

Render reinforced with textile threads

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ABSTRACT

From a sustainable technical building perspective, this research work aims to investigate the potential of using waste products of the textile industry in building applications. In particular, textile threads as an alternative fiber reinforcement solution for cement based coating mortar. Unfortunately, undesirable and unexpected shrinkage cracking coating mortar is still a relevant concern in the building industry. Taking into account that this building pathology has a huge disproportionate depreciative impact on the overall value of a property, it is important to find building solutions that may contribute to mitigate this technical problem. Meanwhile, finding applications for the waste derived from the textile industry may also result in attractive economical and sustainable solutions. Pieces of fabrics or pieces of textile threads are the most common types of waste resulting from this industry. A 70% cotton and 30% acrylic composition thread was the textile waste considered as a reinforcement fiber in this paper. A preliminary characterization of this composite material was experimentally performed. A parametric study including different fiber sizes, fiber contents and ages of the reinforced coating mortar was carried out. The applicability, the durability and the mechanical behaviour of the proposed reinforced mortar were the main material properties studied in this research work. The obtained experimental results indicate that the studied composite

32 material may be interesting from technological, sustainable and economical points of
33 views.

34

35 **Keywords:** Textile waste, fiber, coating mortar, reinforcement, sustainability

36

37 1 – INTRODUCTION

38 Reducing energy consumption, water consumption and CO₂ emission to the
39 atmosphere, without compromising the overall quality of a product, must be a goal to
40 achieve in a production management system. Affordability is another extremely
41 important parameter to take into account. Reusing, opting for green building materials
42 (which must be renewable, local and abundant), retrofitting, choosing low technology
43 production methods and techniques are some practices that have given good results
44 within this context.

45 In the building industry context, it is extremely important to achieve such practices.
46 Therefore, recent different research works have been done in order to find alternative
47 sustainable building solutions. Using different agricultural product wastes [1-4] and
48 other types of residues such as newspaper [5-6] or micro-cellulose fibers resulting from
49 the recycling of cardboard of resinous origin [7] are some practical examples in which a
50 waste product is used as a raw material in a production process of a building product.
51 Textile waste has also been researched for this purpose [8-9]. From both sustainable and
52 affordable construction points of view, the use of natural fibers to reinforce cement
53 based materials may also be a feasible alternative to decrease the brittleness of mortars.
54 Plant fibers have been used such as eucalyptus pulp, coir or eucalyptus [10], sisal [11]
55 and kenaf (i.e. *hibiscus cannabinus*) [12].

56 In this research work, the building scenario of using waste of the textile industry as a
57 fiber for reinforcing cement based coating mortar is put into perspective. Taking into
58 account the expressive variability of types concerning this kind of waste, a 70% cotton
59 and 30% acrylic composition thread was the textile waste selected and considered as
60 fiber in this work. In general, the textile industry waste may be pieces of fabrics or
61 pieces of textile threads. In both cases, the size, the composition (e.g. cotton, wool,

62 acrylic, silk, linen, among other possible materials and mixtures) and the texture are
63 some aspects that contribute to the above mentioned material variability. The
64 complexity of studying this type of waste as a possible raw material in a production
65 management system is proportional to this high material variability expectancy.

66 Prior to the study of the behavior of cement fiber reinforced composite, the textile
67 thread characterization was performed. The microstructure of the fiber was
68 characterized, then its tension strength capacity was assessed. Several reinforced coating
69 mortar samples were processed in order to include two different lengths of fiber (e.g. 2
70 cm and 4 cm) and five different fiber contents (e.g. 0%, 1%, 2%, 3% and 4%). The
71 traditional coating mortar corresponds the unreinforced mortar (i.e. 0% fiber content)
72 incorporated and it works as a reference mortar. In order to figure out the applicability
73 of these proposed reinforced coating mortars, an experimental expedite procedure was
74 done, which consisted on applying each solution on an external brick masonry wall.
75 This preliminary experimental procedure was extremely valuable because it enabled the
76 confirmation that each solution can to be applied on masonry walls. This fact was
77 justified by the acceptable adhesion and the adequate scattering showed by all the
78 samples. This experimental procedure also allowed the monitoring of the material
79 behaviour of those samples under real extreme climate conditions during six
80 consecutive months (from July 2011 to February 2012). In parallel, samples were also
81 processed for bending and compressive tests.

