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Enhancing the Performance and Durability of Eco-Friendly Mortar with Diss Fibers (Ampelodesmos *mauritanicus*)

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ABSTRACT

This study investigates the potential use of Diss fibers as a sustainable alternative in eco-construction and civil engineering. The research introduced Diss fibers as aggregates, partially replacing conventional sand in mortar by volume with proportions of 1/3 and 2/3, aiming to create an eco-friendly and lighter mortar. In this context, various properties of the fresh mortars, such as density, workability, and occluded air content, were examined. Additionally, the mechanical performance in the hardened state, including compressive and flexural strengths, was evaluated. Durability parameters such as water absorption, capillary absorption, and resistance to aggressive media were also assessed. The results demonstrated that mortars incorporating Diss fibers were lighter and more workable. The inclusion of these fibers enhanced the flexural strength and chemical resistance, as evidenced by the low percentages of mass loss in aggressive solutions such as HCl and CH3COOH. However, the introduction of the fibers negatively influenced the mechanical resistance and water absorption—both by immersion and capillarity—due to the porosity introduced into the composites.

1. INTRODUCTION

The use of natural plant fibers in composite materials has been increasing in recent times. The need to use them aligns well with sustainable development goals due to their environmental benefits, because they have considerable environmental interests: annually renewable, biodegradable, recyclable, and have a neutral carbon balance [1].

The introduction of natural plant fibers as reinforcement in composite materials offers several advantages; first of all, it is a local resource, readily available and at a low cost compared to synthetic or artificial fibers. These plant fibers used in composite materials would also reduce the environmental impacts unlike conventional composites because they are renewable raw materials, biodegradable, have a neutral carbon balance and require less energy for their production [2]. Finally, this explains the interest in being a good investment choice in eco-materials.

This project aims to use the plant Diss, known under the scientific name (Ampelodesmos *mauritanicus*) of the lingo cellulosic family; it is a plant widespread in North Africa and the zones of Mediterranean climate, in particular Algeria, and the dry regions from Greece to Spain. The fibers of this plant have been used for a long time for the manufacture of eco-constructions based on earth and traditional materials. Diss fiber has a tensile strength of about 100 MPa, a density of 850 kg/m^3, and a spiny structure which can offer a high adherence to the cement paste [3].

In this work, the introduction of vegetable fibers and in particular Diss fibers, is used to reinforce composite mortars in order to have low-cost materials and less CO_2 emission. In previous studies, several types of fibers such as flax fibers, palm fiber, coconut fibers, sisal fibers, Alfa fibers and Diss fibers, have been used as reinforcement in composite materials.

Christine et al. [4] worked on the effect of the addition of potash-treated coir fibers on the mechanical properties of clay/cement building materials. The results obtained show that the incorporation of coir fibers enhances the mechanical strength and deformability of clay/cement mortars, and the adhesion between the clay/cement matrix and fibers becomes strong with treated coir fiber.

Cement mortars reinforced with sisal and coconut fibers and exposed to alkaline solutions (of calcium and sodium hydroxide) were made by Filho et al. [5]. It was found that these types of fibers completely lost their flexibility and strength after 300 days. The embrittlement of the composites can be mainly associated with the mineralization of the fibers due to the migration of ions resulting from the hydration reactions, especially calcium hydroxide, by exposure to light of the walls and voids of the fibers.

The study of the mechanical properties of a flax fiber reinforced concrete was realized by Page et al. [6], introducing the fibers in three amounts and two different lengths; the results showed a significant alteration of workability and an increase of the air content in the concretes with the addition of fibers. However, the occluded air also caused a decrease in the compressive strength of the different concretes. On the other hand, the tensile strength rose with the fiber length and content.

Gharibi [7] studied the advantages of introducing plant fibers (hemp, chenevotte) in self-compacting concretes; it showed acceptable and effective results in some properties, such as shrinkage, and behavior under high temperatures and in aggressive environments.

The effect of substituting wood chips with barley straw in lightweight sand concrete was investigated by Belhadj et al. [8]. They found that by reason of its greater deformability, barley straw improves the toughness and ductility of sand concrete and reduces its dimensional variations. It also provides good thermal insulation at a low cost. It adheres well to the cement matrix, increases its stiffness and deformability, and does not break after the matrix fracture.

