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Original Research Article

IMPROVEMENT OF THE MECHANICAL BEHAVIOR OF COMPOSITE MATERIALS WITH DIFFERENT BINDERS BASED ON LOCAL PLANT FIBERS ALFA AND DISS

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Abstract

Concerned about the environmental and economic impact, composite materials are increasingly used in the construction sector. Indeed, the use of plant fibers as reinforcement in construction materials have been the subject of several researches in recent years; the main motivation is the weight gain combined with high mechanical characteristics. The objective of this research concerns the study of the physico-mechanical properties of composite materials with cement and clay matrices reinforced with Alfa and Diss fibers with dimensions ranging from 2 to 8 cm. This involves evaluating the performance of these materials according to the formulation, for a volume ratio (Alfa or Diss / Matrix fibers equal to 4), using dry fibers and pre-wetted fibers. The study of the mechanical properties showed a drop of the performance for both compression and bending strength compared to the reference material without adding fibers (cement or clay paste). It should be noted that the best mechanical performance is obtained for the case of composites ~~s~~ materials with cementitious matrix with pre-wetted fibers. On the other hand, in the case of composites with clayey matrices~~s~~, pre-wetting does not improve the

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mechanical characteristics. It is also noted that the best dimensions of fibers which improve the mechanical characteristics in bending are generally 6 cm for composites with a clay matrix and between 2 and 4 cm for cementitious composites. In all cases, the fibers in composite materials with cement or clay matrix create a bridging effect, making it possible to limit the progression of cracks during loading. This phenomenon gives to the various composite materials a ductile behavior.

Keywords: Alfa, Diss, natural fibers, cement, clay

1. INTRODUCTION

In recent years, the building sector has been marked by an awareness of the need to limit the impact of the materials used on the environment. To achieve this goal, sustainable development should be taken into account in the choice of materials. In this context, construction materials the reinforcement of which consists of vegetable fibers are currently subject to an increasing interest. The main motivation is the weight gain combined with high mechanical characteristics. Due to their ability to replace synthetic fibers, plant fibers are biodegradable, renewable and have very interesting specific mechanical characteristics. With regard to their interest in sustainable development, these fibers are likely to provide additional benefits such as increased tensile strength, limit the cracking and improve the ductility of the materials. To this end, composite materials based on lignocellulosic waste have been the subject of several research studies [1-8].

Indeed, the problems often encountered in the production of cementitious composites materials based on natural fibers are essentially linked to the low reactivity of the latter to cement. The presence of water-soluble components in the lignocellulosic material exerts an inhibitory effect on the hydration reaction of the cement. This inhibitory effect is generally attributed to sugars, hemicelluloses, tannins, lignins and other phenolic components contained in the water-soluble components [14, 18, 19, 20, 24]. To overcome this phenomenon, physical treatments of impregnation or surface coating of fibers have been studied [21, 23, 25].

The alkaline environment developed by the hydration of the cement causes hydrolysis reactions and solubilizes certain components, such as sugars, hemicelluloses and pectins [13], Bilba K and al [5] studied the influence of sugars on the setting of cementitious composites and showed that sugar retards the hydration of the cement.

Concrete containing lignocellulosic materials has been the subject of more interesting research in recent decades. In fact, plant material represents a source of renewable products. Several types of these fibers have been the subject of different researches around the world.

Several studies on natural fibers, such as sisal, jute, esparto, hemp, flax, agave, date palm, coconut, etc…, have been carried out to determine their mechanical characteristics and in particular their tensile strength with a view to incorporating them as reinforcing fibers in materials for the automotive sector or in construction materials [10, 11, 15, 16, 21, 24]

Among the plant fibers in Algeria, the date Palm fibers and Alfa and Diss fibers have been used for the first time in cementitious composite materials [19]. With Palm trees being found in very hot regions and increased dryness of the air and climate in general, all conditions are met in hot deserts, and in particular in the Saharan environment. In Algeria, they are usually found in South, and their use in construction dates back thousands of years. Several researchers have discussed the use and characterization of Date Palm fibers in the construction sector, some references are cited [2, 17, 22].

