to 18 mm (0.12 to 0.71 in.) are generally considered **microfibers**. These fibers are excellent at reducing plastic shrinkage cracking and

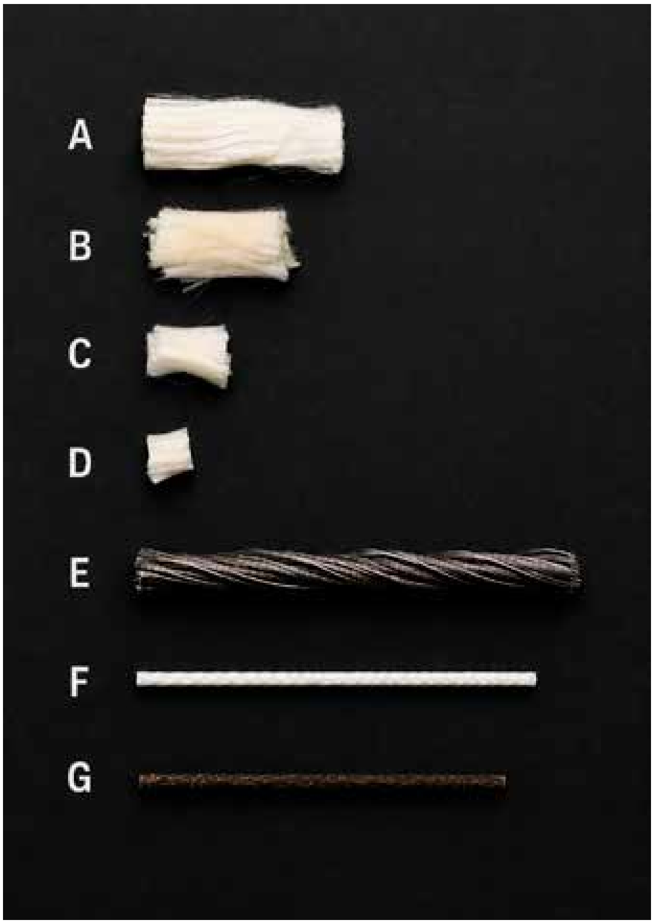

Fig. 4: Showing the differences in fiber size, as well as the size difference between macro and micro fibers. A) 18 mm (0.71 in.) micro; B) 12 mm (0.47 in.) micro; C) 6 mm (0.24 in.) micro; D) 3 mm (0.12 in.) micro; E) 54 mm (2.1 in.) macro; F) 48 mm (1.9 in.) macro; G) 38 mm (1.5 in.) macro

helping control early-age cracking while the concrete is still developing strength.

Fibers ranging from approximately 38 to 60 mm (1.5 to 2.4 in.) are generally considered **macrofibers**. Their longer length allows them to bridge larger cracks and improve the residual strength and toughness of concrete. When properly designed and dosed for the application, macrofibers can replace conventional reinforcing steel in certain applications.

SHAPE

The shape of a fiber (Fig. 5) plays a major role in how it integrates into a concrete mixture and, ultimately, how it performs. As with fiber length, variety is what allows engineers and contractors to tailor reinforcement to specific applications. While countless fiber designs exist, most can be grouped into four general categories.

- **Monofilament fibers** are comparable to a standard finish nail. They provide reinforcement, but their primary purpose is controlling plastic shrinkage cracking rather than carrying significant loads after cracking.
- **Fibrillated fibers** are more like a wood screw; their net-like or fibrillated structure creates greater mechanical interlock within the concrete matrix, improving crack resistance and load transfer. In many applications, they provide enough reinforcement to replace light-gauge welded wire reinforcement used for crack control.
- **Macro fibers** can be thought of as lag bolts. Their larger size and engineered geometry provide strong mechanical anchorage across wider cracks. When properly engineered and dosed, macro fibers can replace traditional welded wire reinforcement or even certain reinforcing steel applications by providing meaningful post-crack residual strength.
- **Ionic Bond fibers** are fibers whose performance relies not only on mechanical anchorage but also on enhanced interaction with the cement matrix. Fibers such as acrylic and cellulose have demonstrated improved adhesion or an 'ionic bond' within the concrete, allowing them to more effectively control plastic shrinkage cracking. In shotcrete placement, this increased cohesion can also reduce rebound and improve material retention, resulting in more consistent placement and higher application efficiency.

