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The Effect of Recovery Fibers and the Sand/Gravel Ratio on the Direct Tensile Behavior of Concrete

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Abstract: The purpose of this research is the experimental analysis of the mechanical behavior of steel chip reinforced concrete. The fibers used are obtained from metal chips recovered in steel machining workshops in Algeria (SNVI), where they are obtained in the form of cylindrical rolls. Once stretched, these rolls take the form of a coil, which is then cut to produce fibers of small lengths. This helical configuration ensures better anchoring in the concrete and prevents the formation of cylindrical voids that could weaken the matrix. The fibers were subjected to tests to assess their mechanical strength and pull-out resistance capacity. Direct tensile tests were conducted on gypsum samples of square section [100x100] mm², requiring the design and fabrication of a special fixing device on the tensile machine. Four percentages of fibers were selected for this study (W=0.3%, W=0.5%, W=0.8%, and W=1%), where W represents the volumetric fraction of added fibers. In order to determine the optimal composition of fiber-reinforced concrete in terms of workability, three concrete mixes with different sand/gravel ratios (S/G=0.642, S/G=0.8, and S/G=1) were made, all with a fixed water/cement ratio E/C = 0.543 for each fiber percentage. Compression tests were carried out on cylinders with a diameter of Ø16 cm and a height of H32 cm, using a computer-controlled hydraulic press. The analysis of the results reveals that the behavior of fiber-reinforced concrete is divided into two distinct phases: an initial linear phase, corresponding to elasticity, followed by a post-cracking phase where the fibers continue to provide resistance. The fibers provide significant ductility to the material after concrete cracking (post-rupture), while limiting cracks and improving strength and stiffness for certain percentages of fibers and specific sand/gravel ratios (S/G).

Keywords: Concrete, Recovered fibers, Direct tensile, Workability, Experimentation

Introduction

Concrete is universally recognized as a composite material, composed of aggregates of various sizes, sand, and cement paste. Its versatility makes it an essential component in all sectors of construction, whether it be industrial or residential buildings, retaining walls, infrastructure such as bridges, tunnels, and dams, or even for sidewalks or airport runways.

Fiber-reinforced concrete has been widely used for many years, primarily in specific applications such as jointless industrial floor slabs, shotcrete, auger-cast piles in seismic zones, as well as beams and floors. However, studies on this subject reveal divergences regarding the objectives of fiber reinforcement. According to some sources, such as Markovic et al. (2003), the main objective is to enhance the tensile strength and ductility of concrete. Conversely, other studies, like Kawamata et al. (2003), suggest that the introduction of fibers aims to control cracking and modify the behavior of the cracked material by bridging the cracks. Under tensile stress, cracks form in the concrete matrix, and fibers can link them, thereby reinforcing resistance to crack opening and delaying their propagation.

Experimental research has been conducted to explore the possibility of replacing traditional reinforcements in reinforced concrete with fibers, thereby offering improved tensile, flexural, and shear strength. (Djebal et al., 2011; Noghabai, 2000; Kwak et al., 2002; Slater et al., 2012; Majdzadeh et al., 2006; Dinh et al., 2010; Cucchiara et al., 2004; Meda et al., 2005; Ding et al., 2011; Statford & Burgoyne, 2003; Cho & Kim, 2003; Chalioris & Sfiri, 2011; Mirsayah & Banthia, 2002; Barragán et al., 2006; Fariborz et al., 2011; Lim & Oh, 1999; Barragán, 2002; Johnston, 1996). Initially, researchers attempted to enhance the mechanical properties of concrete, such as compressive and flexural strength, by adding fibers, but the results were limited (Sukontasukkul, 2004). It became evident that fibers primarily play two roles in a cementitious material:

1. Controlling the propagation of cracks in a service material by reducing their opening.
2. Transforming the brittle behavior of the material into a ductile one, thereby increasing safety during ultimate loads.