The plant fibers of sugar cane, sisal, hemp, bagasse, jute in cement-based composites or other binders such as clay or lime or as reinforcements in synthetic matrices were used [5, 8, 26].

This study concerns the feasibility of a material based on Alfa and Diss fibers. These materials fit into a context of sustainable development with the objective of enhancing renewable natural resources and reducing the energy consumption of buildings. To understand the problems of chemical incompatibility observed in composite materials with a cement matrix, the latter has been replaced by a clay matrix. In this study, the objective is to separately evaluate the physico-mechanical and water properties of the composite materials obtained by these two types of fibers (Alfa and Diss) in cement and clay matrices. The dimensions of the various fibers used vary from 2 to 8 cm

Merzoud M et al [18-20] showed that the mechanical strength of cementitious composites based on natural Diss is very low. This phenomenon is certainly due to the exchanges occurring at the matrix-fiber interface and to the hydrolysis and solubilization reactions of certain components such as sugars, hemicelluloses and pectins caused by a strong alkaline medium resulting from the hydration of the cement.The presence of these soluble fractions was also confirmed by adsorption tests of the Diss fibers in the vapor phase. During these tests, moldiness appeared on the unboiled Diss fiber at the end of the eleventh day while no development was observed in the boiled Diss fibers during the entire test period. It can be noted that the water-soluble fractions are the cause of the poor bonding of the materials.Plant fibers provide to cementitious or clay-based composite materials ductile behavior and retard cracking and are used as infill in structures [20]. Fertikh S and al [12] have tested composite materials based on boiled and unboiled Diss fibers in clay matrices; they found that unboiled Diss fibers give better mechanical performance than those of boiled Diss, because the hydrothermal treatment modifies the morphology of the fibers. The use of plant fibers in their natural state in clay matrices does not require any prior treatment, whereas in the case of a cement matrix, hydrothermal treatment is essential to eliminate the water-soluble constituents responsible for the delay in setting and the loss of strength.

The work of Elhamdouni and al [9] is part of the development of local materials such as clay and Alfa fiber in northern Morocco. These materials are abundant, natural, renewable and they have interesting thermal properties. Their objective was to study the effect of Alfa fiber on the thermal characteristics of clay-based materials. For this reason, they mixed clay (chosen as the base material) with different percentages of Alfa fibers (0.5%, 1%, 2%, 3%, 4%). Then they compared the thermo-physical properties of this new material with those of the clay alone to justify the proposed use of this material as an insulating material in rural construction. This comparison of the energy and performance of these two materials allows to conclude that the new material is less effusive than the clay alone, its lightness exceeds that of the clay alone and its use as brick walls should allow energy saving of more than 30%.

To improve the mechanical and water characteristics of the composite materials with cementitious matrix based on Diss fibers, Sellami and al [25] used two different types of treatment. The first treatment consists in extracting the sugars by boiling the Diss fibers. The second treatment consists of waterproofing the Diss fibers to prevent water absorption. The compressive strength and the flexural strength parameters of Diss-cement composites are used to evaluate the performance of the treatments.

They found that the treatment with boiled water improves significantly the mechanical characteristics of the composite materials but does not affect the structure of the fiber. However, the treatment can eliminate the organic components such as water-soluble sugars in particular, which decreases from 30.78% for the untreated Diss to 1,95% for unwashed and boiled Diss, and to 0.72% for the boiled and washed Diss.

Chenah and Amrani [7] studied the chemical and lignocellulosic compositions of Alfa fibers, known as Esparto grass (Stipa tenacissima) and Diss (Ameplodesma mauritanica) and found the constituents presented in Table 1.

