EXPERIMENTAL INVESTIGATION ON THE USE OF ALFA FIBERS AS REINFORCEMENT OF CEMENTITOIUS MATERIALS

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Abstract

Fibers commonly used in cementitious composites have been derived from non-renewable resources. Economic issues related to the rising costs of fossil resources, their increasing scarcity, and environmental impacts inherent to their production therefore lead to explore other material resources. In this regard, plant fibers could be used instead of non-renewable fibers which can present an important pathway in the future of the construction industry. In North Africa, Alfa is a widespread plant in the dry regions of the Mediterranean highland. In Morocco, the Alfa plant covers a large area estimated at more than three million hectares.

Research has already been conducted on the incorporation of plant fibers in cementitious materials. It was highlighted that in fresh state, the hydrophilic character and the nature of these fibers significantly affect the rheology of the material. In hardened state, these fibers allow to decrease the rheology of the material, and thus enhancing their hydrothermal properties. From a mechanical point of view, plant fibers could increase the compressive and/or the flexural strengths. This study investigates the potential of using Alfa fibers as reinforcement of cementitious composites. Firstly, chemical and physical characterizations of Alfa fibers were performed as well as morphological observations were realized. Secondly, the fibers were added to cement mortar by two ratios 1 and 1.5% by volume to optimize the mix design formulation. Physical and mechanical properties of the composites were tested after 28 days of curing. Results exhibit that Alfa fibers provide a high crystallinity index of about 74.62 wt% and a good thermal resistant which can reach until 360 °C. Furthermore, adding 1% by volume of Alfa fibers allow to produce a lighter composite and improve the compressive strength of the reinforced mortar of about 14.87%. The enhancement of mechanical properties was confirmed by SEM observations (scanning electron microscope) showing the good fiber/matrix adhesion.

Keywords:
Alfa fiber; Cement composite; Ecofriendly; Rheology, Morphology; Hydration.

1 INTRODUCTION

Recently, several studies have been conducted to figure out the benefits of using natural fibers as reinforcement in cement matrix. Indeed the incorporation of theses fibers on the cementitious materials has been proved to diminish pollutant and greenhouse gas emissions, reduce dependence on non-renewable energy/ material sources and enhance energy recovery and biodegradability [Wei 2015, Van Wyk 2015].

Natural fibers contain mainly cellulose, hemicellulose, lignin and in a small proportion of extractable constituents such as proteins or inorganic compounds [Do Thi 2011]. Fibers can be described as composites which cellulose fibrils play the role of reinforcement in a matrix composed mainly of hemicelluloses and lignin [Bledzki 1999]. The proportion of these compounds varies depending on the nature of the fiber, the growth condition, the age of the plant and the climatic conditions [Bledzki 1999, Belkhir 2012]. The variety in composition proportion allows different mechanical properties of the fibers. It's known that the tensile strength and Young's modulus of the fibers increase with the increase of the cellulose content [Do Thi 2011].

Natural fibers have been extensively used in different applications for mechanical and physical interest. Such as: Automotive manufacture [Faruk 2014], aircraft industry for interior compounds [Ho 2012], non-structural construction application [Shah 2013] like door, floor lamination, window frame, wall insulation, etc. Finally, the use of natural fibers in building materials has been evaluated [Faruk 2014]. Numerous fibers widely used as reinforcement in cement matrix, as flax, sisal, jute, hemp, coir, hibiscus, cannabinus fibers [Yan 2016], etc. Alfa fibers were used in various applications such as: paper, decoration, thermoplastic, etc.[Ben Brahim 2007].Few studies were investigated the effect of using Alfa fiber in construction [Elhamdouni 2015, Krobba 2018]. Indeed, the incorporation of plant fibers in a cement matrix in terms of mechanical behavior is to meet the following two objectives [Chafei 2014]; avoiding the sudden crack propagation in the cementitious material because of the opposition of the fibers to the crack opening and change of brittle behavior into a quasi-ductile behavior which improves the safety during the ultimate loadings.

