

Feasibility of using fibrous waste in cement-based material

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Abstract. The use of fibers into cement-based materials has been studied extensively and as a result of this research and development, a wide range of fibers is now available to be used in cementitious materials. However, little work has been done on the addition of fibrous waste to the cement, mortar and concretes to investigate this by-product fiber as reinforcing material due the absence of industrialized fibers in many countries.

The main aim of this experimental study is to investigate the suitability of using fibrous waste as a reinforcing material for cement-based materials. Presentation of such fibrous waste is presented in this paper. The influence of type and content of fibrous waste is evaluated. The results obtained, from series of trials, shown that some physical and mechanical properties of the fibrous waste's composite material are improved

1. Introduction

The application of composite materials in engineering field is growing rapidly. Most of the technical activity or objects produced for everyday life where composites are based on composites materials. Fibre reinforced cement matrices, which contains concretes and mortars reinforced with short fibres, are perhaps the most important group of modern materials applied since 1940's in various fields [1] from building construction up to concrete layers on runways and highways.

The mechanism of reinforcement of concrete by fibres consists of distributing short fibres regularly in the concrete matrix. This network of fibres opposes, as much as it is denser, to the widening of the crack and acts as crack arrestors by producing a pinching force which tend to make its propagation slower and causes transfer of stress across cracked sections allowing the affected parts of the composite to retain some post-crack strength and to withstand deformations much greater than what can be sustained by the matrix alone.

Many studies [2, 3,4] reported that the influence of fibres on the composite behaviour of elements subjected to loading is complex. In the limit of elastic deformation the fibres are not active and their role may derive from the law of mixtures [5]. When the micro-cracks are open, the fibres act as crack-arrestors and control their propagation. The total strength is increased due to the fibre contribution. The load corresponding to the first crack is slightly increased, but the main effect is a considerable increase in deformability and in the amount of energy of the external load.

Although, the use of different types at different amount of fibres in cement, mortar and concrete, are reported in many reviews and reports [6], limited study has been conducted on fibre reinforced cementitious materials using industrial waste fibres. Therefore, little information is available about the use of this kind of fibres as reinforcing materials.



In developing countries, the available of different categories of fibres in market is considerable expensive or sometimes inexistent. To eliminate this lack of availability of fibres at reasonable prices, fibrous waste is used to reinforce cement based-materials. Furthermore, with increase in population and industrial activities, the quantity of fibres waste generated from various industries will increase manifold in the coming years. So that, these industrial waste can be effectively be used for making good-strength and low cost fibre reinforced materials after exploring their feasibility. Otherwise this fibrous waste can be representing a danger to the environment and mankind by leaving it the industrial areas, especially in the absence of clear policy for the successful management of industrial waste.

This investigation is an attempt to study the feasibility of using two kinds of locally available industrial fibrous waste for making fibre reinforced cementitious materials (mortar and concrete). The types of fibrous waste considered in this study include: steel fibrous waste and polypropylene fibrous waste are obtained from machining waste of steel part “chips” and polypropylene factories respectively

2. Proposed approach

Due to the absence of a fibres industry in Algeria, and consequently the possibility of the integration of such fibrous waste as material of reinforcement for the cement-based matrices, our reflection was oriented to the valorisation of local steel and polypropylene fibrous waste (figures 1 and 2) which are the most plentiful are susceptible to be integrated as material for strengthening the cement-based composites. This approach contributes effectively on one hand to the cleanup of the environment and on the other hand, to the reduction of cost of composite, while respecting the mechanical performances needed by the fibres addition.

In this context, this experimental study was carried out in order to get a rational exploitation of this industrial waste generally available in steel workshops, local lathes and steel transformation units. For this purposes of this study, two types of fibrous waste (steel and polypropylene) were used while a manufactured and commercialised fibres were used for comparison purposes.



Figure 1. Steel fibrous waste before mechanical treatment.

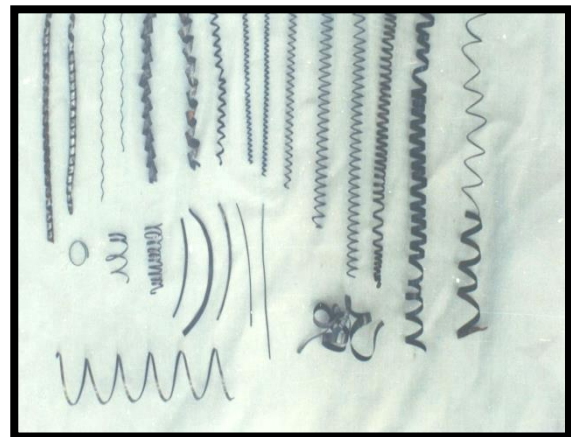


Figure 2. Different shapes of steel fibrous

3. Geometrical characteristics of steel fibrous waste

To study the concrete properties in the fresh and in the hardened state, steel fibrous waste was used in cementitious materials. A preliminary study was made to have a general idea on the proportions of the existing forms in a sample of fibrous waste, taken randomly. This statistical study aims to show the proportion of every existing shape. The table below gives the results and show that 38.45 % of fibrous waste is curved in shape.

4. Materials and experimental procedure

4.1. Materials

4.1.1. Cement. The cement used was type CPJ 45 (Cement Portland with Additive). This cement was chosen because of its wide availability and largely used in the concrete construction sector in Algeria. Its density is 3.1, and its Blaine's specific surface area is 3600 cm²/g. Their chemical and mineralogical compositions are given in table 2 and 2 respectively.

