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Impact of Alfa fibers morphology on hydration kinetics and mechanical properties of cement mortars

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Abstract

The Alfa plant is indigenous and spans a large zone throughout North Africa. Recently, Alfa plant has been used in building materials, notably as a reinforcement. This study aims to valorize the Alfa plant into fiber-reinforced mortar based on a cement-glass composite mix design. Two Alfa fiber morphologies are considered herein: different cutting lengths (10, 20 and 30 mm), and ground using a knife mill (shorter than 2 mm). These fibers were added to mortars at various volume ratios: 1, 2 and 3%. The workability and density of these distinct formulations were then measured in their fresh state. In comparison with the control mortar (CM), the introduction of Alfa fibers (either cut or ground), with ratios below 2% vol., leads to a slight decrease in mixture workability. However, Alfa fibers do not significantly alter the fresh material density. It was recorded a delay in setting time of the composites as a function of fiber addition rate. In the hardened state, an improvement in flexural strength is noticed for mortars reinforced with 1% vol. of fibers compared to the CM. However, results show that the increase in either type of fiber (cut or ground) generates a decrease in compressive strength compared to the CM. This outcome can be confirmed by both the decrease in heat released during the hydration reaction and water-accessible porosity inside the matrix.

Keywords: Mortar, Alfa fibers, Morphology, Workability, Porosity, Mechanical strength, Hydration kinetics.

38 **I. Introduction**

39 Previous studies [1–6] have highlighted the feasibility of producing, under specified
40 conditions, building materials containing natural fibers that are more environmentally-friendly
41 and of a quality comparable to that of conventional materials.

42 Alfa fiber, like all plant fibers, is basically composed of cellulose, hemicellulose, lignin,
43 pectin and extractible elements [7,8]. The presence of these components changes from one
44 fiber to the next and depends on several parameters, including age, growth conditions and
45 source [9]. According to Hajj et al. (2019), such elements rich in hydroxyl groups are
46 responsible for the hydrophilic nature of plant fibers [10]. This characteristic directly
47 influences the rheological and mechanical properties of the cementitious material. It has in
48 fact been reported that the incorporation of plant fibers results in a loss of workability, limited
49 crack propagation, improved tensile and flexural strength, and lastly a more resistant hardened
50 concrete [4,11,12].

51 The stiffness of natural fibers, which is also correlated with their chemical composition,
52 heavily influences the mechanical properties of cementitious composites. According to Li *et*
53 *al.* (2000), the strength and stiffness of natural fibers depend on both the cellulose content and
54 the microfibril direction within the cell wall [13]. A high cellulose content actually causes
55 potentially significant natural fiber deformations. Furthermore, the high ductility of these
56 fibers is beneficial in reducing the fragility associated with cement-based composites [14,15].

57 Several parameters will influence the composite's mechanical and rheological properties, led
58 by the poor level of fiber/matrix adhesion due to a fiber contraction effect subsequent to
59 matrix hardening [16], coupled with the morphology and fiber addition rate parameters [4].

60 A number of works [11,17,18] have actually demonstrated that for lengths ranging from 12 to
61 30 mm and an Alfa fiber addition rate varying between 0.1 and 2.5%, expressed as a
62 volumetric fraction, an increase in the composite's flexural strength combined with a drop in
63 its compressive strength could be observed. For example, incorporating 1% vol. and 1.5% vol.
64 Alfa fibers cut 20 to 30 cm long into a structural concrete induces a 14% decrease in
65 compressive strength. Nonetheless, a tensile strength on the order of 4.58 MPa has been
66 obtained, which amounts to a 3% gain compared to ordinary concrete [17]. This same

67 behavior has been recorded for self-compacting concretes, with an addition rate of 0.1% vol.
68 Alfa fibers cut to 12-mm lengths [18]. These conclusions differ for 2 to 5-mm long patching
69 mortars reinforced with Alfa fibers with a volumetric fraction of 0.70% [19]. The rise in
70 flexural strength and compressive strength of the microfiber-reinforced mortar has been
71 measured at 15% and 30%, respectively.

72 The behavior of Alfa fibers in a cementitious matrix could be influenced by both chemical
73 composition, which is correlated with fiber origin, and the type of selected cementitious
74 matrix. As a case in point, Alfa fibers from Morocco contain 39% cellulose [8], compared
75 with cellulose contents of 43% and 46% for fibers sourced in Tunisia and Algeria [7,20]. This
76 difference in Alfa fiber chemical composition could exert an influence on its mechanical
77 properties as well as on its capacity to reinforce the matrix. It would thus be worthwhile to
78 study the effect of adding Alfa fibers from Morocco on the properties of a cementitious
79 material.

80 Based on a literature review, the use of Alfa fiber as a reinforcement fiber has been explored
81 in only a limited number of applications. A comparison between Alfa fibers and three other
82 types of plant fibers (Diss, date palm and hemp) has been drawn in the study conducted by
83 Belkadi (2018) [21]. This author showed that the incorporation of plant fibers led to reducing
84 both the endogenous shrinkage and drying shrinkage of the composite relative to the reference
85 concrete. From a mechanical perspective, the concrete containing Alfa fibers shows a sharp
86 decline in flexural strength compared to the concrete containing the other types of fibers;
87 however, its incorporation did improve the composite's deformation capacity. These results
88 are in close agreement with the work performed by Khelifa *et al.* (2018) [17], which also
89 revealed that integrating Alfa fibers is able to reduce shrinkage during the early age and
90 provides a composite with characteristics basically similar to those of a structural concrete.
91 Krobba *et al.* (2018) assessed the effectiveness of adding Alfa microfibers, manually cut to a
92 length of 3-5 mm, to a patching mortar containing sand with a 0/0.5 mm particle size range.
93 Their results indicated that the incorporation of volume of 0.75 % served to limit drying
94 shrinkage while improving the composite's compressive strength, as compared to a reference
95 mortar devoid of Alfa fiber [19]. On the other hand, Ajouguim *et al.* (2020) included Alfa
96 fibers 20 to 25 mm long crushed using an electric mixer in a mortar containing sand with a
97 0/4 mm particle size range. The crushed fibers underwent surface treatment by means of an
98 alkaline solution. A set of interesting results were recorded, revealing a 39% gain in flexural
99 strength for the mortar containing 1% vol. of treated Alfa fibers [22]. The choices of

100 cementitious matrix and Alfa fiber condition prove to be critical parameters in the
101 development of an end product featuring good behavioral qualities from either a physical or
102 mechanical standpoint.

103 The objective of this study is to make efficient use of fibers stemming from the Alfa plant,
104 which for the most part is found in North Africa and Spain. This plant grows spontaneously in
105 arid or semi-arid environments and moreover covers a land area estimated at 4,000,000 ha in
106 Algeria, 3,186,000 ha in Morocco, 600,000 ha in Tunisia, 350,000 ha in Libya and 300,000 ha
107 in Spain [23–25]. The application of these fibers derived from natural resources can serve to
108 both lower production costs and mitigate serious pollution problems. The inclusion of these
109 fibers in a cementitious matrix requires a preliminary study of the fiber properties, especially
110 their hydrophilic and mechanical properties, as well as their interaction with the cementitious
111 matrix.

112 The originality of this work program consists in developing an Alfa fiber-reinforced mortar
113 based on a cement-glass composite mix design. According to the literature, this type of
114 formulation that makes use of Alfa fibers has never been officially catalogued. The most
115 fundamental characteristics of the composite produced during this study pertain to the use of:
116 a highly-concentrated cement paste, a fine sand particle distribution (0/1 mm), fillers, and
117 admixtures to adjust the mixing water. The benefit herein consists of obtaining a composite
118 comparable to the cement-glass composite, with low porosity and a high level of mechanical
119 strength, especially in tension. The first part of this effort will be devoted to optimizing the
120 mix design by varying the water-to-cement and sand-to-cement ratios. The second part will
121 examine the influence of both morphology and fiber addition rate on the properties of the
122 fiber-reinforced mortar. Two morphologies have been selected for this part of the study:
123 crushed and cut into various lengths (10, 20 and 30 mm). The effect of incorporating Alfa
124 fibers into the cement mortar will be identified. The flexural strength and compressive
125 strength were measured at various time intervals. A final study will compare the different
126 effects of cut and crushed Alfa fibers on the properties of the resulting composite in both the
127 fresh and hardened state.

128 **II. Materials and methods**

129 **II.1. Materials**

130 The mortar specimens were manufactured by mixing a Portland cement (CEM III/B 42.5N)
131 from “La Grave de Peille” (France), the Blaine fineness is 5300 cm²/g, and the density about
132 3.00 g/cm³. Limestone filler was used (total carbonates equal to 98.8%) with a Blaine fineness
133 of 4620 cm²/g, and with a density of 2.7 g/cm³. A siliceous sand from “ULTIBAT” with a
134 particle size distribution of 0-1 mm (**Fig.1**) and a density of 2.61 g/cm³ was used as
135 aggregates.

136 To improve workability, a polycarboxylates-based superplasticizer form “Sika” with a density
137 of 1.070 g/cm³, was added to the mixture with a ratio of 1 % relative to the cement weight. In
138 addition to avoid segregation, a viscosity-modifying agent (VMA) form “Sika” with a density
139 of 1.025 g/cm³, was also added with a ratio of 0.5% relative to the cement weight. It has been
140 previously reported in the literature that the use of a superplasticizer and VMA in bio-based
141 cementitious composites helps to reduce workability disturbances [4,26].

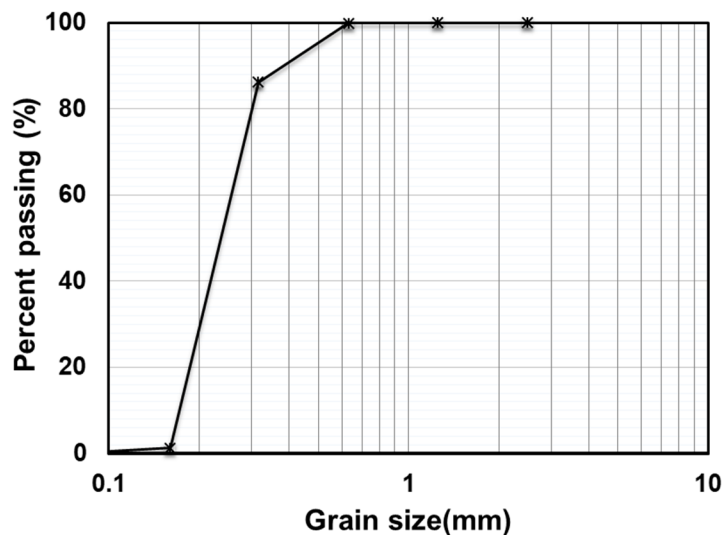


Fig. 1: Grain size distribution of sand aggregates

142 **II.2. Alfa fibers characterization**

143 The Alfa stem (*Stipa tenacissima L*) was harvested in the northeastern region of Morocco.
144 The bulk density of Alfa fibers was determined using a helium pycnometer [4] to be 1.40
145 g/cm³. The Alfa fiber chemical composition was specified in a previous work, with the main
146 fiber components being as follows: 39.53% cellulose, 27.63% hemicellulose, 19.53% lignin,
147 and 13.28% extractible elements [8]. The Alfa fibers were cleaned in order to remove any
148 dust and impurities deposited on the surface. In the present study, two Alfa fiber
149 morphologies have been considered: cutting at different lengths (10, 20 and 30 mm), and
150 ground with a knife mill (length shorter than 2 mm). **Fig. 2** shows the external surface of Alfa
151 fibers observed by means of scanning electronic microscopy (SEM). The micrograph

152 indicates that Alfa stems has a rough appearance, with defects and many impurities (fat, wax,
153 etc.) named as stomata distributed on the surface [8]. **Fig. 3** presents both Alfa morphologies
154 studied in this paper.