Belkadi et al. [9] showed that mortars reinforced with plant fibers have a better deformation capacity than mortar without fibers. The incorporation of fibers in the mortar tends to generate an additional porosity in the matrix and leads to a decrease in thermal conductivity of about 15%.

Still, and in the same context, another approach started by Khelifa et al. [10] showed that the use of Alfa fibers in an eco-concrete negatively affects the workability and compressive strength; as the content of Alfa fibers increases, the strength of concrete decreases. However, Alfa fibers improve the tensile strength of the concrete and reduce crack propagation, especially at the beginning of their appearance. This phenomenon depends on the amount of fibers up to a certain threshold where the effect is reversed.

Other work undertaken by Merzoud [11] on Diss fiber composites gave higher strengths; this confirms that the fibers play the role of reinforcement. The fibers have the main role of taking up the stresses and increasing the ductility of the composite, and also control the crack propagation and delay the final failure of the material by dissipating the excess energy. Fiber-based composites have both the advantages of lower density and thermal conductivity.

Merzoud and Habita [12] studied the development of a cementitious composite based on Diss fiber with samples treated, and others untreated, by boiling water. They found that in compression the failures of the specimens of boiled Diss did not manifest brittle failure, the specimens remained almost intact, unlike the untreated specimens. They indicated that the presence of sugars could be a factor in these contradictory results. Concluding that the use of these composites as fillers, in structures subjected to seismic forces, allowed them to reduce the lightness of the material and they exhibited good ductile behavior. These improvements in tensile strength are mainly due to the adherence of the fibers to the cement paste because of their spiny structure, the formation of "packets" by the cement paste, and their fine structure allowing them to be placed horizontally and thus better participate in the resumption of tensile forces.

Examining the potential of using ground Diss fibers in a cementitious matrix as a composite material (lightweight concretes), Fertikh et al. [13] noted that the boil-processed Diss fibers offers the composite very good ductility in addition to lightness. These two characteristics prove to be important for fillings of structures subjected to seismic loads, without omitting to indicate that the Diss fiber composites with cementitious matrices underwent extreme dimensional variations of the order of 1.8 mm/m, but acceptable for filling materials.

Sellami et al. [14] in their work on the development of cementitious composites, based on local plant fibers (Diss), showed that composites with Diss fibers have better ductile behavior in bending than in compression, but this is inversely proportional to the volume of these fibers, so the more the percentage of fibers increases, the more the mechanical resistance decreases. A loss of strength of the latter in seawater was also found, following chemical interactions affecting the basic structures of the fibers such as cellulose, hemicellulose and lignin.

The study of the performance of mortars reinforced with natural fibers (Doum and Diss), was conducted by Achour et al. [15]. In this study the fibers are treated with NaOH to remove amorphous materials (hemicellulose and lignin), increase crystallinity, decrease water absorption, and improve fiber/matrix adhesion. It has also been observed that the incorporation of vegetable fibers in mortars decreases their density (lightening the mortar) as well as its compressive strength, with an increase in porosity and water absorption. This caused an improvement of the flexural strength and a reduction of the thermal conductivity benefiting the capacity of thermal insulation of these studied composites.

In this research, several beneficial aspects of the use of plant fibers in composite materials have been observed. Therefore, introducing the plant fibers of the Diss plant as aggregates partially substituting ordinary sand in the composition of a mortar will produce a composite that is cheap, less CO_2 emitting, characterized by interesting thermal and sound properties and possesses an acceptable mechanical behavior. The main objective of this research is based on the beneficial use of plant fibers in composite materials and to try to understand the behavior of mortar with plant fibers in aggressive environments in order to determine the possibility of using the fibers in construction.

2. USED MATERIALS

In this study, local materials were used, such as cement of the type CPJ-CEM II 42.5 (S-L) from the cement plant of Hdjar-Soud, Skikda, Algeria. Local quarry sand, from the quarry of Ben-Brahim, Constantine, Algeria. Diss fibers from the bushes near the city of Skikda, East of Algeria. And finally, drinking water (tap water). These local materials are of good quality and available in eastern Algeria, study locations.

2.1 Sand

The used sand is a crushed sand of class 0/4, extracted from the quarry of Ben-Brahim, Constantine, East of Algeria. Its characteristics and particle size curve are illustrated in Table 1 and Figure 1, respectively.