Sedan [2007] have compared the mechanical properties of a cement paste and cementitious paste incorporating hemp fibers. Results show unlike cement specimens with quick fracture, the composite exhibits a post-peak softening behavior and a controlled load drop. Also [Krobba 2018] have studied the effect of using microfibers in cement mortar. The results show that mortar reinforced with microfibers exhibit a better mechanical and physical properties with lower gas permeability compared to reference mortar. Recently [Çomak 2018] have prepared cement mortars reinforced by hemp fiber with different ratios (0%, 1%, 2%, 3%) and different lengths (6 mm, 12 mm and 18 mm). Their results exhibit that the optimum formulation of cement mortar reinforced by hemp by 2–3% amount and 12 mm length. Whereas [Gil 2016] were studied lime-plastic and cement-fluid mixed with different percentages of fibers from end-of-life tires with ratios going from 0% to 1%. The results show that mortar workability changed after adding 0.25% of fiber, on the other hand, young modulus and absorption were also changed after addition. However, no significant changes were notified in mechanical properties and buck density. [Juarez 2015] were investigated a comparison study between the use of natural fibers (flax and agave lechuguilla) and synthetic fibers polyvinyl alcohol (PVA) in cement-based composite as reinforcement. 0.1% and 0.7% by volume were the ratios of fiber incorporation chosen in this work. The results show that the use of both types of natural fiber was efficient to control plastic shrinkage cracking similar to PVA fibers.

Alfa fiber is an abundant plant covers a large surface in Morocco estimated at 3,186,000 ha, it grows spontaneously especially in arid and semi-arid environments [Dallel 2013]. The aim of this work is to study the feasibility of using the raw Alfa fibers with a mild preparation as additive in cement mortar. We investigate the evolution of the mechanical and physical behavior of the mortar with adding Alfa fibers. Chemical and structural characterization of raw Alfa plant was realized to define the chemical and structural properties flowed by a morphological observation to define the Alfa fiber aspect. Secondly, the raw fiber was incorporated in the cement mortar with different ratios. A comparison was performed between the mortar reinforced by Alfa fiber and reference mortar.

2 MATERIALS AND METHODS

2.1 Materials

The mortars were performed by mixing Portland cement type CEM II 32.5 from TITAN Industry in Greece, the river sand with granular size distribution of 0-4 mm. and The Alfa plant (Fig. 1) [ecologie.ma, CRRA 2012]. These plants are harvested from the Northern-East region of Morocco (surroundings of Oujda-city). The plants have a height up to 1 m [Paiva 2007, Omri 2013, Boukhoulda 2017, Turki 2018]. Alfa stems were cleaned beforehand to remove dust presenting on the surface, they were cut to 2-2.5 cm in length then they were blended with a blender machine before adding to cement mixture, no drying process was performed before adding. To perform characterization on the raw Alfa fiber, a powder was prepared with granular size of 50µm.

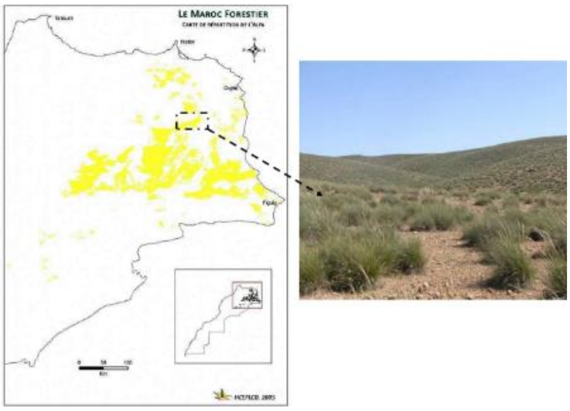

Fig. 96: Alfa plant region distribution in Morocco.

2.2 Formulations and Methods

- **Characterization of Alfa plant:**

The chemical composition of the Alfa fiber was determined according to the standards of the American Society for Testing and Materials (ASTM) [Ajouguim 2018].

The diameter distribution was studied by measuring the diameter by a caliper in the middle of each fiber. The test was realized on 30 stem chosen arbitrarily.

Powdered raw Alfa has been characterized using: X-ray diffraction (XRD) using a Philips X'Pert MPD diffractometer, Fourier-transform infrared spectroscopy (FT-IR) using a Bruker Vertex 70 FT-IR Spectrophotometer, thermal analysis (TGA) were conducted on Setaram Setsys 24 Discovery apparatus. The crystallinity index (Icr) was determined by the method of Segal [French 2013] (1):

$$I_{cr} = \frac{I_{200} - I_{am}}{I_{200}} \times 100 \quad (1)$$

I_{200}: Is the maximum peak intensity of the crystalline phase at 2θ = 23°, I_{am}: is the minimum intensity at the valley near 2θ = 18° of the amorphous material.

