

EFFECT OF CHIPPED FIBER LANGUOR ON THE BENDING BEHAVIOR OF CONCRETE BEAM ELEMENTS

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ABSTRACT:

This article studies the behavior of concrete beams reinforced with metal fibers (chips) randomly arranged in concrete, to improve ductility and bending stiffness and limit crack openings. These fibers come from machining waste from steel parts. The fibers are characterized for mechanical resistance and tearing. Three series of tests were carried out for languor respectively $L = 4$ cm, $L = 5$ cm and $L = 6$ cm. Bending tests (three-point bending) are carried out on prismatic specimens of dimensions $[10 \times 20 \times 120]$ cm³. Compression tests are carried out on cylinders with a diameter of $\varnothing 16$ cm and a height of $H 32$ cm in order to determine the mechanical properties of the concrete used. The composition of the concrete is determined by the experimental method known as "Dreux-Gorisse". Two fiber contents are retained for this study ($W = 0.6\%$ and $W = 0.8\%$) and a BT control concrete ($W = 0\%$) with W : fiber contents in the concrete, of the same composition as the matrix is developed for serve as a reference. The confrontation and comparison of the different results obtained show that the fibers with languor $L = 6$ cm confer significant ductility to the material after cracking of the concrete, better than the other languor's ($L = 4$ cm and 5 cm) with numbers of undulations (spirals) $n = 3.5$ and 6 . Also, the fibers used limit bending cracks and improve strength and rigidity.

1. INTRODUCTION

Steel fibers are increasingly used for the reinforcement of concrete, especially in the case of thin elements. They replace or supplement conventional reinforcement depending on the type of structure. In the case of slabs (thin elements) and shotcrete (vaults), a gain in productivity is observed. As the concrete matrix has a brittle nature and a low tensile strength, the mechanical behavior in tension is conditioned by the cracking of the concrete. The presence of fibers in the concrete plays an important role in the tensile behavior of the composite. Indeed, the fibers intervene on two scales:

- At the scale of the material by "stitching" the micro cracks, they delay the location of the cracking. This action can cause an increase in tensile strength; this increase depends on the percentage of fibers incorporated into the concrete and their orientation in the concrete mass.
- On the scale of the structure, by "retaining" the two cracked concrete blocks thanks to their anchoring on both sides of the crack. The fibers make it possible to attenuate the fragility of the concrete and thus provide it with greater ductility. Good tensile strength and especially ductile behavior after the first crack.

Adding steel fibers to concrete is an unconventional mass reinforcement that improves the mechanical properties of

concrete and helps control crack propagation. This ability is to the tensile stress transfer capability of steel fibers through crack surfaces that provide significant shear strength through developing cracks (Chalioris, 2003). This phenomenon is also known as crack bridging. The cracking of steel fiber reinforced concrete requires a process of peeling and extracting randomly distributed steel fibers in the concrete (Karayannis, 2000). Experimental studies have been carried out in order to replace the reinforcements of reinforced concrete with fibers capable of providing the concrete with good resistance to traction, bending as well as to shear force (Barragán and al., 2006; Mirsayah and Banthia., 2002; Chalioris and Sfir., 2011; Statford and Burgoyne., 2003; Cho and Kim., 2003; Djebali et al., 2011; Atlaoui and Bouafia., 2008; Bouafia et al., 2012; Djebali et al., 2011; Noghabai., 2000; Slater et al., 2012; Dinh et al., 2010; Meda et al., 2005; Ding et al., 2011). At first, researchers tried, by adding fibers, to increase the mechanical characteristics of concrete such as compressive strength and flexural strength, but the result obtained was limited (Fariborz et al., 2006). It is currently established that in the presence of fibers, reinforced concrete beams resist higher load levels (Cucchiara et al., 2004). According to (Lim and Oh., 1999), in the presence of fibers, the cracking and rupture loads are greater. After cracking, the fibers also improve the stiffness and the bearing capacity of reinforced concrete elements thanks to a more effective

