Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2018, Volume 9, Issue 8, Page 2304-2314

http://www.jmaterenvironsci.com

Comparative Study of Cement Mortar Reinforced with Vegetable Fibers Alfa, Date Palm and Diss: Mechanical Properties and Shrinkage

M. Boutarfa[1], R. Belouettar[1], A. Makradi[2]

1 civil engineering laboratory, BadjiMokhtar University, postal box 12, Annaba 23000 Algeria.
2 Luxembourg Institute of Science and Technology (LIST), Esch Luxembourg.

Received 06 Dec 2017,
Revised 21 Feb 2018,
Accepted 27 Feb 2018,

Keywords
- ✓ Mortar,
- ✓ Vegetable fibers,
- ✓ Mechanical properties,
- ✓ Shrinkage.

boutarfa_meriem@hotmail.fr;
Phone: +213662458244;

Abstract

Materials with less impact on the environment can be used if durability in the construction field is improved,incorporation of plant fibers in the cement matrix plays an interesting role. They are available at low cost and are renewable and biodegradable raw materials. The present work consists of studying the effect of cement mortar reinforcing with three types of plant fibers: Alfa(*stipatenacissima*), date palm and diss(*Ampellodesmosmauritaniaus*), with different lengths (0.5-1-1.5- 2 cm) on behavior in the hardened state. (Trial of traction by flexion, compression, endogenous withdrawal and withdrawal of desiccation. The results obtained for the mortars reinforced by the different lengths of vegetable fibers show that with the increase in fiber lengths, the flexural strength increases and a reduction in the compressive strength whatever the types of fibers used. They limit the propagation of endogenous shrinkage and desiccation at daytime and the surface of the fibers play a very important role on this phenomenon.

1. Introduction

In times of increased global population, the sector of civil engineering has to renew its practices and design methods to enhance its efficiency and decrease its environmental impact. Consequently, an increasing number of scientific investigations are aimed at creating new materials to address these environmental concerns. These new materials are often called eco-materials. The goal of using these materials is to bring improvements over traditional building materials on social, economical and environmental aspects.In the industrialized countries, eco-materials in the form of plant fibers offer interesting perspectives due to their association of environmental and technical performances. [1].

These fibers of plant origin attract more and more the whole of their features such as: good mechanical resistance, week weight, biodegradability and week cost. Henceforth, they are used in high stake fields: transportation, building, food, agriculture and plastic industry [2] and [3]. However about plant fibers, their use for concrete remains weak in spite several economic, ecologic and technical advantages they give [4].

the use of non-boiled diss gives very low mechanical strengths. The presence of water-soluble substances in the lignocellulosic part affects the hydration reaction of the cement and causes a delay in setting and curing.The boiling of the dissolution fibers completely suppresses the presence of water-soluble sugars and provides the composite with hydration and hardening comparable to an ordinary mortar [5].

Identify the influence of plant fibers on the shrinkage phenomenon, free and prevented shrinkage measurements, they conclude that the incorporation of (0.2%) sisal fibers limits the free shrinkage of (26) to (34%) [6].

The main properties obtained by incorporating vegetable fibers are thus increased tensile, flexural and impact strengths, limiting early age cracking by decreasing plastic shrinkage and improving ductility. These properties will depend on many factors. It is therefore difficult to compare the results of published research since the number of variables influencing the final characteristics of the composite is high.

Our work consists in studying the mechanical behavior of mortars reinforced by three vegetable fibers: alfa, diss and date palm (tensile test by flexion and compression), and the second part of the article is to measure the endogenous shrinkage and desiccation of the various mortars.

2. Material and Methods

2.1 Materials used

2.1.1 Cement

The cement used in this study is a CPJ-CEM II / A 42.5, with a chemical composition given in Table 1.

Table 1: Chemical composition of cement

Chemical compositions	Ca0	Al2O3	SiO2	Fe2O3	MgO	Na2O	K2O	Cl-	SO3	P.A.F
(%)	58.5	6.58	24.9	3.65	1.21	0.08	0.85	0.00	2.17	1.70

2.1-2 Physical characteristics of used sand

The sand used in the composition of the mortar has the following characteristicssummarized on table 2.

Table 2:characteristics of used sand

characteristics	units	Values
Apparent volumetric mass	Kg/m^3	1380
Absolute density	Kg/m^3	2500
Modulus of finesse	-	2.17
Sand equivalent	(%)	93.72
Absorption coefficient	-	1.45
d / D	-	0/2

2.1.3vegetal fibers

Three types of plant fibers were used in this study: alfa (*stipatenacissima*), a cylindrical stem plant that grows in arid regions of the western Mediterranean basin. About one meter high. For this study we studied the alfafibers of the region of Tebessa (Algeria) (Figure 1.a). For palm fibers, only the fibers extracted from the leaflets of the date palms are concerned. After each harvest, the latter are either burnt or discarded in nature. The leaflets studied were collected from date palms of the Annaba (Algeria) region (Algeria) (Figure 1.b).

The Diss plant (*Ampellodesmosmauritaniaus*), (figure 1.c) is a large grass widespread in the north African Mediterranean. We studied the Diss fibers of Tebessa region (Algeria).

alfa (*stipetenacissima*) (a),

date palm (b),

diss*(Ampellodesmosmauritaniaus)(c)*

Figure 1: Plant fibers

2.2 Treatment of plant fibers

In order to stabilize plant fiber, there are three categories of treatment can be listed: physical, chemical and thermal, many auteurs worked on treatment of plant fibers such as:

As far as physical treatment is concerned, [7] show that treated samples with (15 to 20%) of PEG show final withdrawal of (0.1%) to 56 days (to reduce the withdrawal of factor 10 with unchanged mechanical resistances). treated diss fibers diss and coated with linseed oil, diss coated with bitumen [5].