82 Shrinkage and cracking of cement based coating mortars due to temperature amplitude
83 is still a common building pathology, which tends to reduce the value of the real estate.
84 Bad quality of materials (e.g. binders, aggregates and water), inadequate material
85 proportions (e.g. poor amount of cement or high water content), inadmissible technical
86 errors (e.g. high layer thickness or insufficient curing time), bad weather conditions
87 during application (e.g. extreme dry or freezing conditions) and lack of information in
88 the design are some causes of this type of building pathology. Usually, the related
89 repairing procedures are complex and slow and, therefore, costly. One solution to
90 mitigate this building problem, in particular the shrinkage cracking of coating mortars,
91 consists on reinforcing the mortars. Different and well established reinforcement
92 solutions have already been tested and made available in the building industry. Glass
93 fiber net and metal net are some examples of these solutions. Meanwhile, alternative

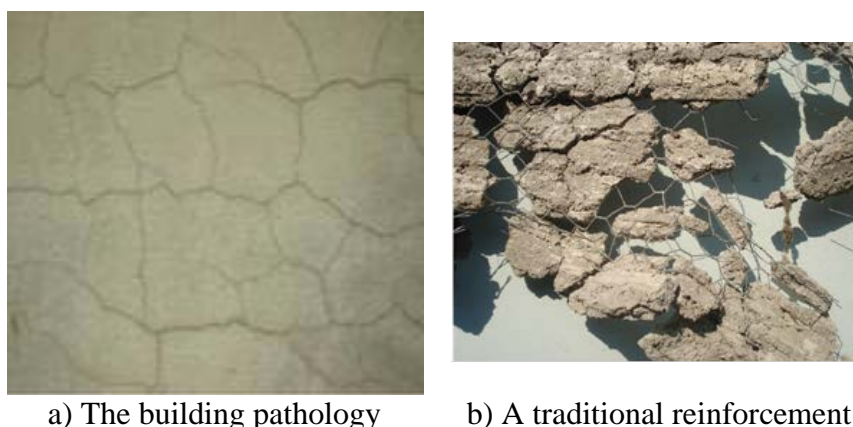
94 sustainable coating mortar reinforcement solutions have been proposed by the research
95 community. For instance, acrylic fiber [13], recycled plastic fiber [14] and sisal fiber
96 [11, 15] are among these possibilities. This paper intends precisely to give a
97 contribution in this matter by proposing textile thread fiber.

98 This paper is structured as follows; firstly, the problematic of shrinkage cracking
99 pathology of cement based coating mortars is briefly put into context; secondly, the
100 proposed textile thread fiber is experimentally characterized. Its microstructure is
101 identified and its tension strength is also evaluated; thirdly, a description of the sample
102 preparation is delivered; fourthly, the experimental results are presented, analyzed and
103 discussed; finally, the main conclusions are drawn.

104

105 **2 – CONTEXT**

106 As stated above, the problematic of shrinkage cracking of cement based coating mortars
107 deeply concerns the building industry agents. This flaw results in a disproportionate
108 depreciative impact on a building. In spite of not putting the overall stability of a
109 construction at risk, it is easily noticed because it affects the façades and it may also
110 contribute for a progressive occurrence of other building pathologies such as water
111 infiltration and premature material degradation. Therefore, repairing building techniques
112 are required to solve this problem. In general, apart from the repairing of the coating
113 mortar itself, it is also necessary to fix the finishing of the façade. These repairing
114 procedures end up being complex and costly. Thus, all the efforts to avoid the
115 occurrence of this pathology must be done, which include rigorous control of the quality
116 of the materials, specialized technicians, detailed design, among other constrains.
117 Additionally, building scenarios in which the likelihood of the appearance of this defect
118 is higher, may require additional preventive measures such as applying a reinforcement
119 of the coating mortar. An example of this building pathology and a traditional
120 reinforcement based on using a metal net are presented in Figure 1.a and 1.b,
121 respectively.

