Experimental Characterization of the Shear Behavior of Fiber Reinforced Concrete Beam Elements in Chips

Djamal Atlaoui, Youcef Bouafia

Abstract**—**This work deals with the experimental study of the mechanical behavior, by shear tests (fracture shear), elements of concrete beams reinforced with fibers in chips. These fibers come from the machining waste of the steel parts. The shear tests are carried out on prismatic specimens of dimensions 10 x 20 x 120 cm^3. The fibers are characterized by mechanical resistance and tearing. The optimal composition of the concrete was determined by the workability test. Two fiber contents are selected for this study (W = 0.6% and W = 0.8%) and a BT control concrete (W = 0%) of the same composition as the matrix is developed to serve as a reference with a sand-to-gravel ratio (S/G) of concrete matrix equal to 1. The comparison of the different results obtained shows that the chips fibers confer a significant ductility to the material after cracking of the concrete. Also, the fibers used limit diagonal cracks in shear and improve strength and rigidity.

Keywords**—**Characterization, chips fibers, cracking mode, ductility, undulation, shear.

I. Introduction

FIBER-reinforced concrete is a material that has been used successfully for many years and mainly for specific applications, such as; industrial pavements without joints, cast concrete, piles drilled with hollow auger in seismic zone, beams and floors. Experimental studies have been carried out to replace reinforced concrete reinforcements with fibers that can give concrete good tensile strength, flexural strength and shear strength [1]-[8]. The objective of this experimental study is to study the mechanical shear behavior of reinforced concrete beams containing fibers "machining chips of steel parts", as well as the possibility of making a mixture (stirrups + fibers) for improve shear ductility and limit crack openings. A series of flexion4-point tests was carried out on prismatic specimens 10x20x120 cm^3 on the Ibertest type machine. The optimum composition of this fiber concrete was determined by the workability test obtained by adding metal machining waste (machining chips) to bare concrete. The resistance and the length of the chips ensure a good anchoring of the fibers reinforced concrete. Two fiber contents were retained (W = 0.6% and W = 0.8%) and incorporated into an S/G of concrete matrix equal to 1. Control concretes of the same composition as the matrix for each test series were developed to serve as references.

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II. Experimental Program

A. Characterization of the Aggregates and the Cement

The aggregates used are crushed aggregates from Tizi-Ouzou region, (quarry rocks); the granular class used is respectively, 0/3 mm, 3/8 mm and 8/15 mm.

The cement used in our study is of Class CPJ-CEMII/B 42.5 R (Region of M'sila (LCM), Algeria).

B. Characterization of Fibers

The chips are cut in three lengths (30, 40, 50 and 60 mm) with 4, 6 and 8 undulations (spirals) for each length. The number of tests performed is three for each type of combination. The tests consist of direct tensile tests with controlled deformation.

C. Geometry of the Fiber and Anchoring System

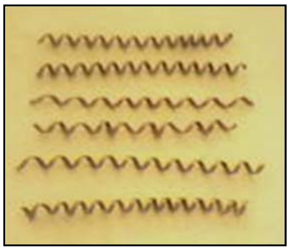

Fig. 1 Chip view

Fig. 2 Anchorage system

The fibers used come from the machining waste of the steel parts. They are recovered in the workshops of the national company of industrial vehicles in Algeria (SNVI). Their wavy geometric shape gives them a perfect anchorage in the cement matrix. A view of these chips is given in Fig. 1. The width, the diameter and the thickness of the fibers are respectively, l = 2 mm, Φ = 7 mm and e = 0.5 mm. Both ends of the chips were sized with a resin to improve their anchorage in the clamping jaws of the hydraulic press during the tensile test on the fiber itself (see Fig. 2). The test device is presented in Fig. 3.

Fig. 3 View of the test device

D. Presentation of the Results

For each test series, the different lengths (30, 40 and 50 mm) and for a number of undulations 8, 6 and 3, the average curve of the stress as a function of strain σ = f (ε%), the fiber having the best tensile strength is shown in Fig. 4.