For chemical treatment, [8] compared immersion effect of sisal and coconut fibers in water at (pH=8.3), in lime substance Ca(OH)2 à (pH=12) and in soda NaOH à (pH=11.9). The treatment is done by immersing the fibers in solution of Sodium hydroxide (NaOH) with a concentration of (0.5%, 1%, 1.5%, 5% and 10%) for one hour under a source of temperature at 100 ° C[9].

To finish thermal treatment [5] have proceeded to thermal treatment by boiling diss fibers in a casserole for four hours, then washing in order to remove sugars and water-soluble components containing in fibers.First of all the stems are being carded mechanically to refine their diameter. The reconstituted wood samples are prepared by heating the poplar to 240 ° C and 260 ° C, with a ramp of 5 ° C / min under an inert atmosphere (N2). This treatment It helps stabilize the wood fiber and eliminate some of the polysaccharides present in the wood[10].

For this study, a thermal treatment of the three fibers (alfa fiber, date palm fiber and diss fiber), the fibers are harvested then are cut and then its slurry in water for two hours at a temperature of (99.4°C), then the fibers rinse with water to remove organic substances, then the fibers are air-dried.

1.3 Chemical composition of the fibers

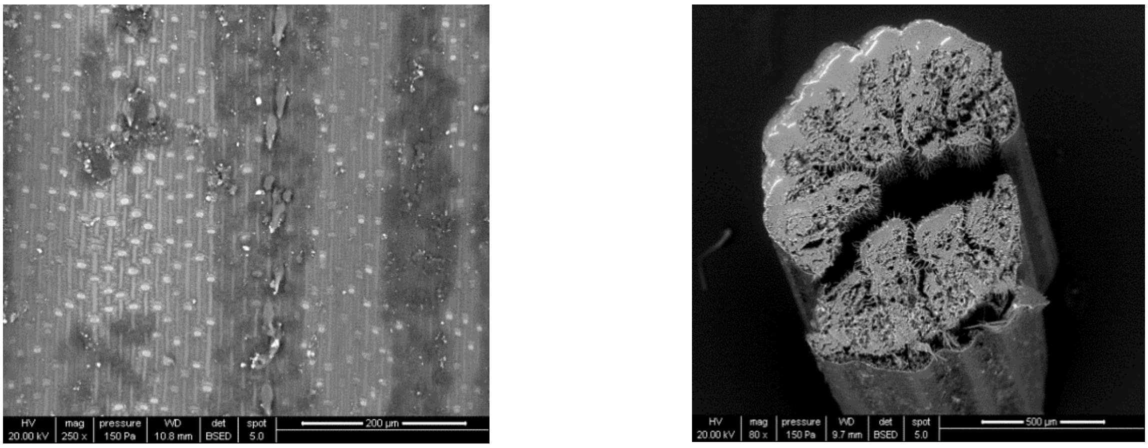
Tables 3 brings together the chemical composition of the three fibersesed Alfa, Diss and date palm

Table 3: Chemical composition of fibers (% in weight)

	Cellulose	**Lignin**	**ashes**	**Hemicelluloses /pectin**	**Selica**	**Extraction & others**
Alfa fiber [11]	46	19.62	4.71	-	26.5	3.17
Palm fibers [12]	35	27	-	28	-	10
Diss fiber [13]	44.1	16.8	-	27	-	12.1

2.4 Microscopic observation of raw and processed plant fibers

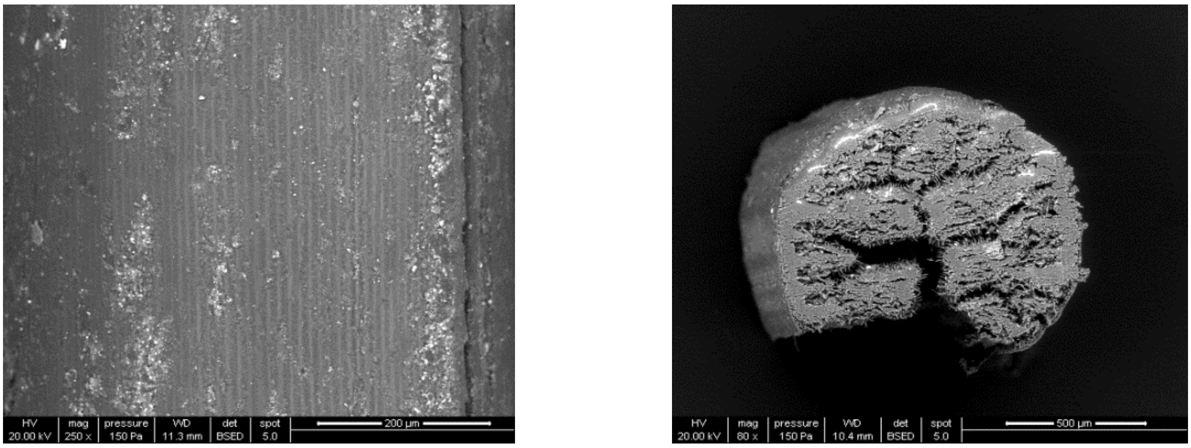
The microscopic images were obtained using a scanning electron microscope (SEM) to characterize the constitution and organization of the cell walls within the Alfa, diss and palm fibers. To do this, were cut transversely and longitudinally, taking care not to alter their native state.Scanning electron microscopy of a cross-section of the Alfa fiber (Figure 2) revealed the internal structure of the alfa rod.