Direct tensile testing is typically recommended to characterize the behavior of a material under longitudinal stress. However, the complexity of conducting this test on concrete specimens often leads to its replacement with a splitting or flexural tensile test.

In our study, we focus on analyzing the behavior of concrete reinforced with chip fibers when subjected to tension. Our main objective is to examine how these fibers, derived from steel machining waste, influence the mechanical properties of concrete. We aim to find an optimal compromise between the workability of concrete and its ability to withstand tension. To this end, we conducted a series of experiments on square-shaped concrete samples (100x100 mm²), varying the percentages of fibers (W%) and the S/G ratios (sand/gravel) (S/G=0.642, S/G=0.8, and S/G=1) in the concrete mix, as well as the fixed E/C ratio (water/cement).

Materials and methods

Materials

Fiber Characterization

The tests involve conducting direct tensile tests with controlled deformation. Subsequently, we present the characteristic value of the rupture stress along with the obtained curve, as well as the comparisons made.

Fiber Geometry and Anchoring System

The fibers used are sourced from machining waste of steel parts, obtained from the National Company of Industrial Vehicles in Algeria (SNVI). Their spiral-shaped geometric form provides optimal anchoring within the cementitious matrix. Figure 1 depicts a view of these chips. Their dimensions are as follows: length (l) = 3 mm, diameter (d) = [missing], thickness (e) = 0.48 mm. During the tensile test on the fiber itself, both ends are coated with a fiberglass resin in a special mold to enhance their fixation in the clamping jaws of the hydraulic press.

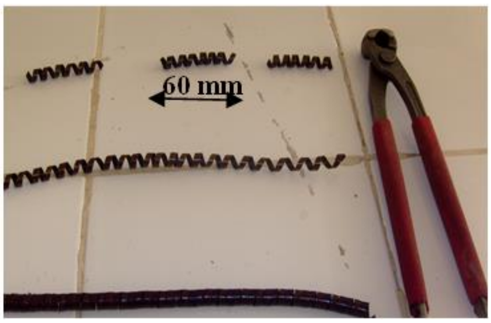

Figure 1. View of fibers in chips

Specimen Composition

Characterization of Aggregates and Cement

Test specimens are made of fiber chips embedded in a concrete matrix. The concrete composition for 1 cubic meter is established according to the Dreux-Gorisse experimental method, as indicated in Table 1. Four volumetric fractions (W) are considered: W=0.3%, W=0.5%, W=0.8%, and W=1%. The aggregates, sourced from the Tizi-Ouzou region, are quarry rocks with a crushed shape. The particle size classes used are 0/3mm, 3/8mm, and 8/15mm, respectively. The particle size distribution curves for each type of aggregate are shown in Figure 2. The cement used in our study is CPJ-CEMII/B 42.5 R NA 442, of class 42.5, sourced from Lafarge Cement in the M'sila region, Algeria.

Table 1. Composition optimized for 1m^3 of concrete

Constituents of concrete for a volume of 1m^3	
Sand 0/3 (kg)	701.35
Gravel 3/8 (kg)	116.61
Gravel 8/15 (kg)	97.,45
Cement CPJ CEMII/A 42.5(C) (kg)	380.00
Watter (E) (kg)	206.52