4.1.2. Dune Sand (Fine Aggregate). The sand's equivalent measured by the NF P18 standard [7] shows that the dune sand used in this experimental study is clean, siliceous and contains very few fine dust or clay elements. The specific gravity and fineness modulus calculated was respectively 2.64 and 1.73.

4.1.3. Crushed Gravel (Coarse Aggregates). Crushed gravel is obtained by crushing limestone rock from the quarry; two fractions 3/8 mm and 8/15 mm of coarse aggregates have been used in this experimental study. The specific gravity was 2.54.

4.1.4. Fibrous waste (Fibres). Different types of waste fibers from different industries, namely, lathe industry, wire winding, wire drawing industries, steel transformation industrial unit were collected and used in this investigation after mechanical treatment (pressing, cutting to small fibrous pieces). They have approximately 1.5 mm in diameter, 20÷50 mm in length and with an average specific gravity of 7.5, while the polypropylene fibrous waste were collected from textile industries, with cut lengths varying from 2cm to 5 cm and a specific gravity of 0.90-0.91.

Table 1. Average proportion of every existing shape






Shape	Straight	Plate-shaped	Drawn	Corrugated shape	Curved-shape	Arbitrary shape
						
Proportion %	5.97	16.40	2.69	27.75	38.45	8.74

Table 2. Chemical composition (%. by weight) of CPJ

Constituent, %	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Ca O	Mg O	Ca O free	SO ₃	P.F	Insoluble
CPJ 45	19.48	5.06	3.72	61.95	0.85	1.63	1.1	3.44	1.26

Table 3. Mineralogical composition (%) for the cement used (according to BOGUE potential)

Compounds,	C ₄ AF	CSH ₂	C ₃ A	C ₃ S	BC ₂ S	C (Free)
CPJ 45	11.31	2.37	7.12	55.03	14.64	1.63

4.1.5. Admixture. The admixture product used in our research (less than 1%) is a super-plasticizer manufactured by the Algerian Granitex Company. This super-plasticizer, named "Medafluid SFA", has a density of 1.2; a content of dry matter of 36.16 % and a PH of the order of 7.

5. SPECIMEN PREPARATION AND CONDITIONNING

5.1. Mixing, Casting and Curing

Three concrete series of trials were carried out to investigate the suitability of fibrous waste as a reinforcing material for normal concrete. The first one concerns the concrete control in which the various parameters were illustrated in the table 4.

Twenty four test specimens of control concrete were made to choose a composition which gives the best results in order to estimate the benefits brought by the fibrous waste on the compressive strength.

Table 4. Different parameters of control concrete

W/C	S/G	Slump(cm)	Air content (%)
0.5	0.51	6	1.75
0.5	0.49	6	1.6
0.57	0.70	6	1.78
0.5	0.76	6	1.65

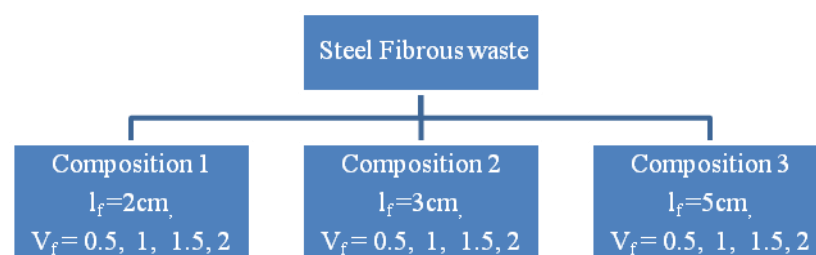


Figure 3. Flowcharts of the

The second series consists in estimating the addition of steel fibrous waste in the concrete made from local materials according to the experimental programme shown in Fig.3, while the third series concerns the addition of commercialized fibres marketed in this concrete. Twenty four test specimens were also made for every composition

A total of twenty four plains for control and seventy two steel fibrous waste reinforced mixes were prepared. Materials were mixed in a linear-cum-flow mixer type 'O' which had a capacity of 0.043 cubic metres and a power driven rotating pan and paddle. This mixer was sturdy enough for fibrous mixes, and a good uniformity of fibrous waste distribution could be achieved. The mixer was first loaded with the coarse aggregate and a portion of the mixing water; after starting the mixer; sand, cement and the rest of water were added and mixed for 5 min. The fibres, in the case of fibrous mixes, were added following the addition of all mix ingredients.

Six 16×32 mm cylinders were cast from each mix. They were cast in cylindrical steel moulds and compacted on a vibrating table. Specimens were placed under plastic sheet membrane for 24 hours in an ambient temperature. Following removal from the moulds, they were individually sealed in plastic bags and stored at room maintained at 24°C and 65% relative humidity until testing at an age of 28 days for compressive.

5.2. Compressive tests

Compressive strength test was carried out according to NF.P.18-406 [8], in a testing machine of 3000KN at a loading rate of 0.5 KN/S. The different values of the compressive strength of concrete at 28 days are depicted in Figures 4a, 4b and 4c. The results show that addition of steel fibrous volume waste in the ratios of 0.5, 1, 1.5, 2 by volume in the concrete will increase the compressive strength at

different percentages. It is seen that the use of steel fibrous waste significantly increased the compressive strength of the normal concrete made of local materials by using an admixture.