Table 1. Analysis of the composition of Alfa and Diss (% W / W)

Content	Alfa or Esparto Grass (%)	Diss (%)
Moisture content	14	12
Minerals matter	2.5	8.63
Organic matter	97.5	91.37
Extractives	13.5	12.03
Holocellulose	51.8	54.39
Lignin	32.2	24.95
Hemicellulose	19.63	26.26
Cellulose	32.17	28.13

The analysis of the chemical components showed that the Alfa and Diss plants contain a large amount of cellulose and α-cellulose, which justifies their use as a source of fiber in several industries. It could be concluded from the obtained results that Alfa and Diss represent an alternative non-woody raw material.

Table 2. Mineralogical Composition of Alfa and Diss (% W / W)

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	MnO (%)	P_2O_5 (%)	SO_3 (%)
Alfa	27.6	0.22	0.14	2.16	1.57	0.49	0.89	<0.05	<0.05	<0.05	1.15
Diss	13.77	<0.05	0.09	1.21	0.97	1.47	3.5	<0.05	<0.05	0.13	0.97

The authors found that the content of SiO_2, Al_2O_3, Fe_2O_3, CaO, SO_3 and MgO was higher in Alfa than In Diss. However, the concentrations of P, K and Na were important in Diss. The main mineral components of Alfa (Esparto Grass) and Diss are silica, with SiO_2 content of 27.6% and 13.77% respectively. These are the main minerals found in grasses.

2. MATERIALS AND EXPERIMENTAL METHOD

2.1 Materials

2.1.1 Fibers

The English name of Alfa (Stipa Tenacissima) is: Esparto Grass or Esparto. The plant is a grass and belongs to the Poaceae family. It is a perennial herbaceous plant that grows in arid regions of North Africa. Alfa grows in clumps about one meter high, forming large "slicks" in areas of medium aridity. The plant covers in particular large areas of the Algerian highlands. The Alfa is also of ecological interest to prevent erosion. The plant is cylindrical and its structure is formed by several bundles of filaments, approximately circular, aligned along the length of the plant.

Diss (Ampelodesmos Mauritanica, poaceae family) is a herbaceous plant widely found in North Africa and in the dry regions from Greece to Spain. Very fibrous in nature, Diss contains a high percentage of silica in the amorphous state, which gives it high tensile strength. However, little work has been done on the use of these fibers in construction materials despite their abundance and their fibrous nature which allow them to provide materials with interesting mechanical performance. Work on composite materials based on Diss fibers has shown that they must undergo a heat treatment to remove sugars and water-soluble components the constraints of which, both economic and environmental, favor the integration of the concept of delayed setting and hardening of the material [18, 19, 20].

- The Alfa collected in the plains of Tebessa (high plateau region) (Fig. 1a).
- The Diss of the mountains of Souk-Ahras region (Fig. 1b).

The two cities are in Eastern Algeria.

Fig. 1a. Plant Alfa

Fig. 1b. Plant Diss

The selected stems were placed in the laboratory for drying them, to be able to grind them and extract the very fine fibers, which will be cut later according to the dimensions chosen beforehand, in fibers of 2, 4, 6 and 8 cm (figures 2a et 2b).

Fig. 2a. Alfa Fibers

Fig. 2b. Diss Fibers

2.1.2 Fiber Morphology

The FEI Quanta 250 type Electronic Scanning Microscope (SEM) was used to characterize the morphology of Diss and Alfa fibers at the acceleration voltage of 30 KV (figures 3 and 4).