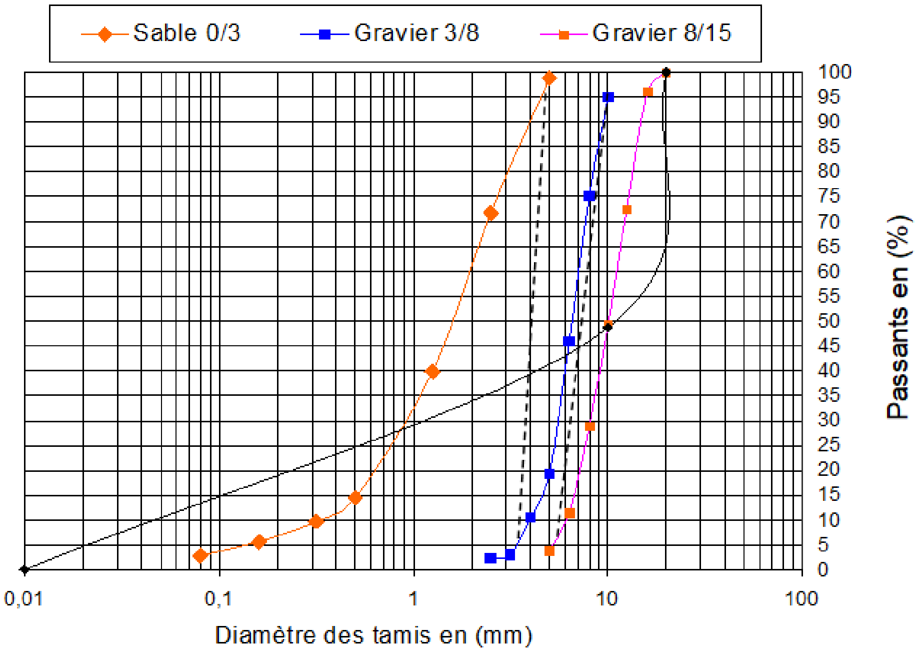

Figure 2. Grading curve

The mass of the different volume fractions for 1m^3 of concrete is indicated in table 2.

Table 2. Mass of the different fiber contents for 1m^3 of concrete

Fractions volumiques des fibres W (%)	0.3%	0.5%	0.8%	1%
Masses en (kg)	17.45	29.09	46.54	58.18

Optimization of Fiber Concrete

We used the L.C.L. maneuverability meter, developed within the Central Laboratory of Bridges and Roads (L.C.P.C), to assess the maneuverability of fiber concrete. This device allows testing a volume of 30 liters of concrete, as illustrated in Figure 3. To examine the maneuverability of fiber concrete, we conducted three separate mixes for each fiber percentage (W=0.3%, W=0.5%, W=0.8%, and W=1%), with varying sand/gravel (S/G) ratios (S/G=0.642, S/G=0.8, S/G=1), and a fixed water/cement (E/C) ratio of 0.543. The masses of the various components for a volume of 30 liters of concrete are shown in Table 3 below.


Figure 3. LCPC handling meter

Table 3. Masses of the different constituents for a mix of 30 liters of concrete

Constituents of concrete for a volume of 30 liters	S/G=0.642	S/G=0.8	S/G=1
Sand 0/3 (kg)	21.04	23.91	26.9
Gravel 3/8 (kg)	3.498	3.19	2.87
Gravel 8/15 (kg)	29.26	26.70	24.03
Cement CPJ CEMII/A 42.5(C) (kg)	11.40	11.40	11.40
Watter (E) (kg)	6.20	6.20	6.20

The mass of the different volumetric fractions for a batch of 30 liters of concrete is indicated in Table 4.

Table 4. Mass of the different fiber contents for 30liters of concrete

Volume fractions of fibers W(%)	0.3%	0.5%	0.8%	1%
Weights en (kg)	0.524	0.873	1.397	1.746

Methods

Fiber Characterization Tests

The tests are conducted on a controlled deformation hydraulic press at the Laboratory of Materials and Civil Engineering Structures Modeling at M.M. University of Tizi-Ouzou in Algeria. This press is equipped with a digital control and acquisition system, as illustrated in the view provided in Figure 4. Geometric characteristics are automatically inputted, with a useful fiber length of 100 mm. The loading speed is 20 mm/min. Chips are cut into three different lengths (30, 50, and 60 mm), and for each length, the number of undulations, or rather spirals, is 3, 5, and 7. Three tests are performed for each combination (length and number of spirals).