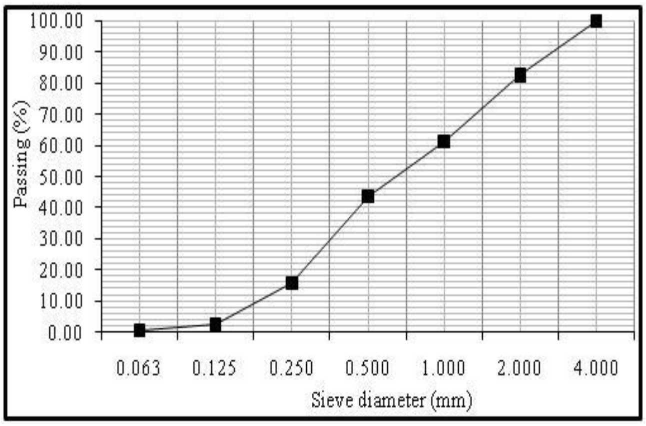

Figure 1. Grain size curve of the quarry sand

Table 1. Sand properties

Properties	Quarry Sand
Apparent density (g/cm³)	1.450
Absolute density (g/cm³)	2.620
Value of blue Methylene (%)	0.7
Fineness modulus (%)	2.93
Sand equivalent (%)	61
Absorption (%)	2.00
CaO (%)	91.60
Cl (%)	0.04

2.2 Cement

The cement used is the CPJ-CEM II 42.5 (S-L) from the cement plant of Hdjar-Soud, Skikda, Algeria; its characteristics are listed in Table 2.

Table 2. Cement properties

Properties	Values
Apparent density g/cm³	1.04
Absolute density g/cm³	3.08
Blaine-specific surface (cm²/g)	3200
Normal consistency (%)	28.6
Initial setting time (min)	186
Final setting time (min)	228
Compressive strength at 28 days (MPa)	55.15
Flexural tensile strength at 28 days (MPa)	7.61
CaO (%)	60.25
Al_2O_3 (%)	5.45
Fe_2O_3 (%)	3.52
SiO_2 (%)	22.21
MgO (%)	1.12
Na_2O (%)	0.16
K_2O (%)	0.8
Cl- (%)	0.003
SO_3 (%)	2.45
P.A.F (%)	7.5
Free CaO (%)	2

2.3 Diss fibers

Figure 2. Diss plant

The "F" fibers of the Diss plant (Figure 2) were picked from the mountains of Algeria. They were cut into stems 2.5 cm tall, and then treated with boiling water for 20 min (Figure 3) to eliminate the cellulose which influences cement setting and hydration and the organic matter impurities which increases the demand for water, according to Fertikh et al. [13], and to improve the adherence with the cement. In these tests, the boiling treatment of Diss allows the reduction of soluble materials due to their incompatibility with the cement paste and improves the mechanical characteristics of the composites regardless of the fiber structure evolution [12]. The treated fibers have a density of 700 g/cm^3 and a high absorption coefficient of the order of 61%, a tensile strength of 100 MPa and an elasticity modulus of the order of 1300 MPa. These characteristics promote the flexural behavior of cementitious materials and their capacity to deform [9].

The spiny structure of Diss fibers, gives them a high adhesion to the cement paste. It contains mainly silica of the order of 75 to 80% [11, 12, 15, 16].

Figure 3. Diss fibers after treatment

3. EXPERIMENTAL PROGRAM

The objective of this work is to make an ecological mortar by incorporating as many Diss fibers as possible and studied the modifications made by these fibers on the properties of this mortar in the fresh and hardened state, thus determining the field of their use. In this experimental program the ordinary sand of a 1/3 mortar (1 volume of cement for 3 volumes of sand), was substituted by Diss fibers with the fixed parameters, i.e., the dosage of cement and water (the required water being fixed by preliminary consistency tests). Three formulations were used:

- RM reference mortar based on ordinary sand.
- Mortar 1/3F is formulated with 2/3 volume of ordinary sand and 1/3 volume of fibers.
- Mortar 1/2F is formulated with a 1/2 volume of ordinary sand and 1/2 volume of fibers.

The Diss fibers are introduced to have their effect on the different properties of the mortar (1/3F formulation), then study the modifications made to this composite if the rate of fibers is increased (1/2F formulation). The effect of the fibers on the properties in the fresh and hardened state obtained on the two formulations is compared with those obtained only on a reference formulation (RM). The composition of the samples is presented in Table 3.