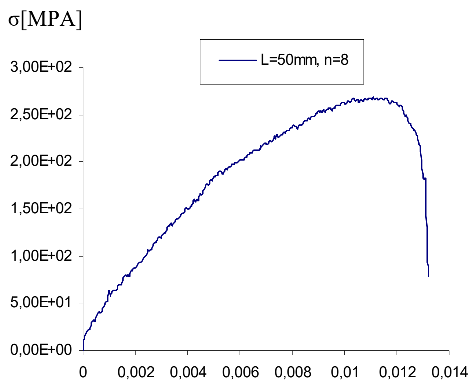

Fig. 4 Average curve σ = f (ε) for L = 50 mm, n = 8

E. Conclusion

This study allowed us to highlight the influence of the length of the fibers and the number of undulations on their tensile strength. The highest average resistance Rm = 270 MPa was obtained for a length of 50 mm with 8 waves. During the test, it can be seen that the corrugations of the fiber open gradually until the fiber is flattened. Beyond, there is a ductile rupture of the steel.

III. Optimization of Fiber Concrete

Since the presence of the fibers requires a matrix enriched in fine elements to coat them well, it is necessary to determine a special granular composition for fiber concrete. In this part of the study, we were interested in the influence of the addition of fibers on the workability of concrete in order to determine the optimal composition of fiber concrete. To this end, we have used the experimental optimization method developed by the Central Bridges and Grades Laboratory (LCPC), based on the Baron Lesage method [9], [10]. The procedure consists of fixing the water/cements ratio (E/C) and varying the S/G from the composition of the control concrete to measure the flow time and deducing an optimum. We therefore realized, for each fiber content (W = 0.2%, W = 0.4%, W = 0.6% and W = 0.8%), four mixes of concrete with a different S/G ratio (S/G = 0.64, S/G = 0.8, S/G = 1 and S/G = 1.4) and a constant W/C ratio of 0.54. The results of the workability test are presented on Fig. 5 give the variation of the flow time as a function of the S/G ratio. We find that the optimal S/G ratio is 0.8 for the fiber percentage of 0.2% and 1 for the other percentages.

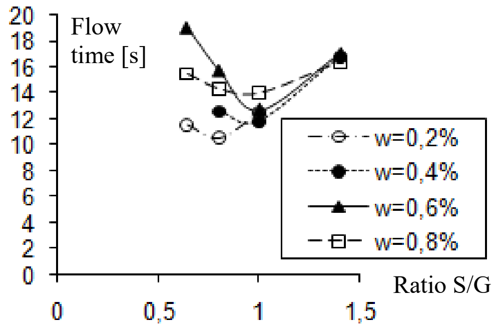

Fig. 5 Evolution of the flow time as a function of the S/G ratio for each percentage of fibers W(%)

A. Results and Discussions

We find that the optimal S/G ratio is 0.8 for the fiber percentage of 0.2% and 1 for the other percentages. The flow times corresponding to these optimums are between 10 s and 15 s. These minimum times correspond to the optimum range recommended by the LCPC. Note that the optimum S/G ratio increases with the increase in fiber content, which can be explained by the fact that fibers behave like large elements because of their shape and their dimensions. This increase in the volume of large elements (gravel + fibers) following the incorporation of the fibers in larger quantities therefore requires the increase of the volume of sand.

IV. Geometry and Composition of Test Pieces

A. Geometry of the Specimens

The test specimens used to carry out bending and shearing tests are prismatic test pieces of width l = 10 cm, a height h = 20 cm and a length L = 120, the prismatic molds [10x20x120] used are shown in Fig. 6.

B. Composition of Test Pieces

The test pieces are composed of metal fibers embedded in a concrete matrix. The optimum concrete composition for 1 m^3 is determined by the workability test. The concrete composition for a 1 m^3 is given in Table I. The mass for the fiber contents corresponding to 1 m^3 of concrete and for a prismatic are given in Table II.