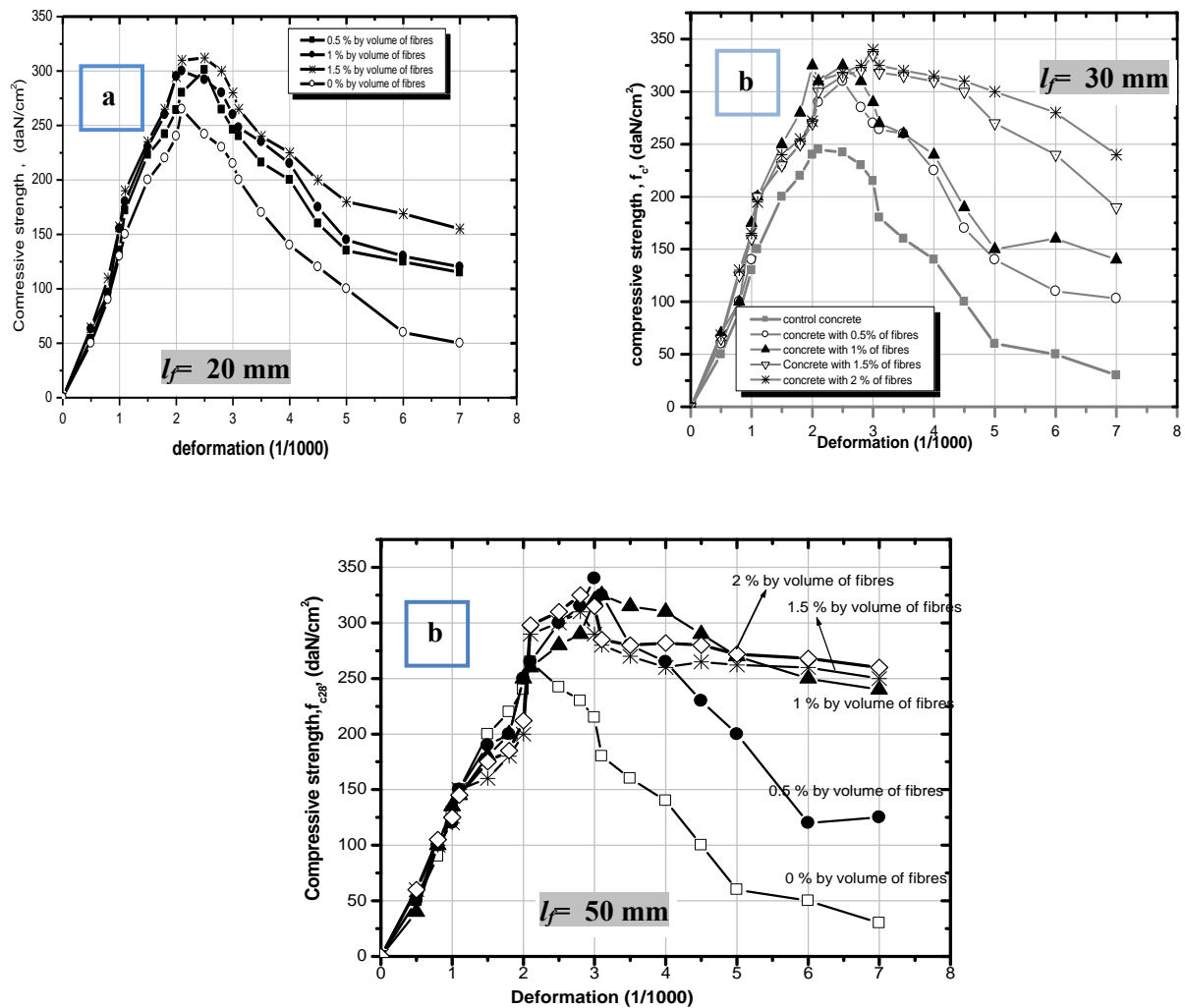


Figure 4. Relationship between compressive strength and deformation of steel fibrous waste reinforced concrete

5.2.1. Effect of steel fibrous waste content on compressive strength. The curves obtained for long steel fibrous waste ($l_f = 50$ mm) and for short steel fibrous waste ($l_f = 20$ mm, $l_f = 30$ mm) are shown Figures 4a, 4b and 4c, which three distinct phases are appeared 5.

5.2.2. The first phase corresponds to an elastic behaviour of fibre concrete. In this part, the addition of the fibres does not bring any significant modification either in terms of the shape of the curve or in terms of modulus of elasticity. In other words, the modulus of elasticity is not modified and this irrespective of the quantity of fibres introduced into the concrete.

The explanation given for this is that the fibres are not added to improve the concrete resistance; but to affect the behaviour of the material once the matrix is cracked and thus control the cracking of steel fibrous waste concrete. This is possible due the sewing effect created by the fibres through the