Table 3. Composition of mixtures

Notations	Cement	Sand	Fibers	Water
RM	1V	3V	0	1V
1/3F	1V	2/3V	1/3V	1V
1/2F	1V	1/2V	1/2V	1V
V	Volume			

The tests performed on the fresh mortar were:

- Density measurement by weighing empty molds and filled with mortar according to NF EN 1015-6 standard.
- Consistency measurement by mini cone according to NF EN 1015-3.
- Measurement of the occluded air by an aerometer of mortar according to NF EN 1015-3.

The tests performed on the mortar in the hardened state were:

- Flexural tensile strength on specimens of size 4×4×16 cm^3 preserved in water with 20°C and compressive strength on half prisms of size 4×4×4 cm^3 at the age of 7, 28 and 90 days, as per NF P18-406 and P18-407 standards.
- Water absorption according to NF EN 12390-2, obtained on test specimens measuring 4×4×16 cm^3 kept in water for 28 days, then dried in an oven at 105°C for 24 hours to obtain their dry weight, the test specimens are immersed in water for 24 hours to obtain their wet weight.
- Capillary absorption on prismatic specimens of size 4×4×16 cm^3, as per NF EN 480-5 standard. After conservation of the specimens for 28 days in water, then 72 hours in an oven at 105°C, the side face subjected to unidirectional absorption of water from below for a period of 257 minutes.

Chemical attack by aggressive solutions of respectively (5%HCl, 5%H_2SO_4, 5%CH_3COOH and 5%NaCl) with 5% of concentration at times of 3, 7, 14, 21, 28, 56 and 90 days of immersion (after 28 days water cure) according to ASTM C-267-96. The chemical resistance is evaluated the loss of mass which is given by the formula:

$$P = \frac{Mj - M0}{M0} \times 100 \qquad (1)$$

where, *P* the loss of mass in %, *Mj* the mass in grams of the specimen stored in the solution at age *j* and *M0* in grams, the mass of the specimen after 28 days of storage in water.

4. RESULTS AND DISCUSSION

4.1 Density

Diss fibers have a lower density than crushed sand which allowed us to confirm a light material quality of Diss fiber-based composites (Figure 4) compared to quarry sand-based cement mortar. The addition of natural fibers increases the porosity of the mortar and makes the composite lighter [8].

The decrease in density is attributed on the one hand to the low density of the fiber compared to ordinary sand and on the other hand to the air voids trapped in the matrix by the introduction of the fibers during mixing [17]. The results obtained are consistent with those found by Sellami et al. [14], Merzoud [11] and Achour et al. [15].

