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Effect of the Steel Fibres into a High Performance Concrete (HPC) Matrix: Experimental Study

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Abstract: The lack of means of characterisation and calculation proper to steel fibre reinforced concrete does not at present allow a rational exploitation of this material but it has not, however, prevented its development in various fields. The aim of this research work is to study the steel fibre behaviour into a HPC matrix. Our approach is based on experiment on the following test specimens: Prisms : 14×14×56 cm and slabs : 60×60×10 cm. The steel fibres have been incorporated at random in HPC matrix to silica fumes. The compressive strength after 28 days is about 80 MPa. The prisms were tested on a 4 points bending; as for the slabs, they were resting on 4 sides and loaded in the centre by a square block of 10 cm on each side.

Key words: HPC, steel fibre, energy, ductility, slab, prism, bending test

INTRODUCTION

A lot of research has been done into the behaviour of steel fibres in a matrix of ordinary concrete. The fibre-matrix joining is similar to that of the interface aggregates non porous-matrix, it depends on the state of the surface of the fibres as well as on their form. In the case of high performance concerte, this interface is a zone of reduced porosity mainly as a result of a strong reduction of the W/C ratio, of the addition of silica fumes and of superplasticizer. In this study we will present the results of bending tests on 14×14×56 cm prisms and 60×60×10 cm slabs in high performance concrete whose compressive strength after 28 days is greater than 80 MPa.

HPC DESIGN

Choice of materials: The HPC design used, is derived from previous study which is carried out within a regional project for development of these new materials (Zeghip, 1997).

Cement: It is a CPA 52,5R. The tests on standard mortar give good results under compression.

$$\sigma_{1d} = 29{,}4 \text{ MPa}; \sigma_{28d} = 67 \text{ MPa}$$

Aggregates:

- The sand used is rounded with granular distribution of between 0 and 3 mm, its fineness modulus is 2,4.
- The gravel is rounded, the grading curve of the first type is between 3 to 7 mm and that of the second is between 7 and 15 mm.
- A crushed sand whose grading curve is between 0 and 4 mm was used in order to rectify the grading curve of rounded sand.

These different types of aggregates are shown in Fig. 1.

Superplasticizers: The superplasticizer choice is a synthesis polymer from the polynaphtalene group, in liquid form and with a density of 1,200.

Silica fumes: We decided to fix the dosage at 8% of silica fumes. This result is confirmed by previous research (Cadoret, 1990; Kaufmann *et al*., 2004).

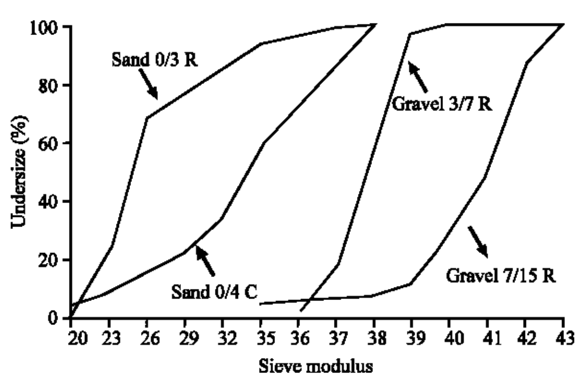

Fig. 1: Particle size analysis

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Steel fibres: Two types of steel fibre are used:

Type 1: 30/0.8 (L_1 = 30 mm, Φ_1 = 0.8 mm)
Type 2: 30/0.5 (L_2 = 30 mm, Φ_2 = 0.5 mm)

These fibres are manufactured from steel wire mesh. They have a tensile strength of 1200 MPa and two hooks at each end.

Concrete mix design: The steel fibres dosages used are: 0, 1.64, 2.45 and 3.25% in relation to the concrete volume. In order to maintain the volume of the concerts, we incorporated the steel fibres in place of sand (Absi, 1994; Imam and Vandewalle, 1996). The design used to produce the elements in HPC with the incorporation of steel fibres are shown in Table 1.

The different concerts were made in a vertical axe concrete mixer with a maximum capacity to 120 litres. The mixing cycle is as follows:

- Dry mix of constituents for two minutes;
- Introduction of mixing water with 1,5% of superplasticizer (% by weight in relation to the cement), mixed for 2 min;
- Introduction of the rest of the superplasticizer, mixed for 1 min;
- Sprinkling of the fibres into the mixture to avoid agglomeration, mixed for 1 min.

Manufacture of samples: The concrete is settled with a slight vibration on the outside of the square moulds 60×60×10 cm and prismatic moulds 14×14×56 cm. While the cylinders are vibrated on a vibrating table for approximately 20 sec.

