Friends, enemies or potential allies? Like synthetic fibres, steel fibres have their qualities, particularities and faults. LCPC's Pierre Rossi gives an account. (Laboratoire Centrale des Ponts et Chaussées)

Fundamental knowledge - Steel fibres or synthetic fibres?

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

- The benefit of conclusive experience (especially for steel fibre concretes which have been used since the 1970s)
- Very good technical understanding of these materials (formulation, use, physical, chemical and mechanical properties, etc.)
- The existence of national and international recommendations on the sizing of the structures or structural elements made up of these materials (today perfectly validated for steel fibre concretes)

Therefore there are markets in constant growth for these materials today.

---

some objective comparisons

There are now two types of fibre available on the markets: steel fibres and synthetic fibres. When confronted by a pair of whisky connoisseurs we want to make sure they don't turn into alcoholics and drink the whole bottle. Indeed when relying on the scientific or technical literature concerning the comparative performances (attractions?) of the two kinds of fibre, to our dismay we find that the "thirst" often justifies the means. In other words, we find approximations, errors and unfortunately even bad faith (or worse) sprinkled in these learned texts. The objective is not to play to the fibre court but to offer some of the most objective elements possible (at least that is what we hope) so that the users of the famous fibre can come to the market without compromising quality. In order to get to this point we have not chosen to make an exhaustive comparative analysis between the two competitors, but to focus this analysis on two important problem areas where they are clearly differentiated. These two problems are mechanical performance and durability.

1. Example of Dramix® steel fibres.

1. Mechanical performances

Firstly it is useful to remember the two indispensable basic points about fibre reinforced concrete. A fibre reinforced concrete is a composite material made up of a matrix - the concrete, and the reinforcement - the fibre. In a fibre reinforced concrete the fibres spread the strain across the cracks created in the matrix. In other terms the fibres are only useful if there are potential cracks in the material. No cracks, no fibres.

When faced with cracks, one mechanical characteristic of the fibre is paramount. The Young modulus defines the rigidity of the fibre. Indeed, the higher the Young modulus of the fibre, the better the control of the cracks created in terms of length and opening. These values diminish as the Young's modulus of the fibre increases.

3. In the industrial flooring, steel fibres are a proven and recognized solution. Already more than 1/3 square meters is reinforced with steel fibres.

This principle is essential as long as the anchoring of the fibre in the concrete is assured. The cracks in the concrete appear at different times in the life of the material. From the first moments (plastic shrinkage…) up to a very advanced age. As a result these cracks appear at times in the concrete corresponding to structural characteristics (e.g. density) and mechanical characteristics (resistance in compression, Young modulus) which progressively develop.
During the first three hours the resistance of the concrete and its Young modulus are very low: compression resistance lower than 3 MPa, traction resistance below 0.3 MPa and Young modulus below 5 Gpa. These figures are only orders of magnitude.
If the concrete cracks during this period, loads to be taken by the fibre and crack openings will be low. After 24 hours and more the mechanical properties of the concrete increase considerably: compression resistance higher than 10 MPa, traction resistance above 1 MPa and Young modulus above 15 Gpa. These are still orders of magnitude.
During this maturation period if the concrete is "pushed" again to crack, the loads taken again by the fibres as well as the openings of the crack will be much more significant.

4. Pouring the foundation of a house in steel fibre concrete.

2. How will the two types of fibre behave when the concrete cracks?

a. Steel fibres, most often in steel have a high Young modulus (200 GPz) and a high resistance in traction (between 800 and 2,500 Mpa). At a very young age, since small openings in the cracks may appear and because of the poor anchoring of the fibre in the not very compact matrix, these steel fibres are not very effective against the cracks. The matrix does not pull on the fibres perpendicularly to the cracks so the cracks also do not react very much. The more the concrete ages, the more the steel fibres are needed by the cracks. They respond very effectively.

5. Concrete cracks by shrinkage or loads. Adding steel fibres not only works on temperature and shrinkage control, but increases the load bearing capacity.

b. The synthetic fibres used on the concrete are mainly polypropylene fibres. They have quite a low Young modulus varying between 3 and 5 GPa. They are offered on the market in very small sizes (in length and diameter).
More recently another type of synthetic fibre has appeared on the market: polymer fibre, also called macro-synthetic. It is "offered" for structural applications.

Its size is more significant than polypropylene fibres. These macro-synthetics also have a higher Young modulus than those of polypropylene fibres, it varies between 5 and 10 GPa approximately.
Finally, two other types of synthetic fibres are also used in concrete, but on a much lower level. These are PVA fibres and aramid fibres with Young Modulus of 30 and 70 GPa respectively. These fibres are now used in very high and ultra high performance fibre reinforced concretes.

6. Example of synthetic fibres used in protection against fire.

c. The following remarks concern polypropylene fibres and macro synthetic fibres.
Because of their low Young Modulus these fibres are very reactive to potential cracks at a very young age, in particular polypropylene microfibres. Indeed, slight displacements on the fibres linked to small openings of the cracks in these fibres generate sufficient loads to combat the propagation of cracks. This effectiveness is increased because certain polypropylene fibres are fibrillated and therefore very well anchored. This is also the case in a not very compact and adherent matrix such as very young concrete.