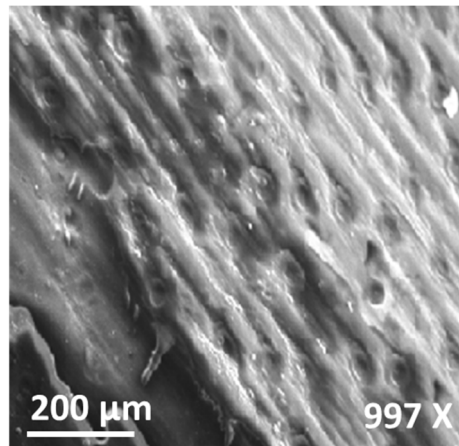


Fig. 2: SEM micrograph of the external surface of Alfa fiber [8]

155

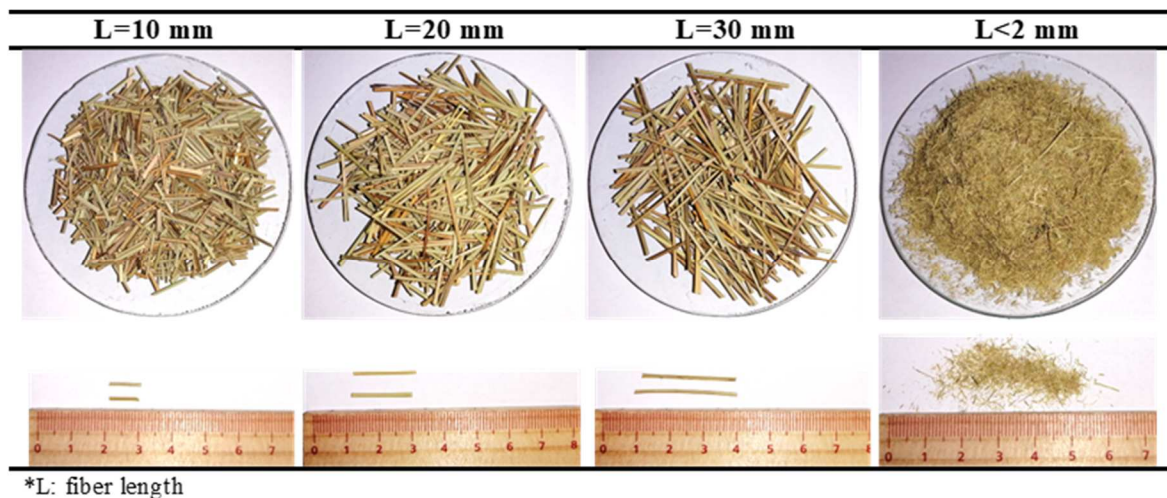


Fig. 3 : Cut and grinded Alfa fiber

156 Because of their chemical composition (mainly cellulose and hemicelluloses), Alfa fibers are
157 very sensitive to water [8]. The water absorption kinetics of Alfa fibers were measured
158 according to the procedure described in a previous work [12]. The applicable test protocol is
159 as follows: (1) Alfa fibers were oven-dried at 60°C for 24 hours; and (2) 3.00 g of Alfa fibers
160 were placed in a micro-perforated plastic bag, then immersed in water for various lengths of
161 time (1 min to 48 h). The water absorption ratio was calculated using the following equation
162 (1), with m_t denoting the mass of fibers at time (t) and m_0 the initial dry mass of fibers:

163 $WA_t(\%) = \left(\frac{m_t - m_0}{m_0} \right) \times 100$ (1)

164 The water absorption kinetics of cut and ground Alfa fibers are presented in **Fig.4**. It should
 165 be noted that extending the immersion time leads to higher water absorption of both fiber
 166 morphologies. The water absorption kinetics of cut and ground Alfa fibers can be
 167 distinguished in two areas, separated by an intersection point at approximately 8 hours. The
 168 first area shows that ground Alfa fibers absorb more water than cut fibers during the first few
 169 minutes of absorption. After 8 hours, a different water absorption behavior was observed;
 170 therefore, the cut fibers display a higher water absorption than ground fibers after 8 hours of
 171 immersion. More specifically, the water absorption of ground fibers was approx. 55% after 8
 172 hours of immersion, with a slow evolution reaching 62% at 48 hours. Cut Alfa fibers thus
 173 seem to possess greater water retention capacity but slower absorption kinetics in comparison
 174 with ground Alfa fibers. Nevertheless, the cut fibers follow a logarithmic evolution law that
 175 depends on immersion time, with the water absorption of fibers reaching about 86%, making
 176 it obvious that the water absorption of fibers increases with immersion time. This increase is
 177 typically correlated with fiber hydrophilicity, which depends on the fibers' chemical
 178 composition and nature. These results are in accordance with the literature [4,27], with a
 179 similar behavior observed for different types of fibers: the water absorption of fibers increases
 180 the longer the water immersion time.

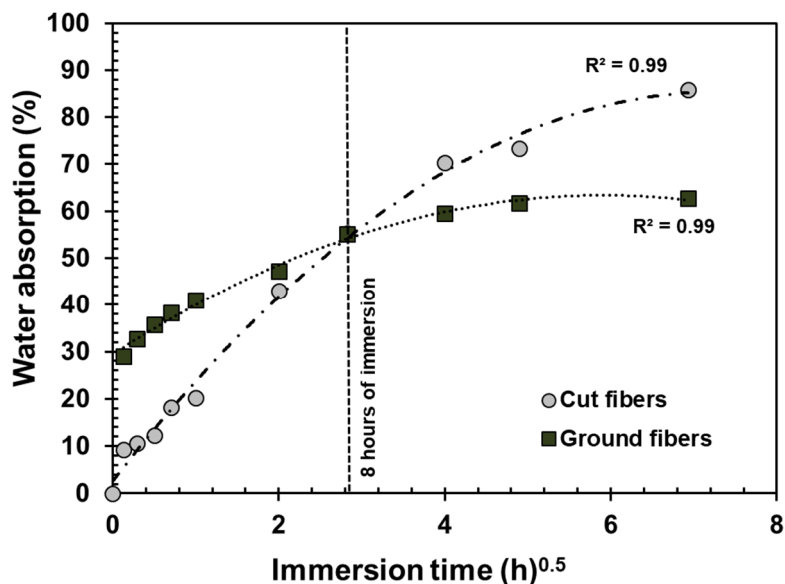


Fig. 4: Water absorption kinetics of Alfa fibers

181 **II.3. Preparation of specimens**

182 The sand and Alfa fibers were oven-dried at 60 °C to remove all traces of moisture. First, a
183 dry mixing of the various constituents (cement, filler and sand) at slow speed ($140 \pm 5 \text{ min}^{-1}$)
184 for 30 seconds. The 2/3 of the mixing water is introduced by mixing for 1 min 30 seconds.
185 The superplasticizer is introduced (mixing for 30 sec), followed by 1/3 of the remaining
186 mixing water (mixing for 60 sec), then, the VMA is added (mixing for 30 sec). Switch the
187 mixer to the high speed ($285 \pm 10 \text{ min}^{-1}$) and continue the mixing for an additional 60 sec.
188 Finally, the Alfa fibers were added progressively with slow mixing for 180 sec. The addition
189 of Alfa fibers in the mixtures was based on volume. Specimens sized 40 x 40 x 160 mm were
190 generated and then cured in a humid room ($\text{RH} > 90\%$, $T = \pm 20^\circ\text{C}$) until testing.

191 **II.4. Methods**

192 **II.4.1. Fresh properties**

193 **• Workability test**

194 The workability of the various mixes was measured by the flow table test, in accordance with
195 the EN 1015-3 standard. In this procedure, a fresh mortar sample is placed on the flow table
196 tamper, by means of a truncated conical mold, and struck with 15 vertical hits by raising the
197 flow table and allowing it to fall freely from a height of 10 mm. The flow value of the mixture
198 is estimated by averaging the slump diameters measured in two orthogonal directions.

199 **• Calorimetry**

200 The cement hydration kinetics were thus measured by a two-channel (I-Cal 2000 HPC)
201 isothermal conduction calorimeter (**Fig. 5**). An isothermal calorimeter consists of a heat sink
202 with a thermostat, two heat flow sensors and a specimen vial holder attached to each sensor.
203 The heat of hydration released by the reacting cementitious specimen is transferred and passes
204 across a heat flow sensor. The calorimeter output is calculated from the difference between
205 outputs from the test specimen heat flow sensor and the inert specimen heat flow sensor.
206 Since the heat is allowed to flow away from the specimen, this measurement will essentially
207 take place at constant temperature (i.e. isothermal conditions). In order to ensure a
208 representative test, the mixture sample here was introduced into the calorimeter immediately
209 after mixing. Next, the heat evolution of the various formulations was monitored for the first
210 48 hours of hydration process.

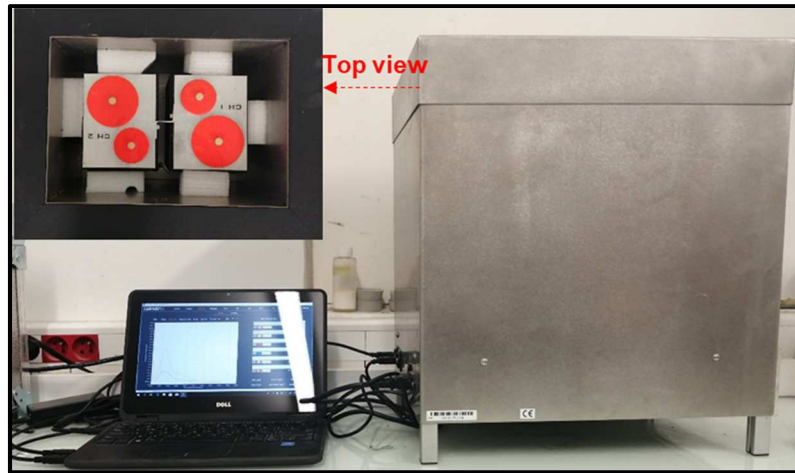


Fig. 5: Isothermal calorimeter I-Cal 2000-HCP

211 **II.4.2. Hardened properties**

212 **• Mechanical properties**

213 The flexural and compressive strengths of the various specimens were measured after curing,
 214 according to the EN 1015-11 standard. For flexural strength, three specimens from each mix
 215 were prepared and tested with a three-point bending. Six portions of the mortar prisms
 216 previously tested in bending were used for the measurement of the compressive strength.

217 **• Water accessible porosity**

218 The measurement of water-accessible porosity was carried out according to Standard NF P18-
 219 459. After 90 days of curing, the various specimens were dried in an oven at 105°C for 24
 220 hours, until attaining constant mass. After cooling in a desiccator, the specimens were
 221 immersed in water under vacuum for 48 hours in order to reach saturation. The specimens
 222 were then weighed using a hydrostatic balance (m_{water}) as well as being weighed in air (m_{air}).
 223 Lastly, the specimens were dried in an oven at 105°C and weighed once again (m_{dry}). The
 224 porosity (ϵ) and specific gravity (ρ_d) were both calculated using Equations (2) and (3),
 225 respectively:

226
$$\epsilon(\%) = \left(\frac{m_{\text{air}} - m_{\text{dry}}}{m_{\text{air}} - m_{\text{water}}} \right) \times 100 \quad (2)$$

227
$$\rho_d = \frac{m_{\text{dry}}}{m_{\text{air}} - m_{\text{water}}} \times \rho_{\text{water}} \quad (3)$$

228 **III. Parametric study of the mortar composite**

229 Both the water-to-cement (W/C) ratio and sand-to-cement (S/C) ratio are crucial parameters
 230 in defining the final properties of a cementitious material. Singh *et al.* (2015) exhibited that
 231 the mechanical properties of cement mortar decreased with an increase in S/C ratio [28].
 232 Those authors also reported that a W/C ratio determination is required to make the mortar
 233 workable; otherwise, the addition of natural fibers is widely known to greatly influence
 234 composite workability and composite mechanical properties [29]. In this regard, when
 235 choosing an adequate mix design, incorporating Alfa fibers has been essential to studying the
 236 combination of the fiber effect with the variation in dosage of the set of constituents.

