



IMPROVEMENT OF THE MECHANICAL PROPERTIES OF CEMENTITIOUS BIO- COMPOSITES REINFORCED WITH GREEN BIO- FIBERS: EFFECT OF THE PRETREATMENT PARAMETERS

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Received 08.08.2024.
Revised 03.02.2025.
Accepted 26.02.2025.

Keywords:

*Green Fibers, Bio-
composites, Ductility,
Flexion*

A B S T R A C T

The valorization of plant fibers in construction and civil engineering is crucial since the products obtained are not subject to strict quality standards. Plant waste, such as Alfa and Diss, has very significant environmental and economic impacts, since these plants are abundant, renewable, cheap, and biodegradable. On other hand, Due to their mechanical resistance and durability, cementitious materials dominate the construction market. In spite of this, they remain perfectible due to their limited deformation capacity and low tensile strength, which makes them susceptible to shrinkage cracks. In addition to pavements and roads, elements on large surfaces that crack due to shrinkage are examples of cracked elements. It is therefore important to improve the deformation capacity of cementitious materials. These composite materials, reinforced with natural fibers, make the desired material very ductile, and with a tensile strength close to the compressive strength. Vegetable fibers contain a high percentage of sugars which interact unfavorably with the cement paste. These total sugars were determined by the colorimetric method. In order to improve the interaction characteristics between the fibers and their matrices, we applied hydrothermal treatments (boiling for four hours in mains water) and chemical treatments (immersion in seawater) to the Alfa and Diss fibers.

To evaluate the treatments applied to the fibers, we carried out three-point flexural strength and compression tests on the cementitious composites.

The results of tests carried out on biofiber-reinforced cementitious composites showed that their ductility increased more than tenfold (the deformation rate exceeded 29% for fiber-reinforced composites immersed in seawater, and over 40% for boiled fiber-reinforced composites) than that of pure cement, which exhibits brittle behavior (the deformation rate of pure cement is less than 3%). These tests have also shown that seawater treatment proves more interesting, since it enables the highest flexural strengths to be obtained.

The results of the tests carried out on the bio-fibrous cementitious composites showed that their mechanical characteristics are improved and that the seawater treatment is more efficiency, as it provides the greatest flexural strength.



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1. INTRODUCTION

Over the past few decades, extensive scientific research has been conducted to enhance the physical and mechanical properties of composites while also considering environmental concerns (Achour, 2017). This includes reducing the cost of production and facilitating recycling by incorporating plant-based fibers as reinforcement in cement matrices. In a study conducted by El-Abbassi et al (2014), the Alfa stalks were mechanically milled to extract the fibers and reduce the percentage of hemicellulose and pectin, thereby improving adhesion with the matrix. The extracted fibers were then washed with saltwater and treated with NaOH. The findings revealed that the incorporation of Alfa fibers enhanced the mechanical strength of the polymer composites, and various chemical treatments exhibited potential in improving both mechanical and hygrothermal capabilities (Arrakhiz et al., 2012). The Alfa plant, scientifically known as *Stipa Tenacissima*, belongs to the monocotyledonous family Poaceae and is indigenous to the mountainous regions of the Mediterranean basin (Arrakhiz, 2012). This perennial herbaceous plant thrives in arid environments and has various applications, including the production of high-quality printing paper. For the purpose of this study, the Alfa plant was sourced from Taoura, a town situated in the wilaya of Souk-Ahras, near the border of Tunisia. One notable characteristic of this plant is its impressive tensile strength, which has been recorded as reaching 154MPa by (Khelifa in 2017; Khelifa et al., 2018). According to Khaldi et al in 2014, the primary lignocellulosic compounds found in Alfa include cellulose (40%-50%), lignin (17.71%-24%), hemicellulose (22.15%-28%), and a small percentage of wax (5%). It is important to note that the structure of Alfa is highly heterogeneous, resulting in a significant degree of anisotropy (Trache et al., 2014).

Furthermore, Ziane et al. (2021) conducted a comparative study of the physical-mechanical properties of the external sulfate attack behavior and durability of two fiber-reinforced concretes, Alfa and hemp (Ziane et al., 2020a). They found that the addition of natural fibers, either Alfa or hemp, resulted in a decrease in compressive strength and dynamic modulus (Ziane et al., 2020b). The content of Alfa is more than 1%, and the content of hemp fiber is more than 0.25%, which is H. The increase in voids is directly proportional to the number of fibers, which also affects the compactness of the concrete, thereby weakening the strength of the concrete.

The Diss (*Ampelodesma Mauritanica*) is a herbaceous plant found throughout the Mediterranean basin up to the highlands. It is an annual plant, very hardy, with a tensile strength of about 100 MPa. Merzoud et al. (2008c) reported the use of Diss fibers as reinforcements for cement-based composites (Merzoud, 2007). They showed that natural Diss fibers interact poorly with cementitious qualities due to the presence of sugars and

other water-soluble compounds in the plant (Merzoud & Habita, 2008b). Removal of these water-soluble compounds by boiling enables the production of composites with acceptable compressive and flexural strengths. And they found that the optimal formulation of the different treatments depended on the water absorption and mechanical strength of the fibers. Sellami et al (2013) found that the optimal volumetric formulation is 4:1:0.7 (Diss: Cement: Water) by varying the fiber volume and W/C (Water / Cement) ratio for different cementitious formulations.

In the same study, they showed that boiling water treatment improved the mechanical properties of composites while maintaining the fiber structure. This treatment removes organic compounds, especially water-soluble sugars, which drop from 30.78% in unboiled DISS to 1.95% in unwashed boiled Diss and finally down to washed boiled Diss 0.72%. The significant removal of sugars allowed the fibers to react well with cement and resulted in relatively strong composites compared to natural fiber composites with very low and negligible strength. Composite materials of boiled Diss fibers and Diss fibers coated with linseed oil have a more or less significant resistance due to the elongated fibers arranged horizontally, while the fibers are coated with grout, which makes them able to act in bunches for better participation in tensile forces.

Zaid (2021) investigated the physical-mechanical properties of a Diss fiber-reinforced cement sample with a fiber/binder volume ratio ranging from 0 (control sample) to 4.0. In order to mitigate the inhibitory effect exerted by plant materials on the hydration of the binder, Diss fibers were boiled to remove water-soluble compounds, while air lime binder (tradical) was selected to replace cement used traditionally as binder. The most important part of this work focuses on the effectiveness of using an air lime binder to develop lightweight building materials containing Diss fibers. Air lime binder is the chosen variety of binder due to its abundance and low emissions from its manufacture. The experimental study of the chemical compatibility between the treated fibers and the binder through the hydration test showed the effectiveness of the boiling water treatment on the changes of morphological and mineralogical properties. Depending on the rate of Diss fibers used in the mixture, it was found that the optimum addition of Diss fibers is on the order of 3 volumes. The corresponding flexural strengthening rate reached a higher value of 86.5%, due to several strengthening mechanisms such as the compaction process. Belkhir and Merzoud (2021) studied the effect of the dimensions of Alfa and Diss fibers using different sizes of fibers from 2 to 8 cm in cementitious and clay matrices, they deduced that in cementitious matrices the optimal flexural strengths are obtained for short dimensions of fibers between 2 and 4 cm, due to the good adhesion of fibers in the matrix (Boutarfa et al., 2018).