Figure 4. Test device view

Compression Tests

To assess the compressive strength of the concrete used, compression tests are carried out on cylinders with a diameter of 16 cm and a height of 32 cm, as illustrated in Figure 5. These tests are conducted using a computer-controlled hydraulic press, with a maximum capacity of 2000 kN (see Figure 6). The press is programmed for compression tests, accommodating different specimen dimensions (cylindrical or prismatic).

Figure 5. Cylindrical specimen (16x32)

Figure 6. Strengh press (2000KN)

Specimen Fixation Device

We have designed a special fixture (see Figure 7) to secure the specimens (see Figure 8) onto the jaws of the tensile testing machine. This design was developed using the value analysis method. . This fixture has been adapted to the 'IBERTEST' 200 KN tensile testing machine. It consists of two identical parts that attach to the upper and lower jaws of the tensile testing machine using fixed jaws. The specimens are positioned inside the fixture on corner supports. An adjustment screw allows for the positioning of the sliding jaws to accommodate specimens of different dimensions. The alignment of the specimen axis with that of the machine is ensured by stops. Since the fixture is attached to the jaws of the tensile testing machine, there is no need to install a ball joint. Vertical force is applied gradually at a controlled loading rate (0.005 MPa/second). The Wintest32 software, specially programmed for this press, records the vertical force value and corresponding deformation at each loading step, as well as stress versus deformation.

Figure 7. Vieu of speecimen claamping device

Figure 8. Tensile test device

Geometry and Composition of Specimens

Specimen Geometry

The specimens used are dumbbell-shaped specimens, with a cross-sectional area of 100x100 mm² (see Figure 9). They feature a U-shaped notch, measuring 5 mm deep by 5 mm wide, with a slight inclination on the sides to facilitate demolding of the specimen.

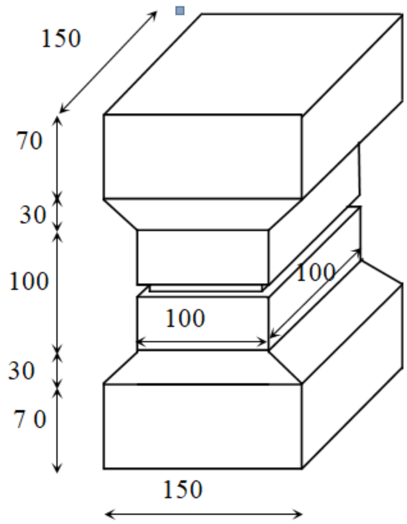

Figure 9. Fiber concrete specimen

Fiber Concrete Optimization

To optimize the composition of fiber-reinforced concrete, ensuring proper encapsulation of fibers by a matrix enriched with fine elements, we conducted a study on the workability of concrete considering the addition of fibers. In this part of our research, we utilized the experimental optimization method developed by the Central Laboratory of Bridges and Highways (LCPC), based on the Baron Lesage method (Rossi, 2002; Casanova, 1995). This approach involves fixing the water/cement ratio (W/C) and varying the sand/gravel ratio (S/G) from the composition of the control concrete, then measuring the flow time to determine the optimum. Thus, for each percentage of fibers (W = 0.3%, W = 0.5%, W = 0.8%, and W = 1%), we conducted four concrete mixes with different S/G ratios (S/G = 0.642, S/G = 0.8, S/G = 1), while maintaining a constant W/C ratio fixed at 0.543.

Results and Discussions

Fiber Tensile Characterization Tests

Figure 10 presents the "average of three tests" curve of the tensile stress as a function of strain σ = f(ε) for the fiber that exhibited the highest tensile strength.