237 III.1. Cement composite mix design

238 To study the effect of incorporating Alfa fibers on the cement mortar properties, a major
 239 preliminary step focused on optimizing the cement paste parameters. The rheological,
 240 mechanical and physical properties of cementitious materials usually depend on the nature
 241 and amount of its various constituents. Likewise, the addition of cellulosic fibers into a
 242 cement matrix influences the behavior of these materials, which means that the amount of
 243 each constituent must be studied beforehand. By varying the water-to-cement ratio (W/C =
 244 0.3, 0.4 and 0.5) as well as the sand-to-cement ratio (S/C = 1, 2, and 3), a set of nine
 245 formulations were mixed, containing Alfa fibers at 2% volume and 20 mm in length. The
 246 length and content of Alfa fibers correspond to the median values tested in the next part of
 247 this study.

248 **Table 1:** Composition of fiber-reinforced mortar with variation of the W/C and S/C ratios

Constituents (g)	Cement	Sand 0/1	Limestone (filler)	Superplasticizer	VMA	Water	Alfa fibers
FRM(0.3) ₁	900	900	225	9	4.5	259.7	28.6
FRM(0.4) ₁						349.7	31.1
FRM(0.5) ₁						439.7	33.7
FRM(0.3) ₂	600	1200	150	6	3	173.1	25.6
FRM(0.4) ₂						233.1	27.3
FRM(0.5) ₂						293.1	29.1
FRM(0.3) ₃	450	1350	112.5	4,5	2.3	129.8	24.1
FRM(0.4) ₃						174.8	25.4
FRM(0.5) ₃						219.9	26.7

249 III.2. Fresh properties

250 The flow diameters measured on fresh mortars are presented in **Fig. 6**. **Fig. 7** shows the
 251 appearance of slump flows across the various mixtures. It is observed that the workability of

252 reinforced mortar decreases as the S/C ratio rises; therefore, an increase in W/C ratio leads to
253 higher composite workability. For S/C = 1, workability increases according to the W/C ratio.
254 FRM(0.3)₁ and FRM(0.4)₁ display a respective workability of 19.5 and 20.9 cm and moreover
255 present a homogeneous appearance, which is indicative of good fiber distribution in the
256 cement matrix. However, FRM(0.5)₁ has a workability of 24 cm along with a fluid
257 appearance, thus suggesting a heterogeneous distribution of Alfa fibers in the cement matrix.
258 For this mixture, segregation has been observed, with a conglomeration of fibers in the middle
259 of the fresh mixture sample (**Fig. 7**).

260 The increase in S/C ratio leads to a decrease in workability, i.e. slump values of 10.0 cm for
261 FRM(0.3)₂ and 10.3 cm for FRM(0.4)₃, with a firm appearance, and a slump of 12.6 cm for
262 FRM(0.5)₃. Based on these values, mixtures with a high S/C ratio and low W/C ratio should
263 be avoided. In addition, the consistency of the FRM(0.3)₃ mixture was unmeasurable;
264 nevertheless, the increase in W/C ratio for mixtures containing a high S/C ratio could improve
265 the workability of a plant-based mortar. This finding has been confirmed by FRM(0.5)₂,
266 which has a slump diameter of 20.2 cm while exhibiting a homogeneous appearance.

267 The correlation between fiber addition and composite workability has been confirmed by
268 several studies. Singh *et al.* (2015) reported that insufficient water content leads to poor
269 workability; therefore, a method for determining the optimal water content and W/C ratio
270 influence on cement mortar should obviously be pursued [28]. Also, Haach *et al.* (2011)
271 confirmed that mortar workability increases with an increase in W/C ratio [30]. Bouhamou *et*
272 *al.* (2009) observed that increasing the water dosage serves to increase concrete fluidity and
273 causes a decrease in solid concentration inside the matrix. An excessive injection of water
274 actually causes segregation phenomena to appear in the fresh state [31].

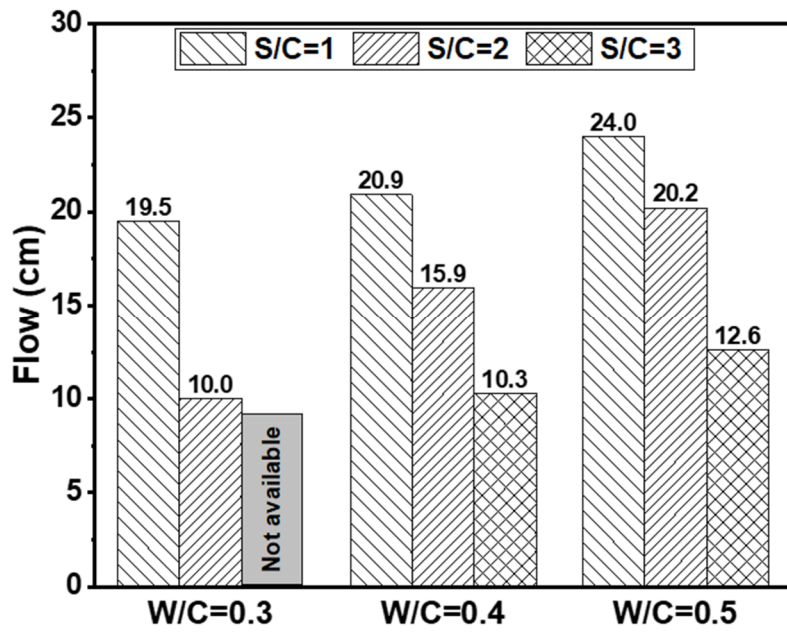


Fig. 6: Slump flow diameter of mortars

275

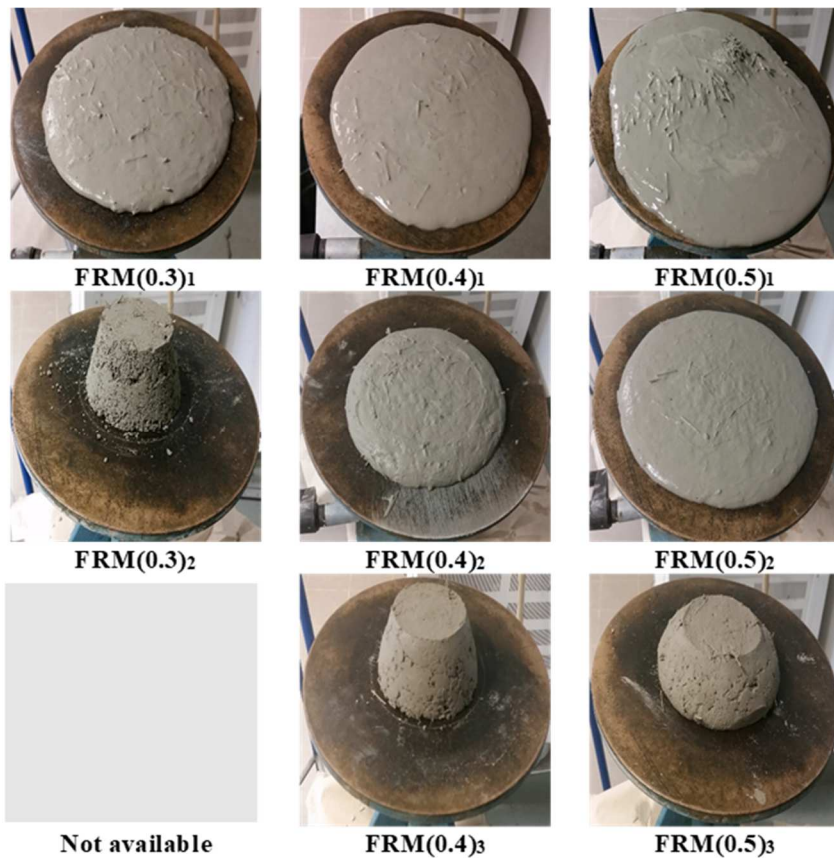


Fig. 7: Pictures of the table test for different mortars

276

277

278 III.3. Mechanical properties

279 To select the adequate formulation, mechanical tests were also performed in order to
280 complement the conclusions drawn from the workability test. The flexural and compressive
281 strengths of the various specimens were measured after curing of 7 days, according to the EN
282 1015-11 standard.

283 **Table 2:** Mechanical strength of different paste mortar

Specimens	FRM(0.3) ₁	FRM(0.4) ₁	FRM(0.5) ₁	FRM(0.4) ₂	FRM(0.5) ₂	FRM(0.5) ₃
Flexural strength (MPa)	6.3±0.8	4.4±0.5	3.2±0.3	4.6±0.3	3.3±0.3	3.5±0.4
Compressive strength (MPa)	39.3±3.4	25.9±3.6	14.8±1.4	24.5±2.4	13.7±1.7	14.8±4.2

284 FRM(X)_y : Fiber-Reinforced Mortar prepared with X corresponding to W/C and with Y corresponding to S/C.

285 Based on results obtained from the workability test, mixtures with very low slump diameters
286 (< 12 cm) were not tested in the hardened state. **Table 2** shows the compressive and flexural
287 strengths of fiber-reinforced mortars with different S/C and W/C ratios. The increase in the
288 W/C and S/C ratios lead to a decrease in the compressive strength of fiber-reinforced mortars.
289 For an S/C = 1, the compressive strength of FRM(0.3)₁ is capped at 39.3 MPa, which reflects
290 the highest compressive strength, in comparison with the other mixtures. Increasing the W/C
291 ratio from 0.3 to 0.5 leads to a 64% reduction in compressive strength, while the compressive
292 strengths of FRM(0.4)₁ and FRM(0.4)₂ are nearly identical. The flexural strength result
293 reveals the same trend observed for compressive strength, when increasing the W/C ratio
294 (**Fig. 8**). However, the increase in the S/C ratio leads to a slight increase of the flexural
295 strength of the reinforced mortar. For instance, for the composite with W/C=0.5, increasing
296 the S/C ratio from 1 to 3 leads to an increase of 9.3%. FRM(0.3)₁ has the highest flexural
297 strength, i.e. 6.3 MPa, compared to the other formulations.

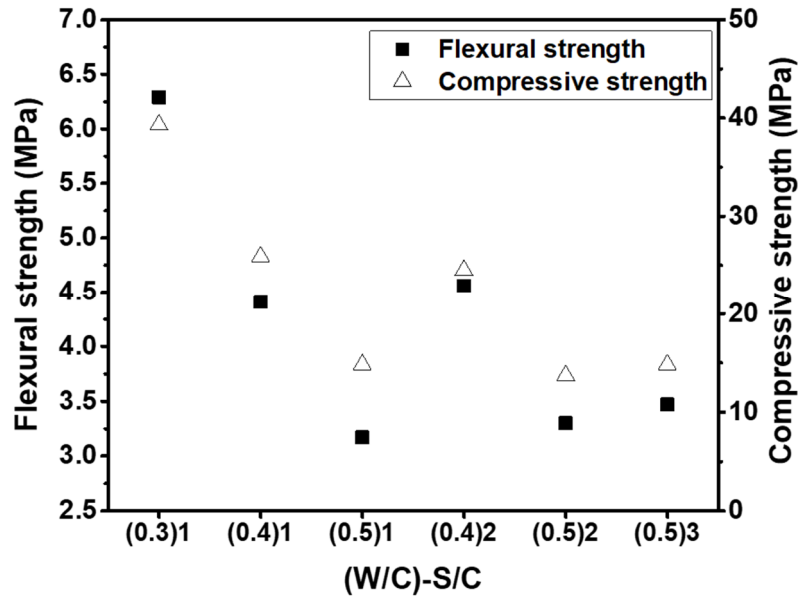


Fig. 8: Flexural and compressive strength evolution of mortar after 7 days of curing
W/C : water to cement ratio and S/C : sand to cement ratio

298 The workability measurements and mechanical testing were complementary in the effort to
299 choose a basic formulation. Based on analysis of the various results, FRM(0.3)₁ shows the
300 best mechanical properties. However, the slump diameter and apparent fiber distribution in
301 fresh mixtures were high enough to confirm the relevance of this mix design in satisfying the
302 objective behind this work, namely manufacturing an Alfa-based composite with good
303 workability and high mechanical strength. Although FRM(0.4)₁ presents a relevant mix
304 design candidate with slightly better workability than FRM(0.3)₁. However, its mechanical
305 performance is lower than that of FRM(0.3)₁. As such, to limit cement content and preserve
306 good workability and mechanical performance, it is preferable to select a W/C ratio ranging
307 between 0.3 and 0.4. The basic formulation used in this work was therefore set at: W/C =
308 0.35, and S/C = 1.