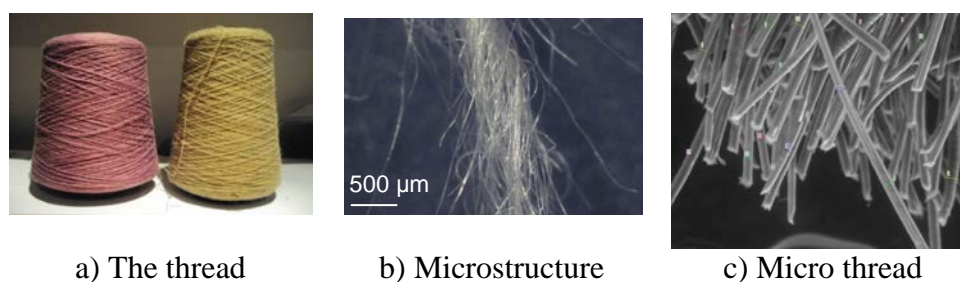


122 Figure 1: Examples of the pathology and of a reinforcement solution possibility

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124 **3 – CHARACTERIZATION OF THE THREAD**

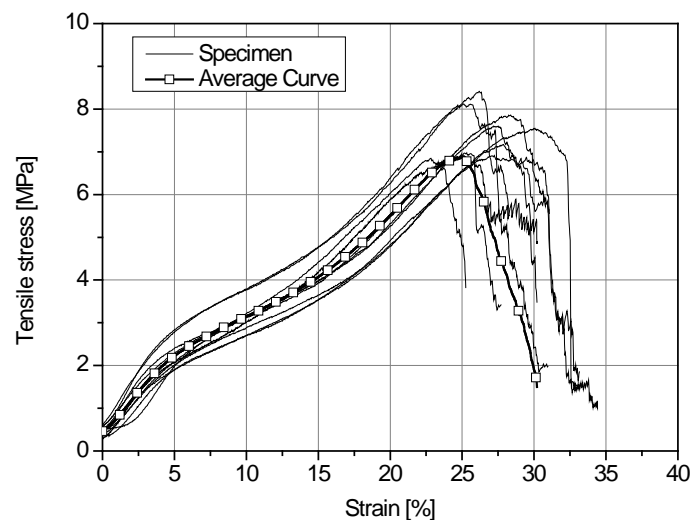
125 A 70% cotton and 30% acrylic composition thread is considered here as a textile fiber
126 reinforcing solution of coating mortar against shrinkage cracking, and as a sustainable
127 and an economical alternative building solution. This thread is a textile industry waste.
128 For instance, this type of fiber is intended as a substitute of the metal net of the
129 traditional reinforcement solution presented in Figure 1.b. The considered thread and its
130 microstructure are shown in Figure 2.a and 2.b. It is possible to realize that the thread is
131 formed by a set of micro threads, Figure 2.b. The thread has a diameter equal to 1 mm,
132 approximately. Meanwhile, the average diameter of the micro threads is 17.75 μm ,
133 Figure 2.c.



134 Figure 2: The considered textile thread

135 In order to evaluate the tensile strength of the thread, ten thread samples were tested in
136 terms of uniaxial tension. Each sample had 10 cm length. An Instron 5848 MicroTester
137 machine was used to perform the tensile tests. These tests were carried out with a
138 displacement ratio of 10 mm/minute. Figure 3 depicts the experimental tensile stress –

139 strain curves. The average tensile strength was 7.44 MPa with a coefficient of variation
140 of 6.8%. A 24.40 MPa modulus of elasticity was obtained. The material shows a linear
141 elastic behaviour up to the peak followed by a sudden rupture.