In order to meet numerous requirements in the housing and public works sectors, traditional inorganic fibers in the composition of building materials are increasingly being replaced by the use of natural plant fibers as reinforcements (Achour et al., 2017). The elaboration and characterization of cement or clay composites based on Alfa and Diss allowed us to understand how these fibers affect the properties of the different composites developed.

Natural fibers do not interact well with cement due to the presence of sugar and water-soluble components contrary to clay. To overcome the incompatibility between natural fibers and cement, it has been possible to boil the fibers in order to reduce or even eliminate the components causing the setting delay and the decrease loss of the resistance.

The aim of this work is to develop cement-based composites based on local Diss and Alfa natural fibers. These fibers are boiled or seawater soaked to improve the mechanical properties of their composites.

The main challenge here is to improve the mechanical properties, in particular to significantly increase the flexural strength through rational and economical treatments.

2. MATERIALS USED AND EXPERIMENTAL METHODS

2.1 Materials

Alfa and Diss fiber

In this work, we used natural Alfa and diss plant material (stalk) (figure 1) and (figure 2), and then processed into longitudinal fibers using an electric knife grinder.



Figure 1. Macrographs showing Alfa Plant (*Stipa Tenacissima*, Diss Plant (*Ampelodesma Mauritanica*) in its Natural state in Souk-Ahras Region/Algeria

Natural plants in the form of stems barely adhere to the cement, forming a strong composite. To do this, we convert the straw into fibers with the aid of an electric mill. However, since these natural fibers contain water-soluble substances, they do not interact well with the cement matrix, so we mitigate these effects by boiling or seawater immersion (Bessadok et al., 2009; Bessadok et al., 2007).



Figure 2. Optical images of Alfa and Diss Natural Stalks

The scanning electron microscope image in figure 3 shows the presence of spines on the stem and boiled fibers of Diss, whereas the fibers of Alfa have a smooth outer surface and consist of longitudinal fibrils.

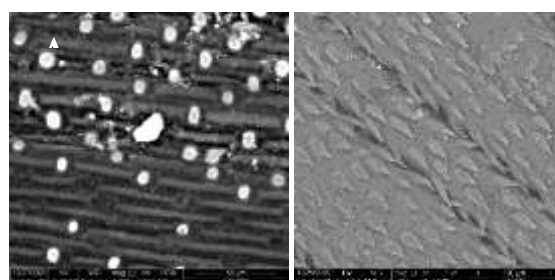


Figure 3. SEM images performed on Alfa and Diss composites (Boiled Fiber)

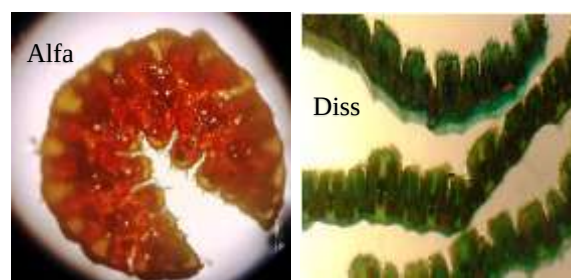


Figure 4. Optical Microscopic image of a Histological Cross-Section of a Stalk of Alfa and Diss composites

Figures 3 and 4 clearly shows the organization of both species and confirms the presence of spines on both sides of the Diss stem and on the inner wall of the Alfa stem. These spines are used to give the fibers good adhesion in the cement matrix.

The densities of the natural and milled fibers used in our mixture are listed in Table 1.

Table 1. Density of Alfa and Diss

Type of Fiber	Natural Alfa (Kg/m ³)	Boiled Alfa (Kg/m ³)	Natural Diss (Kg/m ³)	Boiled Diss (Kg/m ³)
Density	26.25	24.09	26.79	25.18

Cement

The cement used in our study is called "El Matine". It is the trade name for gray Portland cement with limestone, which we use as a matrix for fiber composite development.

It is of type NA442 CEM II/A-L42.5N certified to Algerian Standard (NA442-2013) and European Standard (EN 197-1) and manufactured by Lafarge Cement Works in M'sila, Algeria.

The chemical and mineral compositions are summarized in Table 2.

Table 2. Chemical and Mineralogical Composition of El Matine [EL MATINE data sheet]

Chemical Analysis						
Designation	Loss on Fire %.	Insoluble Residues	Sulphate Content SO ₃ %.	Magnesium Oxide Content MgO %.	Chloride Content	Alkali Equivalent Content %.
%	7.5 – 12	0.7 – 2	2 -2.7	1 – 2.2	0.01 – 0.05	0.3 – 0.75
Hypothetical Clinker Composition						
Designation	C ₃ S %.		C ₂ S%.	C ₃ A %.		C ₃ AF %.
%	58 – 64		12 – 18	6 – 8		10 – 12

The results of the physico-chemical characterization tests applied to the cement used described in Table 3, showed that it complies well with the requirements of CEM II/B 42.5 class.

These values are within the ranges indicated in Table 4 (EL MATINE cement data sheet).

Table 3. Physical and Mechanical properties of Cement (results of tests applied in this work)

Apparent Density (kg/m ³)	894.47
Absolute Density (kg/m ³)	2924
Normal Consistency	w = 26.32 (131.6 g)
Start of Set Time (min)	145
End of Set Time (min)	235
Compressive Strength (Mpa)	28 days 42.52

Table 4. Physical-Mechanical Characteristics of NA 442 Cement (EL MATINE cement data sheet) (source: www.lafargealgerie.com)

Physical Properties	Normal Consistency (%)	25 – 28.5
	Fineness by Blaine's Method (cm ² /g) (NA 231)	3750 – 5250
	Shrinkage at 28 days in μ m/m	< 1000
	Expansion in mm	0.3 – 2.5
Setting Time at 20 °C (NA 230)	Start of Set Time (min)	140 – 195
	End of Set Time (min)	195 – 290
Compressive Strength (NA234)	2 Days (Mpa)	≥ 10
	28 Days (Mpa)	≥ 42.5

2.2 Fiber Treatment

After harvesting the stalks of the plants (Alfa and Diss), they are exposed to the open air to dry. Then these stalks are milled longitudinally by using an electric miller of the Retsch type equipped with a blade with mesh of 10 cm. A part of the obtained fibers will be subjected to a hydro-thermal treatment (boiling for four hours of the time in the water) and the other part will undergo the treatment of immersion in seawater in order to eliminate the undesirable organic substances which present a disadvantage with regard to the mechanical characteristics, as the sugars. The total sugars present in the different samples studied are determined by Dubois (1956).