309 **IV. Influence of adding cut Alfa fibers on mortar properties**

310 Generally speaking, the addition of natural fibers leads to distinct changes in the cementitious
311 materials, in either their fresh or cured state. The length and addition rates require study in
312 order to determine the optimal values of these parameters. The second step of this study aims
313 to assess the effect of Alfa fiber length and addition rate on mortar properties. The Alfa fibers
314 were cut by varying the resulting length (10, 20, and 30 mm) in applying three addition rates
315 (1, 2 and 3% vol.) to the mortar composition. The various mixes are denoted as follows:

316 **RM(CFX)_y** stands for Reinforced Mortar with cut fibers, where X = length (mm) and Y =
 317 addition rate (%). **Table 3** summarizes the previously chosen mortar mix design.

318 **Table 3:** Composition of the control mortar
 319

Components	CEM III	Sand 0/1	Limestone (filler)	Superplasticizer	VMA	Water
Quantity (g)	900	900	225	9	4.5	304.7

320 IV.1. Properties of fresh mixes

321 The measured flow diameters of mortars reinforced with cut Alfa fibers are given in **Table 4**.
 322 The introduction of Alfa fibers does not significantly affect the workability of fresh mixtures,
 323 although Alfa fibers 10 and 20 mm in length do cause a slight reduction in the workability of
 324 mortars with 1% and 2% vol. of fibers compared to the control mortar (CM), which has a
 325 slump flow of 22.7 cm. Mixtures with 3% vol. of Alfa fibers exhibit a relative reduction of
 326 6% in workability for fiber lengths of 10 and 20 mm, and of 15% for fibers 30 mm long. The
 327 increase in fiber length with a high volume content leads to the formation of clusters (i.e.
 328 RM(CF30)₃), which strongly influences the fluidity of fiber mortars (**Fig. 9**). This same
 329 behavior has been reported in the literature; it was highlighted that the plant fiber content and
 330 length significantly influence cementitious material workability: a major reduction in the
 331 slump of flax-reinforced concrete was observed for a fiber length ranging from 12 to 36 mm
 332 [4].

333 **Table 4:** Slump flow of cut Alfa fiber-reinforced mortar
 334

Specimens	Addition ratio (% vol.)	Slump flow (cm)
CM	0	22.7±0.1
	1	22.0±0.1
RM(CF10)	2	21.8±0.1
	3	21.4±0.1
RM(CF20)	1	22.7±0.3
	2	22.2±0.1
	3	21.6±0.1
RM(CF30)	1	23.9±0.1
	2	22.4±0.2
	3	19.3±0.1

335 **RM(CFX)_y** : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%).

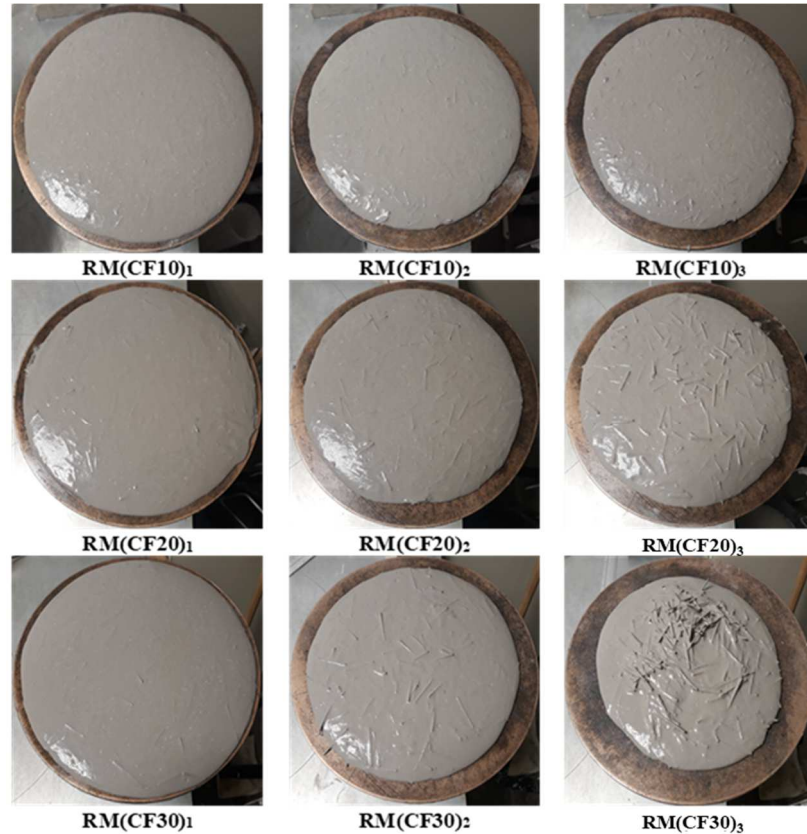


Fig. 9: Flow table test of cut Alfa fiber-reinforced mortar

336 **IV.2. Mechanical properties**

337 **Fig. 10** presents the flexural strength of Alfa fiber-reinforced mortar with different lengths
 338 and addition rates. The cementitious materials are identified by low flexural strength,
 339 typically less than 10 MPa [1]. The control mortar (CM) has a 28-day flexural strength of 7.3
 340 ± 0.3 MPa and 7.4 ± 0.3 MPa after 90 days of curing. The introduction of Alfa fibers into
 341 cement mortar leads to an increase in the flexural strength of cementitious materials. At 28
 342 days of curing, a 39~40% gain in flexural strength was observed for RM(CF10)₁ and
 343 RM(CF20)₁, in comparison with CM. However, the increase in the level of Alfa fiber addition
 344 leads to a 25% and 27% decrease in flexural strength relative to RM(CF10)₁ and RM(CF20)₁,
 345 respectively. Moreover, it was noted that mortar containing cut fibers 30 mm long (denoted
 346 RM(CF30)) has a lower flexural strength, regardless of fiber content. This finding confirms
 347 that increasing either the addition rate or fiber length strongly influences the flexural strength.
 348 The effect of fibers length or addition ratio were studied in certain research work. However,
 349 an opposite fiber behavior was recorded compared to the present work. Page *et al.* (2017) [4]
 350 studied the effect of varying flax fiber length on the properties of a structural concrete. Both
 351 fiber length and addition rate were found to significantly influence the flexural strength of

352 flax-reinforced concrete. It was noted that for each fiber length, the higher the flax fiber
353 content, the greater the flexural strength. Moreover, these authors confirmed that the flexural
354 strength of the composite increased when decreasing fiber length. Similarly, Çomak *et al.*
355 (2018) [32] corroborated this same correlation between hemp fibers and the mechanical
356 properties of cement-based mortars. It was reported that an increase in fiber content leads to
357 an increase in flexural strength of between 1% and 17%. The difference observed by these
358 two authors could be related to the actual fiber length studied. Page *et al.* used flax fibers cut
359 to 12, 24 and 36 mm, which presents a rather high average length. In contrast, the highest
360 length studied by Çomak *et al.* (2018) was 18 mm, a value closer to the optimal length given
361 the higher flexural strength reported in Page *et al.* (2017)'s research. This discordance
362 compared to the present work could be explained by the difference in fiber morphology. Flax
363 fibers are known for their flexibility, which could ensure a great deformation inside the
364 matrix. Unlike Alfa fibers, it was used in its raw state, which exposes diverse parameters
365 including its rigidity that could influence the flexural strength of the composite.

366 After 90 days of curing, the flexural strength of the cut Alfa fiber-reinforced mortar decreased
367 relative to its 28-day strength. For instance, the flexural strength significantly decreased, by
368 27% and 24% respectively, for RM(CF10)₁ and RM(CF20)₁; moreover, slight to medium
369 decreases were found in RM(CF10)₂, RM(CF10)₃, RM(CF20)₂ and RM(CF30)₁.
370 Nevertheless, mortars with fibers cut to a 30-mm length showed maximum flexural strength
371 gains of about 33% and 30% as observed in RM(CF30)₂ and RM(CF30)₃ respectively.

372 This behavior could be explained by the degradation of plant fibers in contact with the cement
373 matrix. According to Wei *et al.*, the degradation of natural fibers in a cement matrix could
374 occur in four steps: (i) lignin and hemicellulose degradation, which serves to expose the
375 holocellulose; (ii) reduction in cell wall stability due to hemicellulose degradation; (iii)
376 dispersion of some cellulosic fiber components in the pore solution of the matrix, thereby
377 promoting cellulose degradation; and (iv) a complete degradation of the natural fibers due to
378 alkaline hydrolysis of their amorphous part [33]. Based on this hypothesis, the decrease in
379 flexural strength ascribed to the addition of Alfa fibers could be correlated with fiber
380 hydrolysis taking place inside the matrix over time.

381

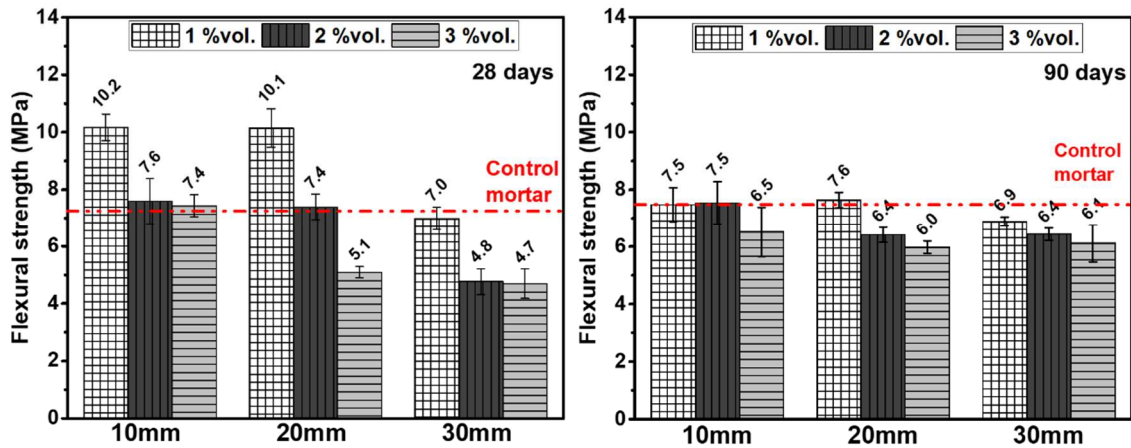


Fig. 10: Flexural strength of mortars reinforced with cut fibers at 28 and 90 days of cure

382 The compressive strengths after 28 and 90 days of curing various fiber-reinforced mortars are
 383 presented in **Fig. 11**. Compared to the control mortar (CM), the introduction of Alfa fibers
 384 reduces the compressive strength of the hardened composite. The CM exhibits a compressive
 385 strength of 83.2 ± 0.34 MPa at 28 days and 85.7 ± 0.10 MPa at 90 days. After 28 days of curing,
 386 the RM(CF10)₁ has a compressive strength of 68.6 MPa, which is the highest value of any
 387 fiber reinforced composition, showing a reduction of roughly 17% compared with CM. As
 388 depicted in **Fig. 11**, the increase in fiber content leads to a lower composite compressive
 389 strength compared to RM(CF10)₁, by 15% and 38% at 2% vol. and 3% vol., respectively, for
 390 a 10-mm length. This observation can be made for all Alfa fiber lengths. Otherwise, the
 391 variation in fiber length reduces the composite compressive strength. For a 30-mm length, the
 392 composite compressive strength also decreases with an increase in the addition rate:
 393 RM(CF30)₁ has a compressive strength of 59.4 MPa, while that of RM(CF30)₂ is 40.4 MPa
 394 and RM(CF30)₃ just 28.5 MPa. Consequently, these figures reveal a reduction of 29%, 51%
 395 and 66%, respectively, in comparison with the CM. Increasing fiber length thus seems to exert
 396 a more significant influence on compressive strength. These compressive strength decreases
 397 have also been highlighted by other authors on bio fiber-reinforced concretes [34,35], as
 398 attributed to greater concrete air content, which consequently reduces its compactness and
 399 hence its compressive strength [4]. These previous studies have also noted that long fibers
 400 produced lower compressive strengths; these fibers would further disrupt the granular
 401 packing, in turn reducing the mixture compactness.