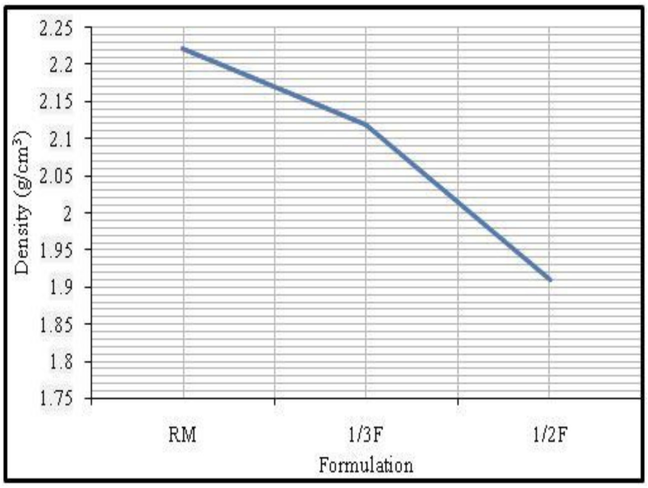

Figure 4. Density variation with fiber content

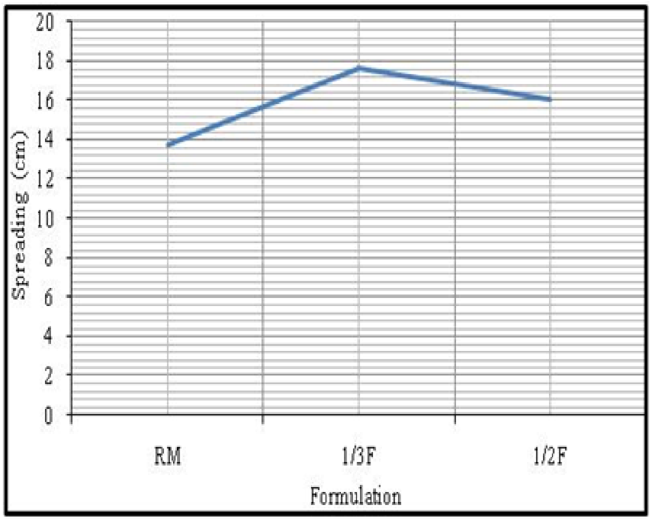

Figure 5. Variation of the consistency according to the fiber content

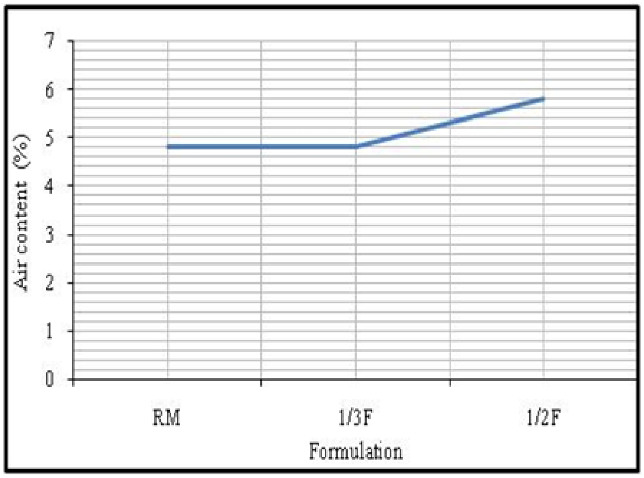

Figure 6. Variation of occluded air as a function of fiber content

4.2 Consistency

Generally speaking, the partial replacement of ordinary sand quarry by Diss fibers leads to an improvement in workability (Figure 5), hence the ease of placement of mortars containing Diss fibers, this is due to the reduction of the water absorption of these fibers by the elimination of the organic matter by their treatment with boiling water. The mortar 1/3F is more workable than 1/2F, the increase in the fiber content decreases the volume of the dough, resulting in a decrease in workability, however these results are inconsistent with those found by Khelifa et al. [10], Page [1] and Page et al. [6].

4.3 Occluded air

The mortar containing 1/3 of the volume in fibers (formulation 1/3F) gave a percentage of air close to that of the reference mortar (Figure 6); this is perhaps due to the compressibility of the fibers, or the surface of coating in the cementitious matrix being superior to that presented in the formulation 1/2F. The 1/2F formulation recorded maximum occluded air content. This is explained by the increase in porosity which is due to the porous structure of natural fibers and their highly hygroscopic nature inducing porosity in the matrix [9]. The addition of fibers resulted in an increase in the occluded air of the composites. One finding made is that: as much as the fiber insertion is important, so is the probability of trapping air bubbles and thus increasing the occluded air volume of the composites [7].

4.4 Compressive strength

The introduction of natural fibers in the mortar formulation leads to a drop in compressive strength as the fiber rate increases (Figure 7); this drop is about 50% from one rate to another. The drop in compressive strength of the mortar is explained by the decrease in its density due to the change in the internal structure of the mortar [18]. The presence of fibers modifies the porosity of the mortar matrix; this porosity increases with the rate of fibers content producing a decrease in mechanical strength [18].

According to Page [1], the low compressive strength of fiber-based composites can be attributed to the increased air content of the composites, which consequently reduces their compactness. These results are consistent with several previous works, and in particular with those of Merzoud and Habita [12], Fertikh et al. [13], Sellami et al. [14] and Achour et al. [15].