In acidic medium and at high temperature, the glycosidic bonds of carbohydrates are hydrolyzed. The simple oses thus released undergo intramolecular dehydration to furfural derivatives (furfural or hydroxy methyl furfural). The aldehyde function of furfurals condenses in acidic media with the hydroxyl of a phenolic compound to give acetals or hemiacetals of reddish color which absorb in the visible range (450-500 nm). This method allows the determination of all the total carbohydrates of a biological material.

A volume of 200 μ L of the used solution containing the soluble extracted from the different milled fibers is placed in a test tube to which 200 μ L of 5% aqueous phenol solution is added. The reaction medium is vortexed after addition of 1 mL of 96% H₂SO₄ and then the mixture is again vigorously homogenized with a vortex. After 30 min as kept time at room temperature, the maximum absorbance was observed at around 490 nm. Thus, this wave number is used to the of the glucose concentration.

2.3 Method of Formulating Composites

At finding the optimum and adequate formula of the fibrous cementitious composites (Alfa and Diss), we adopted four compositions based on different volume ratios. The first formulation is to mix three volumes of natural fibers with three volumes of cement. In the second, four volumes of fibers are mixed with two volumes of cement while in the third five volumes of fibers are mixed with one volume of cement. Finally, a formulation composed of only six volumes of cement mixed by introducing only water will be used as a standard. These methods of elaboration of the composites are summarized in Table 5.

After the choice of the substitution volumes of Alfa and Diss fibers (fibers air-dried beforehand) according to the

formulations of Table 5, we made specimens based on these fibers in molds of dimensions 4x4x16 cm.

Table 5. Composite Formulations

Formulation of Composites				
Composites	Fiber (Alfa or Diss)	Cement	W/C (Water/Cement)	Formulation
	3/6	3/6	0.40	3: 3 :0.40
	4/6	2/6	0.45	4 :2 :0.45
	5/6	1/6	0.50	5 :1 :0.50
Standard	0/6	6/6	0.35	0 :6 :0.35

2.4 Mechanical Tests

After blending the mixtures in a mortar mixer, we proceeded to the vibration with the shock table. The prepared specimens are placed in the humid chamber during 28 days. At the end of the cure, the specimens will be placed in the oven at 50°C until constant mass is obtained.

The three-point flexural tensile strengths were determined in accordance with EN 196-1 on 4 x 4 x 16 cm prismatic specimens. These tests are carried out on a Zwick/Roel type BT1-FR020THW.A50 flexural strength test rig with a capacity of 20 KN (figure 5), specially designed for this type of material and connected to an automatic data acquisition system.



Figure 5. Flexural Tests performed on Fiber Composites

The specimen halves tested in flexure were used for compression tests using the Bera Test 2000 KN capacity press.

2.5 SEM Imaging Characterizations

The morphology of the samples at the level of the zones of rupture was carried out within the National School of Mines and Metallurgy of Annaba using a scanning electron microscope of type Quanta 250 FET.

3. RESULTS AND DISCUSSION

3.1 Determination of Soluble Sugars

The analysis of the accumulated water after treating Diss and Alfa fibers by the phenol-sulfuric acid method, showed the presence of soluble sugars in the different samples as shown in Figure 6.

From the biochemical results performed on the milled fibers we noticed as presented in tables 6 and 7, that the rate of sugar decreased in the stalks after removing a significant value of 47.65% for Diss and 36.56% for Alfa. While for the boiled fibers after being milled, it decreased by 57.23% for Diss and 55.21% for Alfa.

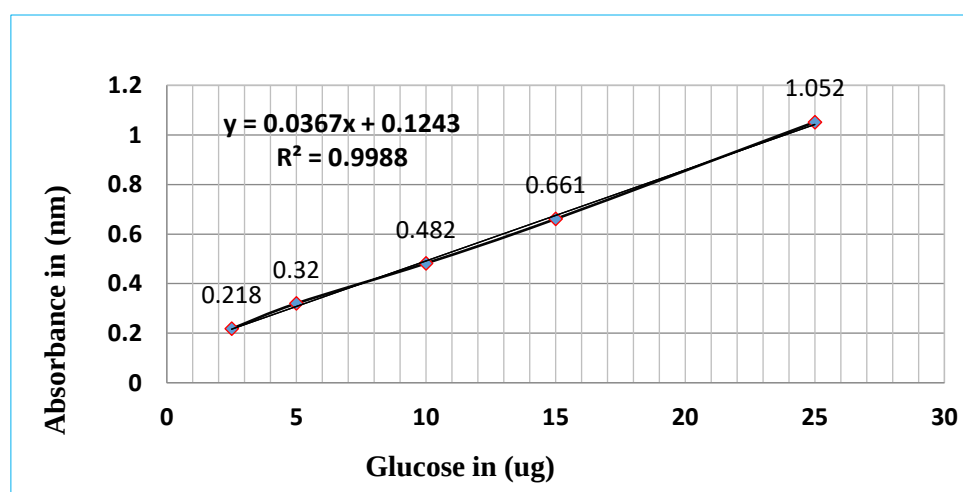


Figure 6. Calibration curve of Glucose (Dubois Method)

Table 6. Soluble Sugars concentration in the Studied Samples of Alfa

Sample	Concentration of soluble sugars mg/ml	Remaining sugar content in %.
Natural Alfa (Stalk)	570.95	100%
Alfa milled	362.23	63.44%
Alfa milled then boiled	162.23	28.41% / Natural stalk 44.79% / Milled stalk
Alfa milled then immersed in seawater		
Alfa / Seawater collected after 30 days	309.37	54.18% / Natural stalk 85.41% / Milled stalk
Alfa / Seawater collected after 60 days	75.59	13.24% / Natural stalk 20.86% / Milled stalk
Alfa / Seawater collected after 90 days	43.71	7.65% / Natural stalk 12.07% / Milled stalk
Alfa /Seawater sampled after 120 days	34.71	6.08% / Natural stalk 9.58% / Milled stalk
Alfa /Seawater collected after 150 days	24.36	4.27% / Natural stalk 6.73% / Milled stalk

Table 7. Soluble Sugars concentration in the Studied Samples of Diss

Sample	Concentration of soluble sugars mg/ml	Remaining sugar content in %.
Natural Diss (Stalk)	909.37	100%
Diss milled	476.13	52.35%
Diss milled then boiled	203.65	22.39% / Natural stalk 42.77% / Milled stalk
Diss milled then immersed in seawater		
Diss / Seawater collected after 30 days	329.96	36.28% / Natural stalk 69.30% / Milled stalk
Diss / Seawater collected after 60 days	133.35	14.66% / Natural stalk 28% / Milled stalk
Diss / Seawater collected after 90 days	25.44	2.80% / Natural stalk 5.34% / Milled stalk
Diss /Seawater sampled after 120 days	21.63	2.38% / Natural stalk 4.54% / Milled stalk
Diss / Seawater collected after 150 days	19.55	2.15% / Natural stalk 4.11% / Milled stalk

Thus, the totality of diminished sugar is respectively 77.61% for Diss and 71.59% for Alfa in the natural stalk.