control of cracking and this, independently of the value of the modulus of elasticity (Lim and Oh., 1999). For the fibers to be effective in the hardened state, it is recommended to choose fibers that are longer than the size of the largest aggregate (Fariborz et al., 2006). An experimental program was conducted by (Ding et al., 2012); the objective was to study the influence of steel fibers and the combined effect of fibers and stirrups on beam deflection and cracking. This study also investigated the feasibility of applying Modified Compression Field Theory (MCFT) for the proper assessment of the combined load in fiber reinforced concrete and steel beams. The authors noted that the combined use of stirrups and steel fibers shows a significant positive composite effect on shear load capacity, energy absorption capacity and toughness of beams subjected to shear and stress bending. In addition, they proposed a new modified compression field theory equation for fiber-reinforced concrete in which cracked fiber-reinforced concrete is treated as a new material with its own stress-strain characteristics. Embedded steel fibers are dispersed in concrete to increase tensile behavior, impact strength and for better ductility (Abdallah et al., 2018a; Abdallah et al., 2018b; Adjrad et al., 2016; Tadepalli et al., 2013). Of these, the greatest benefit of including steel fibers in concrete is to achieve near-ductility behavior after cracking for an otherwise brittle material, so the steel fibers allow the concrete to continue to support the loads even after cracking, this phase is called post-cracking behavior (Slater et al., 2012) (Tadepalli et al., 2013). Another benefit of adding steel fibers, when evenly distributed throughout the concrete matrix, provides very effective crack control as there will always be fibers close to a micro crack, preventing the crack from developing propagate. On the other hand (Sorensen., 2014) presented the results of an investigation on the variations of the fiber content in the concrete unloaded from a ready-mixed truck at the construction site and its effect on the behavior of fiber-reinforced concrete. The type of steel fiber used in this study consists of fibers with hooked ends that have been commonly used around the world for decades. Based on the test results and observations, the authors concluded that adjustments in dosing procedures may be advised regarding steel fiber mixing routines.

It is in an attempt to answer all these questions that we have chosen to focus our research work on the study of the behavior of concrete beam elements reinforced by fiber chips from machining waste parts (Steel), randomly embedded in a matrix of concrete. The experiments on beams that we are carrying out aim to highlight the contribution of the recovered fibers in these two following phases: evolution of the mode of cracking in bending, as well as the effect of the variation of the percentage and the languor (according to the number of crimps) of the fibers on the strength and stiffness of the fiber material.

2. CHARACTERISTICS OF THE FIBERS USED IN THE STUDY

The steel fibers used in the study, are local fibers and come from the recovery; they come from the machining waste of steel parts "chips", recovered at the level of the national company of industrial vehicles in Algeria (SNVI). They have a rather undulating geometric shape; favoring their anchoring in the concrete, the shape of these fibers is shown in Figure 1.

The mechanical and geometrical properties of fibers used are given in Table 1, three lengths of fibers were used (4, 5 and 6 cm) with 3, 5 and 6 undulations (spirals) for each length, the various percentages in volume tested are given in Table 2, The experimental program consists of carrying out direct traction tests with controlled deformation. Three tests for each type of combination are carried out; the anchoring of the ends of the fibers in the clamping jaws of the hydraulic press is improved by a fiberglass resin (see Figure 2).



Figure 1. View of the chips



Figure 2. Anchoring system

Fibre type Chips	L_f (mm)	L_r (mm)	e_p (mm)	γ (kg/m ³)	σ_e (MPa)
	40- 50- 60	2	0.6	7883.33	1100

Table 1. Characteristics of mechanical properties of fibers under the study concrete

Volume fractions of fibers W (%)	Masses in (kg)
W= 0.6%	47.30
W= 0.8%	62.90

Table 2. Percentages of fibers incorporated

3. PROCEDURE FOR THE PREPARATION OF TEST SPECIMENS AND MIXING PROCEDURE

It was decided that only one concrete composition will be used, the specimens were designed and produced keeping the amounts of the ingredients exactly the same using ordinary Portland cementis of type CPJ-CEMII/B 42.5 R NA 442 of class 42.5 (Lafarge cement region of M'sila (LCM), Algeria), and the aggregates used come from the Tizi Ouzou region

(quarry rocks) their shape is crushed. The Dreux Gorisse experimental method was used for determined a composition of the concrete for 1m^3 . Table 3 summarizes the mixture proportions of all batches employed in this testing program. The granulometric curves for each type of aggregates are presented in Figure 3. The concrete mixture was made out in a rotary mixer, while respecting the following procedure of mixing scrupulously.

- Introduction of sand, the aggregate and cement, mixed during 60 seconds,
- introduction of the water, mixed during 40 seconds,
- introduction of the fluidifying, mixed for 30 seconds,
- For fiber concrete mixes; these are introduced last, in small quantities, with each addition, there is mixing for 20 seconds.