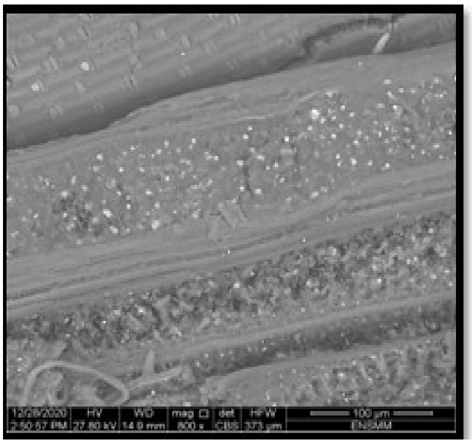

Fig. 3. Photo (ESM): Alfa Natural Fiber, Mag 800

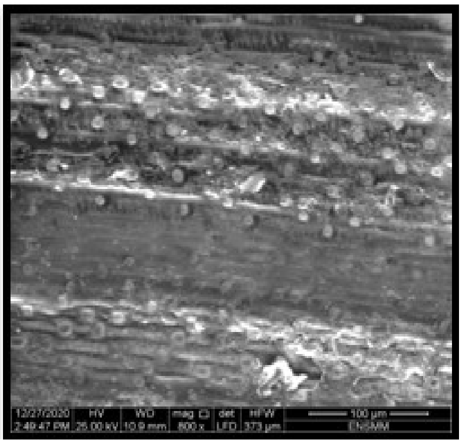

Fig. 4. Photo (ESM): Boiled Alfa Fiber, Mag 800

The Alfa fibers are chosen for the reason of its availability and price. Alfa fibers are in most cases composed of 45% cellulose, 24% hemicellulose, 24% lignin, 2% ash and 5% wax. The bundles of Alfa fibers are characterized by an average diameter of 113 µm and a density of 0.89 g.cm-3 [9].In addition, the Alfa fibers have stems which are tough, long and very strong. Analysis of the Scanning Electron Microscope (SEM) (Figures 5 and 6) shows that the surface of the stem is rough, which makes it possible to create a very good bond between the fibers and the binder.

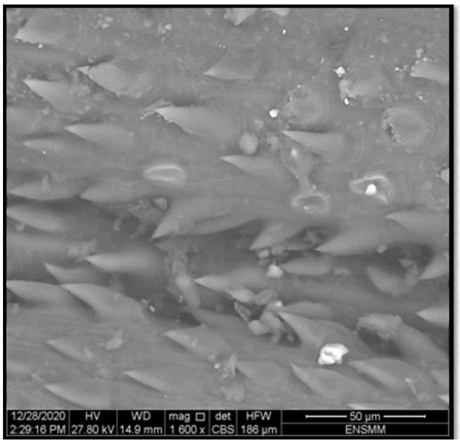

Fig. 5. Photo (SEM): Natural Diss Fiber, Mag 1600

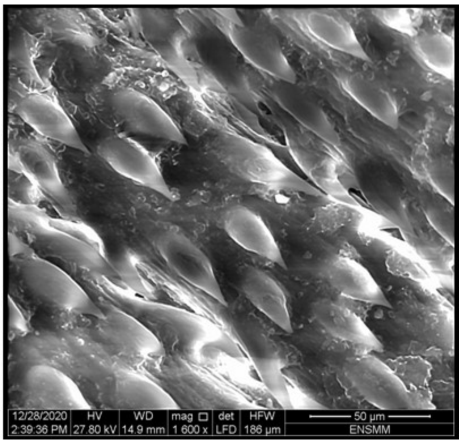

Fig. 6.Photo (SEM): Boiled Diss Fiber, Mag 1600

The SEM observations in Figure 5 show a fiber covered on its inner surface with spines about 20 µm long and 10 µm in diameter at the base. These spines are spaced approximately 10 µm apart and distributed relatively evenly over the surface. The surface of the spines is not homogeneous and seems covered with a component the texture of which evokes a natural wax. The areas between the spines are arranged in more or less noticeable streaks, which are covered with fine tangled needles distributed evenly. We will see later that the various treatments have made it possible to dissolve or at least "release" the components (wax type) present on the surface of the needles.
The observation of the boiled fibers using SEM in Figure 6 from the inside of a Diss fiber that had been boiled shows that the spines did not disappear as a result of the treatment (Figure 6). On the other hand, it is noticeable that the surface of the thorns is cleaned of a number of impurities. It is the same for the surface between the thorns on which the chains observed on the raw fiber can no longer be distinguished.