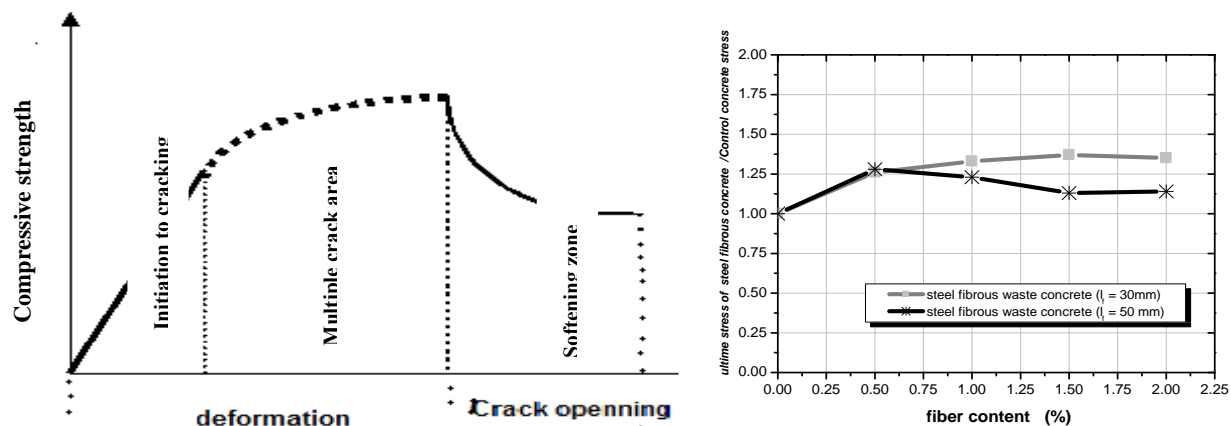


Figure 6. Rate of increase in% of the ultimate stress for $l_f=50\text{mm}$, $l_f=30\text{mm}$

cracks. This effect improves the energy absorption capacity of the material. During this relatively short phase, there is a rapid progression of the deformation due to propagation of the pre-existing defects in the matrix.

In the second phase which occurs immediately after the cracking of the matrix, the fibres contribute not only to the improvement of the ductility of the concrete material but also to a significant increase in the strength of the composite. This increase in stress is associated with the appearance of multiple cracking through the specimen, which requires a greater energy input to open the micro-cracks. Once the rupture is reached, the third phase begins with a rapid propagation of the cracks, the stress decreases until the total break of the specimen.

It is noted that, in the second phase, a marked improvement in the ductility of the concrete is observed for the different quantities of fibres introduced. Figure 6 shows that with 0.5% fibre volume, a 25% increase in the ultimate fibre concrete stress is reached for both lengths ($l_f = 30\text{ mm}$, $l_f = 50\text{ mm}$), 0.5% volume, the continuous increase for both fibres in a different way.

For fibres of length, $l_f = 30\text{ mm}$, the increase is 32.6% with the fibre addition of 1% by volume, 36.7% with the addition of 1.5% volume of waste fibres. This increase remains within about 36% with the addition of 2% volume of waste fibre. With long fibres ($l_f = 50\text{mm}$), this increase is 28% with the addition of 0.5% fibre in volume, 22.6% with the addition of 1% fiber volume. These percentages of the increase are decreased towards 13.2% with the addition of 1.5%.

The addition of a percentage greater than 2.5% of fibre volume creates a problem of maneuverability of waste fibre concrete and implicitly a problem of the implementation. For this reason, every precaution must be taken when adding quantities exceeding 2.5% fibre volume with $l_f \geq 50\text{mm}$. It will be noted that the rates of increase of the ultimate compressive strength of the waste fibre concrete are shown in Figs 7a, 7b and 7c for $l_f = 2\text{cm}$, 3cm and 5cm respectively.

It can be said that the presence of fibres derived from the fibrous waste brings a gain to the rupture strength of concrete reinforced with waste fibres. This gain, which depends on the concentration and the geometry of the fibres, reaches a maximum value of 25% for a length of 20 mm with a concentration of 2% by volume, 37% for fibres of 30 mm length with a concentration of 2% volume and a value of 28.8% for fibres of length 50 mm with a concentration of 0.5% of volume. This means that the longest fibres have the lowest efficiency. In other words, with a length of 50 mm and a concentration of 2% of volume, the gain recorded does not exceed 13.25%.

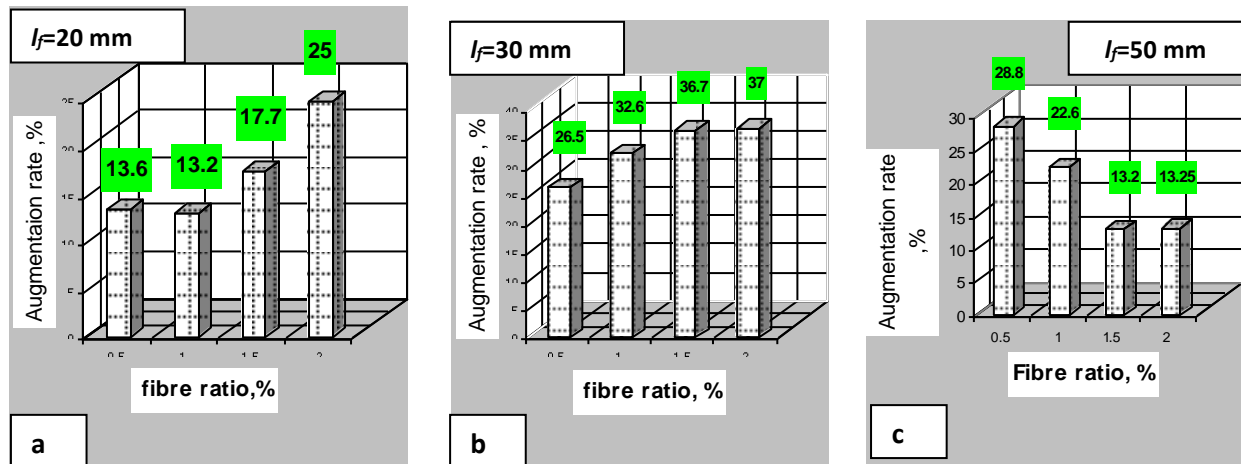


Figure 7. Augmentation rate in compressive strength

5.2.3. Influence of fibrous length on the compressive strength Influence of fibre length. By comparing the results obtained with the fibre length of 20 mm, 30 mm and 50 mm, it can be seen that the parameter (fibre length) is of great influence on the behaviour of the concrete subjected to compression.