Ingredient	Amount (Kg/m ³)
aggregate (8/15)	880
aggregate (3/8)	218
Sand (0/3)	775
Portland cement CPJ CEMII/A 42.5 (c)	400
Water	195
fluidifying (0.5% of cement weight (ml))	2.00

Table 3. Optimized composition for 1m^3 of concrete

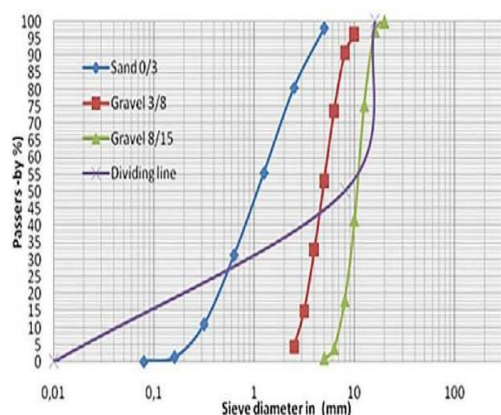


Figure 3. Particle Size Curve

4. EXPERIMENTAL PROCEDURE

4.1 Fiber characterization tests Experimental procedure

The chips are cut into three lengths (4, 5 and 6 cm) with 4, 6 and 3 spirals for each length. The number of tests carried out is 3 for each type of combination. The tests consist of carrying out direct tensile tests with controlled deformation.

4.2 Specimen geometry

The specimens used to carry out the 3-point bending tests are prismatic specimens $[10 \times 20 \times 120] \text{ cm}^3$ of width $l = 10 \text{ cm}$, height $h = 20 \text{ cm}$ and length $l = 120 \text{ cm}$. Three lengths of fibers used in this study after characterization of the mechanical and tear resistance, $L = 4 \text{ cm}$, $L = 5 \text{ cm}$ and $L = 6 \text{ cm}$ with 6 spirals (see Figure 4). The chipped fibers are randomly arranged in the cementitious matrix. A vibration of the mixture was carried out during casting. The prismatic molds used are shown in Figure 5.



Figure 4. Fiber lengths used



Figure 5. Prismatic molds used $[10 \times 20 \times 120] \text{ cm}^3$

5. METHODS

5.1 Fiber characterization tests

The tests are carried out on a hydraulic press with controlled deformation of the "Ibertest" type at the modeling laboratory for civil engineering materials and structures at the M.M. University of Tizi Ouzou in Algeria. The press is equipped with a digital control and command (see view given in Figure 6). The geometric characteristics are introduced automatically and the useful length of the fiber is 100 mm.



Figure 6. Test device view

5.2 Compression tests

The compression tests are carried out on an AUTOTEST brand hydraulic press with a capacity of 2000 KN (Figure 7), on cylindrical specimens of dimensions $[16 \times 32] \text{ cm}^2$ (Figure 8). The force and stress values are read directly on the screen of the machine and the displacements are measured using a comparator placed on the mobile plate of the press. For each step of loading, we record the values of the force and the corresponding deformation until the rupture of the specimen



Figure 7. Cylindrical test tubes



Figure 8. With hydraulic press

5.3 Bending tests (three-point bending)

Bending tests were carried out on prismatic specimens $[10 \times 20 \times 120] \text{ cm}^3$, on the test machine, for the three series of tests, for the two volume fractions of ($W = 0.6$ and 0.8%) and the control concrete. In total, 30 beams were implemented, for languor's $L=4 \text{ cm}$ (series 1), $L=50 \text{ cm}$ (series 2) and $L=60 \text{ cm}$ (series 3) with $n=6$ undulations.

Figures 9 and 10 illustrate the principle and static diagram of the 3-point bending test.



Figure 9. View of the "Ibertest" test device

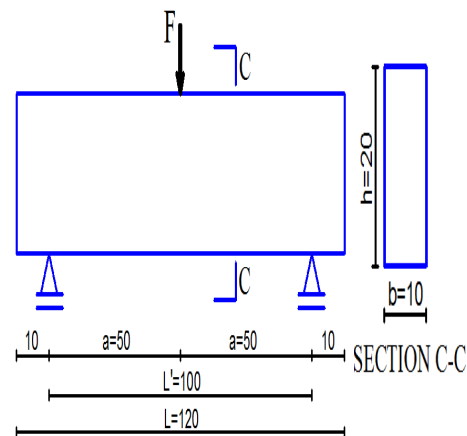


Figure 10. Static schema of the three-points bending test

6. Results and discussion

6.1 Tensile fiber characterization tests

We give in Figure 11 the superposition of the average stress-strain curves for the three lengths considered (4,5 and 6 cm) and for a number of undulations equal to 6 ($n=6$).