(a) (b)

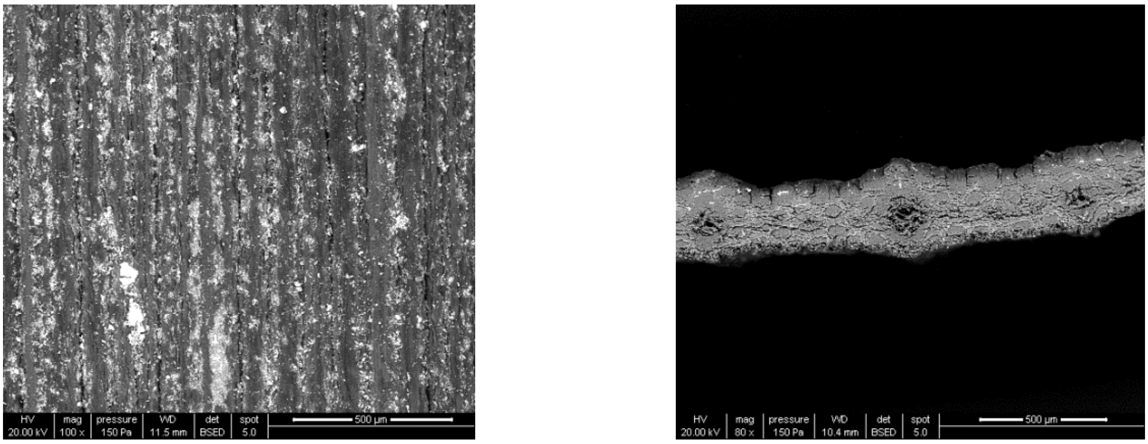
Figure 2: Observation of texture and (a) longitudinal and (b) transverse section of natural alfa fiber

SEM observations of larger magnifications have allowed to show in more detail the structure and the cellular organization within the fibers of the alfa. In fact, one finds there the different tissues which constitute the main components in this (Figure 2a and b) and sclerenchyma fibers (or long cells or mature cells) (Figure 2 (a, b)). In the Alfa, bundles of conductive vessels wrapped in a bundle of fibers (or surrounded by fibers) are observed. The width of a vessel can reach 5 µm (Figure 2b) [14]. The morphology of the date palm fibers was studied by scanning electron microscopy. The cross-section of a leaflet shows that it is formed by ultimate fiber bundles (Figure 4.b) and grooves composed of libro- the diameter of the ultimate fibers is of the order of 10 µm and the lumen has a diameter of the order of 1 to 2 µm [12].



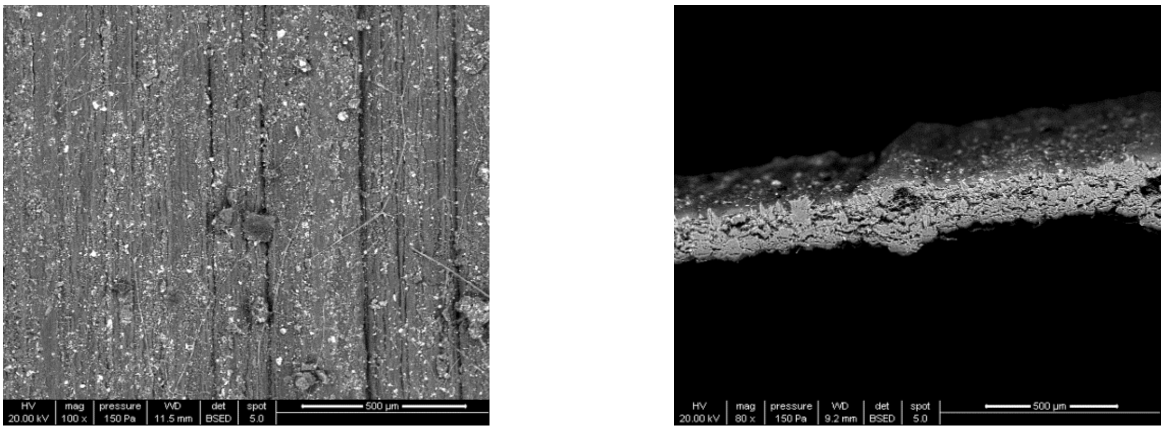
(a) (b)

Figure 3: Observation of texture and (a) longitudinal and (b) transverse section of the fiber of alfa treated



(a) (b)

Figure 4: Observation of texture and (a) longitudinal and (b) transverse section of natural date palm fiber



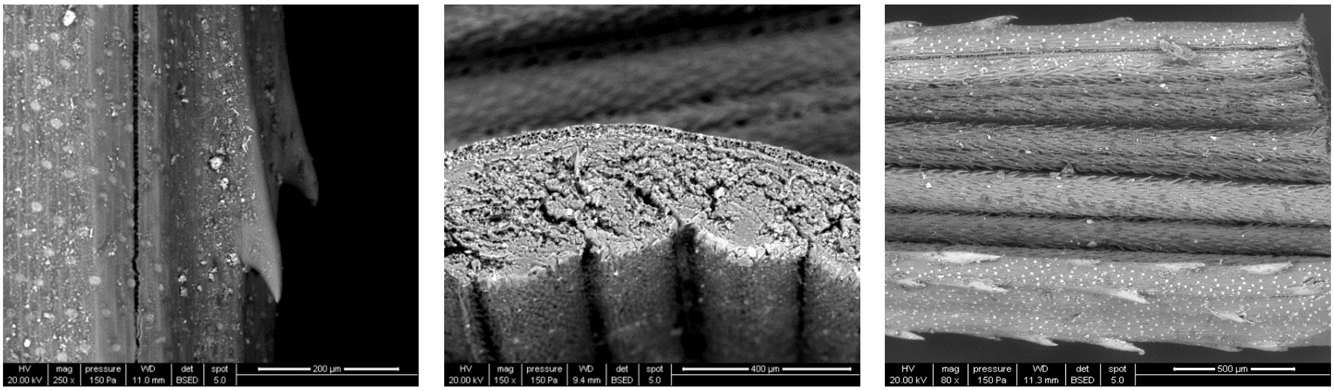
(a) (b)