EXPERIMENTATION

Slabs: After 28 days of hardening, the slabs were tested as shown in Fig. 2 in the following order:

- Presentation of the slab under the loading cone, the planed side face down on the square block of 10 cm on each side;
- The cast surface of the slab was centred and wedged in relation to the loading cone, then a 5 cm wide strip was coated in a fine layer of mortar on each edge of the slab;
- Contact and tightening of the slab and the loading cone with two diagonally placed clamps;
- The slab and loading cone unit is raised with to jack;
- A sufficient quantity of mortar is spread on the square block to eliminate any irregularities from the planed surface;

Table 1: Design of different HPC (Kg m^{-3})

	Fibres dosage (%)			
	0	1.64	2.45	3.25
Cement	420	420	420	420
S (0/3) R	456	446	442	436
S (0/4) C	195	191	188	186
G (3/7) R	228	228	228	228
G (7/15) R	913	913	913	913
Silica Fumes	33.6	33.6	33.6	33.6
Fibres	0	40	60	80
Water	155.4	155.4	155.4	155.4
Super Plasticizer	12.9	13.5	14.1	14.5
Slump (cm)	19	15.5	15	14

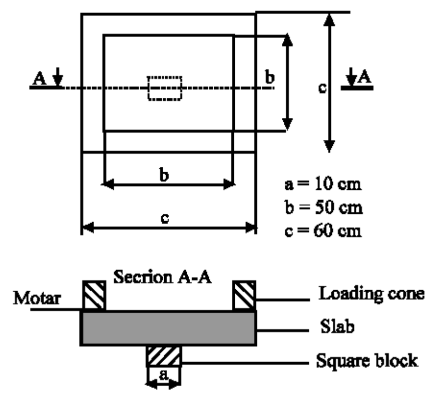

Fig. 2: Slab test

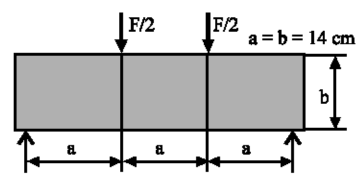

Fig. 3: Prismatic sample test

- Contact of the slab loading cone unit with the square block;
- Loading and withdrawal of the clamps.

The load is supplied by a 640 KN jack fixed on a pendular portal frame. To measure displacement at the centre of the slab, an inductive transducer was set up inside the loading cone. In this case, the servo control was established based on the movement of the jack at 1 mm min^{-1}.

Prisms: The prismatic samples (14×14×56 cm) underwent four points bending with a system set up on a compression frame (Fig. 3). The upper and lower rollers of the bending system had a 40 mm diameter which facilitated movement from the samples in relation to the testing machine. Deflection was measured with the two inductive transducers of symmetrical movement, fixed to a stirrup placed in the middle of the span to measure the variation of distance to a frame placed on the upper side of the sample, vertical to the bearing. The loading sides were those that were moulded. Servo-control was through deflection at a speed of 0,2 mm min^{-1}.

RESULTS

The results of compression testing on cylinders capped with a HP sulphur meant for HPC, give results contained between 80 and 85 MPa, for the different types of concerts.

The load-deflection and energy-deflection diagrams for the slabs and the prisms are shown below. Each curve is respectively representative of 3 prisms and 2 slabs.

The load-deflection curves for the prismatic sample (Fig. 4 and 5) show that maximal loads are not very sensitive to fibre dosage; on the contrary, a big difference appears after the maximal loads. However, if the behaviour or fibreless high performance concrete is elastic-brittle, the behaviour of the same concrete reinforced with steel fibres (for type 1 and type 2) shows a post cracking residual resistance which depends on the fibre dosage.

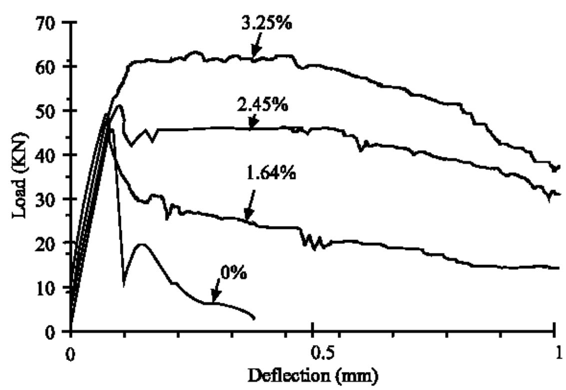

Fig. 4: Load-deflection curves prisms 14×14×56 cm with fibers (30/0.8)

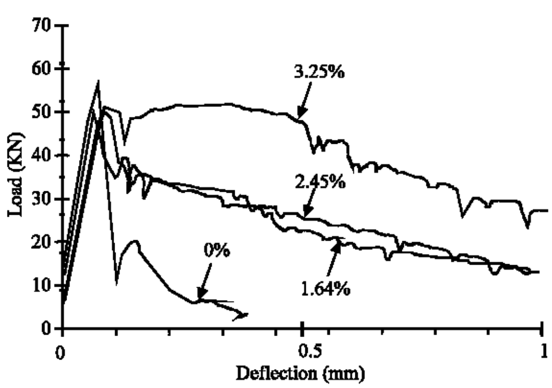

Fig. 5: Load-deflection curves prisms 14×14×56 cm with fibers (30/0.5)