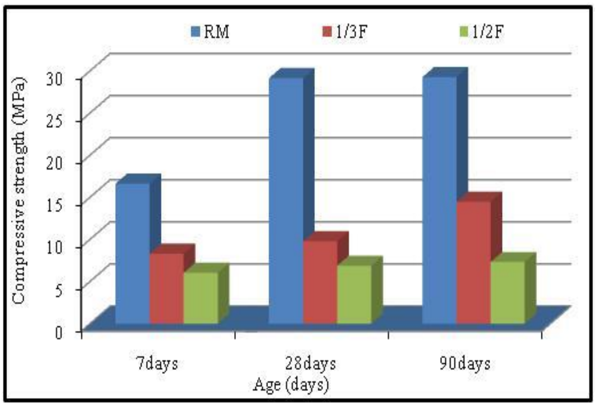

Figure 7. Influence of fiber content on compressive strength

4.5 Flexural tensile strength

From the 7th day onwards (Figure 8), the samples present tensile strength values that are more or less identical. Nevertheless, it can be seen that at the 90-day period, the improvement is confirmed with a slight difference between the two fiber composites 1/2F and 1/3F. The increase in porosity leads to a decrease in tensile strength but remains acceptable; this strength is sensitive to the rate of fiber in the long term [5].

As indicated by Fehri [19], the incorporation of plant fibers in composite materials causes an increase in porosity which leads to a degradation of mechanical properties. These results are consistent with those found by Menadi et al. [17].

The tensile failure of fiber-based composites is ductile. In addition, the lightness justifies the importance of the characteristics for fillings of structures subjected to seismic loads [13].

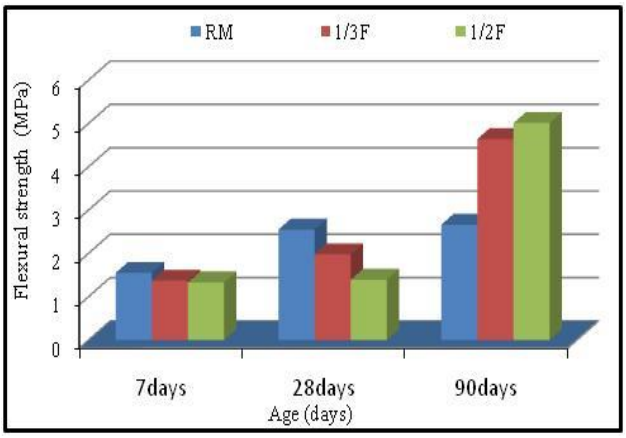

Figure 8. Influence of the fiber content on the flexural tensile strength

4.6 Water absorption

The water absorption increases with the fiber content (Figure 9); this finding is due to the highly hygroscopic nature that induces porosity in the composite [20, 21]. These results are consistent with those found by Fertikh et al. [13].

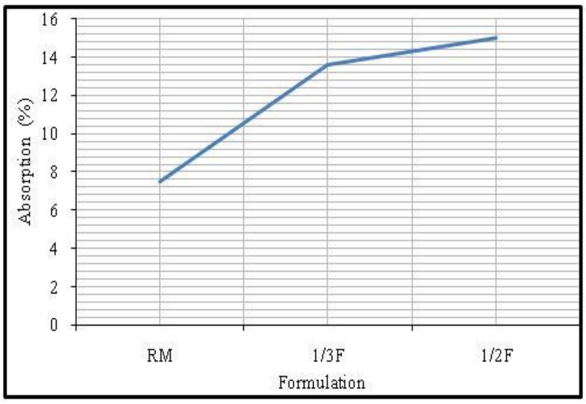

Figure 9. Variation of water absorption function of fibers rate

4.7 Capillarity absorption

The capillary absorption aspect of the Diss fibers, thus determined (Figure 10), confirms an almost similar behavior with their immersed states. This is more important according to the rate of fibers and due to the high absorption of fibers, the results being in agreement with those found by Merzoud [11].

