Building Blocks

updates and information on structural materials

Steel or Synthetic Fiber Reinforcement?

By Pierre Rossi

Pierre Rossi is the Research Director at the LCPC (Laboratoires Centrale des Ponts et Chaussées), Paris, France.

Figure 1: Example of Dramix® steel fibers.

After over 30 years of technical research and development, engineering and construction professionals no longer consider fiber reinforced concrete as exotic. This positive assessment is the result of several factors, including:

- Conclusive experience (especially for steel fiber concretes which have been used since the 1970s);
- Technical understanding of the materials (formulation, use, physical, chemical and mechanical properties, etc.);
- National and international recommendations on the sizing of the structures or structural elements made up of these materials.

Comparisons

There are now two types of fiber available on the market: steel and synthetic fibers. Unfortunately, when reviewing the available literature on these two types, certain approximations are made and even errors can be found in the texts. Our objective is not to call out these discrepancies but to offer some of the more objective elements regarding these fibers, so that users can make their own determinations. We have chosen not to make an exhaustive comparative analysis between suppliers, but rather to focus on two important problem areas where differences between the fibers can be found. The two problem areas are mechanical performance and durability.

Mechanical Performance

It is useful to remember the two main points about fiber reinforced concrete. Fiber reinforced concrete is a composite material made up of a matrix – the concrete, and the reinforcement (e.g. the fiber). In a fiber reinforced concrete, the fibers distribute the strain across the cracks created in the matrix. In the simplest analogy, fibers are only useful if cracks exist in the material. If the material does not present the potential for cracking, there would be no need for the addition of fiber. And, the potential for cracking makes concrete a prime candidate for the addition of fibers.

When cracks occur, the mechanical properties of the fiber are important. The modulus of elasticity defines the rigidity of the fiber. The higher the modulus of elasticity of the fiber, the better it will control the cracks in terms of length and opening. And, it goes without saying that the anchoring of the fibers is essential as well.

In industrial flooring, steel fibers are a proven and recognized solution. Already more than ⅓ square meters is reinforced with steel fibers.

Cracks appear at different times over the life of the material, from the initial shrinkage up to advanced age. Although cracks result from shrinkage, creep and cyclic loading, the structural (e.g. density) and mechanical characteristics (resistance in compression, Young modulus) of concrete, which develop progressively, also have an effect on crack development.

- During the first three hours after placement of the concrete, its resistance and Young modulus are very low: compression resistance is lower than 3 MPa, traction resistance is below 0.3 MPa and Young modulus is below 5 GPa. If the concrete cracks during this period, loads to be taken by the fiber and the size of crack openings will be low.
- After 24 hours, the mechanical properties of the concrete increase considerably: compression resistance higher than 10 MPa, traction resistance is above 1 MPa and Young modulus is above 15 GPa. During this maturation period if the concrete is "pushed" again to crack, the load resisted by the fibers and the size of the crack widths will be more significant.

Behavior

Steel fibers have a high modulus of elasticity (200 GPz) and a high resistance in traction (between 800 and 2,500 MPa). At the very earliest age of the concrete matrix, small cracks may appear as the concrete shrinks. Also during this period, the fibers are not yet adequately anchored in the immature concrete matrix. As such, these steel fibers are not very effective against crack propagation. As the concrete ages, the effectiveness of the steel fibers increases and crack propagation decreases.

The most common synthetic fibers used in concrete mixtures are primarily polypropylene fibers. They have a low modulus of elasticity, varying between 3 and 5 GPa. Available polypropylene fibers are typically short in length and small in diameter.

Recently, another type of synthetic fiber has become available for structural applications – polymer fiber, also called macro-synthetic. In comparison to the polypropylene fibers, these macro-synthetics are larger in length and diameter, and have a higher modulus of elasticity (between 5 and 10 GPa, approximately).

Two other types of synthetic fibers are also used in concrete, but less frequently. These are polyvinyl alcohol (PVA) fibers and aramid fibers, with Young Modulus of 30 and 70 GPa respectively. These fibers are used in very high and ultra high performance fiber reinforced concretes.

Polypropylene and other synthetic fibers restrain plastic shrinkage during the first 24 hours after concrete is poured. This is primarily due to their low Young Modulus, making them very reactive to potential cracks. Indeed, slight displacements on the fibers as small crack openings begin generate sufficient loads to combat the propagation of cracks. Some types of polypropylene fibers are fibrillated and therefore anchor into the matrix very well, increasing their effectiveness.