The morphological observations of Alfa fibers were conducted by an optical microscope using G.BOYER apparatus, and Scanning Electron Microscopy (SEM) using JEOL JSM-5500 (VEGA3 TESCAN) apparatus.

- **Formulations**

Two formulations were performed, reference mortar (RM) and mortar reinforced by raw Alfa fiber (AM). The Alfa fiber was added to cement matrix by two ratios 1% and 1.5% by volume. Therefore, the mortar denotation is as follows: (AM1); Alfa mortar with 1% by volume. A Superplasticizer were added (2% by volume) to maintain the same workability during all formulations (12±1 cm). The workability test was performed by the flow table method [EN 1015-3].

The preparation of RM was done in accordance with [EN-169-1] standard. The preparation of AM was realized differently to avoid agglomeration behavior, a dry mixing of all compound was performed in prior then the mixing water was added. Specimens of 40x40x160 mm^3 were prepared, demolded after 24 hours, and then stored at a humid chamber (RH 95%) for 28 days.

After curing, the performance of different samples was tested by mechanical and physical test. Compression and flexural strength were performed according to [EN 1015-1], porosity test was realized in accordance with RILEM RECOMMENDATION [CPC11.3] and capillary test in accordance with [EN1015-18]. SEM micrographs was also performed to confirm the adhesion properties.

3 RESULTS AND DISCUSSION

3.1 Alfa fiber characterization

Fig. 2 presents the diameter variation of Alfa fiber clipped to 2-2.5cm, the thirty samples show a variety of values between 1.4 and 1.73 mm measured on the central portion of the fiber. 34% of the samples have a diameter about 1.7 mm. The analysis of the different values of fiber diameter shows that the difference between the highest and lowest value was 0.33 mm which represents a negligible difference, thus providing an average diameter of about 1.7 mm.

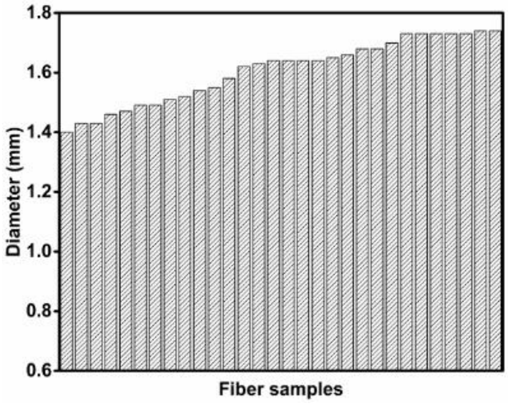

Fig. 97: Diameter variation of Alfa fibers.

Chemical analyses were performed according to ASTM standard showed that Alfa fibers contain about 1.40 wt% and 98.6 wt% of organic matter. This later composed mainly of cellulose, hemicellulose and lignin. Alfa fiber is composed about 39.53 wt% of cellulose, 27.63 wt% of hemicellulose, 19.53 wt% of lignin and other extractable compounds. These results are in accordance with [Mouhoubi 2017, Youssef 2015]. Compared to other research work [Hanana 2015, Ben Mabrouk 2012], the amount of the different constituent remains lower. This discordance probably due to the origin and the growth history of the plant [Bledzki 1999, Belkhir 2012].

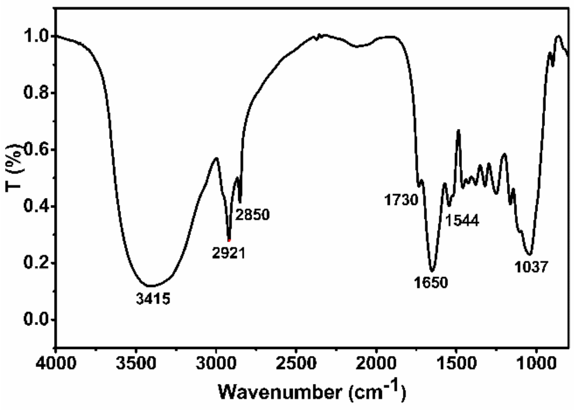

Fig. 98: FTIR spectrum of Alfa fibers.

Fig. 3 presents the FTIR analyses of the powdered samples of Alfa fiber operating in the range [4000–400 cm^{-1}].