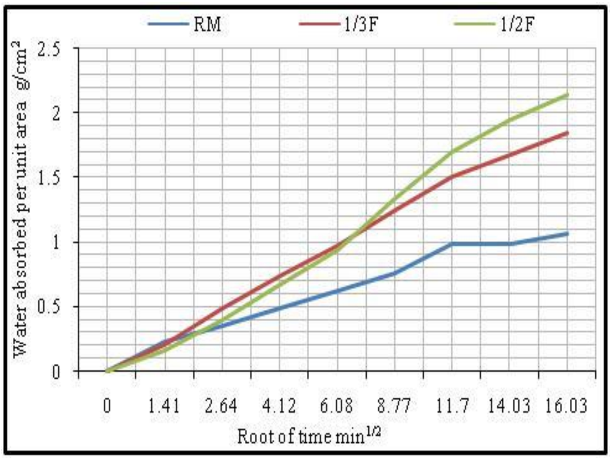

Figure 10. Influence of fiber content on capillary absorption per unit area

4.8 Chemical attack in aggressive environments

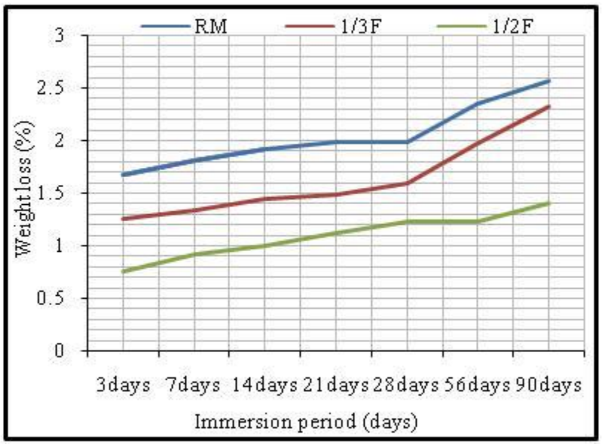

Figure 11. The variation composites weight loss function of the immersion period in the aggressive medium 5% HCl

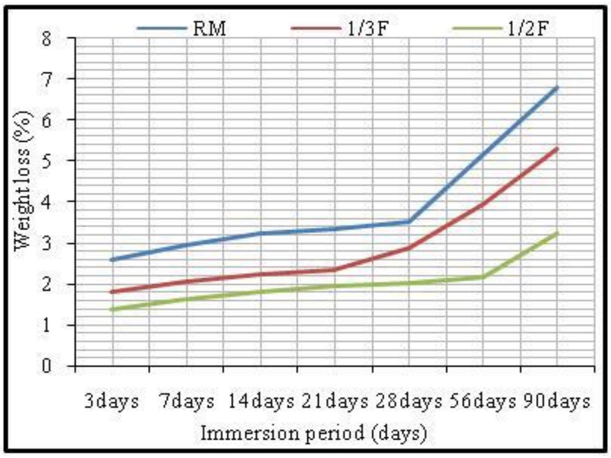

Figure 12. The variation composites weight loss function of the immersion period in the aggressive medium 5% CH_3COOH

The addition of plant fibers in the mortar formulation decreases the weight loss with increasing fiber content in HCl (Figure 11) and CH_3COOH (Figure 12), reflecting good chemical resistance in acid solutions.

Composites based on plant fibers are more resistant in HCl solution compared to those immersed in an CH_3COOH. Diss fibers also increase the composites durability in HCl and CH_3COOH solutions.

These results can be explained by the presence of silica in Diss fibers which contributes to the formation of C2S, which gives a great durability in aggressive environment [22].

Analyzing the behavior of different formulations (Figure 13), the control composite shows better resistance to sulfuric acid attack compared to the fiber-based ones. This increase in mass loss of the developed composites is related to the matrix porosity [10]. Increasing the fiber content (1/2F formulation) results in a decrease in mass loss. The fiber-based composites durability against attack by H_2SO_4 can be improved when modifying their cementitious matrix [23].

The introduction of plant fibers in cementitious composites (Figure 14) leads to a swelling that reflects a decrease in strength in alkaline environments and is more accentuated with increasing fiber content. This degradation of fiber composites in alkaline environments is mainly due to the presence of the fiber's lignin [24]. Tolêdo Filho et al. [25] explained this weakening pathology of fibers by a combination of alkaline attack and mineralization following the migration of the products of hydration towards the lights and spaces.

To decrease the negative effect of alkaline attack on the reinforcement so as to improve the durability of fibers and composites, it is necessary to add silica fume, meta kaolin, or slag and fly ashes [23, 26-28].

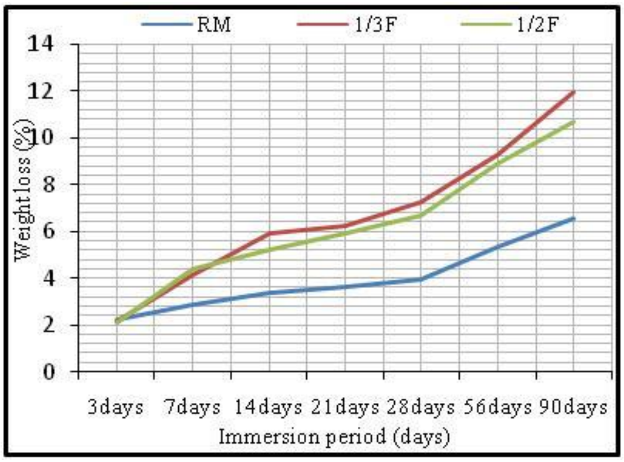

Figure 13. The variation composites weight loss function of the immersion period in the aggressive medium 5% H_2SO_4