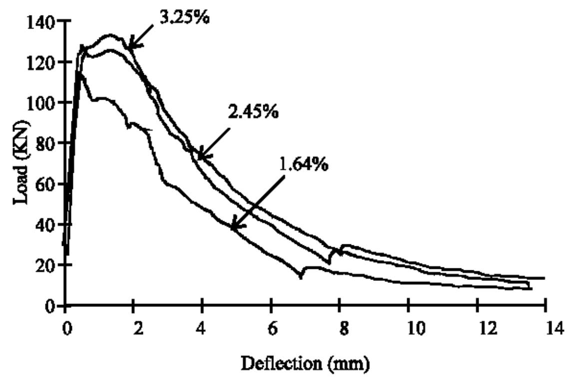

Fig. 6: Load-deflection curves slabs 60×60×10 cm with fibers (30/0.8)

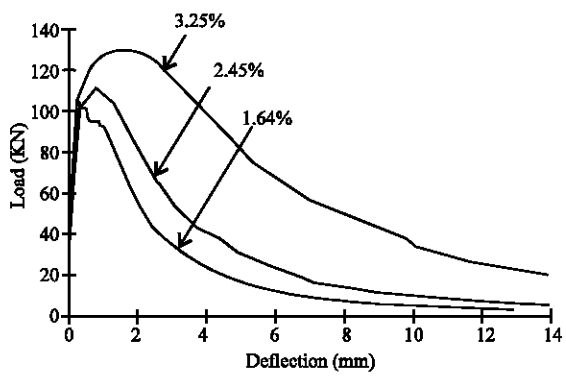

Fig. 7: Load-deflection curves slabs 60×60×10 cm with fibers (30/0.5)

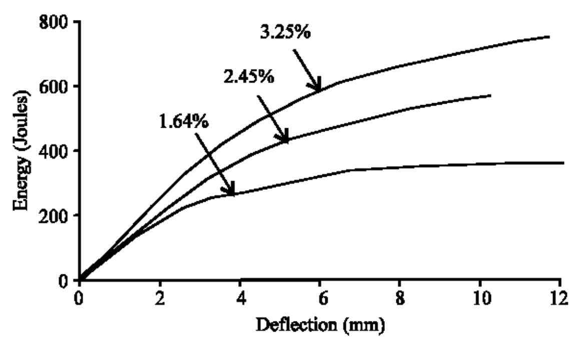

Fig. 8: Energy-deflection curves slabs 60×60×10 cm with fibers (30/0.8)

The bending tests for slabs (Fig. 6 and 7) show that after matrix cracking, the load transfer matrix-fibre is made with relative plastification and sliding (after hooks deformation). For the same dosage of fibres, we have 2,56 once more fibres when we use the fibre type 2 instead of the fibre type 1.

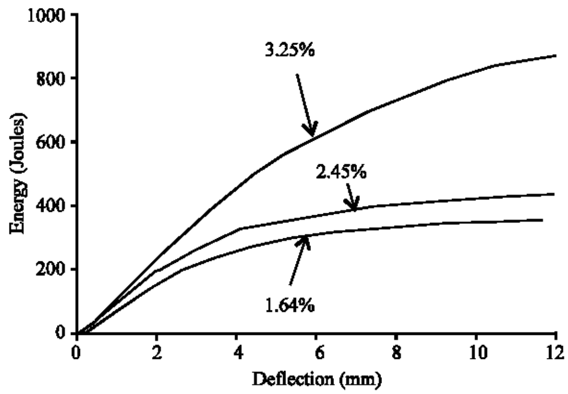

Fig. 9: Energy-deflection curves slabs 60×60×10 cm with fibers (30/0.5)

$$\frac{V_2}{V_1} = \frac{(\Phi_2)^2}{(\Phi_1)^2} = 2,56$$

On the load-deflection curves, we note a progressive decrease with a 0,5 mm fibre.

With a great number of fibres, we control much well the cracking progression, while the energy consummate during the hooks deformation is more important in 0,8 mm fibre case (Fig. 8 and 9). This is favoured by the good compacity of the matrix.

CONCLUSION

Based on the previous analyses we can deduce that the behavior in post cracking depends strongly on the dosage in fibers. The complexity of the failure mechanism specific to slabs increases the significance of the role of fibers on the structural scale (Banthia and Guptan, 2004). The fissuration schema of the slabs after testing which numbers at least 4 cracks (close to the medians) shows that no starting crack takes precedence over the other whereas in the case of prisms we see the development of a single macro-crack. This phenomenon is magnified by strong fibers dosages. If the critical dosage is not attain, the load falls quickly to join the fibre's load capacity or their sliding resistance. For our HPC, the fibre's critical dosage is 2,45 %.

NOMENCLATURE

W/C	:	(Water/Cement) ratio
σ_{1d}	:	Compressive strength at 1 day age
σ_{28d}	:	Compressive strength at 28 days age
L_1 and L_2	:	Length of fiber type 1 and 2
Φ_1 and Φ_2	:	Diameter of fiber type 1 and 2
V_1 and V_2	:	Volume of fiber type 1 and 2

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