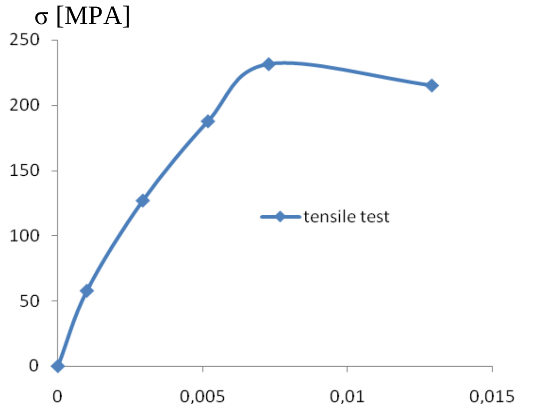

Figure 10. Average curve σ = f (ε)

During the test, it is observed that the ripples of the fiber gradually open until the fiber flattens out. Beyond this point, a ductile rupture of the steel is observed. It is noteworthy that the tensile strength increases with the number of ripples: it reaches Rm = 232 MPa for a length L = 60 mm and a number of ripples n = 5.

Compression Tests

The stress-strain curves obtained for the different compression tests after 28 days are presented in Figure 11.

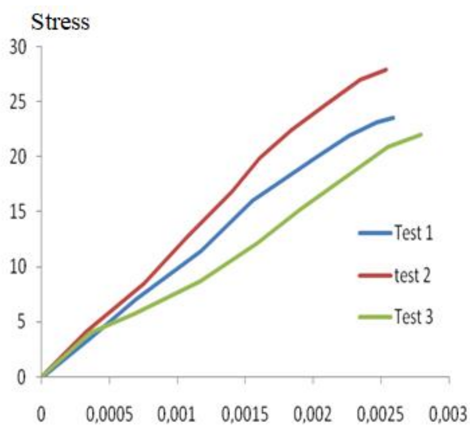

Figure 11. Superposition of stress-strain curves in compression

The maximum stresses for each test, as well as the measured mechanical characteristics, are provided in Table 5.

Table 5. Measured mechanical characteristics

Tests	Compressive stress σ [MPa]	Young's modulus E [MPa]
Test 1	23.48	30934
Test 2	27.73	29305
Test 3	22.02	33932
Average	24,41	31390.33

The results of the workability test are illustrated in the graph (see Figure 12), which shows the variation of flow time as a function of the S/G ratio.

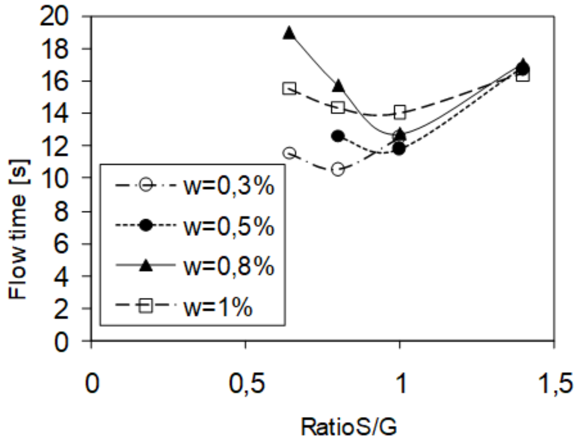

Figure 12. Evolution of the flow time as a function of the S/G ratio for each percentage of fibers W(%)

We observe that the optimal S/G ratio is 0.8 for a fiber percentage of 0.3%, and 1 for the other percentages. The flow times corresponding to these optima are between 10 and 15 seconds. These minimum times fall within the recommended optimum range by the LCPC. It should be noted that the optimal S/G ratio increases with the increase in fiber content. This increase can be explained by the behavior of the fibers, which act as large elements due to their shape and dimensions. Thus, increasing the volume of large elements (gravel + fibers) following the incorporation of higher fiber quantities requires an increase in the volume of sand.

Direct Tensile Tests of Fiber-Reinforced Concrete

After subjecting the fiber-reinforced concrete specimens to compression using the "IBERTEST" tensile machine, for various fiber contents (0.3%, 0.5%, 0.8%, and 1%) and different numbers of undulations, as well as for different sand/gravel ratios (S/G = 0.642, S/G = 0.8, and S/G = 1), the stress-strain curves are provided respectively in Figures 13, 14, 15, and 16.