- The Diss contains a 62.79% higher quantity in its stalk than that contained in the Alfa stalk.
- The milling allows the reduction of the contained sugar in the stalks of Diss and Alfa.
- The decreases in sugar levels in Diss and Alfa fibers immersed in seawater after 60 days as immersion time are 65.48% and 46.6%, respectively, which are higher than during the boiling thermal treatment.

3.2 Results of Mechanical Tests on Milled Fiber Composites for Different Formulations

The effect of boiling fibers on the mechanical properties of the composites (Figure 7 and Figure 8) seems to increase the flexural and compressive strength after reducing the percentage of the setting retardation-causing sugars and water-soluble compounds.

From the mechanical test results in the histogram (Figure 7 and Figure 8.), we found that the best composite formulation exhibiting excellent compression resistance was the formulation with a volume ratio of 3:3, whereas for the requested sample, the volume ratio was 3:3 while for the samples that will be solicited to the flexion is the one of the ratio 5:1 volumes. Nevertheless, the optimal formulation for both efforts is the 4:2 volume ratio. This formulation will be adopted for the rest of the tests.

SEM image in Fig. 9 shows scattered cement fragments on the contact surface where a poor adhesion on the walls of the milled Alfa fibers is observed since the cement disbanding occurred at the direct surface of the cement/fiber interface.

The SEM images in figure 9 and figure 10 show scattered cement fragments on the contact surface, demonstrating poor adhesion to the walls of the ground Alfa and Diss fibers, as cement detachment occurred at the direct surface of the cement/fiber contact.

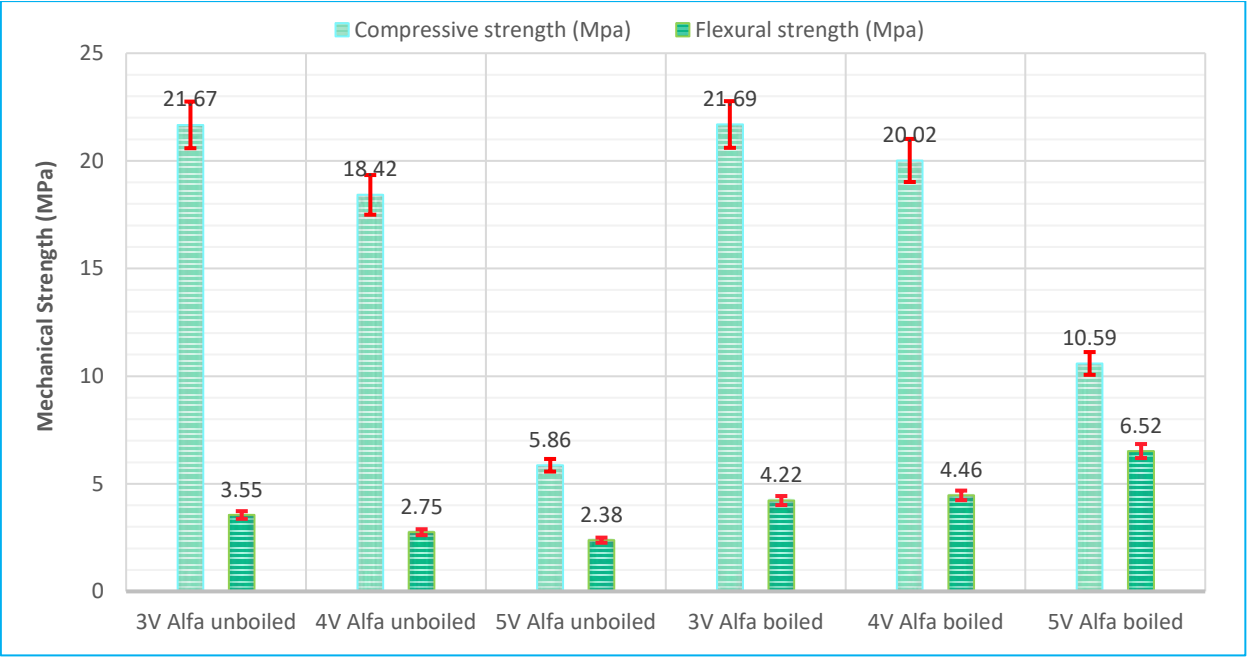


Figure 7. Flexural and Compressive Strength of Alfa-Based Fiber Composites

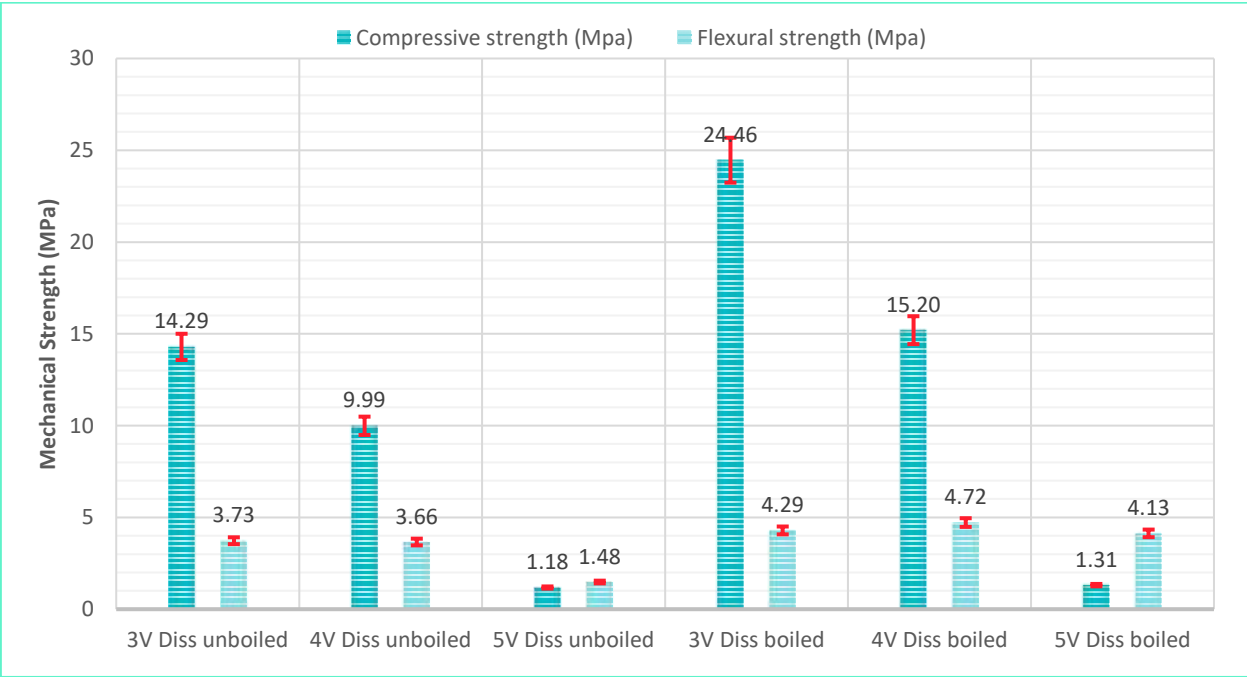


Figure 8. Flexural and Compressive Strength of Diss

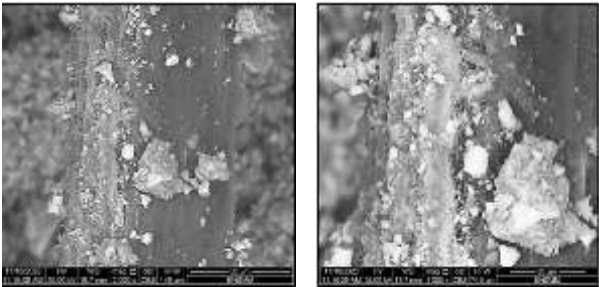


Figure 9. SEM Images of the Contact Surface of a Milled Natural Alfa Composite/Cement Fiber.

