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Effect of steel fibers on the shear behavior of high strength concrete beams

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HIGHLIGHTS

- High strength concrete becomes very ductile with the addition of steel fibers.
- The shear cracking is very much restrained with the use of sufficient quantity of steel fibers.
- The steel fibers contribution to the shear strength of high strength concrete is investigated.
- A proposed model is calibrated against experimental data and compared to exiting models.

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ABSTRACT

Shear failure of reinforced concrete beams is generally affected by a large number of parameters among which the a/d ratio (shear-span/effective depth) is the most important. The other main parameters are the compressive strength, the longitudinal reinforcement ratio, the aggregate and the presence of transverse stirrups. The addition of steel fibers as reinforcement could be another parameter which contributes to the shear resistance. Such shear contribution will be assessed qualitatively and quantitatively for high strength concrete in the present work.

Twenty four steel fiber reinforced high strength concrete beams without stirrups and with stirrups were tested in bending under two concentrated loads; the concrete beams were designed to have a pronounced shear behavior. The possibility of replacing traditional transverse reinforcement by steel fibers was studied. In this sense, the main testing parameters were the volume fraction of steel fibers, the aspect ratio of fibers and the presence of stirrups; five volume fractions of fibers were used (0%; 0.5%; 1.0%; 2.0% and 3.0%), with two aspect ratios (l_f/d_f of 65 and 80). The experimental results show that the shear behavior of the fiber reinforced high strength concrete beams without stirrups is similar, if not better, to that of high strength concrete beams containing stirrups reinforcement. The fiber reinforced beams had very narrow diagonal cracks and improved shear strengths, particularly for fiber fractions from 1% to 3%. Based on the present experimental work, a new empirical model is proposed for the contribution of the fibers to the shear strength of high strength concrete beams. The proposed model was assessed against other existing models and against varied experimental data taken from the literature and found relatively more satisfactory.

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1. Introduction

Shear behavior of structural concrete is a research topic that continues to have much interest despite the abundance of literature. The principle of shear in reinforced concrete remains insufficiently explained and no widely accepted analytical solution unifying all the factors influencing shear behavior of reinforced concrete members exists up to now. In the absence of such analytical solution, a number of empirical design methods are used throughout the world to avoid the disastrous effects of this solicitation force on reinforced concrete structures, particularly in the presence of seismic actions. These empirical methods are primarily based on testing reinforced concrete members and hence are not able to provide a wider understanding of the shear behavior since any given testing investigation can only cover certain aspects of

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shear and not all of them at one time and obeys to local testing conditions. Moreover, there is a lack or at least an insufficient testing data for high strength concrete which is considered as a relatively new concrete material. There is an acute need to assess the applicability of the existing empirical design methods to this structural material, particularly when new resisting components such as steel fibers are added to this concrete. More investigation work is then required to cover this aspect and provide further information.

In this experimental work, steel fibers are added in various volume fractions to a high strength concrete mix in the aim of studying the shear behavior of the hardened concrete material. This goes through an examination of the internal parameters that influence the shear resistance and also through a qualitative and a quantitative assessment of the contribution of the steel fibers to the structural behavior of this relatively new concrete material.

The present work would lead to recommendations with a view to improve the behavior of reinforced concrete members towards shear, and thus ameliorate the performances of the built environment to meet the requirements of a sustainable development. In particular, the risk of excessively wide cracking that might lead to durability problems at the longer term or even to premature collapses would be greatly reduced. It has been reported in the literature [1–3] that high strength concrete is not highly resistant towards shear, because the cracks are relatively smooth and trans-granular, with no interlocking between the aggregates particles, indicating that the contribution of aggregates to the shear strength of the material is slightly reduced. In the absence of sufficient aggregate interlocking, the cracking of high strength concrete appears in the form of a straight fracture and widens up. This needs to be efficiently stitched up by steel fibers added to the concrete mix in the same manner as aggregates to improve the shear behavior.

2. Experimental program: Materials, testing specimens and testing procedure

2.1. Materials and concrete mix design

The concrete used to prepare the test specimens is made from the following constituents:

1. Ordinary Portland cement (CEM I 52.5 N). The density of cement is 3160 kg/m^3 and its specific surface is 3520 cm^2/g. The particle sizes vary between 0 and 100 μm.
2. River rounded sand with a granular class of 0/4 (mm).
3. Crushed gravel from quartz, with a granular class of 4/15 (mm).
4. Fine mineral additions consisting of blast furnace slag and limestone fillers. The slag additives were finely ground to give a specific surface of 7000 cm^2/g and were used in proportion of 10% by weight of cement. The fine limestone fillers were used in proportion of 23% by weight of cement. The mineral additives were used to fill in the finer gaps between the aggregates and hence to improve the density and the compactness of the concrete material. Moreover, their use increases the volume of paste and hence facilitates the fibers dispersion inside the fresh concrete.
5. A high range water reducing admixture (HRWRA) in a liquid form, based on polycarboxylates (CHRYSO Fluid Optima 206), was used in a proportion of 2.5% by weight of cement for high strength concrete and 3% for fiber reinforced high strength concrete.
6. The steel fibers used are high strength cold-drawn wires in round smooth shapes. They present anchor hooks at both fiber ends for improvement of anchorage in concrete and are supplied in plates of 40–44 fibers glued together with a water soluble material as in Fig. 1.