2.1.3 Binders

Two types of binders have been used:
- CPJ CEM II 42.5 Cement from Hadjar Essoud (Wilaya of Skikda), Algeria
- Clay from the Benouhiba brickyard located at Treat (Wilaya d'Annaba), Algeria.

2.1.4 Preparation of Testing Samples

During the manufacture of the materials, a paste of cement and natural clay (matrix + water) was initially prepared, to which are added Alfa and Diss fibers of different sizes and different treatments of dried and pre-wetted boiled fibers with a volume ratio equal to 4.0 (fibers / matrix equal to 4.0), a water / cement ratio equal to 0.7 and a water / clay ratio equal to 0.4.
After mixing and homogenizing the fresh material, it was placed in prismatic molds (4 x 4 x 16 cm) using shock table: 20 blows in two phases (Figure 7).

Fig. 7. Shock Table

Fig. 8. Samples (4x4x16 cm)

The samples of cement matrix composite materials were placed in a humid chamber (20-2 ° C, RH = 98%) for up to 28 days. At the end of the treatment, the test samples have been placed in the oven at 50 ° C until obtaining a constant mass (Figure 8).
The clay matrix samples were placed in the open air at a temperature of 20 ° C.

2.2 Experimental Methods

2.2.1 Fiber Tensile Test

The fiber tensile tests were carried out by the same machine on fibers of different dimensions and the results are given in stress-strain in figure 9.

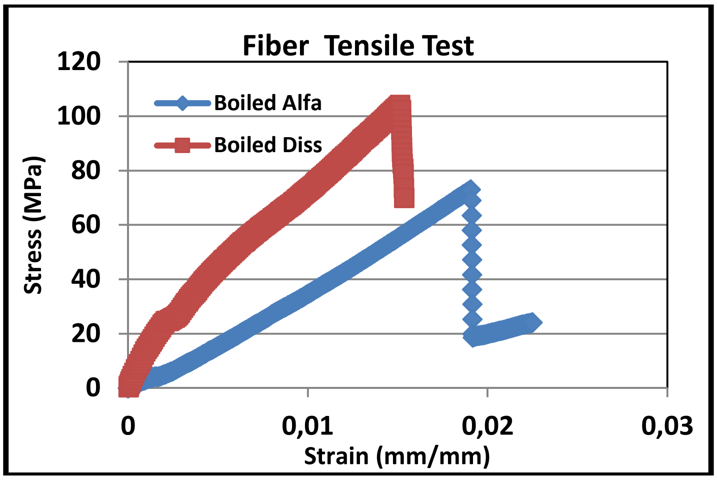

Fig. 9. Stress-Strain Diagram of Boiled Alfa and Diss Fibers

2.2.2 Mechanical Tests of Composite Materials

The mechanical resistances in compression and in traction by three-point bending test were determined according to the standard EN 196-1, on prismatic samples of 4 x 4 x 16 cm. These tests were carried out using a Zwick / Roel type BT1-FR020THW.A50 test bench with a capacity of 20 KN (Figure 10), specially designed for this type of material testing, connected to an automatic data acquisition system (Figures 12 and 13).

Fig. 10. Universal Machine type Zwick / Roell,

Fig. 11. Fiber Tensile Bench Capacity 20 KN

Fig. 12. Three Points Flexural Bench

Fig. 13. Compression Bench

3. RESULTS AND DISCUSSION

3.1 Fiber Characteristics

The characteristics of Alfa and Diss fibers are presented in table 3.

Table 3. Fiber Characteristics

Parameters	Alfa	Diss
Bulk density (g/l)	32.8	31.6
Tensile strength (MPa)	73	104
Modulus of elasticity (MPa)	3900	6500
Maximum déformation (%)	1.9	1.5
Absorption (%)	100	120

3.2 Fiber Analysis with EDX

Analysis of Alfa and Diss fibers with EDX (Energy-Dispersive X-ray spectroscopy) allowed to determine the mineralogical components contained in natural or boiled fibers (Tables 4 and 5).