Curve 8 shows the tests prepared with waste fibres of length 20, 30 and 50 mm with a volume concentration of 0.5, 1 and 1.5%. It shows that the length of fibre affects the behaviour of concrete in compression. The breaking strength increases with the length of the fibres.

Table 5 presents the results obtained with the three lengths used in our work. It will be noted here that the deformation corresponding to the maximum resistance increases by 19% for $l_f = 30$ mm, more than 42% for fibres of length $l_f = 50$ mm whereas for $l_f = 20$ mm no increase was observed.

To explain this, it must be said that the addition of fibres, in general, and waste fibres in particular modifies the behaviour of concrete in the fresh state (decreased of workability, increase in air content, etc.) and a modification of the microstructure of the concrete in the cured state. Thus, the addition of a high percentage of fibre will increase the stiffness of the solid phase. This will lead to contacts and clutter reactions which increase the workability time, which translates into a slowing down of the flow of the fresh concrete. In this case, there are two cases: either sufficient energy is used to be able to distribute all the fibres in the matrix with an excess of vibration or in this case an increase in the ultimate compressive strength will be obtained. Either the same operating conditions as the control concrete are used, or in this case a slight decrease in the ultimate compressive strength will be observed, as several researchers have reported [9,10].

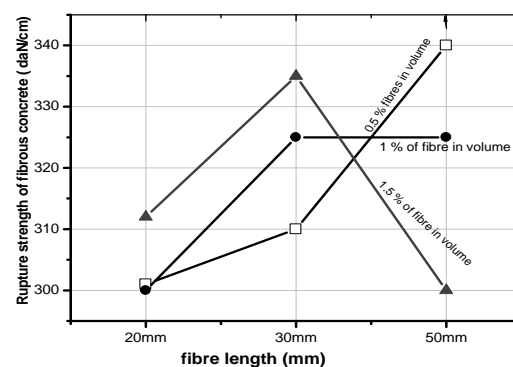


Figure 8. Effet de la longueur de fibres sur la résistance de rupture de béton de fibres

Table 5. Some results of steel fibrous waste concrete

	Fiber length								
	$l_f = 20 \text{ mm}$			$l_f = 30 \text{ mm}$			$l_f = 50 \text{ mm}$		
Fibre content %	0.5	1	1.5	0.5	1	1.5	0.5	1	1.5
Slump (cm)	7	6	4	6	4	3	6	3	1.5
air content (%)	5.4	5.1	5	5.1	4.8	4.6	4.9	4.8	3.5
Rupture strength (daN/cm ²)	301	300	312	310	325	335	340	325	300
Corresponding deformation $\times 10^{-3}$	2.5	2.1	2.5	2.5	2.5	3	3	3.1	2.5

6. Shrinkage of mortar by using fibrous waste

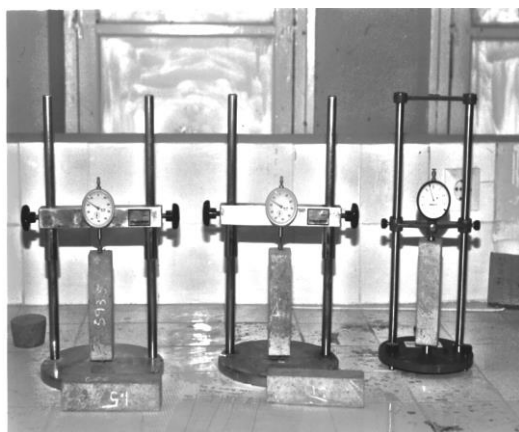
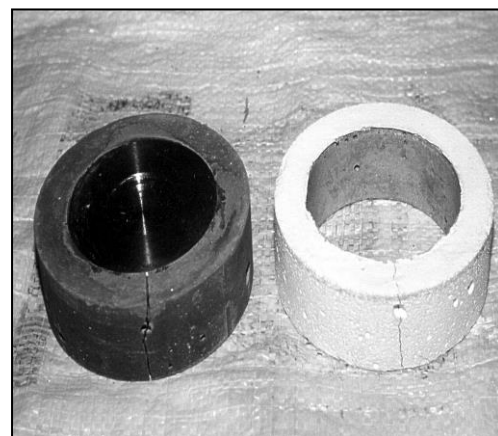
6.1. Materials and procedure

The main aim of this part of the study is to evaluate the influence of the fibrous waste used (metallic and polypropylene) on the phenomenon of cracking caused by shrinkage in a mortar prepared from sand of dune (important shrinkage). The method described in this part to evaluate the restrained shrinkage consists in using a rigid ring made of steel that is coated of mortar. After hardening the sample is submitted to conditions wanted to evaluate the effect of restrained shrinkage. In a given moment, the resistance to the cracking, the number of cracks and the total maximal widths, are measured and compared to what obtained with a plain mortar.