A useful way to think about the reinforcement provided by different fiber shapes is to compare them to common construction fasteners (Fig. 6).

ASPECT RATIO

Aspect ratio is arguably the least intuitive characteristic of a fiber, but it is also one of the most important. In the fiber industry you'll hear terms like 'denier' and 'linear density', but for the purpose of understanding fiber performance, think of aspect ratio as one simple question: How long is the fiber compared to how thick it is?

Aspect ratio plays a critical role in balancing reinforcement and workability. In general, the higher the

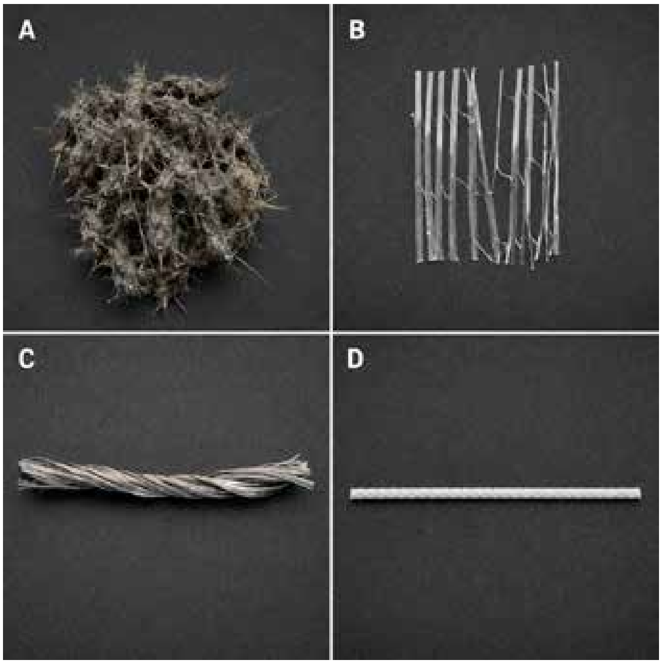

Fig. 5: Different fiber shapes: A) Monofilament; B) Fibrillated fiber; C) Macro twisted; D) Macro helictical stick

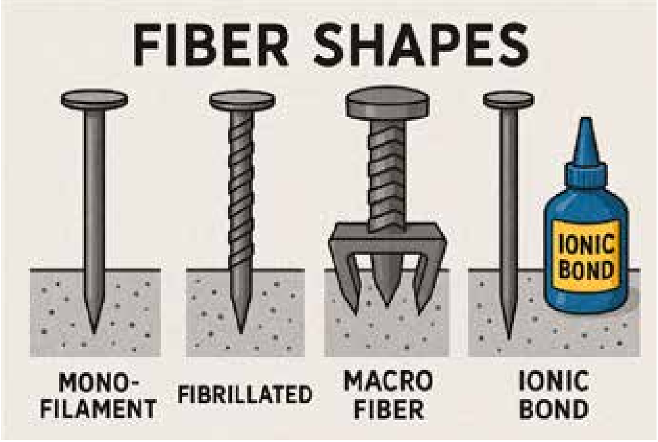

Fig. 6: Fiber shapes in terms of construction fasteners

aspect ratio, the better a fiber is at bridging cracks and reinforcing the concrete. The tradeoff is that high aspect ratio fibers are more difficult to disperse uniformly throughout the mixture and are more susceptible to balling. Lower aspect ratio fibers disperse much more easily but provide less crack-bridging capability.