Table 4. Chemical Components of Alfa Fibers

fiber	Natural Alfa	Boiled Alfa
Element	Atomic %	Atomic %
C K	63.34	73.71
O K	35.55	24.91
Al K	0.16	0.26
Si K	0.45	0.69
S K	0.08	/
K K	0.11	/
Ca K	0.31	/
Mg K	/	0.43

Table 5. Chemical Components of Diss Fibers

fiber	Natural Diss	Boiled Diss
Elément	Atomic %	Atomic %
C K	59.68	62.95
O K	38.55	36.43
Al K	0.18	0.09
Si K	1.33	0.53
K K	0.19	/
Ca K	0.07	/

It can be seen from Tables 4 and 5 that the plant fibers Alfa and Diss contain roughly the same mineralogical constituents, namely carbon C, oxygen O, silica Si and aluminium Al, which give the fibers their resistance.

3.3 Mechanical Resistance

3.3.1 Mechanical Strength of Matrices

The results of the mechanical strength of clay and cement pastes are presented in Table 6.

Table 6 : Strength of Binders

Matrice	Flexural Strength (MPa)	Compressive Strength (MPa)
Clay	0.84	3.47
Cement	5.34	14.2

3.3.2 Mechanical Strength of Clay-based Composite Materials

Figure 14 presents the flexural strength of Alfa and Diss composite materials in an argillaceous matrix, where it can be seen that the best flexural strength is obtained for the 8 cm fibers for the Alfa fibers and of 6 cm for the Diss fibers. This is explained by the fact that the flexural strength of the clay paste is low and therefore requires significant anchoring of the fibers in the matrix. In all cases, the flexural tensile strength remains low, but exhibits ductile behavior.

The pre-wetting of Alfa fibers has no influence on the flexural tensile strength of clay matrix composites since the hydration problem does not arise.

Figure 15 shows that the compressive strength is very important as soon as the fibers reach 6 cm in length for the Alfa and Diss fibers, and the pre-wetting has no influence on the compressive strength.

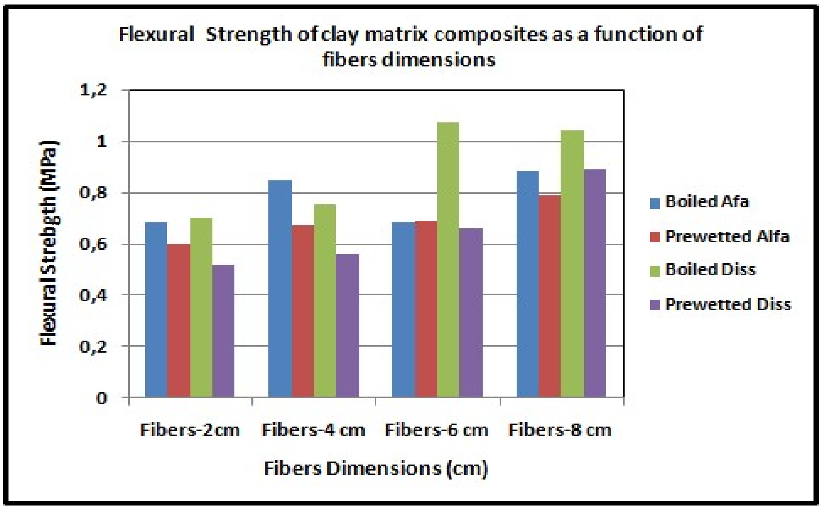

Fig. 14. Flexural Strengths of Clay-based Composites as a function of Fiber Dimensions