Figure 5: Observation of texture and (a) longitudinal and (b) transverse section of the fiber of date palm treated

The outer surface of the Diss fiber has spines of about 100 mm in size, 5 times larger than those on the inner surface. The morphology of these spines is the same but their distribution is much less dense (Figure 6a).In addition, the SEM examination (Figure 6c) shows that the inner surface of the diss fiber is covered with spines 20 µm long with a diameter at the base of 10 µm. These spines are distributed over the entire surface of the fibers homogeneously.

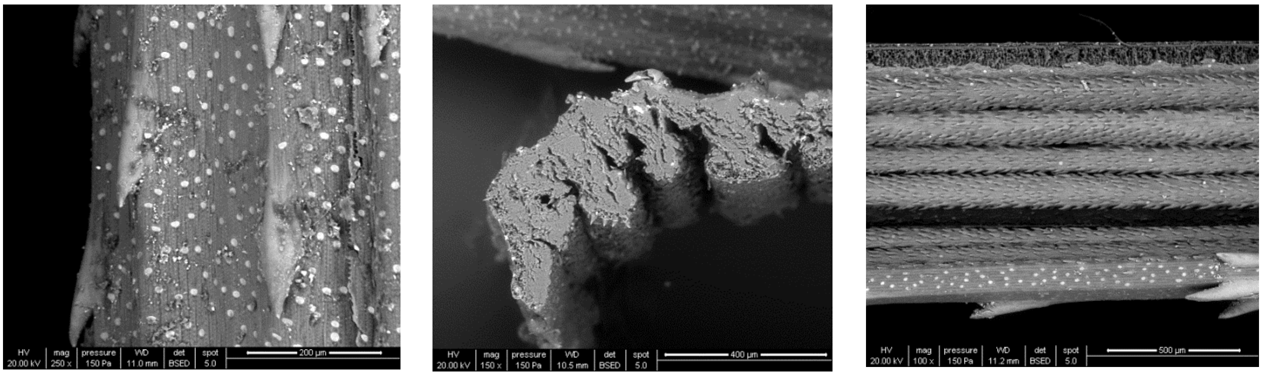
A mixed tubular -cavernous structure is observed within the depth of the fiber wall. Most cavities are closed; however, they do not carry the sap (Figure 6b) [15].

The heat treatment of the fibers does not modify the external and internal structure of that if, but it removes the impurities in the fibers (Figure 7).



(a) (b) (c)

Figure 6: Observation of texture and (a) longitudinal, (b) transverse section (c) inside the natural diss fiber

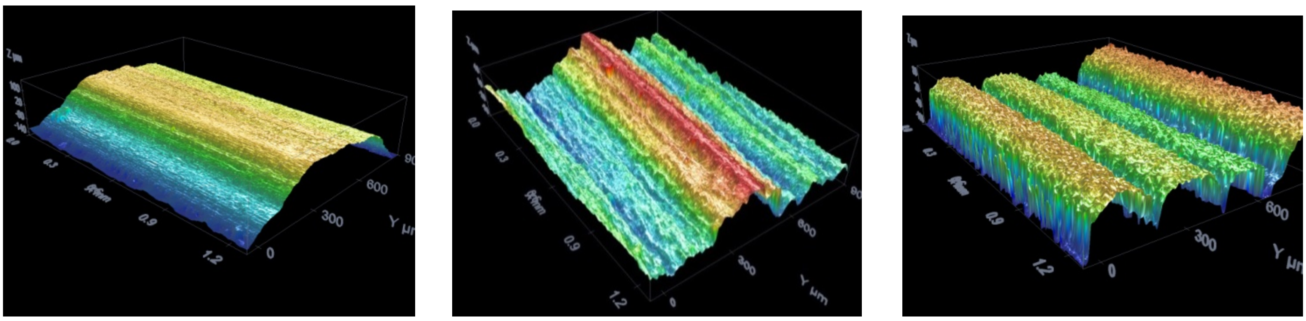


(a) (b) (c)

Figure7: Observation and texture and (a) longitudinal, (b) transverse section (c) inside the diss treated

2.5 Confocal observation of the roughness of the surface of plant fibers

The confocal images were obtained by the ticket of a Leica DCM3D apparatus in order to determine the roughness of the surface of the vegetable fibers used. As seen in (Figure8) respectively alfa fiber, palm fiber and dissolving fiber, the figures clearly show the roughness of the surface of the fibers. Diss and palm fibers have a rough surface and the Alpha fiber has a smooth surface.



(a) (b) (c)

Figure 8*:* Confocal image of the surface of the vegetable fibers (a) Alfa fiber, (b) Palm fiber and (c) Diss fiber

3. Results and discussion

3.1 Direct traction test on vegetable fibers

The direct traction tests were carried out on the three types of raw and treated vegetable fibers, the test was carried out according to the NFEN ISO 5079 standard under climatic conditions (t = 30 ° c ± 2) and (HR = 65 % ± 5) [16] sample length for the three fiber types is 100mm. The machine is set at a speed of 10 mm / min.The tensile behavior of the fibers depends on the nature of the fibers, so if the tensile behavior of the steel is defined with precession (hardenableelas to plastic) because the steel is a homogeneous material, the behavior of the fibers is dependent on several parameters such as chemical composition, morphology and slenderness (L / d).