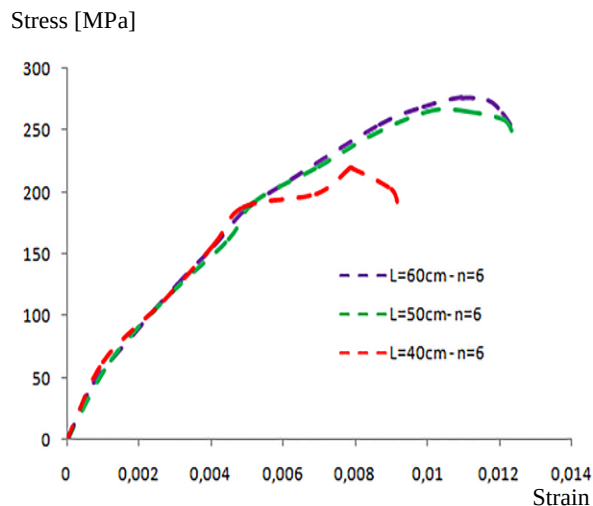


Figure 11. Average curve Stress- Strain

During the test, it is observed that the undulations of the fiber gradually open up until the fiber flattens. Beyond that, a ductile fracture of the steel is observed. The tensile strength increases as a function of the number of undulations: it reaches $R_m = 280 \text{ MPa}$ for a length $L=6 \text{ cm}$ with 6 undulations shown in Figure 12.



Figure 12. Fibers used $L=6 \text{ cm}$ with 6 undulations

6.2 Compression tests

The measured mechanical properties of the concrete used obtained for the various tests after crushing at 28 days are given in table 4.

Tests	Testing compression stress σ [MPa]	Young's modulus E [MPa]
Test 1	26.69	32.405
Test 2	25.42	29.205
Test 3	25.79	31.333
Average	25.97	30.98

Table 4. Mechanical properties of the concrete used

6.3 Bending tests (three-point bending)

6.3.1 First series of tests “series 1”

Figure 13 shows an example of the failure mode of beams reinforced with short fibers (chips) of length $L=4$ cm, $n=6$ (series 1) tested during bending tests.

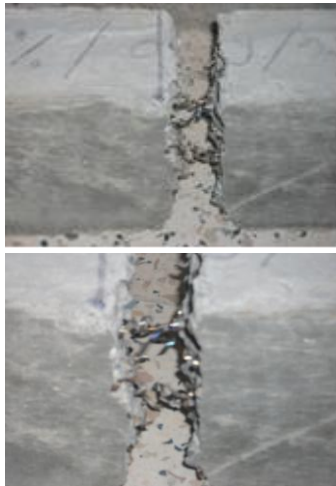


Figure 13. Example of failure mode of series 1 beams

Figure 14 shows the superposition of the average strength-deflection curves at mid-span of the beams with languor fibers $L=4$ cm, $n=6$ (series 1), for fiber contents $W = 0.6\%$, 0.8% and a BT control concrete ($W = 0\%$).

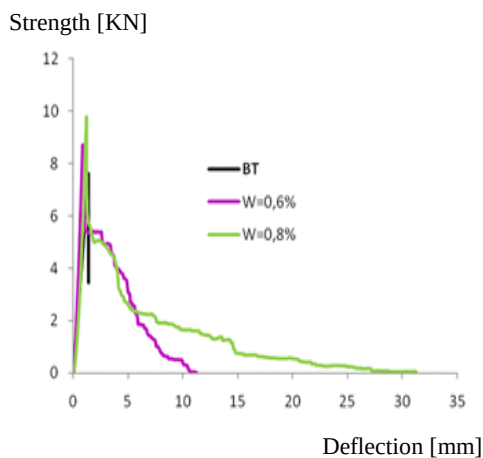


Figure 14. Superposition of strength-deflection curves for $L=4$ cm, $n=6$ undulations

6.3.2 Second series of tests “series 2”

Figure 15 shows an example of the failure mode of beams reinforced with short fibers (chips) of length $L=5$ cm, $n=6$ (series 2) tested during bending tests.