The free shrinkage tests were carried out on prismatic test specimens of dimension (4×4×16 cm) whose Plexiglas plates were fixed. To improve the contact mortar-plates, the latter have been perforated (in the middle) and studs were fixed. On the first stud (the upper end) will come to butt a comparator, the second (lower end) will be arranged on other plate glued to a motionless frame and ensuring a free rotation of the test specimen submitted for testing (Figure 9). The precision of our measurement comparator is 0.01 mm.

The restrained shrinkage has been evaluated by the test with the ring which consists in using a steel ring (Figure 10) of thickness 8mm, external diameter 143mm, internal diameter 127 mm and height of 44 mm, while cementing material ring has an external diameter of 127mm, internal diameter of 83 mm; and 44 mm height and 22 mm thickness (Figure 10).

The casting in two layers in this circular mould is carried using a steel shaft. Three rings were made for each test. The specimens prepared were cured at 20°C during 24 ±1hour in a wet condition. The apparatus allows a release from the mould and an easy cure of the test specimens.

**Figure 9.** Free shrinkage measuring apparatus**Figure 10.** Mortar ring under (black) and after test (white)

Those specimens submitted for testing with the ring were cured during 24 hours, and then they were placed in an environment similar to that of free shrinkage until the formation of cracks. For better viewing of the cracks and the microscopic cracks propagation, the test specimen submitted for testing with the ring were covered by a white painting.

Cementitious mortar was employed for these tests using superplasticizer admixture to maintain a constant workability, without varying the quantity of mixing water among the various mixes. Materials used in the tests to evaluate the free and restrained shrinkage are : Sand of dune grade 0/5 ; Cement CPJ45; Mortar of fraction 1/3 (C:S = 1:3)E : C = 0.58 (to have a constant and normal workability), Fibres : (fibrous waste of metal and polypropylene), Superplasticizer : 1 %

6.2. Results and discussions

6.2.1. Free Shrinkage.

The average curves of the shrinkage according to the time (days) are presented on figures 11a and 11b. It is noticed, according to the figures 11a and 11b, that the steel fibrous waste decreases the shrinkage. This reduction is about 16 % compared to a mortar without fibres at 28 days, for a proportion of 0.5 % of volume of fibres. But, with 1% of volume of fibres, this reduction is ranged from 11 to 13 %. Regarding the experimental tests results, we have noted the maximum percentage of fibres to reduce the effect of shrinkage is 1.5 %, beyond this percentage of volume of fibres; the presence of fibres in a mortar is not significant.

These results confirm those already obtained from former studies [11] by using fibres marked under various types, to know that deformations of shrinkage are generally smaller for the fiber reinforced mortars compared to those of the mortar without fibres. This reduction is affected by several parameters like the duration of drying, the shape and the quantity of fibres. The loss of weight of the test specimens was checked. The results are illustrated in figure 11c. It is noted that the loss in weight is more significant for the fibre mortars than for the mortar without fibres. The presence of dispersed fibres increases the size of pores in material as well as volume and decreasing, thus, intensity of the capillary pressures by facilitating the evaporation of water. On the other hand, according to the experimental tests, the use of fibrous polypropylene waste, with percentage higher than 1% in volume of fibres, do not give any improvement to the free shrinkage of mortar. This result confirms those obtained by other researchers [12, 13, 14]. It is noted, according to figure 8, that there is an increase in the shrinkage of approximately 20% for a content of 1 % in volume of fibres. But this increase reaches the 30 % for a content of 1.5% in volume of fibres. The increase in the free shrinkage of mortar reinforced with polypropylene fibres may be explained by the fact that these fibres are thin, very flexible and generally coated by layers of fines which causes the increase in free shrinkage by increasing the percentage of fibres.