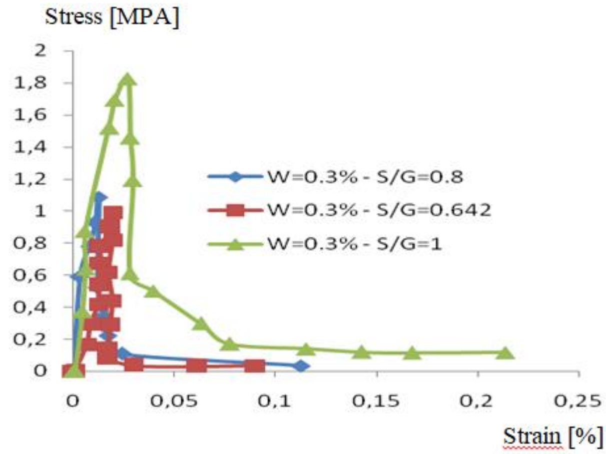

Figure 13. Stress-Strain curves for W=0.3% and S/G=0.642,0.8 and 1

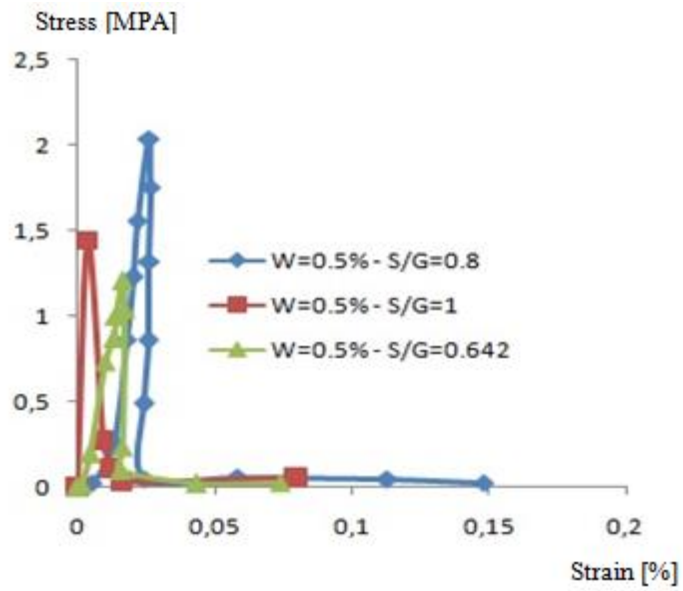

Fig.ure 14. Stress-Strain curves for W=0.5% and S/G=0.642, 0.8 and 1

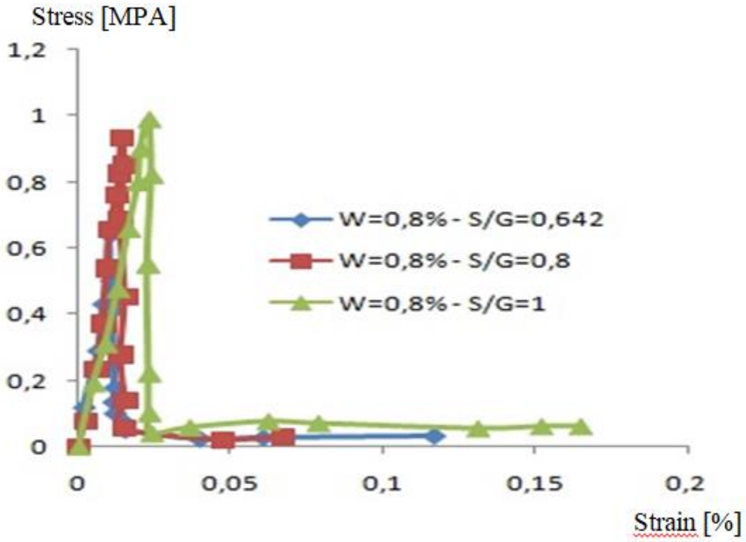

Figure 15. Stress-Strain curves for W=0.8% and S/G=0.642,0.8 and 1

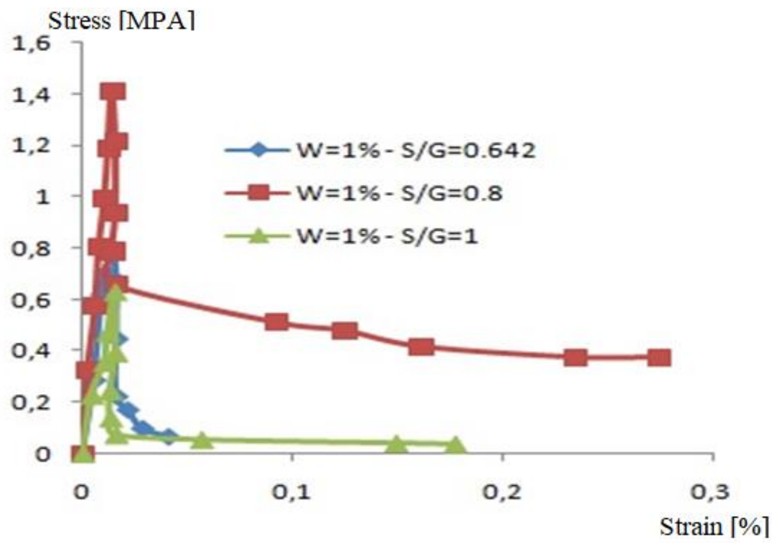

Figure 16. Stress-Strain curves for W=1% and S/G=0.642, 0.8 and 1

Figure 17 presents the overlay of stress-strain curves for different fiber contents (0.3%, 0.5%, 0.8%, and 1%), as well as for different sand/gravel ratios (S/G = 0.642, S/G = 0.8, and S/G = 1).

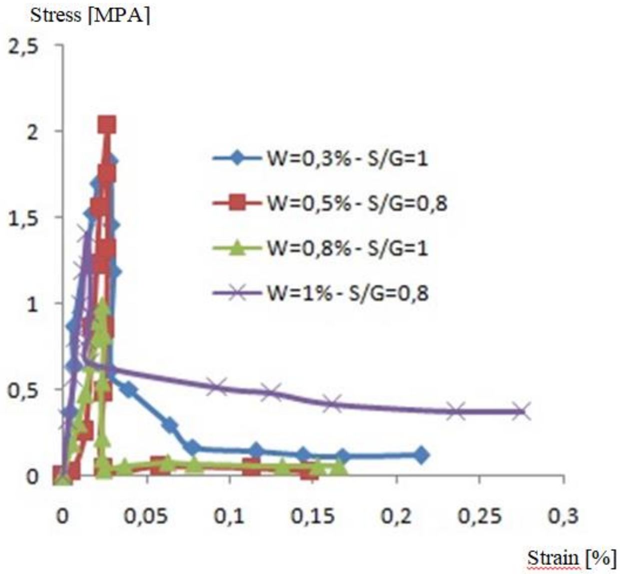

Figure 17. Superposition of the maximum stress-strain curves for the different w and S/G

The results from Figures 13, 14, 15, and 16 indicate that fiber-reinforced concrete is characterized by two distinct phases. The first phase is linear, corresponding to a quasi-elastic behavior of the material, marking the pre-cracking of the concrete. This phase ends with the appearance of a macro-crack. The second phase is characterized by a sudden drop, without abrupt rupture of the specimen, in the load-carrying capacity of the material, representing post-cracking. In this phase, the concrete matrix breaks while the fibers bridge the edges of the crack (see Figure 18), thus avoiding abrupt failure. The results also reveal that the addition of fibers imparts significant ductility to the material for different fiber percentages (W = 0.3%, W = 0.5%, W = 0.8%, and W = 1%), and this holds true for different sand/gravel ratios (S/G = 0.642, S/G = 0.8, and S/G = 1). Figure 17 shows that the maximum tensile stress of the fiber concrete is achieved for a fiber content of W = 0.5%, corresponding to a Sand/Gravel ratio (S/G = 0.8). This maximum stress is 2.04 MPa. It is interesting to note that adding fibers at low percentages leads to an increase in strength, as observed for a fiber percentage of W = 0.5% corresponding to S/G = 0.8. However, with an increase in fiber volume, this strength tends to decrease. This decrease could be attributed to the reduction in material compactness, which weakens it. This result is consistent with the observations of (Rossi, 1991).