Since fibers are added to the concrete mix, they are assimilated to a special aggregate with a very elongated shape. They can improve the tensile strength of the cement matrix and restrain the cracks by sewing them and hence improving the post cracking behavior of the hardened cement paste with maintained loaded capacity under increasing deformations. The quantity of fibers used in any concrete mix is better defined as the volume occupied by the fraction of fibers, ρ_f, in relation to the total volume of the structural element. In the present work, such volume fraction, ρ_f, varied from 0% to 3%. The l_f/d_f ratio of the fibers, referred to as the aspect ratio, is an important parameter taken into consideration in fiber technology. Two aspect ratios were used in the present study, namely l_f/d_f of 65 and 80. Table 1 presents the main characteristics of the fibers used.

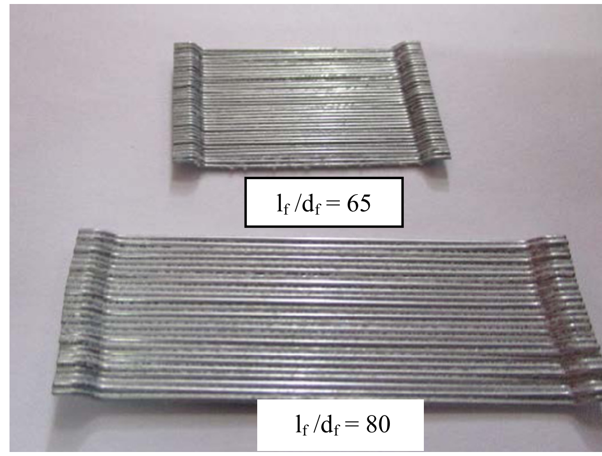

Fig. 1. Shape of fibers used in the concrete mix.

During the mixing and pouring of concrete, the fibers move easily within a fine paste to have an adequate distribution but are blocked in clusters in the presence of higher coarse aggregate content. In the hardened state, the residual strength beyond cracking of the structural element is provided by fibers crossing the crack and hence it is important that the fresh concrete allows for a uniform distribution and a better orientation of these fibers. Inversely, a too much firm concrete and an insufficient paste result in a fiber distribution in clusters which are not correctly covered by concrete. This justifies the use of higher paste content by using higher quantity of fine mineral additives and limiting the coarse aggregates. The use of a higher dosage of superplasticisers (3% by weight of cement) as recommended by the supplier allows a sufficient lubrication of the fiber reinforced concrete mix.

The mix designs used in making the concrete beam specimens are presented in Table 2.

2.2. Mechanical strengths of the different concretes

The compressive strengths of the seven types of concrete (see Table 2) used in making the beam specimens without steel fibers and with steel fibers were measured through the crushing of cylindrical concrete specimens of 11 cm diameter by 22 cm in height. The results given in Table 3 below indicate that the presence of fibers has an insignificant influence on the compressive strength of high strength concrete. As indicated by many researchers [4,5], the effect of fibers on the compressive strength of concrete is really not apparent and a marginal increase or decrease could be recorded. The variations in the results of the present work are within the differences that can occur from one concrete batch to another.

Measurements of the longitudinal compressive strains were carried out with the help of an extensometer (Fig. 2) and enabled the modulus of elasticity to be worked out for the seven types of concrete. The results were recorded in a data acquisition system for the complete stress–strain curve to be drawn for the different concretes (Fig. 3).

A close examination of the results in Table 3 reveals that the values of the modulus of elasticity obtained for the five types of high strength concrete are comparable, indicating that the presence of fibers has practically no influence on the early elastic behavior of HSC. This is illustrated further by the comparable shapes of the ascending portion of the stress–strain curves of the five types of high strength concrete (Fig. 3). The descending portions of these curves, however, present a considerable difference. For high strength concrete without fibers, this portion is very abrupt and sharp, expressing the brittleness of the concrete material, whereas in the presence of fibers, such descending portion softens and flattens, translating a relatively ductile concrete material, particularly with higher quantities of fibers.

Table 1
Properties of the steel fibers.

Length (mm)	Diameter (mm)	Aspect ratio l_f/d_f	Specific gravity	Tensile strength (MPa)	Elastic modulus (GPa)	Number of fibers per kg
35	0.54	65	8	1100	210	14,500
60	0.75	80	8	1100	210	4600

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