142

143 Figure 3: Tensile stress – strain curves

144

145 4 – REINFORCED COATING MORTAR SAMPLE PREPARATION

146 4.1 – Mixture compositions

147 As it was mentioned earlier, a parametric study was conducted in order to assess the
148 mechanical behaviour improvement of a traditional coating mortar when textile thread
149 fibers are incorporated. The fiber content to incorporate and the fiber length were the
150 selected parameters to be analyzed. At this stage, four fiber contents, FC, (e.g. 1%, 2%,
151 3% and 4%) and two fiber lengths (e.g. 2 cm and 4 cm) were the parameters considered.
152 Therefore, five different reinforced coating mortar compositions were prepared based
153 on the typical volume ratio of 1:1:6 (i.e. cement (C):lime (L):sand (S)) commonly
154 adopted in traditional cement based coating mortars. Each composition was related to a
155 certain fiber content. For instance, the 1% fiber content composition corresponds to the
156 ratio of 0.02:1:1:6 (i.e. fiber (F):cement (C):lime (L):sand (S)). A 70% water (W)/binder
157 (C and L) weight ratio was adopted in order to guarantee an adequate workability of the
158 reinforced mortar, in particular, for the 4% fiber content case. It is worth to underline
159 that the first composition is related to the traditional one in which there is no fiber
160 incorporated (i.e. 0% content). A detailed presentation of this information is displayed

161 in Table 1.

162 Table 1: Reinforced coating mortar compositions

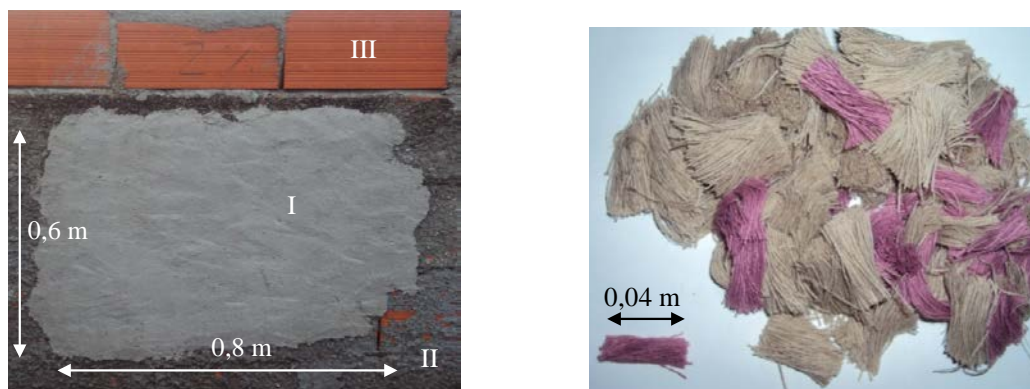
Composition	FC (%)	F (g)	C (g)	L (g)	S (g)	W (g)
1	0	0,0	710	710	4260	994
2	1	14,2	710	710	4260	994
3	2	28,4	710	710	4260	994
4	3	42,6	710	710	4260	994
5	4	56,8	710	710	4260	994

163

164 4.2 – Preliminary testing procedure

165 Before testing the proposed reinforcement solutions in terms of bending and
166 compression, a preliminary testing procedure was performed in order to evaluate the
167 practical feasibility of applying this composite material as a coating mortar. In other
168 words, it was important to evaluate the practicability of the reinforcement solutions in
169 an early stage of this research. In general, the technical aspects of adherence to the
170 support and the scattering are fundamental in the cement based coating mortar
171 applicability performance context. Therefore, an 11 cm thickness brick masonry model
172 was built outside in the north region of Portugal (Figure 4.a) and nine different cement
173 based coating mortar samples (e.g. Case 1: fiber content = 0%; Case 2: fiber length = 2
174 cm and fiber content = 1%; Case 3: 2 cm and 2%; Case 4: 2 cm and 3%; Case 5: 2 cm
175 and 4%; Case 6: 4 cm and 1%; Case 7: 4 cm and 2%; Case 8: 4 cm and 3%; Case 9: 4
176 cm and 4%) were applied on the support (i.e. the brick masonry wall). These samples
177 were approximately sized 0,01 m × 0,8 m × 0,6 m (i.e. thickness × width × height),
178 Figure 4.a. This task started on 22nd of July of 2011. It was verified that all the tested
179 coating mortar samples showed an adequate workability performance. However, it was
180 also concluded that the 4% content of incorporated fiber reduces the water content of
181 the mixture and, therefore, it slightly decreases its workability. Furthermore, the
182 samples that had 4 cm length fiber incorporated (Figure 4.b) required additional
183 application care. This fact indicates that the workability of the reinforced mortar tends
184 to decrease when the fiber length increases. On the other hand, this preliminary
185 experimental procedure also made it possible to monitor the behavior of the reinforced