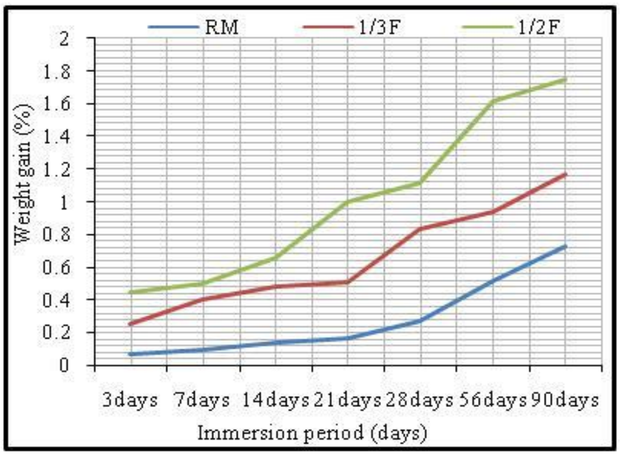

Figure 14. The variation composites weight loss function of the immersion period in the aggressive medium 5% NaCl

5. CONCLUSIONS

In this study aimed at the characterization and durability of a natural fiber reinforced composites, and based on the analysis of the obtained results, there are multiple criteria linked to the utilization of natural plant fibers in cementitious composites according to the chosen variants 1/2F and 1/3F.

On the physical-mechanical qualities aspects of the structure of the cementitious matrix based on Diss fibers:

- The lightness of the mortars, as determined by their densities, is predominantly due to the volume of voids and occluded air.
- The advantage of the lightness aspect of the composites, observed from a certain threshold rate in the substitution of Diss fibers, makes it possible to use the composite mortars as a filling material in structures designed to undergo a seismic event.
- The treatment of fibers with boiling water improves the workability of fiber-based mortars.
- The substitution of ordinary sand by Diss fibers negatively affects the compressive strength, depending on the increase in the fiber content.
- The relative gain in tensile strength at long term from one sample to another is due to the spiny morphology of Diss fibers which gives them a good adhesion to mortars and makes them usable as reinforcement.
- Their good ductility allows them to limit the propagation of the fractures in the structures used to protect against seismic events.
- Capillary and immersion absorption increases with increasing fiber content due to increased pore volumes in composites.
- Diss fibers improve chemical resistance in hydrochloric and acetic acid environments by forming C2S beneficial to the rigidity of the components of the cementitious matrix; due to the presence of silica in the Diss fibers.
- Composites based on Diss fibers are the most degraded in H_2SO_4 and NaCl media due to the presence of lignin in these fibers which can be improved by adding fumed silica or metakaolin.

On the environmental aspects:

- The use of Diss fibers in the production of a cementitious composite confers an added value to this natural resource due to the quality of inherited biodegradable material.
- They are nature friendly because they are non-polluting and do not generate waste (completely cut into fibers when used in mortars). Another observation made, is the non-perennial nature of this annually renewable resource (does not affect the soil).

On the economic aspect:

- The use of cementitious composites based on Diss fibers does not require expensive new equipment and processes.
- Thus, the lower costs can be judged compared to the mortar based on crushed aggregates and quarry sands.
- Therefore, the valuation of Diss fibers, for different uses as reinforcement and fillings in building structures, proves to be profitable and deserves to be pursued by other researchers to reveal other qualities which have not been determined in the current study.

Finally, tests on characterization and durability of natural fiber reinforced composite, have proved to be interesting in view of the results obtained and this will encourage us to continue research refining the still unexploited sides of Diss fibers.

PERSPECTIVES

It is necessary to fully understand the internal phenomenon and the mechanism of degradation of composites after chemical attack to make a microstructure study, statistical study and economic study which will be the subject of future work.

A continuation of this work has been carried out on the reuse of recycled aggregates on the same fiber-based composites partially replacing ordinary sand in order to eliminate waste, preserve natural resources and protect the environment which will be the object of the next release.

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