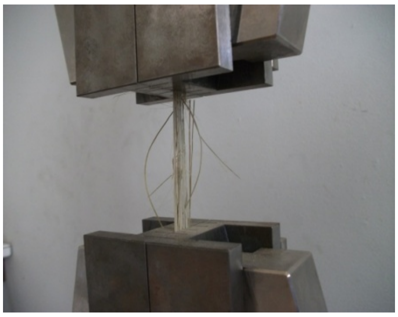
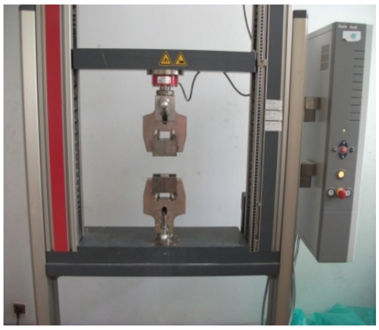
 

Figure 9: Mounting used for direct fiber pull test

Table 4: Tensile strength and elongation of alfa, palm and diss.

Fibers	F max(N)	dl of Fmax(mm)
Alfa	159.285	2.7420
Treated Alfa	147.510	3.5247
Date palm	162.117	3.6291
Treated date palm	162.063	4.9041
Diss	363.492	5.0556
Treated Diss	356.705	4.6941

F max: Tensile strength
dl: Elongation

The results of the direct traction test on treated and untreated fibers (Table 4) show that diss fiber has a high traction force value while the dissolution fiber has a value of (363.492 N)for the untreated fiber and(356.705 N) for the treated fiber. Alfa fiber gave low values compared to the other two (159 N)fibers on average. The treatment of the fibers by boiling slightly decreases their resistanc but does not modify the morphology of the fibers, it just eliminates the cellulose.

3.2 Water absorption tests of vegetable fibers

The water absorption coefficient of the plant fibersalfa, diss, and palm was determined according to the standard, the measurements were carried out on samples of fibers previously cut into strands of (0.5-1-1.5- 2 cm). For each type of fiber, 3 samples of about (4.5 g). The samples were initially dried in an oven at 105 ° C. until the mass was stabilized. They were then immersed in distilled water for (5 min) and(24h). The fibers were superficially dried using absorbent paper to remove inter-fiber water as well as water absorbed on their surface. The water absorption coefficient is then determined by the following equation[17].

$$\%\ \text{sbsorption} = \frac{(Msss - Ms)}{Ms} \times 100$$

Ms: mass of the dry sample.
Msss:mass after absorption.

The Table 5 summarizes the results on the water absorption coefficient of plant fibers used as reinforcement.

Table 5: Water absorption of the vegetable fibers used

Absorption %	5 min				24 h			
lengths (cm)	**0.5**	**1**	**1.5**	**2**	**0.5**	**1**	**1.5**	**2**
Alfa	32.22	39.77	44.44	48.88	71.55	87.33	92.66	95.77
Diss	68.80	69.33	72.22	29.77	131.55	140.22	144.88	156.22
Date Palm	54.88	62.44	66.00	70.22	110.00	114.88	128.22	130.66

At first, we can notice that the water absorption coefficient of vegetable fibers is very high. They are able to absorb a mass of water greater than their own mass.

The absorption coefficient after 24 hours, the diss fibers have an absorption coefficient that can be described as very high, in comparison with those of alfa and palm fiber, and it was noticed for the three fibers that when the length of the fibers is increased the absorption of water increases.

3.3 Preparation of fiber-reinforced mortar specimens

The matrix of our model composite is a cement mortar which report C/S equals to 1/3 with report E/C equals to 0.55. The matrix is reinforced with fibers of different length (5, 10, 15, 20 mm) and mixture of 1% of cement mass. The 4 x 4 x 16 cm test specimens are removed after 24 hours and then conserved in water for 27 days for mechanical testing.

3.4 Flexural strength of fiber-reinforced mortar specimens

Flexion test were realized by the help of hydraulic press of capacity of 30 KN. Test was proceeded according to EN 196-1 standards and machine starting which goes on with speed of 2 mm/min. on (figure 10) we noticed that, incorporation of plant fibers into mortar will improve their flexion behavior, this increasing goes with used plant fibers length, (the best values are obtained with diss fibers, its rude surface ensures their adherence with matrix). [18], [19], [20] noticed that, flexion resistance of these matrices such mortars or cement parte, can be considerably ameliorated thanks to mechanic features of fibers (high traction resistance). As far as alfa fibers and palm fibers are concerned, at first, more fibers length is important more flexion resistance is ameliorated, in the meantime, beyond 1.5 cm critic length, flexion resistance does not increase.

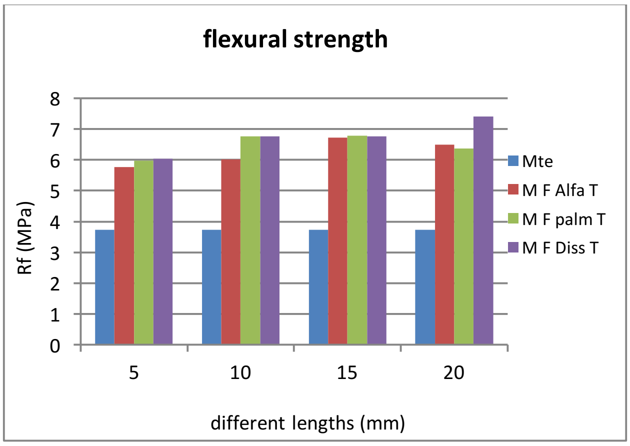


Figure 10: Evolution of the flexural strength of reinforced mortars of treated vegetable fibers

3.5 Compressive strength of fiber-reinforced mortar specimens

Compression test was realized with hydraulic press of 200 KN. Test was preceded according to standards and machine starting which goes on with speed of 2 mm/min. (figure 11) represent results compression resistance obtained during 28 days for model mortars as well as for plant fibers mortars (afla, palm date and diss fibers) as far as these results are concerned.