- Conversely as the concrete becomes more mature, synthetic fibres become less significant. Indeed, because of their low Young modulus synthetic fibres must undergo large displacements, corresponding to the large openings of the cracks, to generate appropriate seams in the cracks. Therefore, in aged and cracked structures in concrete with macro-synthetic fibres, cracks are much more open than with steel fibres and the deformation of these structures may be (too) significant.

7. Creep test - only steel fibres have a creep control and as such strength on age.

d. Another point to consider concerns the mechanical aspects. It concerns the problems of creep of the fibres.
The creep of a material describes how it deforms in time even under constant strains. Steel fibres at the levels of strain in concrete do not creep or hardly ever. This is not the case for synthetic fibres. Indeed these creep in a non negligible fashion. This may have negative effects. Indeed, one may encounter a situation where in a given situation the concrete with synthetic fibres responds correctly to the specifications of the structure (mechanical stability, deformation, openings of cracks) and the creep of fibres (between cracks) makes the structure "sway" in a situation which is not acceptable with deformation (good use of the structure) and crack openings which become too significant (durability problems). Figure A, taken from the literature, illustrates what we have said. It presents a comparative study of the creep of pre-cracked girders in steel fibres and macro-synthetic fibre reinforced concrete concrete. This is only an illustration because the size of the creep depends on the initial opening of the cracks which is not specified here.

8. Immediate reinforcement with steel fibre concrete planned according to EN standards.

3. Durability

When people talk about the durability of fibre reinforced concrete concretes there are two factors involved: the material and the structure.

a. The first aspect concerns the problem of corrosion of the fibres (material). Regarding synthetic fibres, apart from some aramid fibres, there is no durability problem in the fibre in the concrete.

Regarding steel fibres, corrosion of the fibres may obviously occur. Experience and research conclude:

- Superficial corrosion of the fibres may cause discolorations on the surface of the exposed structures
- Surface corrosion of the fibres does not cause any fault or disturbance in the mechanical operation of the structures using it

This potential corrosion of steel fibres may be minimised in practice by:

- Optimising the formulation of the fibre reinforced concrete
- Using non steel frameworks or ones with an "internal skin" (synthetic tissue for example)
- Using galvanised fibres

b. The second aspect regarding the durability of fibre reinforced concretes concerns the fire resistance of structures. Steel fibres are not a determining factor in the fire resistance of structures. What we can underline is that a structure in fibre reinforced concrete behaves rather better in the presence of fire than a normal reinforced concrete structure (fewer breaks).

9. Example of macro synthetic fibres

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

10. Steel fibres are increasingly used in arches partially or completely replacing steel armatures. Introducing polypropylene microfibres into the composition of the fibre reinforced concrete reduces the risks of scaling. The combination of steel fibres and polypropylene microfibres is therefore an optimum solution.

c. Regarding the durability of the fibre reinforced concrete structures, a last important point concerns maintaining a function required for a given structure over time. Like any covering in fibre reinforced concrete which has to ensure a seal (e.g. in presence of water infiltrations). Because of the creep of synthetic fibres, mentioned above, this function, currently ensured by a concrete structure in synthetic fibres, may not be so some time afterwards. This is a problem for which steel fibre concretes are not concerned.
Finally, in the case of prefabricated portable elements, or structures which may come into direct contact with users, safety problems may arise if these are steel fibre concretes. This phenomenon mainly concerns fibre reinforced concrete concretes the fibres of which have small diameters, that is under or equal to 0.25 mm. Indeed one can never guarantee 100% that any steel fibre will not show on the surface of the structure, which may cause injuries.
Technical solutions exist to mitigate this inconvenience, solutions which should not be skipped. The problem of injury caused by the fibres does not occur with synthetic fibres.

11. Steel fibres are used more and more in heavy structural structures. Using just the same rules for non structural macro synthetic fibres we would be a big mistake.

What do we need to remember?

Summarising the above, it can be said that:

• Steel fibre concretes do not perform well with regard to young age cracking, but they are very effective for the cracking in concrete structures which have reached maturity

• Polypropylene micro fibre concretes are effective in young age cracking (plastic shrinkage)

• Macro-synthetic concretes are technically less significant than steel fibre concretes (with a problem of keeping certain functions over time) in relatively stressed structures

• Polypropylene microfibres are recommended to improve the fire resistance of concrete structures

• Care is needed regarding portable structures or in contact with the user when they contain micro steel fibres. These micro steel fibres can cause cuts if no technical solution is adopted.

To conclude, those who have assessed the respective performances of the two fibres and who have left sectarianism and bad faith at the door, may chose, in some cases to combine the two reinforcements which are not as hostile as you might have thought

translation of the Pierre Rossi papers published in “Béton Magazine” March 2009

Pierre Rossi
Laboratoire Central des Ponts et Chaussées Université Paris Est
[East Paris university central laboratory for bridges and roads]