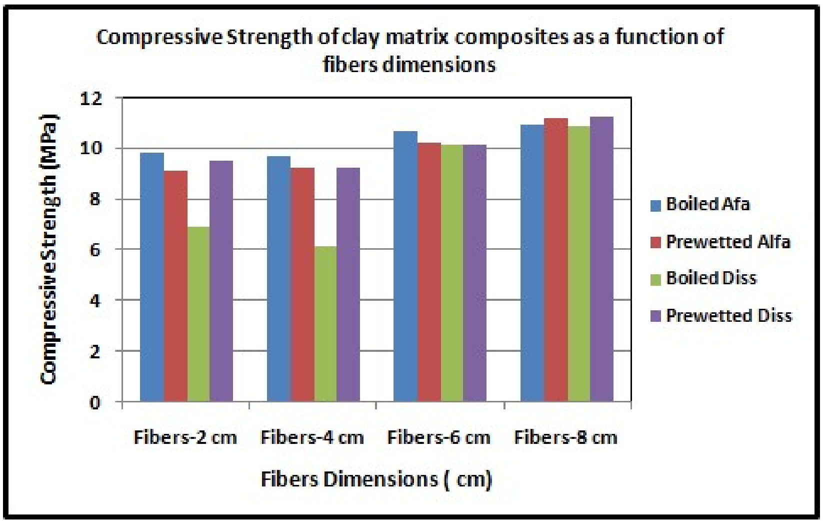

Fig. 15. Compressive Strength of Clay-based Composites as a function of Fiber Dimensions

3.3.3 Mechanical Strength of Ciment-based Composite Materials

The results presented in figure 16 show that the best flexural strength of cement composite materials based on Alfa and Diss fibers is obtained for Alfa and Diss fibers of length varying between 2 and 4 cm. This is because the fibers adhere well to the cement matrix.

It should be noted that the flexural strength test of Diss composite materials gives higher strength than those of Alfa, because Diss fibers contain spines which surround the fibers and have good adhesion between the fibers and the cementitious matrix and a high tensile strength.

Pre-wetting does not bring any improvement to composites based on Alfa fibers, on the other hand it improves the mechanical strength of composite materials based on Diss fibers, this is due to the high water absorption rate of these fibers compared to those of Alfa.

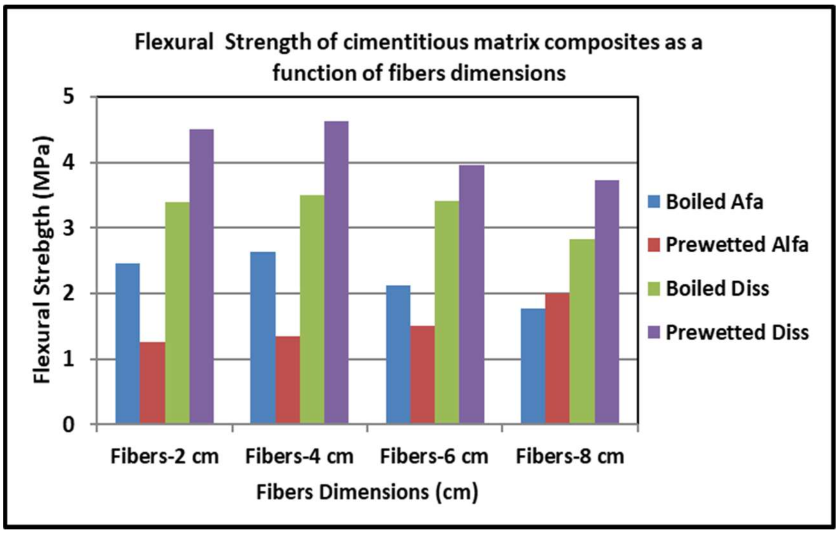

Fig. 16. Flexural Strength of Cementitious Matrix Composites as a Function of Fiber Dimensions.