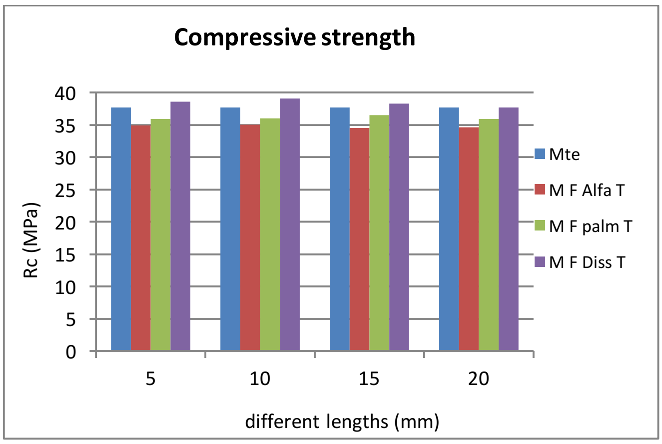


Figure 11: Evolution of the Compressive strength of reinforced mortars of treated vegetable fibers

Wenotice net decreasing in terms of compression resistance of fibers samples in relation to reference sample, this decreasing in recorded for all lengths of alfa fiber as well as for date palm and is due to increasing of fiber defaults number (non uniformity, fibers distribution, its morphology and smooth surface). These results are confirmed by other studies [19], [20], [21]. In the meantime, with addition to fibers compression resistance of composite decreases in relation to reference mortar.
As regards to the reinforced mortar by diss fibers, we observe high values to model, and due to rough features of diss fibers surface which fiber is well joined to matrix order to ameliorate its mechanic features.

3.6 Effect of fibers on withdrawal of drying and endogenous

3.6.1 Drying shrinkage

The drying shrinkage deformation of a concrete is the deformation caused by the drying of the material due to the hygrometric imbalance with the environment.
To determine the shrinkage according to the French standard NF P 15-433, the mortars were cast in the prismatic molds of 4x4x16 cm, two inserts (brass plaster) are placed at the end of the test pieces and will be used to position on the measuring bench can be used to measure the axial dimensional variations using a micrometer. (Figure 12).

Figure 12: Retractomerter

The specimens intended for desiccation removal are cast and protected from drying by a film for 24 hours and then stored in a chamber in which the air is permanently at a temperature of (20 ± 2) ° C. and a relative humidity of (50 ± 5%)

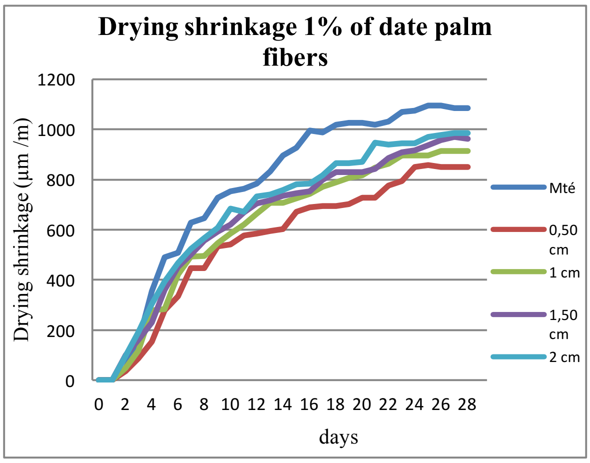
Fig. 13: Device for measuring the shrinkage formations in desiccation mode

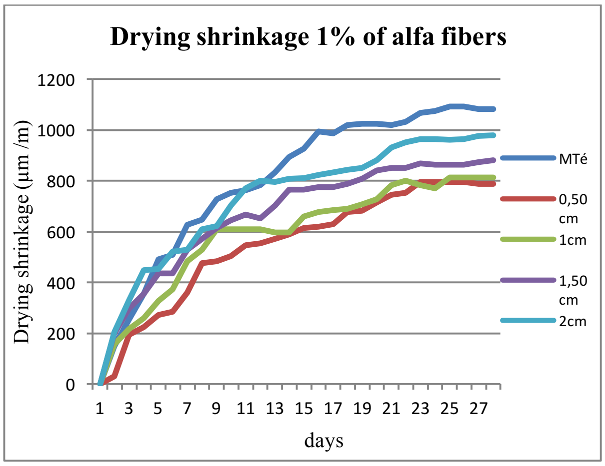
Measurements of both withdrawals start 24 hours after the samples have been manufactured. Prior to each measurement series, the comparator has been previously calibrated using an invar calibration rod (insensitive to ambient variation). The invar rod is adapted to the height of the specimen. The studs must be cleaned before each measurement.
The evaluation of the drying shrinkage as a function of the length of the fibers is shown in (figure 14, 15 and 16) respectively for the types of used fibers, alfa, date palm and diss. The three curves show that each fiber has a behavior that differs from the other. We observe that the diss fiber has abilities to decrease shrinkage this could be attributed to its rough surface and the matrix that penetrates into the fiber which ensures good matrix adhesion / fibers, and allows to control crack opening and thereafter it limits the shrinkage. Same behavior that was observed for palm fiber, it decreases shrinkage when decreasing length and it limits the crack propagation

with different lengths and (1%) of Alfa fibers different lengths and (1%) of date palm fibers

of withdrawal because of its surface which makes up grooves or even (figure 4a).Our results are validated by those of [22].