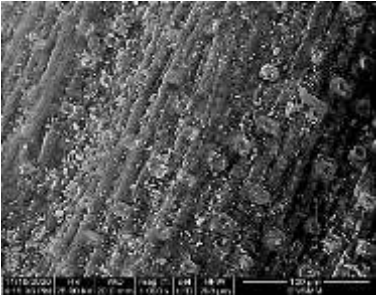


Figure 10. SEM Images of the Contact Surface of a Milled Natural Diss/Cement Composite Fiber

The results of the mechanical tests performed on the samples of pure cement paste showed that its compressive strength is 34.08 MPa which was higher than all the studied composites, while it is the opposite for the flexural strength which is about 2.54MPa. But in all cases the fiber composites show ductile behavior both in flexion and compression, while the tests on pure paste show a weak behavior.

The images in Figure 11 and Figure 12, showing a very rough surface of the cement fragments on the contact surface, demonstrate good adhesion to the walls of the ground Alfa and Diss fibers, as the breakage occurred at the level of the cement and not at the level of the direct surface of the cement/fiber contact.

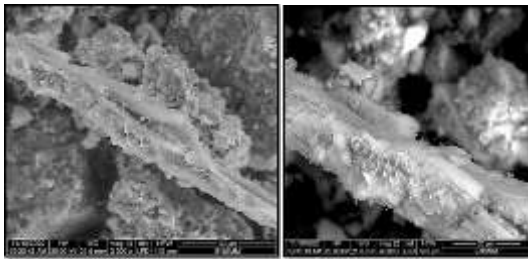


Figure 11. SEM Images of the Contact Surface of a Boiled Alfa/Cement Composite Fiber

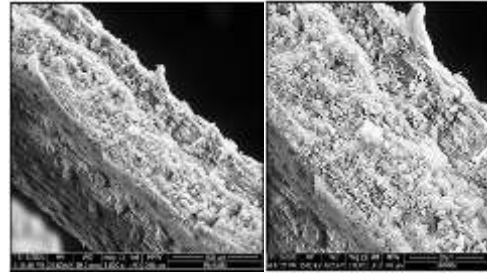


Figure 12. SEM Images of the Contact Surface of a Boiled Diss/Cement Composite Fiber

3.3 Mechanical Tests Performed On Fiber-Based Composites Immersed In Seawater At Different Immersion Time

In addition to the fact that boiling the fibers improves the mechanical properties of the boiled Alfa and Diss fiber composites, we also performed immersion treatments of the Alfa and Diss fibers in seawater for different immersion times. The flexural strength results of Alfa and Diss fiber composites immersed in seawater at different immersion period are shown in Figure 13.

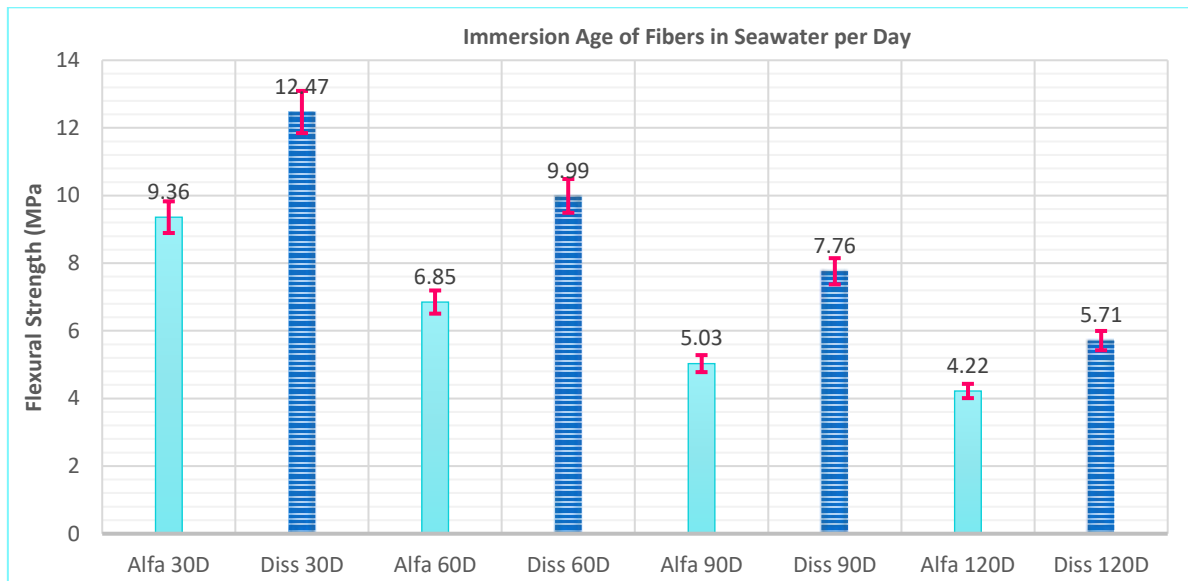


Figure 13. Flexural Strengths of Fiber Composites Immersed in Seawater

Figures 14 and 15 also show the curves of the best flexural strength results for the Alfa and Diss biocomposites immersed in seawater for 30 days, these same figures also clearly show the greater variation in the strain rate of bio-fiber composites compared with cement paste, as shown in Figure 16, which provides significant evidence that the ductility of bio-fiber composites is tangibly improved (strain rate varies between 16% and 29%) compared with that of cement paste, which exhibits

brittle behavior (strain rate varies between 2.9% and 3.06%). From the results of the mechanical tests performed on the samples, we found that the flexural strength of composites reinforced with Diss fibers in seawater is higher than that of composites reinforced with Alfa fibers. Moreover, the flexural strength of the composites immersed in seawater reached a maximum at 30 days of immersion, decreased after this time, but remained higher than the value of the boil treatment.