V. 4-Point Bending Tests

In order to follow the behavior of these "chip" recovery fibers at the shear (shear), a series of flexion 4-points tests were carried out with S/G = 1 for the two fractions W = 0.6% and W = 0.8%), as well as control concrete (without fibers). Fig. 7 illustrates the principle and the static diagram of the series of tests carried out.

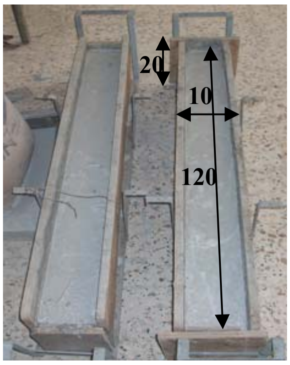

Fig. 6 Prismatic molds used

TABLE I
OPTIMIZED COMPOSITION FOR 1 M³

Constituents of concrete for 1 m³	Gravel ratio S/G = 1
Sand 0/3 (kg)	896.67
Gravel 3/8 (kg)	95.67
Gravel 8/15 (kg)	801
Cement CPJ CEMII/A 42.5(C) (kg)	380
Water (E) (kg)	206.52
Fluidizers (0.05% weight of cement) (ml)	190

TABLE II
MASS OF DIFFERENT FIBER CONTENTS

Volume fractions of fibers W (%)	0.6%	0.8%
Masses for 1 m³ (kg)	47.3	62.9
For a prismatic beam (kg)	1.13	1.51
For a cylindrical specimen (kg)	0.250	0.334

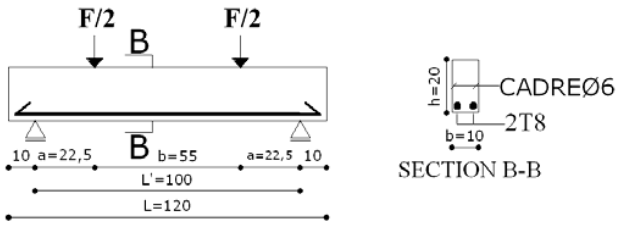

Fig. 7 Static diagram of the 4-point bending test series

A. Results of Tests 4-Point Flexion

Fig. 8 illustrates the failure mode of the beams for the two test series during the 4-point bending tests.

Fig. 8 Beam breaking mode

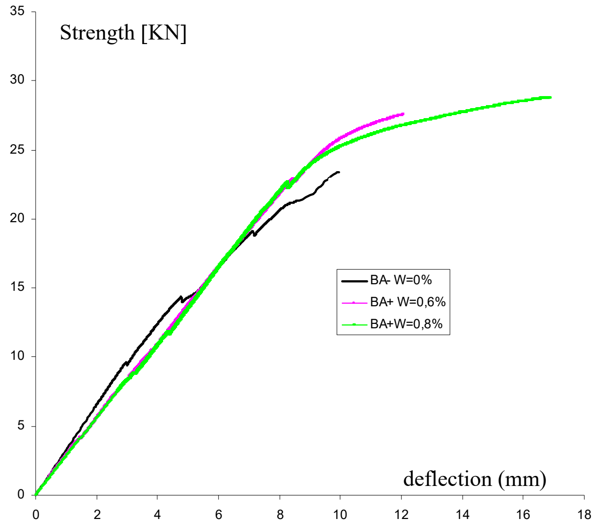

Fig. 9 Superimposition of the strength–deflection curves

Fig. 9 illustrates the superimposition of the mean strength–deflection curves in the span of the test series.

B. Discussions and Conclusions

The results presented in Fig. 9 allowed us to conclude: The addition of fibers (machining chips of steel parts) in the concrete improves the strength and the rigidity for a content W = 0.8% compared to W = 0.6% and the BT (without fibers) of the concrete shear and gives it a significant ductility. During these tests diagonal cracks were observed on the beam before the rupture, which explains a shear failure (see Fig. 8).