- The attachment of the fiber to the matrix will be better with a fiber having a rough surface than a fiber having a smooth surface.
- The shrinkage increases with increasing the length of the latter





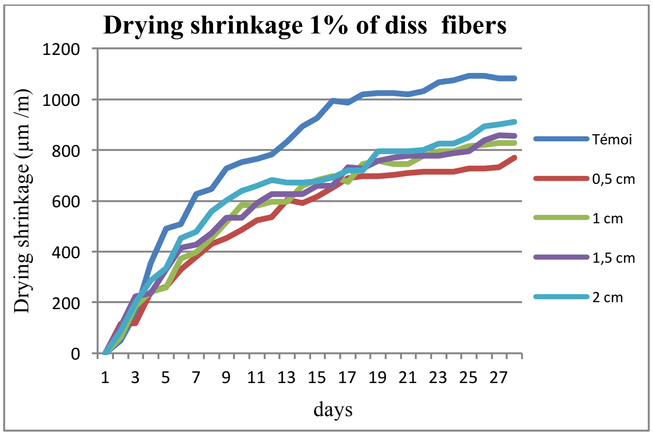


Figure16*:* Drying shrinkage of specimens with different lengths and (1%) of diss fibers

3.6.2 Endogenous shrinkage

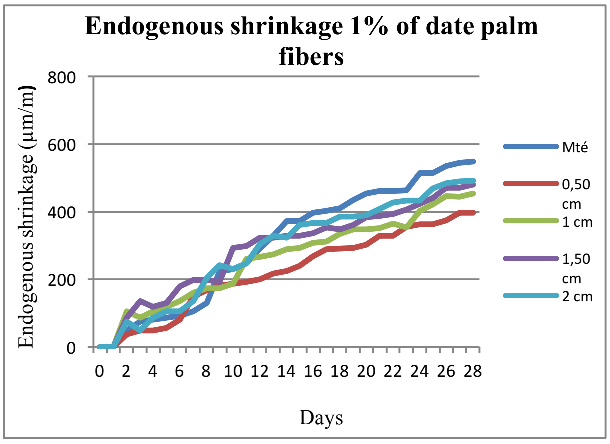
The endogenous shrinkage deformation of a mortar, it occurs under isothermal conditions and without water exchange between the test piece and the external environment.

The specimens are cast and protected from drying by a 24 hour film to measure the endogenous shrinkage, the specimen is totally covered by two layers of the food film and double layers of the aluminum film, so as to avoid any exchange of moisture, and are kept in a chamber in which the air is permanently at a temperature of (20 ± 2) C ° and a relative humidity of (50 ± 5) %.

The evaluation of the endogenous shrinkage as a function of the length of the fibers is shown in (figure 18, 19 and 20) respectively for the types of used fibers, alfa, date palm and diss. For the endogenous shrinkage when the E / C ratio is low plus the amplitude and kinetics of this shrinkage will be important [16], the ratio in our study will decrease with whith increasing fiber length, according to the president test of water absorption (Table 6). the diss and palm fiber have a high water absorption so the E / C ratio will decrease when the fiber length is increased but these two fibers have a rigid structure which prevents the shrinkage to develop.For the alfa fiber the hypothesis of [23] will be validated by what it absorbs of water and the ratio E / C will diminish when the length of the fibers is increased and the endogenous shrinkage will subsequently increase as seen in (figure 18).

- The fiber of diss limits the withdrawal at the young age

Figure 17: Device for measuring endogenous shrinkage formations



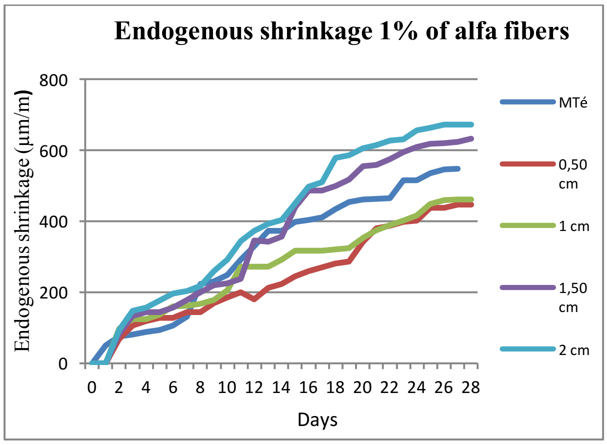
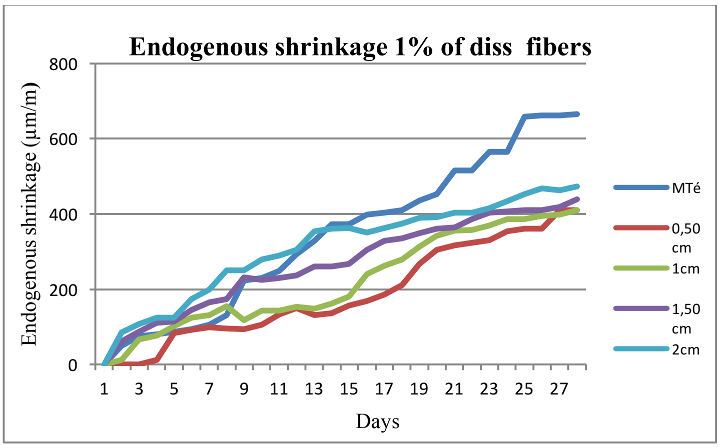


Figure 18: Endogenous shrinkage of the specimens with different length and (1%)alfa fibers

Figure 19: Endogenous shrinkage of the specimens with different length and (1%) date palm fibers



Fifure20*:* Endogenous shrinkage of the specimens with different lengths and (1%) of diss fibers

Conclusion

We can draw some conclusions from the results obtained in our study:

The observation by SEM on the vegetable fibers (alfa, date palm and diss) shows clearly the different surfaces and structure which constitute the main components of these. The thermal treatment that was done on the fibers does not modify their morphology.