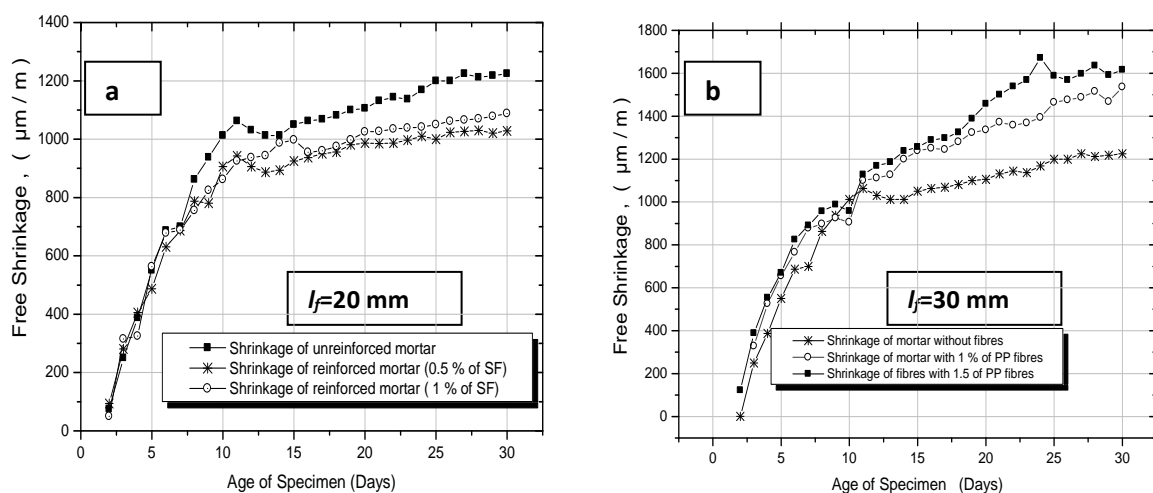


Figure 11a, b. Free shrinkage of mortar without and with fibrous waste

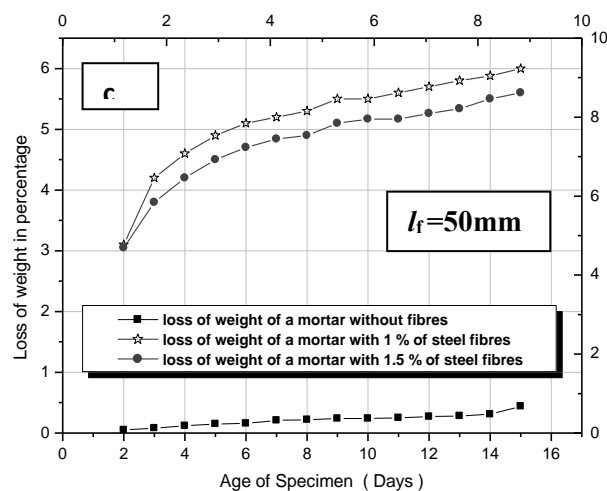


Figure 11c. % loss weight of mortar without and with fibrous

6.2.2. Restrained shrinkage

The second part of the experiment programme was oriented towards the study of the effect caused by the introduction of fibre content on the cracking tendency of the mortar. The mixes of mortar were prepared with constant workability by using a superplasticizer in order to have always the same quantity of mixing water, and therefore the same water/cement ratio.

Cracking resistance of mortar was evaluated by the ring test. It was evaluated by the number of days and the thickness of the crack. Figures 12 and 13 give an idea on the effect of the fibre addition in a cementing matrix like that of a mortar. In all the cases we observed a formation of macro-cracks with thickness varies between 0.6 to 0.8 mm. Also, two deep macro-cracks on the fourth day have been remarked as seen in Figure 10. But with 0.5 % of steel fibres, microscopic cracks have been observed (seen with a magnifying glass) after 9 days. Whereas with a content of 1 % of steel fibres the appearance of the microscopic cracks was not observed at early age less more than two weeks. By adding 1.5 % of steel fibres many microscopic cracks have been appeared after more than 4 weeks. The appeared cracks are very thick (less than 0.1mm) and less deeper.

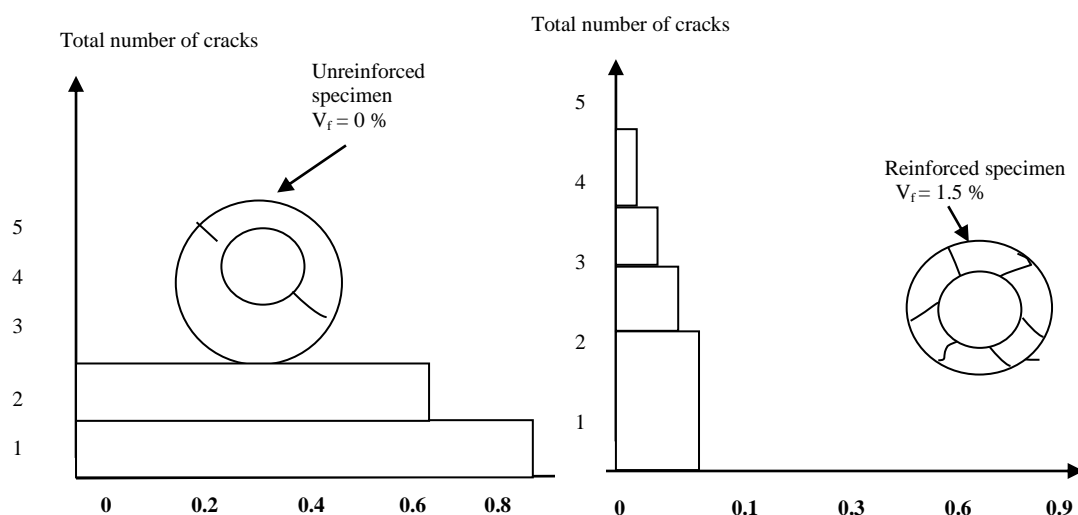


Figure 12. Results of the tests showing the number and the thickness of the cracks of a mortar without (left) and with (right) fibrous waste.