402

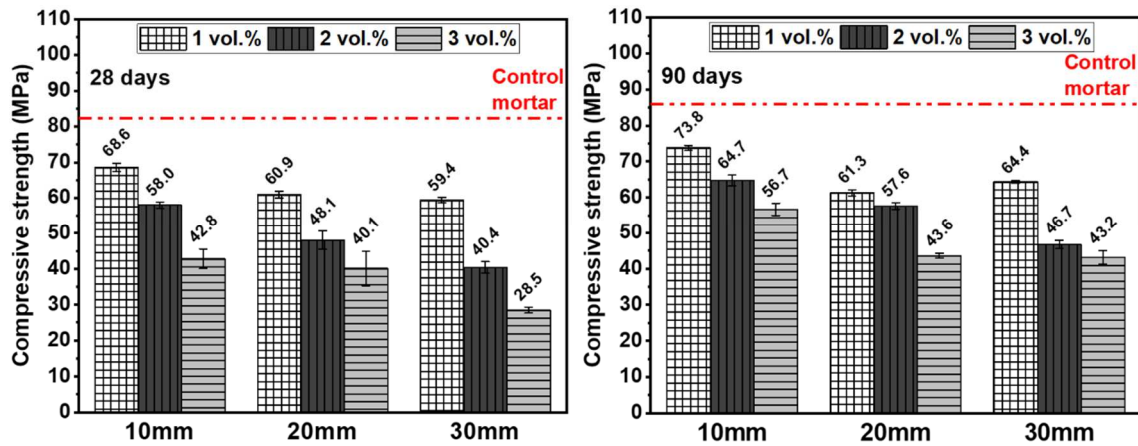


Fig. 11: Compressive strength of mortars reinforced with cut fibers at 28 and 90 days of cure

403 V. Comparative study between ground and cut Alfa fibers

404 The results of the previous section indicate the effectiveness of incorporating cut fibers into a
 405 cementitious matrix. An improvement in the flexural strength of reinforced mortar was
 406 definitely observed, at least for $RM(CF10)_1$ and $RM(CF20)_1$ formulations; however, this
 407 finding was coupled with a loss of strength after 90 days of curing. Such behavior is most
 408 likely related to fiber deterioration over time. Several works have tied fiber degradation to the
 409 presence of calcium hydroxide and, consequently, fiber mineralization inside the matrix [36–
 410 38]. Wei and Meyer (2015) reported that the water released from fibers is captured by the
 411 cement matrix during the hardening process, leading to the formation of a highly alkaline pore
 412 solution, which promotes fiber deterioration [33]. In this context, the objective herein is to
 413 incorporate the ground Alfa fibers in order to study their behavior in comparison with cut
 414 fibers. Grinding makes it possible to both shorten the Alfa fibers and increase their specific
 415 surface area. A comparative study between the two morphologies will now be conducted to
 416 examine the difference in behavior inside the matrix. The ground fibers were incorporated
 417 into the cement mortar, in maintaining the same addition rate previously studied (i.e. 1, 2 and
 418 3% vol.). The cement mortar composition also remains the same ($W/C = 0.35$ and $S/C = 1$), as
 419 do the test specimen storage conditions ($RH > 90\%$, $T = 20^\circ C$).

420 V.1. Effect of Alfa fiber morphology on mortar workability

421 The appearance of fresh mixtures produced using ground Alfa fibers is presented in **Fig. 12**.
 422 The ground fibers were added to the mixture at three addition rates (1, 2 and 3% vol.). The
 423 various formulations are denoted as follows: $RM(GF)x$ stands for Reinforced Mortar with
 424 ground fibers at an $x\%$ vol. addition rate.

425 Compared to the control mortar (CM), with a flow diameter of 22.7 cm, introducing ground
426 Alfa fibers up to a 2% vol. rate did not significantly affect workability on the reinforced
427 mortar. A slight variation of about 1% and 4% was measured for RM(GF)₁ and RM(GF)₂,
428 respectively; however, an RM(GF)₃ flow diameter of 19.8 cm was measured on the RM(GF)₃
429 mixture, thus corresponding to a 12% reduction relative to the CM.

430 Based on the observations shared in a previous section (IV.1), the cut Alfa fibers do not exert
431 any significant effect on the reinforced mortar workability. Results show that incorporating
432 Alfa fibers up to 2% vol., whether cut or ground, lead to an acceptable workability of the
433 fresh mixture. Nevertheless, a high addition rate does reduce mortar workability, yielding an
434 agglomeration of fibers inside the matrix. Similar observations have been reported in other
435 studies [4,39]. However, unlike other plant fibers (e.g. flax), Alfa fibers exert less influence
436 on the workability of fresh mixtures. This outcome might stem from the large Alfa fiber
437 diameter (approx. 1-2 mm), which for example is much greater than that of flax fibers (10-20
438 μm) [40]. Flax fibers do in fact significantly modify the rheology of the blends, due to their
439 high specific surface area [12,41]. In our case, the Alfa fibers, given their larger diameter,
440 have a much smaller specific surface area, hence reducing the effect of these fibers on
441 workability.

442

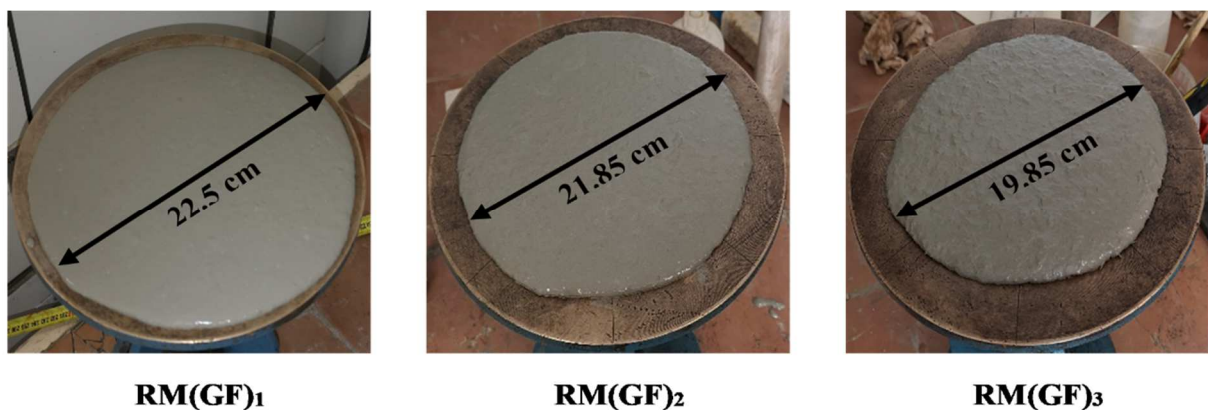


Fig. 12: Slump diameter of grinded Alfa fiber-reinforced mortar

443 RM(GF)_x : Reinforced Mortar with ground fibers at an x% vol. addition rate (%).

444 **V.2. Influence of Alfa fiber morphology on hydration kinetics**

445 Given the setting or hydration issues highlighted in the literature when incorporating plant
446 fiber particles in cementitious materials, it becomes necessary to assess the influence of Alfa
447 fibers on cement hydration. This step can be quantified by following the hydration kinetics of

448 Alfa-based mixtures with a calorimeter. This test was conducted on the following
449 formulations: CM, RM(CF10) and RM(GF) with 1, 2 and 3% vol. fibers.

450 The cement hydration process is constituted of several steps beginning with setting, followed
451 by hardening, crystallization and, lastly, release of heat of hydration [42,43]. Generally
452 speaking, the heat flow curve is characterized by three distinct times, such as the minimal flux
453 time (t_1), the first peak time (t_2) and the second peak time (t_3) [42]. **Fig. 13a** presents the heat
454 flow released during the hydration reaction of the cementitious composite. The heat flow
455 curve of the CM exhibits a two-step evolution. A rapid exothermic peak is observed during
456 the first 30 min, due to the dissolution of various clinker phases and the initial hydration of
457 aluminates [44]. Then the minimum flux time t_1 , corresponding to the induction period or
458 dormant period associated with relatively low chemical reactivity, lasts between roughly 30
459 minutes and 2 hours, depending on the cement type [45]. After this period, the hydration step
460 carries into an acceleration period, characterized by an increase in heat evolution over
461 approximately 10 hours until reaching a maximum heat flow corresponding to the main
462 exothermic peak (t_2), which is mainly due to alite (C3S in cement chemistry notation)
463 hydration to calcium silicate hydrate (CSH), i.e. the principal cementing reaction product. The
464 second peak (t_3) reported above did not appear in the CM heat flow curve, as the authors
465 attributed the appearance of this peak to the C3A content in cement when exceeding 12%,
466 which is not the case for the Portland cement used in this study [42]. Finally, the deceleration
467 period starts up, leading to a slow reaction period due to C3S consumption and aluminates. In
468 comparison to CM, a decrease in the main peak intensity can be observed when adding Alfa
469 fibers into the mixture. The induction periods of the Alfa-reinforced mortars are extended by a
470 time ranging between 30 min and 8 hours for RM(CF)₁ and RM(CF)₂ and between 30 min
471 and 16 hours for RM(GF)₁. The main hydration peak is therefore shifted to the right and
472 delayed; consequently, the main peak is observed at 18 h for both RM(CF)₁ and RM(CF)₂ and
473 at 25 h for RM(GF)₁, corresponding to a delay of 2 h and 9 h, respectively. A clear
474 relationship can be drawn between the Alfa fiber addition rate and heat flow. In fact, the
475 increased addition rate leads to a decrease in the maximum heat flow of Alfa fiber-based
476 mixtures. The change observed in hydration kinetics of the reinforced mortars could be
477 caused by soluble organic matter from Alfa fibers passed into solution in the mixture during
478 the mixing process. It has indeed been reported that extractive components from plant fibers,
479 such as saccharides, could significantly delay cement setting, even with a low content of these
480 carbohydrates [46–48]. Moreover, other studies have also highlighted that pectin is a
481 chelating agent of calcium ions that is capable of entrapping the cement ions inside its

482 structure [49,50]. Alfa fibers undoubtedly retain the calcium ions inside the pectin structure,
483 which could explain the delay observed in the hydration peaks of Alfa fiber-reinforced
484 mortars. The lower calcium ion concentration serves to create deficiencies in the cement
485 hydration reaction, thus inhibiting the formation of silica calcium gel, which is chiefly
486 responsible for the mechanical properties of cementitious materials. However, mortars
487 reinforced with ground fibers show a different behavior compared to mortars made with cut
488 fibers. For a 1% vol. of fibers, the main exothermic peak of RM(GF)₁ is more intense than the
489 same mortar containing cut fibers (RM(CF)₁). The increase in addition rate therefore leads to
490 lower heat flow peaks for the remainder of mortar compositions. Also, RM(GF)₂ did not
491 reveal any evolution during the 48 hours of calorimetry monitoring. The lack of RM(GF)₂
492 heat flow could be correlated with fiber composition. This behavior was pronounced for
493 RM(GF)₃, no significant evolution was detected after the 48 hours of measurement.