186 solutions during six consecutive months (i.e. from 22nd of July of 2011 to 22nd of
187 February of 2012). In this scenario, the samples were directly exposed to the natural
188 weather conditions, which included exposure to severe temperatures (e.g. 40°C in
189 August of 2011 and -4°C in February of 2012). During this period of time, all the
190 samples showed an adequate material performance because there was no visible
191 shrinkage cracking appearance, the material kept its integrity, and there was no
192 delamination from the masonry wall.



a) A coating mortar sample (February 2012)

b) 4 cm fiber

Key: I – reinforced coating mortar layer; II – coating mortar base layer; III – brick masonry wall

193 Figure 4: A mortar sample application and the 4 cm fiber thread

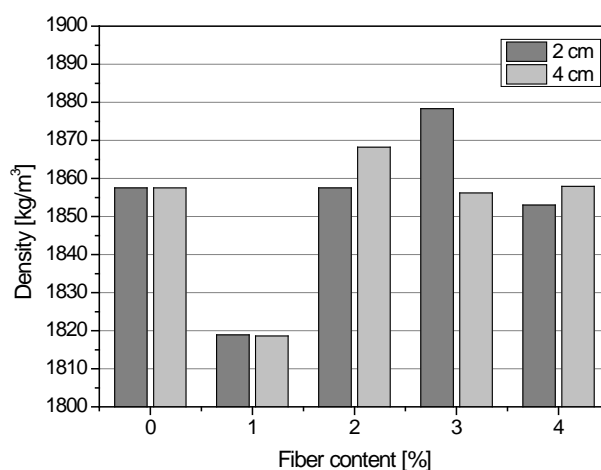
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195 5 – BENDING AND COMPRESSION BEHAVIORS

196 5.1 – Preliminary considerations

197 Bending and compression tests were performed in order to evaluate the mechanical
198 benefit resulting from the incorporation of the 70% cotton and 30% acrylic thread fiber.
199 Therefore, reinforced coating mortar samples sized 0,04 m × 0,04 m × 0,16 m (i.e.
200 width × height × length) were processed according to [16, 17], considering the
201 compositions presented in Table 1, and using 2 cm and 4 cm fiber lengths separately.
202 The evolution process of these mechanical properties during the curing time was also
203 another technical aspect analyzed. Thus, the samples were tested at the ages of 14 days
204 and 28 days. In order to achieve all these objectives, it was necessary to prepare 108
205 samples. Considering the procedure prescribed in [16], the curing process of the
206 samples occurred as follows: Step 1 - during the first two days the samples were kept

207 under the controlled thermo hygrometric conditions of the laboratory; Step 2 - during
208 the subsequent five days the samples were put in a climatic chamber under a constant
209 temperature of 65°C; Step 3 - the samples were kept in the laboratory under t similar
210 curing conditions as in Step 1, and until the testing date. In general, the density is an
211 important physical property to assess in a characterization process of a material. In this
212 research, the density was evaluated when the samples were aged 2 days, 14 days and 28
213 days, and in order to understand how this measure changed during the curing time.
214 Taking into account the above described curing condition process, the density of the
215 samples related to the cases from 1 to 10 tended to decrease according to the progress of
216 the curing, and because of the associated evaporation progress of the retained water. It
217 was verified that the density tends to increase slightly as fiber content increases. The
218 length of the incorporated fiber does not seem to affect the density directly, no pattern
219 was noticed. The evaluated densities also allow to state that there was an adequate
220 material uniformity among the processed samples. The existing regular discrepancy is
221 very likely to be related to the sample preparation. In order to complement this
222 information, the average densities of the different cases, at 28 days, are presented in the
223 diagram of Figure 5. For simplification sake, the respective diagrams for ages of 2 days
224 and 14 days are not presented here.