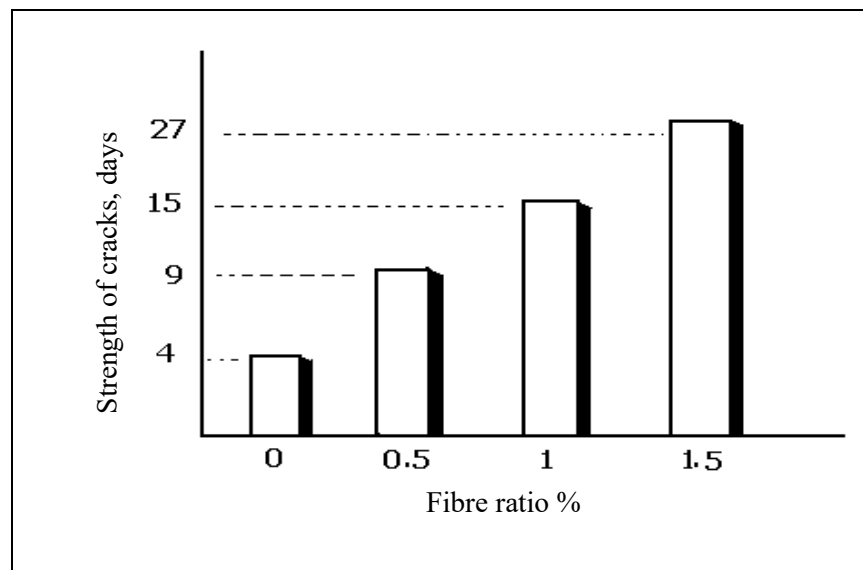


Figure 13. Typical example from the tests showing the strength of cracks,

With the same mixture of mortar, specimens were prepared by adding polypropylene fibres. It is announced here that the tests of restrained shrinkage (ring tests) were carried out by using percentages of fibres of 0.5 and 1 %. The observation from the test series confirm that the microscopic cracks in this kind of shrinkage did not appear before 4 weeks. This fact confirm also the results of a recent research[11] which shows that the introduction of a fibre content equal or higher than 1 % make in evidence that cracking processes is completely illuminated. The results obtained are illustrated in the table 6.

Table 6. Effect of polypropylene fibrous waste on restrained shrinkage with constant workability

N° of mix	Cement	sand	Water	Admixture %	Fibres	Cracking strength (days)
M01EP	1	2	0.5	1	0 %	Micro-cracks on 4 days
M02EP	1	2	0.5	1.25	0.5%	No cracks after 35 days
M03EP	1	2	0.5	1.75	1 %	No cracks after 56 days

7. Conclusion

Steel fibres are commonly used in cement-based materials to improve their mechanical properties. But; little information is available on the use of fibrous waste to reinforced cementitious materials.

The main conclusions drawn from this experimental work are:

- It is possible to use steel and polypropylene fibrous waste as a reinforcing element in the concrete to improve some mechanical properties on the one hand, and of developing fibrous waste on the other hand which is, in the majority of the cases, thrown in the urban zones leading to an environmental and human damage.
- Compressive and shrinkage tests were performed on the concrete and mortar specimens with and without those fibrous waste inclusions and the testing results were reported and compared. From this study, it was found that the compressive strength and both free and restrained shrinkage were improved with fibrous waste addition. This means that the benefit brought by this kind of fibrous waste was not only to remove this kind of waste but also to have great potentials to become a cost-effective resource and provide performance enhancement for concrete material in building industry where the use of these fibrous wastes is possible and can brought enough strength to the mechanical properties.
- In addition to the improvement in compressive strength and shrinkage phenomena; greater deformation ability was observed for concrete and mortar reinforced by these fibrous waste.

- Unlike many researches in the field of fiber reinforced concrete, which resulted in a compressive strength decrease, this experimental research carried out by using steel and polypropylene fibrous waste leads to an improvement in both compressive strength and shrinkage phenomena. However, this conclusion is based on a limited number of test specimens; further research is being done with more testing specimens and dosage rates to confirm these benefits.

References

- [1] Beddar, M, 2002, Steel fibre reinforced concrete: Past, Present and Future . *Technical report*, National Project, pp 9
- [2] Fattuhi, N, I, April 1974 Properties of steel fibre reinforced cement- based matrices Thesis submitted to the university of shellfield for degree of *M.Eng* pp 357.
- [3] Alghamdh, M, 1984 , Effect of matrix composition on SFRC properties, *PhD thesis* submitted to the university of Michigan, U.S.A, pp 276.
- [4] Hughes, B.P et al, sept 76, The workability of steel reinforced concrete *Magazine of concrete* Vol **28**, N° 96 , pp 157-61 .
- [5] Brandt, A.M, 1995, Cement –based Composites: materials, Mechanical properties and performance. E & FN Spon, London, pp 470.
- [6] Beddar, M. April 2004 Fibre reinforced Concrete : Past, Present and Futur *Concrete magazine*, Vol **38**, N° 4, U.K
- [7] AFNOR N.F.P. 18-301, dec 1982, Granulats naturels pour le béton hydraulique,
- [8] AFNOR N.F.P. 18-406, dec 1981, Essai de compression,
- [9] Dardare, J. Contribution à l'étude du comportement mécanique des bétons renforcés avec des fibres de polypropylène *RILEM Neville (A)*, 120, communication 5.2, pp.227-235.
- [10] Gopalaratnan, V.S.; Shah, S.P, May-June 1985 , Softening Response of plain concrete in Direct Tension. *ACI Journal*, Vol. **82**, N° 3, pp 310-323
- [11] Mesbah, H.A; Buyle, B. and Siwak, J.M, 1996 , Influence de l'ajout des fibres sur le retrait des mortiers a base de granulats recycles. 2^e *Colloque International Francophone sur les bétons renforcés de fibres métalliques*, Toulouse, pp163-172.
- [12] Edington, J.; Hannant, D. J; Williams.R.I.T. 1974. Steel Fibre Reinforced Concrete; G.B.Building . *Res.EST-Current paper*, c.p.69/74
- [13] Elhachem , M. , 1990 . Etude de l'influence de la fibre de fonte sur le retrait et le fluage du béton.*Thèse de Doctorat*, Ecole Centrale, Paris.
- [14] Houari , H. , 1993 Contribution à l'étude du comportement du béton renforcé de fibres soumis à l'action des charges maintenues et cycliques. *Thèse de Doctorat*, INSA Lyon,