494 The presence of sugar in the fiber structure strongly influences the setting mechanism, a
495 finding which is in agreement with certain studies. Delannoy *et al.* (2020) for instance
496 reported that hemp concrete did not show an exothermic peak during six days of monitoring
497 [51]. Garci Juenger and Jennings (2002) also confirmed that cement hydration in the presence
498 of a powerful delayer, e.g. sucrose, characterizes an exothermic peak corresponding to the
499 hydration of tricalcium silicate (C3S) that becomes visible after 90 days of monitoring [52].

500 The cumulative heat release during the hydration reaction was determined by integrating the
501 heat flow curve. **Fig. 13b** displays the curve variations of the various mortars, with CM
502 showing the highest cumulative heat release, at 157.6 J/g. The inclusion of Alfa fibers, either
503 cut or ground, leads to a decrease in the heat release of the composite. This effect becomes
504 more pronounced when using a higher addition rate. For instance, decreases of about 78% and
505 60% were recorded for RM(GF)₂ and RM(CF)₃, respectively; nevertheless, RM(GF)₁ has a
506 cumulative heat release of 141.9 J/g, which represents a slight decrease (roughly 9%)
507 compared to the CM. Moreover, RM(CF)₁ has a cumulative heat release of 116.4 J/g, which
508 represents a decrease of about 26%, again compared to the CM. This behavior was related to
509 the hypothesis that fibers could inhibit the formation of calcium silicate hydrate, which acts as
510 the most fundamental element in obtaining good mechanical properties. It is clearly observed
511 that including Alfa fibers reduces the heat flow values, which might also be correlated with a
512 reduced amount of calcium silicate hydrate in the composite; consequently, the compressive
513 strength has decrease.

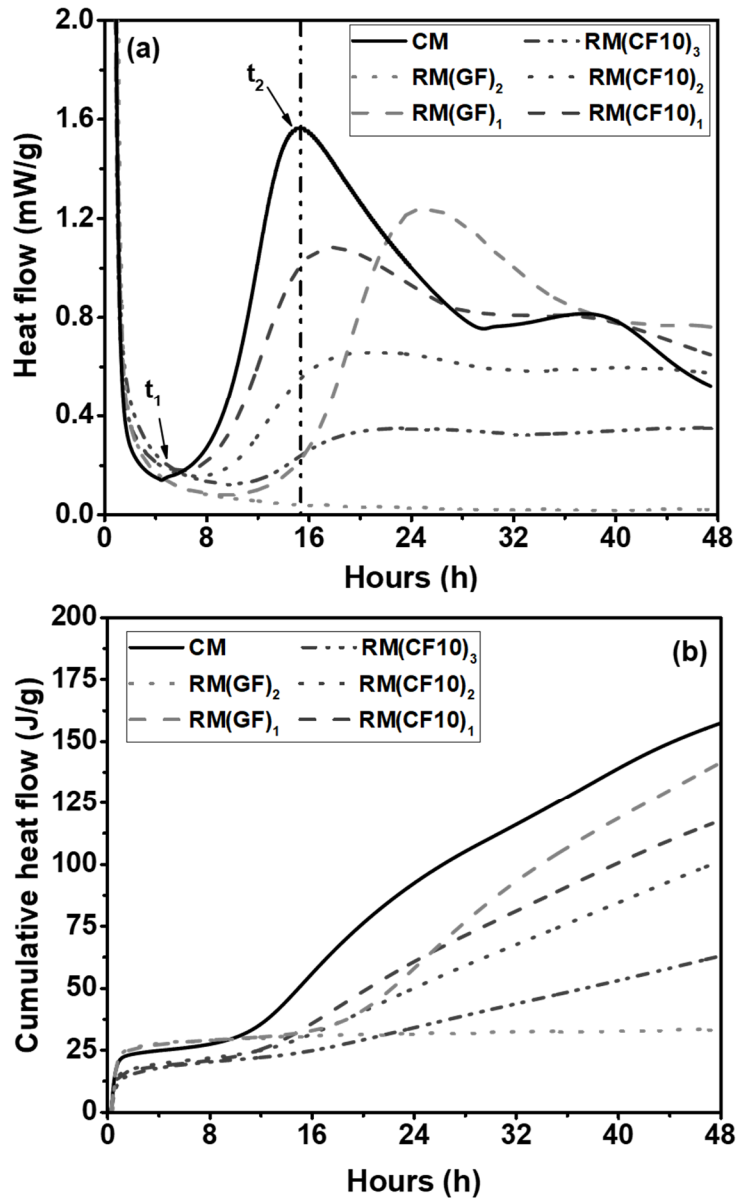


Fig. 13: Instantaneous heat flow (a) and cumulative heat released (b) for Alfa reinforced mortars

514
 515 **RM(CFX)_y** : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%)
 516 **RM(GF)_x** :Reinforced Mortar with ground fibers at an x% vol. addition rate (%)

517 **V.3. Physical properties of Alfa fiber-reinforced mortar: Water-accessible porosity and**
 518 **dry density**

519 Porosity is an essential parameter capable of influencing the mechanical properties of a
 520 cementitious material. Thus, the incorporation of Alfa fibers would likely exert an influence
 521 on the porosity of the hardened composite. Moreover, porosity commonly serves as an
 522 indicator of durability for cementitious materials since it determines the penetrability of
 523 aggressive agents into the material [53].

524 **Fig. 14** presents the water-accessible porosity of the reinforced mortar vs. Alfa fiber addition
525 rate. It should first be pointed out that the water-accessible porosity of the various mortars
526 depends on the fiber addition rate: increased fiber addition leads to higher mortar porosity.
527 The evolution of mortar porosity with ground fibers is somewhat similar to mortar with cut
528 fibers, by virtue of displaying a linear evolution with respect to fiber content. Compared to the
529 control mortar (CM), a 61 % relative increase in water-accessible porosity for RM(CF10)₃
530 and 54 % for RM(GF)₃ have been recorded. Furthermore, RM(CF20) and RM(CF30) exhibit
531 a similar curve, trending up to 2% vol. of fibers, with a maximum relative increase of 67%
532 compared to the CM. Beyond 2% vol., the water-accessible porosity remains nearly constant
533 for RM(CF20) and slightly increases for RM(CF30). These results are in agreement with the
534 literature. Previous works have confirmed that the inclusion of natural fibers in a cement-
535 based matrix increases the porosity of the composite [54,55]. The additional porosity created
536 inside the matrix is mainly due to the volumetric changes of the natural fibers from casting to
537 curing of the reinforced mortar. Plant fiber hydrophilicity does indeed heavily contribute to an
538 increased level of porosity. It has been reported that natural fibers absorb water during the
539 mixing step, thus leading to a volume variation with shrinkage/swelling phenomena of the
540 fiber [56]. This variation disturbs the cement hydration reaction while also promoting the
541 creation of pores.

542 The difference observed in the water-accessible porosity of cut fiber-reinforced mortars
543 (RM(CF)) and ground fiber-reinforced mortars (RM(GF)) could be explained by the different
544 fiber morphology. During composite curing, the cut fibers exhibit a major volume change,
545 leading to more voids within the matrix. This behavior is more pronounced for RM(CF30),
546 when taking the workability value of this composite into account. The formation of a cluster
547 along with reduced workability were observed, resulting in a potential change to composite
548 capacity and consequently an increase in its porosity. This outcome could explain the high
549 water-accessible porosity for the mortar with cut fibers. Moreover, regarding the water
550 absorption of Alfa fibers (**Fig. 4**), ground fibers have shown a lower absorption rate compared
551 to cut fibers, which might also explain the difference observed in composite porosity. The
552 lower absorption capacity of ground fibers would in fact reduce the volume variation due to
553 the swelling/shrinkage phenomena [57].

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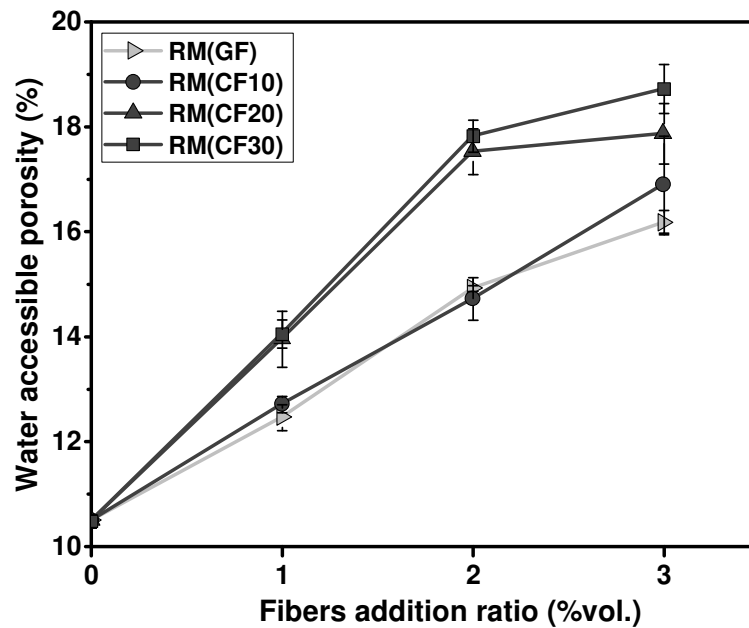


Fig. 14: Porosity of Alfa fiber-reinforced mortars according to fiber addition ratio

558 **RM(CFX)_y** : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%)

559 **RM(GF)_x** :Reinforced Mortar with ground fibers at an x% vol. addition rate (%)

560

561 The addition of Alfa fibers, either cut or ground, in mortars leads to increased porosity inside
562 the cementitious matrix. This finding could be due to the increased amount of entrapped air
563 inside the mixture, which probably reduces the composite compactness [4]. **Fig. 15** presents
564 the correlation between water-accessible porosity and composite density. It can be observed
565 that increasing fiber length and addition rate serves to increase composite porosity, as a result
566 of decreasing and reducing the density. For instance, with a 3% vol. of ground Alfa fibers, a
567 density reduction in RM(GF)₃ on the order of 3% compared to the CM is noted. Similarly,
568 lower densities are obtained with mortars containing the highest Alfa content, i.e. 3% vol.,
569 regardless of fiber length. However, the 1% vol. addition rate yields a composite with a
570 density near that of the CM. According to Djelal *et al.* (2020), comparable results have been
571 presented, with similar changes being recorded for sawdust-based mortars. The authors linked
572 the difference observed in results to the morphology of wood aggregates. Due to the wood
573 fiber morphology, in its slender form, these natural fibers are capable of entrapping a high air
574 volume [1].