225

Figure 5: Average density at 28 days

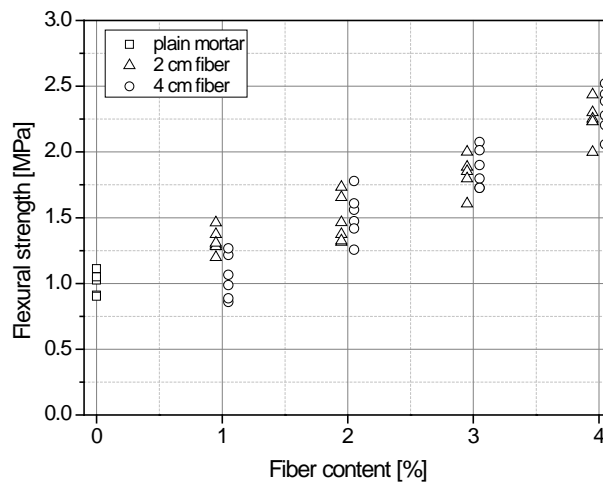
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228 5.2 – Bending test

229 A Seydner Mega 10/250/15D testing rig was used in the three-point bending test. The

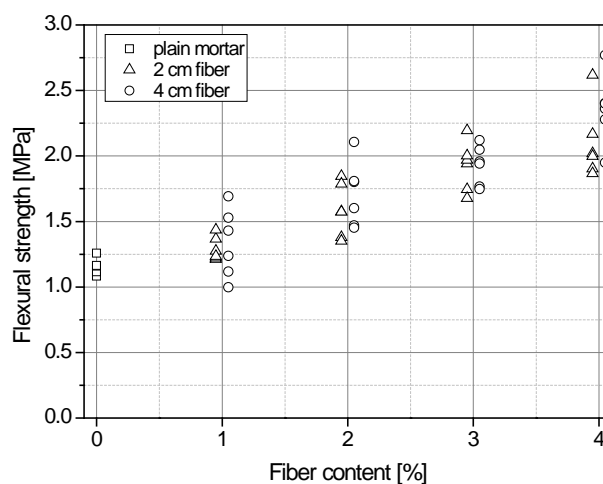
230 span was 100 mm. The 108 cement based coating mortar samples related to the cases
231 from 1 to 9 were tested at the ages of 14 days and 28 days. The evaluated ultimate
232 bending stresses, σ_{b14} and σ_{b28} , are presented in Figures 6 and 7 for these ages. The
233 experimental results obtained indicate that the bending strength of the reinforced
234 coating mortar tends to increase with the increase of the fiber content. There is no clear
235 evidence that it is advantageous to use high lengths of fiber. Taking the adopted curing
236 conditions into account, the main bending strength capacity was achieved before 14 days
237 days. From that age, there was only a residual strength capacity improvement with time.



238

239 Figure 6: Flexural strength (σ_{b14}) at 14 days. 2 cm fiber vs 4 cm fiber

240



241

242 Figure 7: Flexural strength (σ_{b28}) at 28 days. 2 cm fiber vs 4 cm fiber.

243 In order to complement this analysis, Table 2 summarizes the above data and presents

244 similar values obtained in other research works done on the same subject but concerning
 245 sisal [15] and acrylic [13] fibers. Apart from the differences in terms of fiber type, fiber
 246 length (L) and nature of cement and aggregate used, all the results match the above
 247 conclusions.

248 Table 2: σ_{b28} of some cement based coating mortars reinforced with different types of
 249 fibers

Fiber content (%)	σ_{b28} (MPa)			
	Sisal [15]	Acrylic [13]	70% cotton and 30% acrylic thread	
	L = 25 mm	L = 35 mm	L = 20 mm	L = 40 mm
0	1,02	1,03	1,17	1,17
1	1,26	1,23	1,29	1,33
4	2,01	-	2,10	2,36

250

251 5.3 – Compressive test

252 Similarly, a compressive test was also performed. In this context, the obtained
 253 experimental results converge to the same conclusions identified in Section 5.2. The
 254 quantified average compression stress (σ_c), for each case and for the ages of 14 days
 255 (σ_{c14}) and 28 days (σ_{c28}), is presented in Table 3.