The bands observed in the FTIR spectrum confirmed the presence of the constituents determined by chemical composition test. The band observed at the range of 3400 to 3500 cm^{-1} is attributed to the O-H groups presenting in cellulose structure [Essabir 2013]. The bands located at 2921 and 2850 cm^{-1} were attributed to C-H groups present in cellulose and hemicellulose structure [Essabir 2013]. The hemicellulose is also confirmed by the bands located in 1730 and 1544 cm^{-1} [Arrakhiz 2013, Bessadok 2007]. Finally, the presence of lignin is confirmed by the band observed in 1650 cm^{-1} [Qaiss 2015].

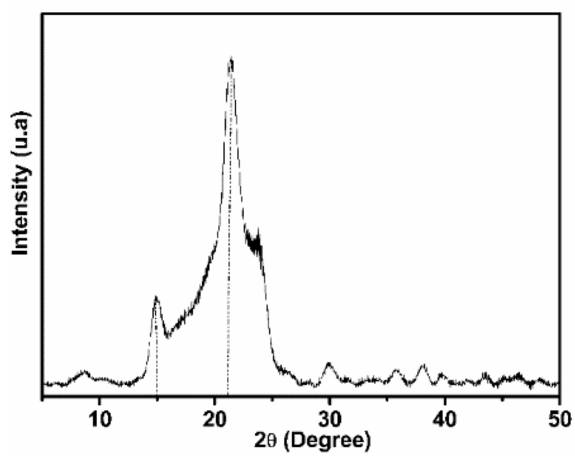

Fig. 99: XRD diffractogram of Alfa fiber.

Fig. 4 show the XRD analyses of Alfa fibers. The crystallographic structure of Alfa fiber was presented at the range of 2Θ = [5-50°]. The characteristic peak is located at 2Θ = 21.5° and two superimposed peaks located at 2Θ = 14.8° and 2Θ= 15.4°. The peaks present the structure of the native cellulose I [Trache 2016]. Compared to others research work [Elachaby 2018], the peaks of Alfa fibers were slightly shifted to low angles which could be explained by structure disorganization of the lateral wall of Alfa fibers. Thus can suggest the presence of a second cellulose polymorph presented as cellulose IV [Chanzy 1979].

Alfa fibers have an important crystallinity index of about 74.62 wt% which was higher than other Alfa fibers harvested from other regions [Mouhoubi 2017, Elfehri Borchani 2015].

Fig. 5 shows the TGA analyses, Alfa fiber decomposed totally at 360°C. Three weight loss was defined the temperature of decomposition of each compound of Alfa fibers. The first weight loss is the structural water present in the fiber structure, the second weight loss is hemicellulose, and then the important weight loss presents the decomposition of cellulose and lignin. These results exhibit that Alfa fibers provide an important thermal resistance which could expand the application fields of Alfa fibers.

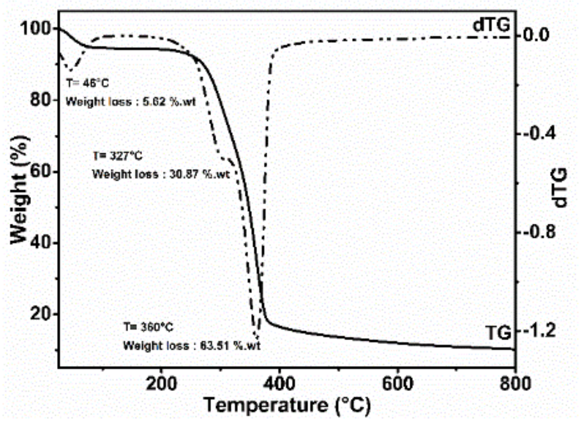

Fig. 100: TGA curves of Alfa fiber.

Fig. 6 presents the morphological observation by Optical Microscope. Fig. 6-a shows the cross section of Alfa fiber, it's clearly seen that the fiber from the outside to the inside of the beam is organized in several concentric layers, these layers present the up view of the cylindrical fibrils. Fig. 6-b shows the longitudinal view of the Alfa fiber, the beam has a rougher aspect containing a regular form called trichome, this latter is mainly composed by silica [Ajouguim 2018]. Fig. 7-A presents the SEM micrograph realized on the longitudinal section of the Alfa fiber. The SEM micrograph confirms the presence of the regular form inside the fiber.