Conversely, as the concrete becomes more mature, synthetic fibers become less effective. Indeed, because of their high elongation or "stretchiness" relative to their low Young modulus, synthetic fibers are able to undergo larger displacements as cracks widen. Therefore, in aged and cracked concrete structures with macro-synthetic fibers, cracks can be much wider than with steel fibers and the deformation of these structures may be (too) significant.

It is also important to consider mechanical properties related to problems of creep with fibers. The creep of a material describes how it flows in the direction perpendicular in time under sustained strains. Steel fibers in strain in the concrete matrix do not creep, or hardly ever creep. However, creep associated with synthetic fibers is potentially significant. This may have negative effects. Indeed, one may encounter a situation where the concrete with synthetic fibers responds correctly to the specifications of the structure (mechanical stability, deformation, openings of cracks) but the creep of fibers (between cracks) makes the structure "sway" which is not acceptable with deformation (good use of the structure) and crack openings which become too significant (durability problems). *Figure 1*, taken from the literature related to the product, illustrates this phenomenon. It presents a comparative study of the creep of pre-cracked girders with steel fibers and macro-synthetic fiber reinforced concrete. This is only an illustration; the size of the creep depends on the initial opening of the cracks, which is not specified here.

Durability

Apart from some aramid fibers, there is no durability problem associated with synthetic fibers in concrete. Corrosion of steel fibers may occur. Superficial corrosion of the fibers may cause discolorations on exposed surfaces. However, surface corrosion of the fibers does not affect the load carrying capacity of the structures of which it is comprised. This potential corrosion of steel fibers may be minimized in practice by:

- Optimizing the formulation of the fiber reinforced concrete;
- Using non steel frameworks or ones with an "internal skin" (synthetic tissue for example);
- Using galvanized fibers.

The second aspect regarding the durability of fiber reinforced concretes concerns the fire resistance of structures. Steel fibers are not a determining factor in the fire resistance of structures. What we can underscore is that a structure with fiber reinforced concrete behaves no worse in the presence of fire than a normal reinforced concrete structure.

Conversely, some synthetic fibers, particularly polypropylene microfibers, have a significantly positive impact in a fire. This is due to a very simple phenomenon: in the case of a fire, polypropylene fibers disappear (they have reached their fusion point) to leave in place a significant network of fine canalizations (capillaries) shared through the volume of the structure. These canalizations act as expansion vessels for the water vapor generated under pressure by the fire (evaporation of the water present in the concrete).

Additionally, the durability of the fiber reinforced concrete structures is affected by the progression of time. A fiber reinforced concrete matrix must ensure a seal, e.g. prevent water infiltrations. As discussed above, the problem of creep with synthetic fibers increases over time. Because of this, the ability of the synthetic fiber and concrete matrix to provide sealing properties to the structure may diminish with time. This problem is not encountered in steel fiber concrete matrixes.

Finally, in the case of prefabricated portable elements, or structures which may come into direct contact with users, safety problems may arise when using steel fiber concretes. When the steel fibers have small diameters, less than approximately 0.25 mm, any protrusions at the surface may be "sharp" and cause injuries. And, regardless of size, one can never guarantee 100% that any steel fiber will not show on the surface of the structure. Designers should examine technical solutions to mitigate this problem. Protrusion of synthetic fibers does not present the same hazard level.

Example of macro synthetic fibers.

Conclusions

In conclusion, the following is a brief synopsis of the pros and cons of various fiber additives.

- Steel fiber concretes do not perform in the early stages of the concrete matrix cure, but they are very effective for the cracking in concrete structures which have reached maturity.
- Polypropylene micro fiber concretes are effective in young age cracking (plastic shrinkage).
- Macro-synthetic fibers in concrete are technically less significant than steel fiber concretes in relatively stressed structures, due to varying abilities to maintain certain functions over time;
- Polypropylene microfibers can improve the fire resistance of concrete structures;
- Care is needed regarding portable structures or surfaces in contact with users when they contain micro steel fibers. These micro steel fibers can cause cuts if no technical solution is adopted.

There are pros and cons to both synthetic and steel fibers; in some cases the two fibers have been combined, which is not as strange as you may have thought.▪

This article is a translation of Pierre Rossi's papers published in *Béton Magazine*, March 2009.