256 Table 3: Results of the compression test

Case	σ_{c14} (MPa)	σ_{c28} (MPa)
1	3,96	4,37
2	4,21	4,58
3	4,71	5,14
4	6,20	5,90
5	6,93	6,78
6	3,76	3,80
7	4,99	5,16
8	6,64	6,26
9	6,98	6,82

257 Meanwhile, Table 4 gives additional information related to the compressive strength
 258 obtained in other reinforced cement based coating mortar contexts (e.g. sisal and acrylic
 259 fiber types). In terms of compressive strength, there is a high variability in terms of this
 260 mechanical property among the considered reinforced solutions. Taking into account the

261 differences indicated in Section 5.2 and the data of Table 4, a compressive strength
 262 decreasing for the sisal [15] and the acrylic [13] fiber solutions when the fiber content
 263 increases is featured. In contrast, in the 70% cotton and 30% acrylic thread fiber
 264 solution an opposite behavior seems to occur. In this case, the compressive strength
 265 increases according to the increase of the fiber content. The different water absorption
 266 ability of each considered fiber type may justify this mechanical behaviour discrepancy.

267 Table 4: σ_{c28} of some cement based coating mortars reinforced with different types of
 268 fibers

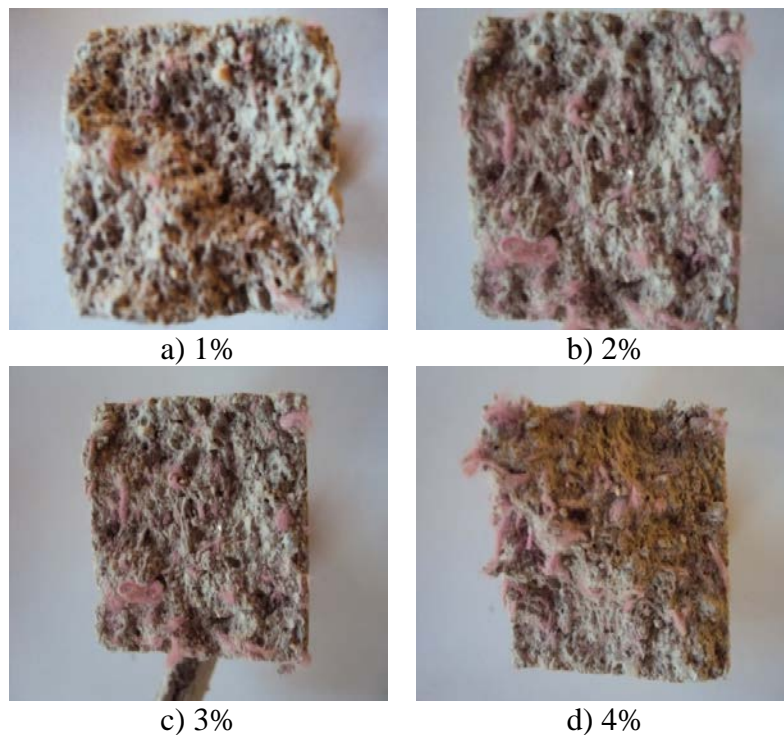
Fiber content (%)	σ_{c28} (MPa)			
	Sisal [15]	Acrylic [13]	70% cotton and 30% acrylic thread	
	L = 25 mm	L = 35 mm	L = 20 mm	L = 40 mm
0	7,57	5,69	4,37	4,37
1	7,03	5,44	4,58	3,80
4	5,41	-	6,78	6,82

269

270 6 – APPLICABILITY AND MATERIAL COMPACTIBILITY

271 As it was mentioned in Section 4.2, in an early stage of this research, a preliminary
 272 experimental procedure was done to verify the applicability of the proposed reinforced
 273 solution. In order to complement this analysis the fiber dispersion, the material
 274 adherence and the fiber failure mode were additional technical aspects taken into
 275 consideration. Thus, the sample bending rupture surfaces were carefully analyzed in
 276 order to find evidence related to these aspects that may influence the workability of the
 277 material.