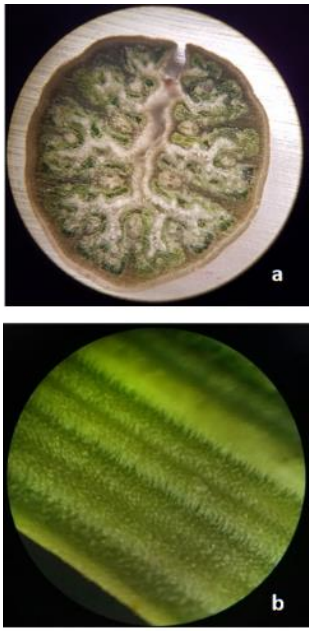

Fig. 101: Views by optical microscope: (a) cross section (b) longitudinal view.

Fig. 7-b shows the lateral view of Alfa fiber, it's clearly seen that Alfa fiber provides a waxy surface with irregular form named stomata [Ajouguim 2018]. This aspect could present an issue when using fiber at their initial state, which must need a fiber preparation before use.

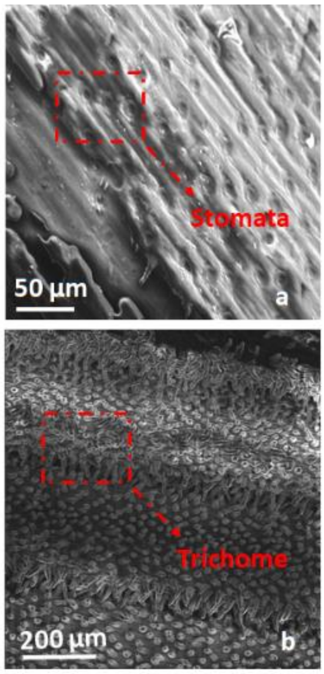

Fig. 102: SEM micrographs of Alfa fiber: (a) lateral (b) longitudinal view.

3.2 Cement mortar characterization

Tab. 1 presents the physical and mechanical properties of mortar reinforced by Alfa fibers. It's clearly noticed that the incorporation of Alfa fibers increases the porosity ratio of mortar specimens which conduct to raise the water absorption values when added high fiber ratio. Thus it's mainly due to the hydrophilic character of Alfa fibers as a result the water absorption of the reinforced mortar is highly superior to reference mortar. Fig. 8 presents the water absorption by capillary of mortar specimens versus square of time. For the three mortar samples, the same trend is observed, the longer the square of time, the higher the water absorption by capillary. It was noticed that adding fibers also enhances the capillary absorption. These results were in accordance with the porosity values. Moreover, the increase of the amount of fibers promote the water absorption. Thus can be explained by pores created inside the matrix. Indeed, the hydrophilicity of the fiber could contribute to the absorption of the mixing water during preparation of specimens [Ferreira 2015, Roy 2012]. As a result, a dimensional variation of the fibers could be induced inside the matrix and after curing time the void could be created [Ferreira 2015]. This phenomenon may become more pronounced by increasing the amount of fiber addition. However, the AM1 specimen shows a similar behavior to RM which could be attributed to the good homogenization between the fiber and the matrix.

Tab. 32: Physical and mechanical properties of cement mortar.

Samples	Physical test				Mechanical test		
Code	**Absorption (%)**	**Specific gravity**	**Porosity (%)**	**Shrinkage (%)**	**Compression (MPa)**	**Flexural (MPa)**	**Static modulus (MPa)**
RM	3,47	2,12	7,34	-0,410	21,510	3,657	26,383
AM 1	5,82	2,07	12,07	-0,320	25,270	1,335	22,243
AM 1,5	7,60	2,05	15,57	0,200	23,310	1,263	19,149

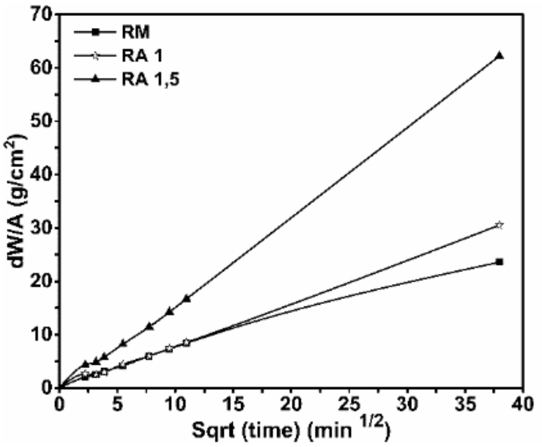

Fig. 103: Capillary test of mortar reinforced by Alfa fiber.