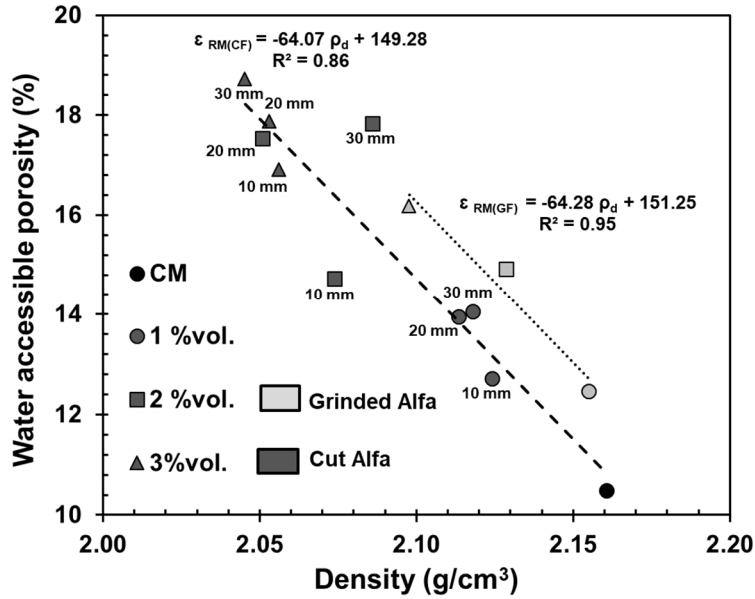


Fig. 15: Water absorption porosity and density correlation of Alfa fiber-reinforced mortars

575
576
577

RM(CFX)_y : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%)
RM(GF)_x : Reinforced Mortar with ground fibers at an x% vol. addition rate (%)

578 V.4. Influence of Alfa fiber morphology on mortar mechanical properties

579 V.4.1. Flexural strength

580 Flexural strength was measured for the reinforced mortars after 7, 28 and 90 days of curing.
581 **Table 5** summarizes the compressive and flexural strength values of mortar reinforced with
582 ground Alfa fibers. Compared to the CM (without fibers), ground Alfa fibers have a
583 significant effect on the composite's mechanical properties. The addition of ground Alfa
584 fibers, up to 2% vol., leads to a maximum increase in flexural strength of about 62% at 28
585 days of curing. Meanwhile, the 3% vol. addition also generates an 18% increase in flexural
586 strength. The optimal Alfa fiber addition rate thus seems to be 1% vol. At this fiber content,
587 the highest flexural and compressive strengths of mortars reinforced with ground fibers are
588 indeed obtained. Moreover, it is necessary to take the workability discussed above into
589 consideration. It has been noted that the increased addition rate could reduce mixture
590 workability. Consequently, the addition of 3% vol. of ground Alfa fibers leads to a reinforced
591 mortar with low workability, which is outside the scope of this work. At 90 days of curing,
592 the flexural strength slightly decreases compared to 28 days. These results are in agreement
593 with the literature. Krobbba *et al.* observed that using Alfa fibers cut to 2-5 mm in length led to
594 an exponential variation in flexural strength with an increase in the addition rate. A 16%
595 enhancement was found in comparison to the reference mortar at 1.25% fiber content [19].

596 **Table 5:** Flexural and compressive strength of grinded Alfa fiber-reinforced mortars

Specimens	Compressive strength (MPa)				Flexural strength (MPa)			
	CM	RM(GF) ₁	RM(GF) ₂	RM(GF) ₃	CM	RM(GF) ₁	RM(GF) ₂	RM(GF) ₃
7 days	64.4±1.4	59.0±1.4	33.7±5.2	26.4±0.6	6.2±0.2	8.6±0.5	8.8±0.5	5.1±0.1
28 days	83.2±1.9	74.3±1.9	54.6±4.1	36.8±3.9	7.3±0.1	11.8±0.6	11.3±0.1	8.6±0.1
90 days	85.7±0.1	81.8±0.6	63.2±1.4	48.7±1.9	7.4±0.3	10.9±0.2	10.5±0.5	9.4±0.4

597 RM(CFX)_y : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%)

598 RM(GF)_x :Reinforced Mortar with ground fibers at an x% vol. addition rate (%)

599 **Fig. 16** presents the effect of fiber morphology on the flexural strength of reinforced mortar.
 600 Using ground Alfa fibers serves to raise composite flexural strength compared to cut fibers.
 601 For instance, a 1% vol. addition results in a rise of approx. 17 % for RM(GF)₁ compared to
 602 RM(CF10)₁ and RM(CF20)₁. Even at a high addition rate, the flexural strength of ground Alfa
 603 fiber-reinforced mortar remains greater than that of the CM, as opposed to cut fiber-reinforced
 604 mortars. These results could be attributed to fiber morphology, which influences the adhesion
 605 between fiber and matrix. Morphology has also been found to exert a strong influence on the
 606 mechanical properties of fiber-reinforced cementitious composites [58,59].

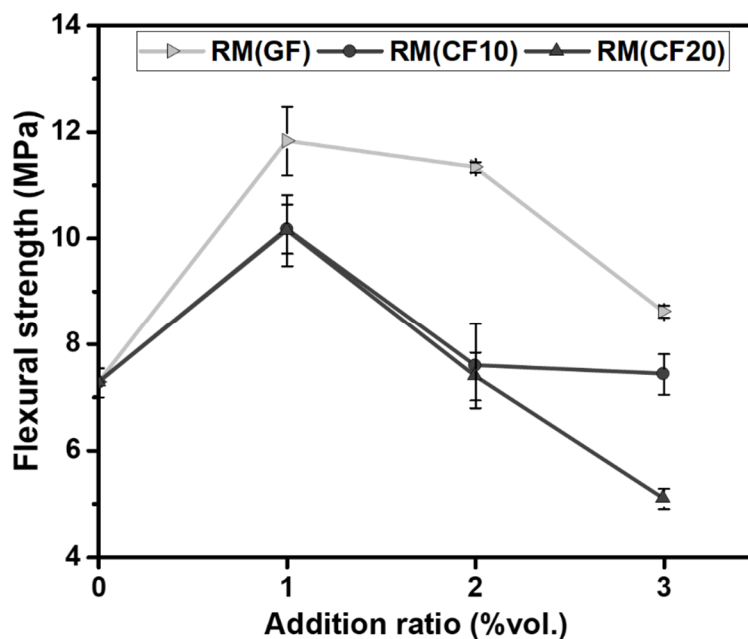


Fig. 16: Flexural strength comparison of RM(CF) and RM(GF) at 28 days of curing

607 As regards the flexural behavior of mortars, **Fig. 17** shows the load vs. load point
 608 displacement curve of the CM and Alfa fiber-reinforced mortars. The flexural tests were
 609 carried out on the various mortars cured at 28 days with displacement-control at a rate of 0.5
 610 mm/min. The mechanical properties of a fiber-reinforced composite depend mainly on fiber

611 content and orientation, but also on the load transfer capability of the fiber-matrix interface
612 [60,61]. Different phenomena acting simultaneously at different degrees, such as the physical
613 and chemical adhesions between matrix and fibers at this interface, govern such load transfer
614 capability [62]. The CM specimen exhibits a totally brittle behavior; however, the various
615 fiber-reinforced materials exhibit the same failure mode, i.e. brittle fracture. This
616 determination could be related to the shape and morphology of Alfa fibers. The cut Alfa fibers
617 did not show any apparent flexibility, which likely influences their behavior inside the matrix;
618 furthermore, their slippage out of the matrix could impact bending properties. Therefore, the
619 fibers do not serve to overcome the stress applied in order to achieve the expected ductility.
620 This hypothesis has already been reported in the literature. Zhang *et al.* (2020) specified that
621 poor interfacial bonding led to a weak bridging effect; as a result, the fibers easily slip out and
622 promote low composite ductility, with an appearance of deep crack widths [63]. Moreover,
623 Belkadi *et al.* (2018) observed the same failure mode when using Alfa fibers and other natural
624 fibers (Diss, palm date and hemp) as reinforcement of metakaolin-based mortars. These
625 authors also exhibited that natural fiber types, length and texture directly influence the
626 composite's mechanical behavior [11]. However, incorporating Alfa fibers improves the
627 composite's reinforcement capacity before reaching the maximum breaking load. Ground
628 fibers present a large peak area that could be tied to fiber morphology, as opposed to cut
629 fibers. Olivito *et al.* (2014) reported that due to the larger fiber cross-sectional area, the
630 composite samples measured a lower tensile strength [64].

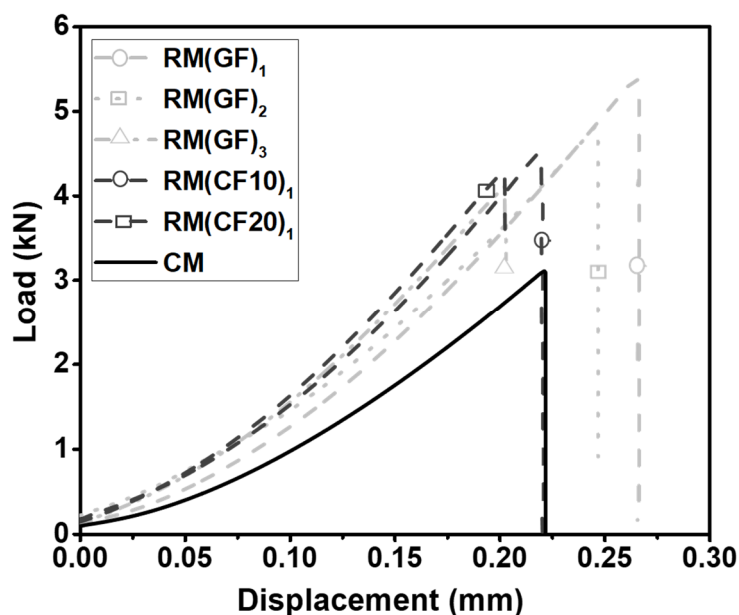


Fig. 17: Strain-displacement of Alfa reinforced mortar

631 **RM(CFX)_y** : Reinforced Mortar with cut fibers, where X = length (mm) and Y = addition rate (%)
632 **RM(GF)_x** :Reinforced Mortar with ground fibers at an x% vol. addition rate (%)

633 To evaluate Alfa/matrix adhesion, pictures were taken using digital video microscope on
 634 small fragment of 90 days cured mortar. **Fig. 18** illustrate the interfacial zone and distribution
 635 of Alfa fibers inside the matrix for both mortar formulation (grinded and cut fibers). A poor
 636 fiber/matrix adhesion is observed on mortars with fibers cut in different lengths, with a fiber
 637 slipping from the cement matrix (**Fig.18-a and Fig.18-b**). According to the literature, the
 638 SEM micrographs of the lateral view of Alfa fibers confirm that the Alfa fiber surface has a
 639 thick layer of impurities with a rough appearance, which in turn could affect the adhesive
 640 properties of the fibers [10]. Otherwise, an apparent homogeneous distribution of ground
 641 fibers in the matrix is observed (**Fig18-c**), which could improve the adhesion between fibers
 642 and matrix and therefore enhance the flexural strength of the reinforced mortar (**Fig18-d**).
 643 This change in Alfa fiber behavior is probably due to the different fiber morphology and
 644 specific surface area. Ground fibers do in fact possess a small fiber length compared to cut
 645 fibers, which leads to a high specific surface area and results in a larger contact surface area
 646 between fiber and cement matrix. According to the literature, Silva et al. (2011) corroborated
 647 that these fibers' cross-sectional area variation has a great influence on the adhesive force.
 648 Hence, the authors reported that fibers with arcuate or twisted shapes tend to more often
 649 display the highest adhesive stress values [12,62].