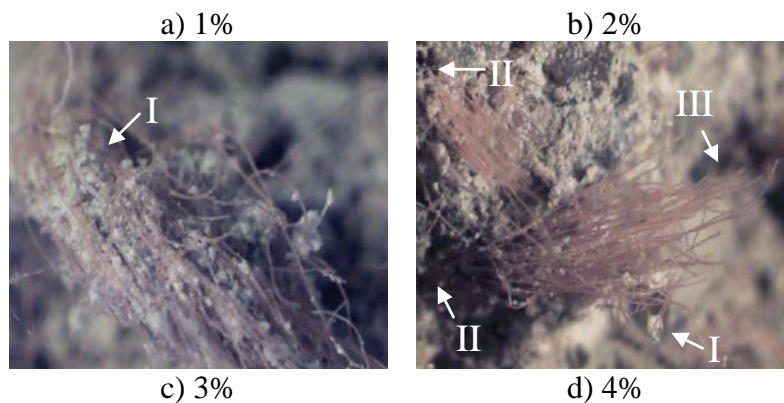
278 In Figure 8, those surfaces are presented for the cement based coating mortar samples
 279 reinforced with 2 cm fiber and for the different fiber contents. Acceptable uniform fiber
 280 dispersion seems to be achieved. A similar conclusion was obtained for the samples
 281 reinforced with 4 cm fiber.



282 Figure 8: Bending rupture surfaces of samples reinforced with 2 cm fiber

283 The same surfaces made it possible to obtain evidence about aspects related to material
284 adherence and fiber failure mode. These two technical aspects are fundamental in a
285 composite material. In this respect, amplified pictures of the mortar fracture surfaces
286 were specifically prepared in order to focus in the bond between fiber and mortar. These
287 pictures are shown in Figure 9 and for the different fiber contents. On the other hand,
288 these pictures also allow figuring out the fiber failure mode in the bending tests. This
289 fiber failure mode is characterized by the cut of the fiber followed by an unrolling of the
290 micro threads (III, Figure 9). These observations may indicate that the adopted thread
291 length (2 and 4 cm) is higher than the critical embedment length, favoring the fiber
292 rupture occurrence. However this failure mode is undesirable, since it will lead to less
293 ductile behavior of the composite.





294 Figure 9: Amplified pictures of the connection between fiber and mortar after failure

295

296 7 – FINAL REMARKS

297 An alternative cement based coating mortar reinforcement technique was proposed
298 based on the incorporation of textile threads. This building solution may be interesting
299 from a sustainable point of view because the thread may be a textile industry waste.
300 Taking into account the expressive material variability of that waste, a 70% cotton and a
301 30% acrylic composition thread was selected as the fiber considered in this research.
302 Therefore, it was necessary to perform a material characterization of the fiber. As a
303 result, it was concluded that this type of fiber has an approximate 1 mm diameter and it
304 is formed by a set of micro threads rolled to each other. It has an elastic behaviour, and
305 an approximate tensile strength and modulus of elasticity of 7.44 MPa and 24.40 MPa,
306 respectively. Fiber length and fiber content were two technical aspects considered
307 relevant and thus analyzed in detail. Consequently, an exhaustive parametric study was
308 done in which nine different compositions of reinforced coating mortar were defined.
309 Meanwhile, a preliminary experimental procedure allowed the verification of the fact
310 that the proposed building solution has adequate workability and durability. Bending
311 and compressive tests also led to the conclusion that the mechanical behavior of the
312 coating mortar may increase according to the increase of the fiber content. In contrast,
313 this tendency does not seem to occur when the fiber length increases. Additionally, high
314 fiber lengths may reduce the workability of the mortar. Moreover, it was noticed that it
315 is possible to obtain adequate uniform fiber dispersion, and that there is an adequate
316 bond between the fiber and the mortar. These two technical aspects are relevant in a
317 composite material (e.g. reinforced coating mortar), in particular, the material

318 compatibility. In a practical building scenario, a mixture of different types of threads as
319 a waste product resulting from the textile industry is expected to occur. Therefore,
320 further research is required to be done on this subject. Furthermore, the experimental
321 results obtained may give guidelines for other possible applications of textile thread as a
322 reinforcement fiber for other building elements with non-structural purposes.

323

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