VI. COMPRESSION TESTS

In order to determine the compressive strength of the concrete used, compression tests on cylinders with diameters of 16 cm and height 32 cm (Fig. 10) are carried out on an AUTOTEST hydraulic press driven by a microcomputer represented by Fig. 11. Its maximum capacity is 2000 KN. It is programmed for compression tests and for different dimensions of test bodies (cylindrical or prismatic test pieces). Two volume fractions are retained: W = 0.6% and W = 0.8%, the control concrete is BT (W = 0%). The values of the strength and the stress are read directly on the screen of the machine, the evolution of the reformation is controlled with the aid of an extensometer placed directly on the specimen. The values recorded for each loading step are the slotted in the form of a stress-strain curve until breaks in compression.

The average stress-strain curves obtained for the different tests for the volume fractions W = 0.6% and W = 0.8%, the control concrete is noted BT (W = 0%) after crushing at 28 days are given by Figs. 10-12.

The maximum stresses for each volume fraction as well as the measured mechanical characteristics are given in Table III.

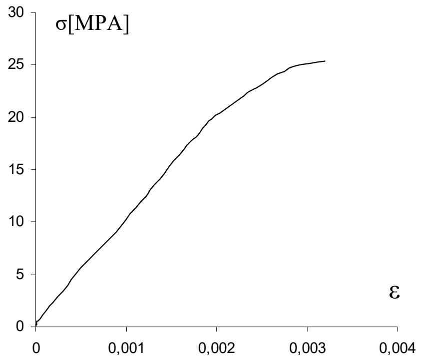

Fig. 10 Mean curve σ = f (ε) for W = 0.6%

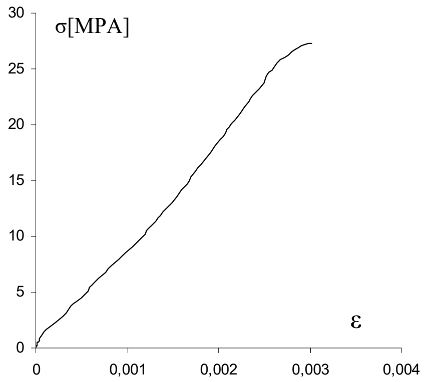

Fig. 11 Mean curve σ = f (ε) for W = 0.8%

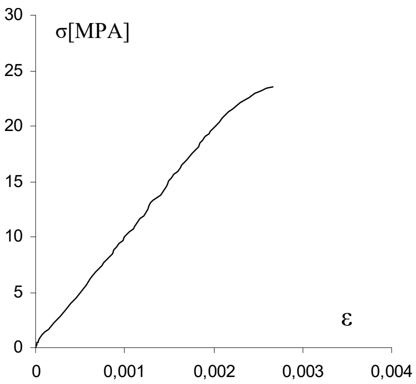

Fig. 12 Mean Curve σ = f (ε) for BT (W = 0%)

TABLE III
MEASURED MECHANICAL CHARACTERISTICS

Testing compression stress	σ [MPa]	Young module E[MPa]
BT (W = %)	24	98 31325
W = 0.6%	25	32 32202
W = 0.8 %	27	22 31325

VI. CONCLUSION

This experimental study allowed us to conclude that:

- The addition of fibers in the concrete improves the strength and rigidity of the concrete in shear, and gives a significant ductility (here fiber contents W = 0.8% compared to W = 0.6% and BT without fibers).
- This study allowed us to highlight the influence of the length of the fibers and the number of undulations on their tensile strength. We obtained the best resistance for a length l = 50 mm with n = 8 undulations.
- The fibers play, as to the handling, the role of the largest granulates. Indeed, the workability of the composite material (concrete of metal fibers) decreases when the percentage of fibers increases. This step allowed us to set the S/G giving better maneuverability for the different fiber contents, as well as the proper concrete compositions.

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