It can be seen in figure 17 that the best compressive strength of composite materials based on Alfa and Diss fibers is obtained for fibers of length between 2 and 4 cm. This can be explained by the fact that at the same rate, the 2 cm fibers are more numerous, which generates high lateral tensile strengths, delays the breakage of their composites and therefore increases the compressive strength.

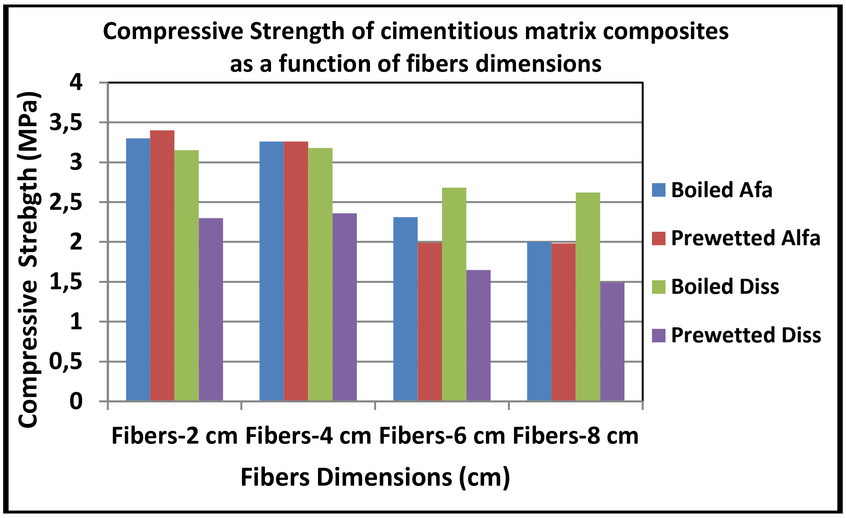

Fig. 17. Compressive Strength of Cementitious Matrix Composites as a Function of Fiber Dimensions

4. CONCLUSIONS

The introduction of natural fibers in different matrices improves the mechanical behavior of their composites. Although in general the strengths obtained are low compared to the pure paste, which exhibit a fragile behavior, the incorporation of fibers in the matrix guarantee a ductile behavior both in bending and in compression.

1. The Alfa and Diss fibers used in this study have sufficiently large tensile forces and can limit crack progression and delay the rupture.
2. The flexural strength of Alfa and Diss fiber composites in clay matrices are of the same order of magnitude as the flexural strength of the paste, but they have a ductile behavior which slows down the cracking. The best flexural strength of Alfa fiber composite materials is obtained for 8 cm long fibers, and for Diss fiber composites the best flexural strength is found for 6cm long fibers. This is explained by the fact that the flexural strength of the clay paste is low, requires strong anchoring of the fibers in the matrix. It is also noted that pre-wetting does not improve the strength of all clay matrix composite materials.
3. In contrast, the compressive strength of Alfa and Diss-fibers based composite materials with clay matrix is shown to have high strength exceeding 10 MPa, while the compressive strength of clay paste is only of 3.47 MPa. This is explained by the fact that the fibers exhibit high lateral strength caused by the compression of the composite material which delay the rupture.
4. Cementitious composite materials based on Alfa and Diss fibers have lower flexural strength than cement paste (5.34 MPa), but acceptable. It is to be noted that the flexural strength of composites based on Diss fibers is higher than those of the flexural strength of Alfa fibers. The best values are achieved for the dimensions of Alfa and Diss fibers of 2 cm. This is explained by the fact that the fibers are well anchored in the cement paste.
5. The compressive strength of Alfa and Diss fibers is much lower than the compressive strength of cement paste (14.2 MPa). The best values of this strength are obtained for fibers with dimensions of 2 to 4 cm, due to the large number of fibers of these dimensions which will oppose the lateral strength and would therefore prevent brittle fracture.
6. It is observed that pre-wetting improves the flexural strength of composite materials based on Diss fibers due to their high absorption kinetics.

ADDITIONAL INFORMATION

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