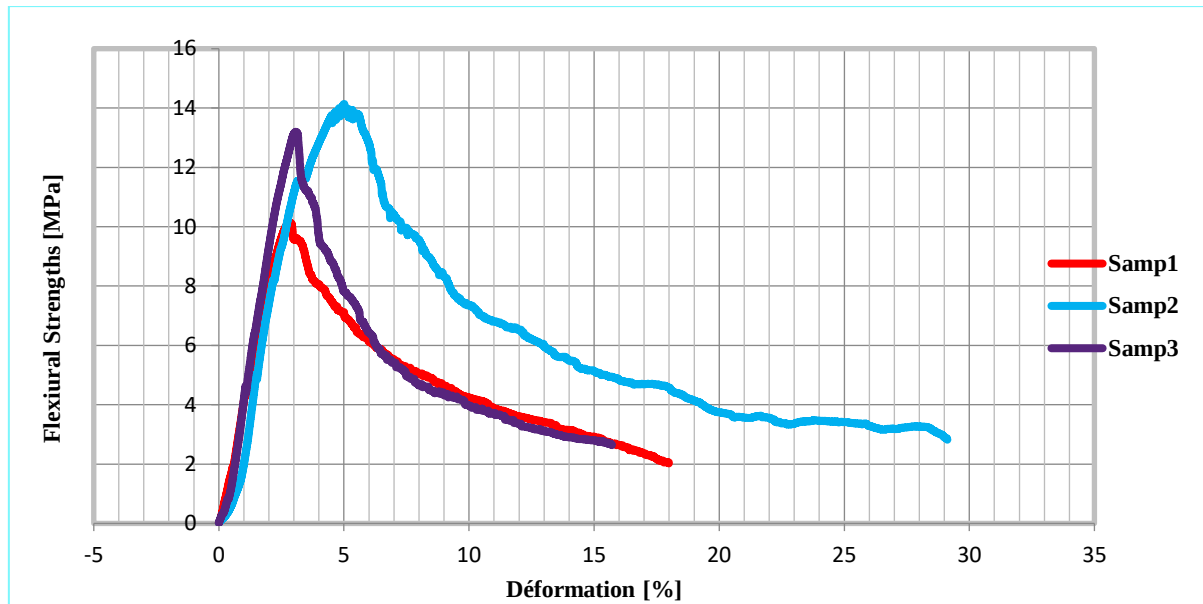


Figure 14. Flexural strengths curves for Diss fiber-based bio-composites immersed in seawater for 30 days

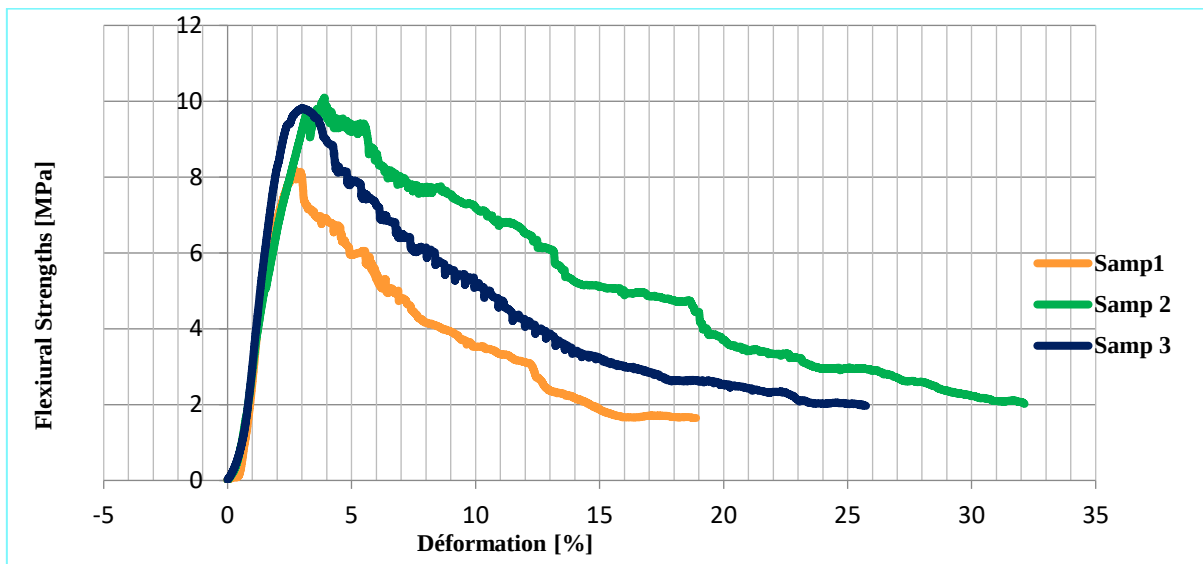


Figure 15. Flexural strengths curves for Alfa fiber bio-composites immersed in seawater for 30 days

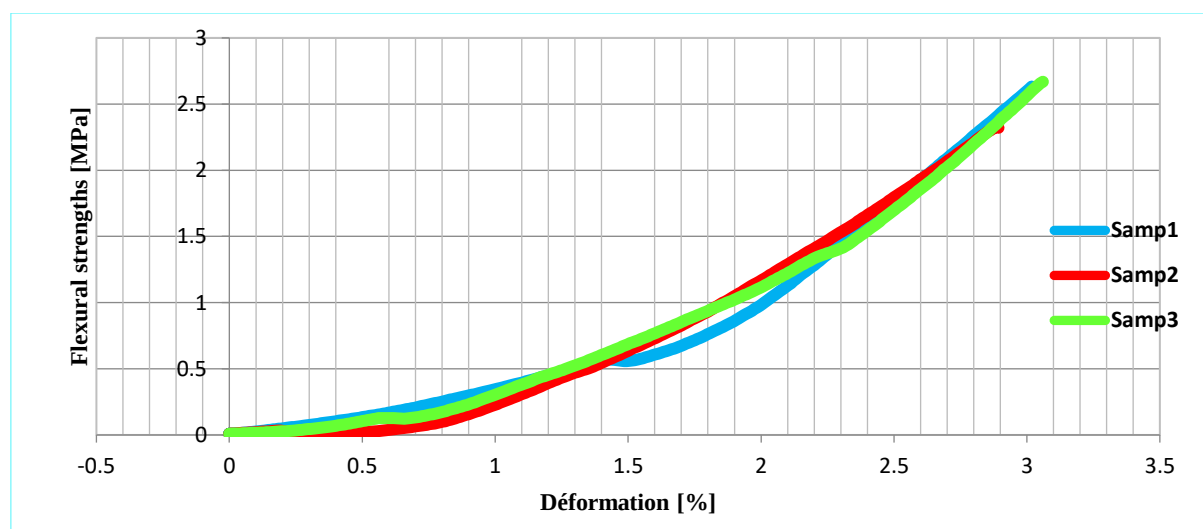


Figure 16. Flexural strengths curves for pure cement

The results of the compressive strengths of seawater immersed fiber composites at different immersion time are shown in Figure 17. It's clearly observed that the compressive strengths of Diss fiber reinforced composites immersed in seawater are higher than those of Alfa fiber reinforced composites. The compressive strength of composites reinforced with Alfa fibers immersed in seawater reached the highest value after 30 days of immersion time, then after it decreases beyond this period. For composites reinforced with Diss fibers, the best strength is reached after 30 days of immersion time while it decreases after 60 days of immersion period.