Figure 15. Example of failure mode of series 2 beams

Figure 16 shows the superposition of the average strength-deflection curves at mid-span of the beams with languor fibers $L=5$ cm, $n=6$ (series 2), for fiber contents $W = 0.6\%$, 0.8% and a BT control concrete ($W = 0\%$).

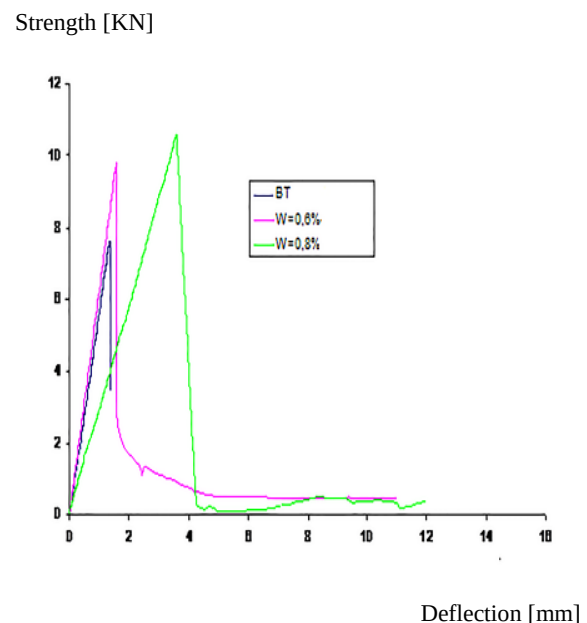


Figure 16. Superposition of Strength-deflection curves for $L=5$ cm, $n=6$ undulations

6.3.3 Third series of tests “series 3”

Figure 17 shows an example of the failure mode of beams reinforced with short fibers (chips) of length $L=6$ cm, $n=6$ (series 3) tested during bending tests.



Figure 17. Example of failure mode of series 3 beams

Figure 18 shows the superposition of the average strength-deflection curves at mid-span of the beams with langur fibers $L=6$ cm, $n=6$ (series 3), for fiber contents $W = 0.6\%$, 0.8% and a BT control concrete ($W = 0\%$).

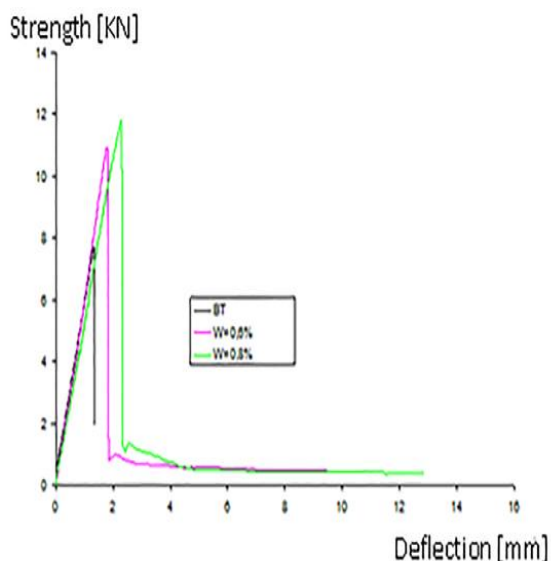


Figure 18. Superposition of strength-deflection curves for $L=6$ cm, $n=6$ undulations

The results obtained by three series of bending tests after superposition (Figure 16, Figure 17 and Figure 18), show that

the strength and bending stiffness of beams with a fiber content $W = 0.8\%$ are better than in the case of beams with a content $W = 0.6\%$ as well as the beams without BT fibers ($W = 0\%$), for the three series of tests.

These results also show that the addition of fibers gives the material significant ductility compared to the control concrete (without fibers).

On the other hand, the behavior in bending of the fiber-reinforced concrete for the three series of tests is characterized by the presence of two (2) phases.

A linear phase corresponding to a quasi-elastic behavior of the material, it is the phase of pre cracking of the concrete.

This phase ends with macro-cracking.

A second phase in which there is a sudden drop in the bearing capacity of the material (without a sudden break in the beam): this is the post-cracking phase, which stabilizes when the fibers are put under tension; thus providing post-cracking ductility. In this phase, the concrete matrix breaks and the edges of the cracks are connected by the fibers (see Figures 13, 15 and 17); avoiding a sudden break.

According to these figures, there was a very clear opening of the bending crack, where the fibers are under tension. Comparatively, failure occurs faster in the case of the control concrete.