So, how do manufacturers achieve excellent reinforcement while still maintaining good dispersion? One common solution is what many in the industry refer to as 'fooling the aspect ratio'. While the aspect ratio of the individual fibers never actually changes, the fibers are temporarily packaged in a way that behaves like a lower aspect ratio reinforcement during mixing. Twisted bundles, pucks, and other bundled fiber groupings enter the mixer as compact packages that disperse more easily throughout the concrete. As mixing continues, these bundles separate into individual filaments, allowing each fiber to regain its high aspect ratio and provide the reinforcement it was designed to deliver. This packaging strategy gives contractors the best of both worlds: Improved mixing and fiber distribution without sacrificing the reinforcing performance of high aspect ratio fibers.

DOSAGE

The amount of fiber introduced into a concrete mixture can have a significant impact on performance, fiber dispersion, and ultimately which applications it is capable of meeting. Anyone familiar with fibers, whether in shotcrete placement, slab on grade, or precast applications, can attest that fiber dosages are all over the map. Depending on the application, dosages can range from as little as 0.5 lb/yd^3 (0.3 kg/m^3) to more than 60 lb/yd^3 (36 kg/m^3).

This is where the first four key characteristics begin to come together. Understanding a fiber's chemistry, length, shape, and intended application provides a good indication of the dosage range required to achieve the desired performance. For example, steel fibers are typically dosed at much higher rates, often between 50 and 60 lb/yd^3 (30 and 36 kg/m^3) , while acrylic fibers are commonly dosed between 0.5 and 1 lb/yd^3 (0.3 and 0.6 kg/m^3) depending on the application. Likewise, longer fibers in the 38 to 54 mm (1.5 to 2.1 in.) range are generally used to provide residual strength reinforcement. In polypropylene macrofiber applications, there are commonly accepted ACI-engineered dosage rates of approximately 3, 5, and 7.5 lb/yd^3 (1.8, 3.0, and 4.4 kg/m^3) for replacing conventional temperature and shrinkage reinforcement in appropriate applications.

While there are always exceptions, understanding the first four key characteristics provides a practical starting point for determining the appropriate dosage. From there, project-specific performance requirements and engineering design can be used to fine-tune the final dosage.

		Micro					Macro		
	Fiber Type	**Micro PP**	**Acrylic**	**Cellulose**	**AR Glass**	**PVA**	**Basalt**	**Steel**	**Macro PP**
In Service Performance	Pumpability	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆	☆	☆☆
	Mix Dispersion	☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆	☆	☆☆
	Sprayability	☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆	☆	☆☆
	Rebound	☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆	☆☆	☆☆
	Finishability	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆	☆	☆
	Plastic Shrinkage Control	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆☆	☆☆	☆☆
Placement Performance	Post Crack Strength	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆
	Rebar Replacement						☆☆☆	☆☆☆	☆☆☆
	Wire Mesh Replacement	☆☆☆	☆☆☆		☆	☆	☆☆☆	☆☆☆	☆☆☆
	Durability	☆☆☆	☆☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
	Fire Resistance	☆☆	☆☆☆		☆☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆

A Comparison of Fiber Options in Shotcrete Applications

Table 1: Structural reinforcement ratings assume engineered dosage rates and compliance with applicable design standards. The performance ratings presented in this chart are based on published engineering data, industry testing, and field experience. They are intended to serve as a general selection guide only. Final fiber selection should be based on project-specific performance requirements and the judgement of the specifying engineer, contractor, or concrete producer.

☆☆☆*: Excellent – One of the most effective fiber options for this performance characteristic.*

☆☆*: Good – Provides sufficient performance, although other fiber types may be better suited for this application.*

☆*: Limited – Provides some benefit but is generally not the preferred choice for this performance characteristic.*

: No stars – Not Recommended / Not Common Practice. This characteristic is generally not associated with or recommended for this fiber type.

Conclusion

The main objective of this article is to provide you with the tools to identify the type of fiber that might fit your needs based on its five key characteristics. Instead of naming multiple fibers (some you may have heard of and many you may not), it's far more valuable to understand how fibers work and what separates them in terms of their key characteristics, so the end user can make an educated decision on which fiber best fits their specific application. No fiber is a one-size-fits-all solution, but by understanding these five key characteristics, you can identify the fiber that is best tailored to your needs.

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