According to the SEM images shown in Figures 18 to 21, (images of the contact surface of an Alfa composite fiber) and Figures 22 to 25, (images of the contact surface of a Diss composite fiber), the quantity of cement fragments on the fracture surface is directly related to the number of days the fibers have been immersed in seawater. We also note that Alfa and Diss fibers adhere well to cement paste due to the progressive loss of sugars contained in the fibers, and that the presence of salt beyond 30 days in bio-composites certainly deteriorates certain components responsible for their rigidity, but not to the same extent as Alfa fiber-based cementitious bio-composites.

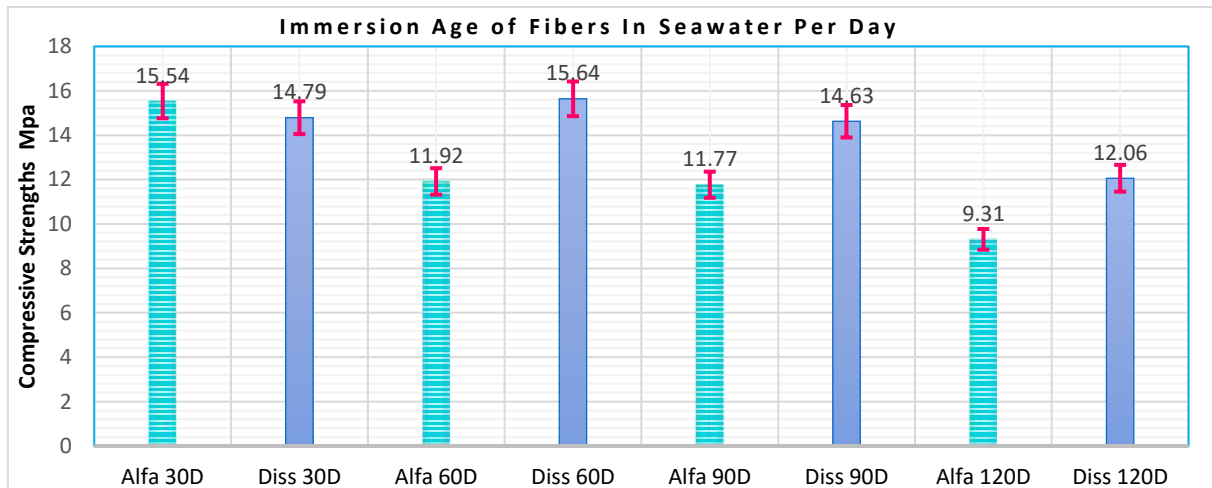


Figure 17. Compressive Strengths of Fiber Composites Immersed in Seawater

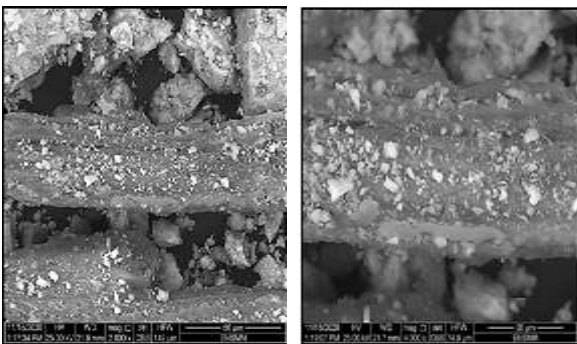


Figure 18. SEM Images of the Contact Surface of an Alfa Composite Fiber Immersed in Seawater 30D/Cement

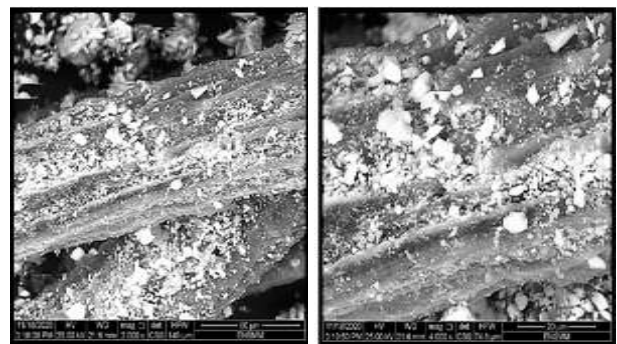


Figure 20. SEM Images of the Contact Surface of an Alfa Composite Fiber Immersed in 90D Seawater/cement

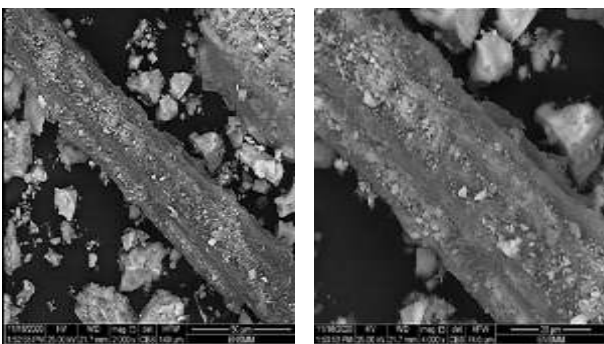


Figure 19. SEM Images of the Contact Surface of an Alfa Composite Fiber Immersed in 60D/Cement Seawater

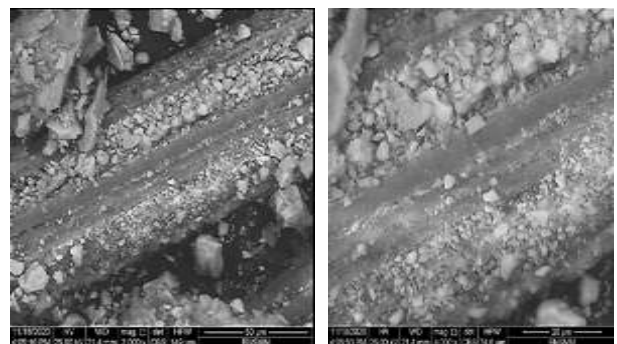


Figure 21. SEM Images of the Contact Surface of an Alfa Composite Fiber Immersed in 120D/Cement Seawater

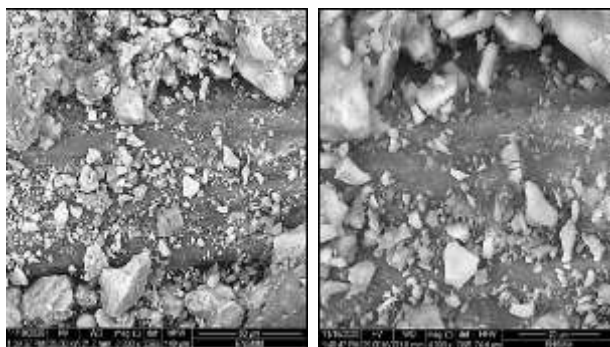


Figure 22. SEM Images of the Contact Surface of a Diss Composite Fiber Immersed in 30D Seawater/Cement