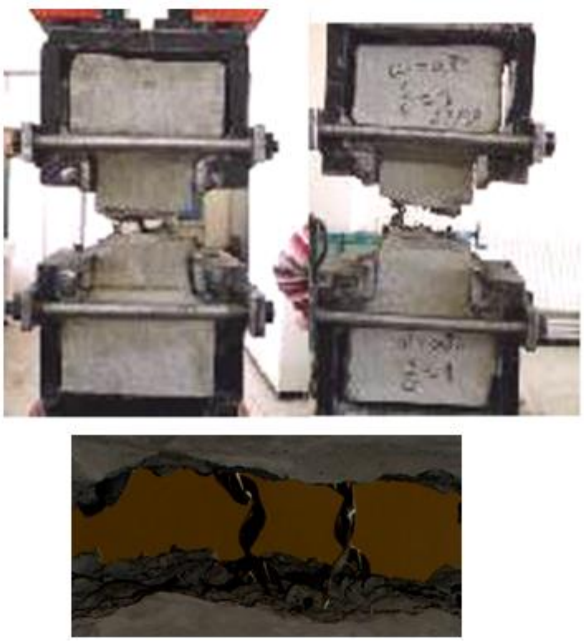

Figure 18. Failure mode of fibers in tension

Conclusion

This study revealed the impact of fiber length and the number of undulations on their tensile strength. The results indicate that the best strength is achieved with a fiber length of 60 mm and 5 undulations. During the tensile tests, the undulations tend to flatten out before the fiber steel elongates. The workability test helped determine the concrete composition with different sand/gravel ratios (S/G = 0.642, S/G = 0.8, and S/G = 1) and different fiber contents (0.3%, 0.5%, 0.8%, and 1%), thus ensuring good bond between fiber-reinforced concretes to enhance their stiffness and tensile strength. Analysis of the curves from this experimental study reveals that fiber-reinforced concrete exhibits two distinct phases. The first phase is linear, corresponding to quasi-elastic behavior of the material, while the second phase is characterized by a sudden drop in load-carrying capacity, without abrupt specimen failure. This experimental study enabled us to track the behavior of recycled fiber-reinforced concrete under tensile stress and determine the optimal fiber content and sand/gravel ratio (S/G) that yielded the highest peak stress, which was approximately 2.04 MPA for (S/G = 0.8).

In conclusion, we can state that the apparatus designed and implemented for conducting direct tensile tests has been successfully proven, and machining waste (chips) can be effectively utilized by incorporating them into fiber concrete preparation for industrial flooring and shotcrete applications, particularly in tunnels and the repair of large-diameter pipelines (Casanova, 1995; Rossi, 1991; Bouafia et al., 2002; Rossi et al., 1989; Lim et al., 1987) Furthermore, this concrete can be employed to enhance the fire resistance of reinforced concrete, as the fibers would restrict crack openings and shield traditional reinforcements from thermal radiation. In perspective, it would be interesting to carry out tests on test specimens of real large dimensions, to carry out tests with flat fibers instead of wavy ones in order to reduce the voids (cavities) in the cement paste, and also to associate these fibers to traditional reinforcements. Looking to the future, it would be intriguing to conduct tests on large-scale specimens to better simulate real-world conditions. Additionally, experimenting with flat fibers instead of wavy fibers could help minimize voids and cavities in the cement paste. Furthermore, exploring the combination of these fibers with traditional frameworks could provide valuable information on the synergistic effects of their interaction.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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