Fig. 9 present the compression strength of mortar specimens after 28 days of curing. AM1 present the higher compression strength by an increase of about 14.87%, followed by AM1.5 by an increase of about 8.36%. The Alfa fiber preparation by blending allows to a surface modification of the fiber which creates more reaction and rougher site improving the homogeneity and adhesion with cement matrix. This can be confirmed by SEM micrographs of AM1 (Fig. 10); the figure exhibits that Alfa fiber was embedded with cement mortar which proving a good adhesion fiber/matrix. The result obtained was in accordance with other research work [Krobba 2018].

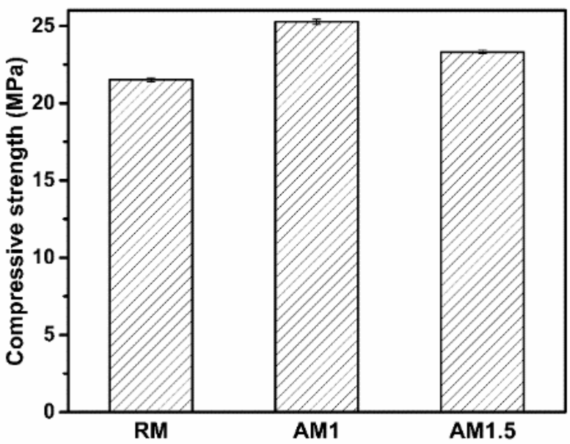

Fig. 104: Compression strength of mortar reinforced by Alfa fibers.

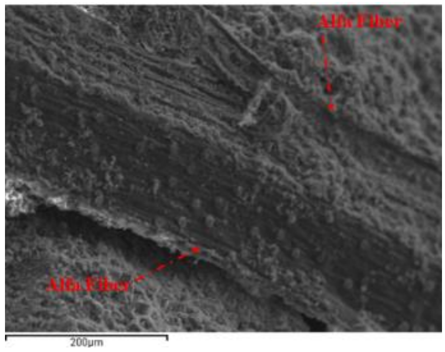

Fig. 105: Fiber/matrix adhesion.

Fig. 11 shows the flexural strength of mortar reinforced by Alfa fibers. The addition of Alfa fiber was not efficient to reinforce cement mortar and the flexural strength decrease presenting a lower value than RM. The same trend was noticed in the static modulus of AM1 and AM1.5 (Tab. 1).

The decrease of mechanical properties confirmed the values obtained in physical properties, the higher porosity the lower mechanical property.

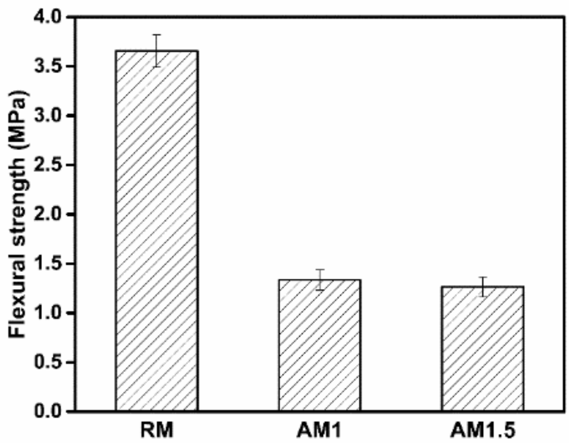

Fig. 106: Flexural strength of mortar reinforced by Alfa fibers.

4 CONCLUSION

The studied Alfa fiber is mainly composed of cellulose, hemicellulose, and lignin. It presents a high crystallinity index of about 74.62 wt%. In addition, Alfa fiber provides a good thermal resistance reaching up to 360°C for total decomposition.

The study of mortar with and without fiber shows the positive effect of the use of Alfa fiber as reinforcement. It was proved that the addition of 1% by volume provides a better result compared to reference mortar. Mortar with 1% by volume Alfa fiber presents a lighter composite with high compression strength, this it was confirmed by the good fiber/matrix adhesion observed by SEM.

Unfortunately, the presence of fiber decreases the flexural strength and increases the percentage of water absorbed by the mortar. To overcome this problem a surface modification of the fiber is necessary to improve the surface properties and reduce the hydrophilic nature of the fiber.

As a perspective of this work, chemical treatments of the Alfa fiber surface will be performed in order to improve its surface properties.

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