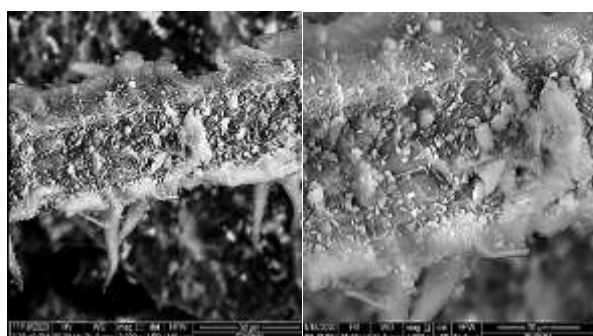


Figure 23. SEM Images of the Contact Surface of a Diss Composite Fiber Immersed in 60D/Cement Seawater

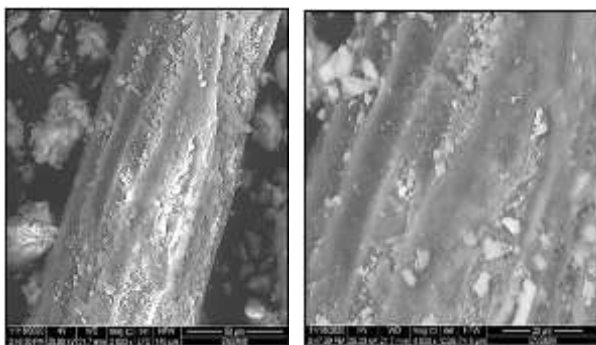


Figure 24. SEM Images of the Contact Surface of a Diss Composite Fiber Immersed in 90D/Cement Seawater

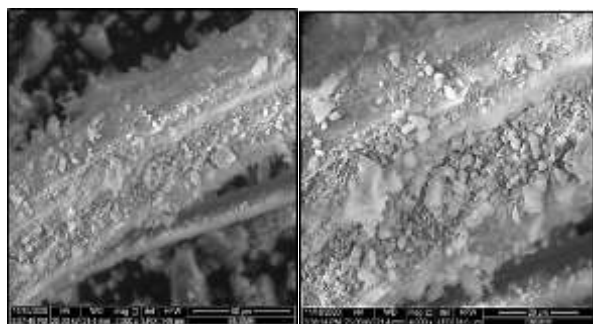


Figure 25. SEM Images of the Contact Surface of a Diss Composite Fiber Immersed in 120D Seawater/Cement

The results of the total sugar tests, as well as the SEM images performed on the surface of a fiber after the specimens ruptured, confirm that the fiber/cement adhesion is caused not only by the thorny structure of the fibers but also by the sugar losses obtained either by the thermal treatment of the fibers or by their immersion in seawater.

4. BEST RESULTS OF MECHANICAL TESTS APPLIED TO BIO-FIBROUS CEMENTITIOUS BIO-COMPOSITES WHOSE FIBERS ARE SUBJECTED TO DIFFERENT TREATMENTS

The most relevant interest in integrating green bio-fibers into the development of cementitious bio-composites is certainly to improve their mechanical characteristics and even increase their flexural strength. Of course, all this is necessarily part of a framework of respect for the environment (reducing energy consumption and greenhouse gas emissions, etc.) as well as good waste management, through the appropriate choice of treatments applied to these bio-reinforces.

All the results obtained from flexural strength tests applied to cementitious bio-composites reinforced with green bio-fibers are influenced by several variables, in particular the rate and form of the reinforcement added to the matrix (rate of fibers cut into strands or ground, ..., Ets), as well as the treatments applied to this natural substance (refined: Bagasse, Wheat, Eucalyptus (Morteza, 2011); Physical chemicals contributing to the dissolution of lignocellulosic materials: Jute (Menadi, 2013); Untreated: Diss (Sellami, 2010); Linseed oil: Diss (Sellami, 2013) (Belkhir, 2021) (Fertikh, 2013); Hygrothermal (boiled): Diss (Sellami, 2013) (Belkhir, 2021) (Fertikh, 2013), Alfa (Belkhir, 2021); Pre-wetted boiled: Diss (Sellami, 2013) (Belkhir, 2021) (Fertikh, 2013), (Fertikh et al., 2024), Alfa (Belkhir, 2021)), ...Ets.

In order to target the most reliable treatment processes and the proportions of suitable formulations to improve the mechanical properties of the composites developed in this study, and despite this diversity of variables, it is essential to network the results of this work with those of previous and similar research work, (flexural strengths vary between 2.1 and 6 MPa according to the references cited in this manuscript), it is remarkable that these results are more or less weaker than those approved in this work.

Table 8 groups together the best results from flexural strength tests applied to cementitious bio-composites reinforced with green bio-fibers.

Table 8. Best results of mechanical tests applied to bio-fibrous cementitious bio-composites whose fibers are subjected to different treatments

Bio-fibers	Treatments applied to Bio-fibers	Flexural test results in (Mpa)	Compressive test results in (Mpa)
Diss	Untreated	3.73	14.29
	Hygrothermal (boiled)	4.72	24.46
	Sea water	12.47	14.79
Alfa	Untreated	3.55	21.67
	Hygrothermal (boiled)	6.52	21.69
	Sea water	9.36	15.54

5. CONCLUSION

The aim of this work is to improve the mechanical properties of fiber composites, as well as to value natural fibers found in Algeria's eastern region, such as Alfa (*Stipa Tenacissima*) and Diss (*Amplidosma Mauritanica*), and to incorporate them into the construction sector as reinforcement in cement matrices.

The mechanical tests (flexure and compression) revealed that:

The strengths of composites reinforced with milled and boiling fibers, as well as milled and immersed fibers in seawater, are higher than those of composites reinforced with natural milled fibers.

The flexural strength of composites reinforced with milled fibers (Alfa and Diss) immersed in seawater is higher than that of composites reinforced with milled and boiled natural fibers, and is significantly higher than that of cement paste and milled natural fiber composites, and exhibits ductile behavior, as opposed to cement paste, which exhibits brittle behavior. The flexural strength of fiber composites is proportional to the increase in reinforcing volume, whereas the compressive strength is inversely proportional. This demonstrates that the fibers can withstand the traction forces that solicit composites in flexion and the lateral tensions that occur in compression.

- The mechanical strength of Diss fiber reinforced composites are significantly higher than those

reinforced with Alfa fibers for the different treatments applied, due to the more condensed presence of thorns on Diss fibers, which increase the adhesion between the fibers and the cement paste.

- The mechanical strengths of composites reinforced with esparto fibers immersed in seawater decrease after 30 days of immersion time (Rabii, 2016).
- The flexural strength of Diss fiber reinforced composites immersed in seawater decrease after 30 days while the compressive strength decreases after 90 days of immersion time.

Despite the absence of soluble sugars, the mechanical strength of composites reinforced with Alfa and Diss fibers immersed in seawater is likely related to decomposition of the structural constituents of these two species (cellulose; lignin; hemicellulose.....).

Because of the effect of salt in saltwater on the amounts of sugars in fibers, the flexural strengths achieved for Alfa and Diss fiber composites immersed in water provide higher resistance than those treated with boiled water.

In contrast to the findings of some works, our study revealed that the usage of El Matine cement had no significant deleterious effect on untreated natural fibers. This demonstrates that the El Matine cement interacts more effectively with natural fibers.

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