These results in Figure 14 also showed that the breaking strength of beams with $W = 0.8\%$ fiber content: $F_r = 9.98$ KN, is increased by about 30.28% compared to beams without fibers (BT, $F_r = 7.66$ KN).

In contrast, deformation (deflection) at mid-span is increased by approximately 61.48%.

The results in Figure 16 also showed that the breaking strength of beams with $W = 0.8\%$ fiber content: $F_r = 10.59$ KN, is increased by about 38.25% compared to beams without fibers (BT, $F_r = 7.66$ KN).

On the other hand, the deformation (deflection) at mid-span is increased considerably (3 times) compared to the BT control concrete (without fibers) it is of the order of 88.32%. This can be explained by the large number of fibers crossing the rupture zone of the beams tested (see Figure 15).

The results in Figure 18 also showed that the breaking strength of beams with $W = 0.8\%$ fiber content: $F_r = 11.83$ KN, is increased by about 54.43% compared to beams without fibers (BT, $F_r = 7.66$ KN).

On the other hand the deformation (arrow) at mid-spans doubled. This can be explained by the large number of fibers crossing the rupture zone of the beams tested (see Figure 17).

Table 5 summarizes the forces (loads) at break in bending of the beams tested for the three series of tests and for the control concrete (without fibers), as well as for the two fiber contents ($W=0.6\%$ and $W=0.8\%$).

Fiber content W(%)	BT (W=0%)	W=0.6%	W=0.8%
Series 1			
Strength at break [KN]	7.66	8.70	9.98
Series 2			
Strength at break [KN]	7.66	9.80	10.59
Series 2			
Strength at break [KN]	7.66	10.93	11.83

Table 5. Strength at break in bending of the beams tested

7. CONCLUSIONS

This experimental study was conducted with the aim of grasping and understanding the impact or the effect that the introduction of corrugated spiral fibers from the machining waste of steel parts "chips" of different lengths $L = 3.5$ and 6 cm, randomly dispersed in the cementitious matrix on the bending behavior of concrete beams.

The tests carried out to characterize the mechanical behavior of the fibers have made it possible to highlight the influence of the length of the fibers and the number of undulations on their tensile strength.

It appears that the best resistance is reached for a length of 6 cm with 6 undulations.

The length of fiber $L=6$ cm with 6 undulations improves better than the fibers $L=4$ and 5 cm the resistance and the rigidity in bending of the elements of beam and confers a significant ductility.

This improvement is significant for a fiber content of $W = 0.8\%$.

The increase in the breaking load is about 30.28% ($F_r = 9.98$ KN) greater than the beams without fibers (BT; $F_r = 7.66$ KN), for a length of fibers $L=4$ cm (series 1).

Deformation (deflection) at mid-span is increased by approximately 61.48% .

The breaking load is about 38.25% ($F_r = 10.59$ KN) higher than the beams without fibers (BT; $F_r = 7.66$ KN), for a length of fibers $L=5$ cm (series 2). The deformation (deviation) at mid-span is increased considerably (3 times) compared to the BT control concrete (without fibers) it is of the order of 88.32% .

On the other hand, the breaking load is about 54.43% ($F_r = 11.83$ KN) higher than the beams without fibers (BT; $F_r = 7.66$ KN), for a length of fibers $L=6$ cm (series 3).

The deformation (deviation) at mid-span doubled: this is explained by the large number of fibers crossing the rupture zone of the beams tested (see figures 13, 15 and 17).

On the other hand, the flexural behavior of fiber concrete is characterized by the presence of two (2) phases.

A linear scene: corresponding to a quasi-elastic behavior of the material. A second phase in which there is a sudden drop in the

bearing capacity of the material (without a sudden break in the beam), from which ductile breaks are obtained instead of brittle ones.

This experimental study also allowed us to conclude: that the fibers of recovery resulting from waste of parts machined out of steel "chips" can be used like reinforcements for elements of beam subjected to the inflection.

Their uses are also interesting for the repair of floors, concrete pavements and road surfaces, and they can also increase the fire resistance of reinforced concrete; limit the opening of cracks.

The presence of fiber-reinforced concrete on the surface makes it possible to protect the traditional reinforcing bars against thermal radiation and other external aggressions.

In perspective, it would be interesting to conduct tests on beams of greater and real-life length, increase the number of fibers used in thin elements, and also associate these fibers with traditional reinforcements.

It would also be interesting to carry out tests with flat fibers instead of corrugated fibers in order to reduce the voids (cavities) in the cement paste.

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