The mechanical and physical properties of the used vegetable fibers vary considerably; this variation is controlled by the chemical and structural composition and depends on the type of fibers and on the growth conditions.A high water absorption of the plant fibers is due to their hydrophilic character and to their porous structure, the penetration of water through the fiber increases the water / cement ration in the vicinity of the fiber / cement interface [4].

The compressive strength of the fiber mortars in general is lower than that of the control mortar, but its strength can be slightly improved by the roughness and good orientation of the plant fibers in the matrix. The incorporation of the plant fibers in the mortar makes it possible to improve the flexural strength and subsequently the ductility when the length of the latter is increased.

Mortars reinforced with vegetable fibers (alfa, palm and diss) improve shrinkage by crack propagation limit over time, when fiber length is reduced, shrinkage decreases, surface and morphology of the fibers plays very important role in reducing the shrinkage and also allows to control the opening of the crack after wards It can be said that the fibers used may constitute an interesting alternative for improving the cracking resistance of cement materials. [24]

The E / C ratio is a key parameter in the results of deformations caused by endogenous shrinkage and desiccation, the lower this ratio the greater the amplitude and the kinetics of this shrinkage.

References

1. Z. Khelifi, M.A. Allal, N. Abou-bekr, S. Taibi, B. Duchemin, *Int. J. Appl. Eng. Res.* 11(8) (2016) 6007-12.
2. K. Ghavami, *Cem. Concr. Compos.*27(6) (2005) 637-649.
3. R.D. TolêdoFilho, K. Ghavami, M.A. Sanjan, G.L. England, *Cem. Concr. Compos.* 27(5) (2005) 534-544.
4. J.H. Savastano, V. Agopyan, A.M. Nolasco, L. Pimentel, *Constr. Build. Mater.* 13(8) (1999) 433-438.
5. M. Merzoud, F. Habita, A. Gouasmia, *Afriq. Sci.*04(2) (2008) 231-245.
6. R.N. Swamy, H. Stavrides,*J. Amer.Concr. Inst.* 76(3) (1979) 443-460.
7. F.W. Broker, M.H. Simatupang, *Holz. als. roh.*32 (1974)188-193.
8. R.D. TolêdoFilho, K. Scrivener, G.L. England, K. Ghavami, *Cem. Concr. Compos.* 2 (2000) 127-143.
9. H. Brahmi, A. Hamouine, *Amer. J. Civil. Eng. Archit,* 4(6) (2016) 211-215.
10. A. Govin, P. Grosseau, B. Guilhot, R. Guyonnet, *Journées Annuelles du Groupe Français de Céramique, Montpellier*. 26 au 28 Mars 2003.
11. O. Akchiche, M.K. Boureghda, *J. Chem. Raw. Plant.* 4 (2007) 25-30.
12. A. Sbiai*, Thèse Doct.Univ. Lyon.* (2011) 111.
13. M.E.H. Bourahli, H. Osmani, *J. Natur. Fib.* 10(3) (2013) 219-232.
14. A. Ben Elmabrouk, *ThèseDoct. Univ. Grenoble*. (2011) 78.
15. A. Sellami, M. Merzoud, S. Amziane, *Constr. Build. Mater.*47 (2013) 1117-1124.
16. A. Kriker, A. Bali, G. Debicki, M. Bouziane, M. Chabannet, *Cem. Concr. Compos*.27 (2005) 554–564.
17. A. Bessadok, S. Marais, F. Gouanvé, L. Colasse, I. Zimmerlin, S. Roudesli, M. Métayer, *Compos. Sci. Tech*, 67 (2007) 685-69
18. P.R.L. Lima, J.A.O. Barros, D.J. Santos, C.M. Fontes, J.F.M. Lima, R.T. Filho, *Europ. J. Environ. Civil. Eng*.(2016)https://doi.org/10.1080/19648189.2016.1271357
19. T. Ali-Boucetta, T. Tioua, M. Behim, A. Kriker, Ch. Belebchouche, W. Laifa, *J. Mater. Proc. Enviro.* 4(2016) 2335-10205
20. A. Mokhtari, A. Kriker, Y.Guemmoula, A.Boukrioua, M.M. Khenfer, *Energy. Procedia.* 74 (2015) 344-50
21. S. Chafei, F. Khadraoui, M. Boutouil, M. Gomina, *Constr. Build. Mater.*79 (2015) 229-235
22. M.R. Khelifaa , N. Lekloud, T. Bellala , R.L. Hebertb, B.A. Ledesertb, *Europ. J. Environ. Civil. Eng.* (2016) 1964-8189 http://dx.doi.org/10.1080/19648189.2016.1217792
23. A.M. Naville*, Propriétés Des Bétons,* ISBN2-212-01320-5 (2000) 406.
24. W. Laifa, M. Behim, A. Turatsinze, T. Ali-Boucetta, *Sci. Tech. Synth.* 29 (2014) 100-110.

Norms

- NF EN ISO 5079, Fibres textiles Détermination de la force de rupture et de l'allongement de rupture des fibres individuelles. AFNOR, France, (1996) 20.
- NF P 15-433, The shrinkage according to the French standard.
- EN 196-1, The tests were carried out according to the standard Flexural strength.