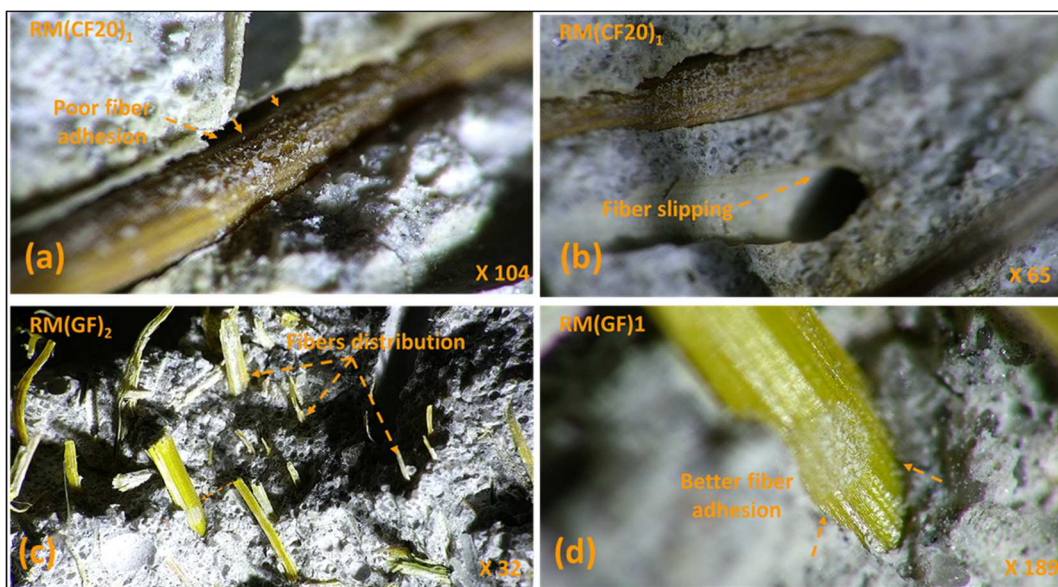


Fig. 18: Microscope observation of RM(CF) and RM(GF)

650 **V.4.2. Compressive strength**

651 **Table 5** summarizes the compressive strengths of mortars reinforced by means of ground Alfa
 652 fibers. The evolution in strength is similar to mortar using cut fibers, with values increasing
 653 over time for all of the various mixes. Compared to CM, the inclusion of ground Alfa fibers

654 reduces the compressive strength of the composite. The increase in addition rate leads to a
 655 significant decrease in compressive strength. For instance, at 28 days of curing, RM(GF)₁ and
 656 RM(GF)₂ indicate a decrease of 11% and 34%, respectively, compared with the CM. These
 657 results are similar to those of mortar made with cut fibers. **Fig. 19** presents the evolution in
 658 the relative compressive strength vs. fiber addition rate. Relative compressive strength is the
 659 ratio of the compressive strength of the fiber-reinforced mortar (RM(GF) or RM(CF)) to the
 660 compressive strength of the control mortar (CM). The incorporation of Alfa fibers, either cut
 661 or ground, reveals the same trend in the evolution of relative compressive strength when
 662 increasing the fiber content. This trend was also reported in a recent work; the authors noted a
 663 significant reduction in compressive strength when increasing the wood fiber substitution rate
 664 [1]. Also, it was reported by Boumhaout *et al.* that compressive strength significantly
 665 decreases with an increase in the addition rate of a date palm fiber (DPF) mesh. The authors
 666 attributed this behavior to the increased composite porosity and low DPF mesh mechanical
 667 strength [65].

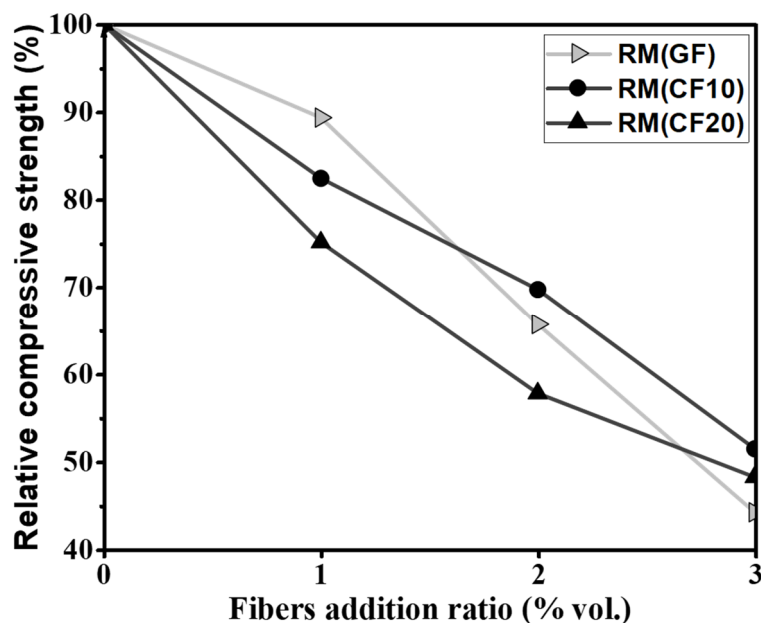


Fig. 19: Relative compressive strength of Alfa fiber-reinforced mortars at 28 days of curing

668 This decrease in the compressive strength of the reinforced mortar might be explained by two
 669 hypotheses. On the one hand, the modification of hydration kinetics has been corroborated by
 670 calorimetric tests previously performed on various formulations. The increase in the Alfa
 671 addition rate leads to a drop in the composite heat release; otherwise, the formation of silica
 672 calcium gels would be reduced, thus resulting in a decrease of compressive performance. On

673 the other hand, the water-accessible porosity strongly influences the compressive strength of
 674 cement composites. **Fig. 20** presents the correlation between water-accessible porosity and the
 675 compressive strength of specimens after 90 days of curing. A clear linear correlation between
 676 compressive strength and porosity can be discerned. The increase in addition rate therefore
 677 leads to a higher water-accessible porosity; consequently, the composite compressive strength
 678 declines. This finding confirms the results discussed above, namely a high addition rate of
 679 Alfa fibers, either cut or ground, raises porosity while decreasing density, resulting in a
 680 compressive strength reduction. This increase in porosity with the incorporation of plant
 681 fibers has been noted by other authors [66,67]; it is attributed to increased porosity at the
 682 interfacial transition zone (ITZ) between plant fibers and matrix [68].

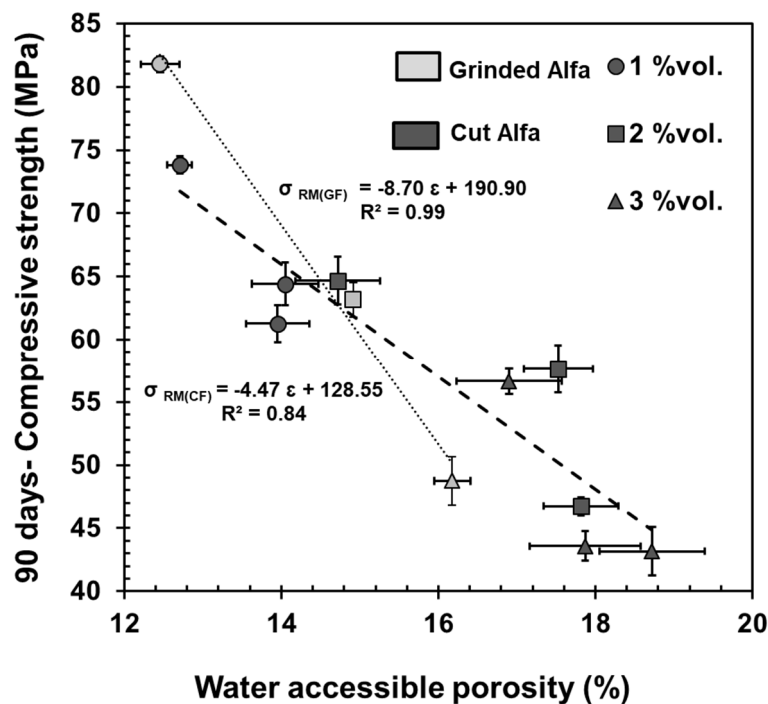


Fig. 20: Correlation between the water accessible porosity and the compressive strength after 90 days of curing

683 VI. Conclusion

684 This work has aimed to investigate the efficiency of Alfa fiber incorporation into a
 685 cementitious material. Two Alfa fiber morphologies were studied: cut Alfa fibers with three
 686 different lengths (10, 20 and 30 mm); and ground Alfa fibers (shorter than 2 mm). The post-
 687 saturation water absorption rate equaled 86% and 62% for cut and ground fibers, respectively.

688 A preliminary study was performed to select the appropriate mix design from both
 689 workability and mechanical property specifications. It was confirmed that W/C = 0.35 and

690 S/C = 1 were the optimal parameters with respect to these properties. The incorporation of
691 fibers 10 mm and 20 mm in length at up to 1% vol. allows improving the flexural strength of
692 the composite by about 28% at 28 days of curing, compared to the control mortar.
693 Nevertheless, at 90 days, the flexural strength has decreased, most likely due to fiber
694 degradation over time, although the values remain close to those of the CM. As regards
695 ground fibers, the reinforced mortar exhibits similar behavior, as the addition of ground Alfa
696 fibers up to 2% vol. leads to a maximum increase in flexural strength by approx. 62% at 28
697 days of curing. The addition of cut or ground Alfa fibers did not however improve the
698 compressive strength of the composite.

699 A comparative study was conducted to compare the effect of a fiber morphology change on
700 composite properties. The addition of Alfa fibers increases the composite's water-accessible
701 porosity; this effect is more pronounced for cut fibers than ground fibers. The longer fiber
702 contributes to creating more voids between fibers and matrix, which in turn raises the level of
703 water-accessible porosity and consequently decreases composite density. This finding was
704 also confirmed by the failure cross-section observations. It was noted that cut fibers were
705 slipping out from the matrix after the flexural test, which indicates poor fiber/matrix adhesion.
706 A modification in the hydration process was indeed recorded as a function of fiber addition
707 rate. An increased addition rate extends the induction period and decreases the main peak
708 intensity, which was mainly due to fiber composition. Based on these results, the compressive
709 strength reduction can be explained by both hypotheses; Fiber addition leads to a composite
710 with high porosity and low cumulative heat flow, compared with the control mortar.

711 Lastly, the addition of Alfa fibers might be effective when using ground or cut fibers up to 20
712 mm long at an addition rate of 1% vol. The delay observed in hydration kinetics could be a
713 positive during fabrication of the final product, which allows for sufficient time before setting.
714 By virtue of this work, it is recommended to modify the Alfa fiber surface in order to enhance
715 its adhesive properties.

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722

723 **Figure Caption**

724 **Fig. 1:** Grain size distribution of sand aggregates

725 Fig. 2: SEM micrograph of the external surface of Alfa fiber [8]

726 Fig. 3 : Cut and grinded Alfa fiber

727 Fig. 4: Water absorption kinetics of Alfa fibers

728 Fig. 5: Isothermal calorimeter I-Cal 2000-HCP

729 Fig. 6: Slump flow diameter of mortars

730 Fig. 7: Pictures of the table test for different mortars

731 **Fig. 8:** Flexural and compressive strength evolution of mortar after 7 days of curing

732 Fig. 9: Flow table test of cut Alfa fiber-reinforced mortar

733 Fig. 10: Flexural strength of mortars reinforced with cut fibers at 28 and 90 days of cure

734 Fig. 11: Compressive strength of mortars reinforced with cut fibers at 28 and 90 days of cure

735 Fig. 12: Slump diameter of grinded Alfa fiber-reinforced mortar

736 Fig. 13: Instantaneous heat flow (a) and cumulative heat released (b) for Alfa reinforced mortars

737 Fig. 14: Porosity of Alfa fiber-reinforced mortars according to fiber addition ratio

738 Fig. 15: Water absorption porosity and density correlation of Alfa fiber-reinforced mortars

739 Fig. 16: Flexural strength comparison of RM(CF) and RM(GF) at 28 days of curing

740 Fig. 17: Strain-displacement of Alfa reinforced mortar

741 Fig. 18: Microscope observation of RM(CF) and RM(GF)

742 Fig. 19: Relative compressive strength of Alfa fiber-reinforced mortars at 28 days of curing

743 Fig. 20: Correlation between the water accessible porosity and the compressive strength after 90 days of curing

744

745

746 **Table Caption**

747 Table 1: Composition of fiber-reinforced mortar with variation of the W/C and S/C ratios

748 Table 2: Mechanical strength of different paste mortar

749 Table 3: Composition of the control mortar

750 Table 4: Slump flow of cut Alfa fiber-reinforced mortar

751 Table 5: Flexural and compressive strength of grinded Alfa fiber-reinforced mortars

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