TEXTILE WASTE FIBER-REINFORCED MORTAR: PERFORMANCE EVALUATION

Gonilho-Pereira, C.N., Civil Engineering M. Eng. – IPS - Portugal – cristiana.pereira@estbarreiro.ips.pt
Martins, A., Civil Engineering M. Eng. – IPS - Portugal – ana.martins@estbarreiro.ips.pt
Faria, P., Civil Engineering Ph. D. – FCT/UNL - Portugal – paulina.faria@fct.unl.pt
Fangueiro, R., Textile Engineering Ph. D. – UMinho - Portugal – rfang@det.uminho.pt

ABSTRACT

The increase of extraction and processing of natural resources is accompanied by the formation of significant amount of waste materials. Comparative studies on recycling and waste management options reveal significant environmental advantages of recycling over landfilling and incineration. Therefore, the cost, quality and availability of raw materials became of paramount importance and a significant number of companies are currently developing secondary manufacturing processes for their waste materials and by-products.

Among the industries producing wasting materials, textile industry produces large amounts of waste which are used with success in second-line products. Although the usage of waste fibers in the building construction industry is already a reality, namely in the production of thermal and acoustic insulation panels, their disposal in landfills is still a reality. An interesting application seems to be fiber-reinforced mortar mixtures for masonry applications, new or replacing existing mortars, which have not been extensively studied. The selection of appropriate mortar mixtures is an important research problem once four main factors should be considered in their design - durability, flexural resistance, compatibility and, consequently, economy. The addition of reinforcing fibers reduces the size of cracks in cementitious materials, which also reduces the ingress of water, the primary factor in the deterioration which influence durability and compatibility with the support.

In this paper an experimental work is presented which main objective is the evaluation of the influence of different percentages of waste fibers usage on the performance of fiber-reinforced mortars. Mortars performance evaluation was carried out through flow table, dynamic modulus of elasticity, flexural and compressive strength, capillary absorption, drying index, open porosity, thermal conductivity and adherence tests.

From the research work carried out, one may conclude that when the percentage of waste fibrous material increases: is very difficult to obtain an homogeneous fiber dispersion; the mortar consistency tends to be constant as well as the capillary absorption, drying index, open porosity; the dynamic modulus of elasticity decreases as well as the flexural and compressive strength; adherence strength increases and the thermal conductivity various in a very interesting way.

Keywords: waste fibers, solid waste, cement, mortar, mechanical/ physical properties, mortar characterization.

INTRODUCTION

The increase of extraction and processing of natural resources is accompanied by the formation of significant amount of waste materials - only 1/3 of extracted raw material is used to produce industrial output; the rest 2/3 turn into waste materials and by-products (AABMCI, 2009).

Comparative studies on recycling and waste management options reveal significant environmental advantages of recycling over landfilling and incineration. Therefore, the cost, quality and availability of raw materials became of paramount importance and a significant number of companies are currently developing secondary manufacturing processes for their waste materials and by-products.

Among the industries producing wasting materials, textile industry produces large amounts of waste which are used with success in second-line products. Although the usage of waste fibrous materials in the building construction industry is already a reality, namely in the production of thermal and acoustic insulation panels, their disposal in landfills is still a reality. Waste fibrous materials are accumulated at textile factories and the technical challenge is the search for new applications for waste products of fibrous materials.

An interesting application seems to be fiber-reinforced mortar mixtures for masonry applications, new or replacing existing mortars, which have not been extensively studied.

The selection of appropriate mortar mixtures is an important research problem once four main factors should be considered in their design - durability, flexural resistance, compatibility and, consequently, economy. Fiber reinforced cement based mortars have been suggested as one of the most effective methods to improve performance behaviour, namely: mechanical; shrinkage, expansion and related phenomena which lead to cracks; and durability (Segre et al, 1998; Puertas et al, 2003). Fibers present the ability to act as a bridge between the grains of the mortar matrix. When the fibers are uniformly distributed into the mortar, plastic shrinkage may be minimized and micro cracks are prevented from developing into macro cracks. Therefore the consequent strength reduction, water intake increase and subsequent decay of the mortar by freezing–thawing cycles, and aesthetic involvements may be avoided.

EXPERIMENTAL WORK

MATERIALS

The waste fibers used in the present research work derive from waste fibrous materials collected from textile industries in the outskirt of Minho area, in the northern part of Portugal. The fiber mass consists of many unknown fibers, since it was collected from several textile industries producing a various range of textile qualities and consequently using many different fiber materials and fiber/ fabric treatments (Figure 1. a)). The collected waste fibrous material was used for the production of nonwovens and the waste fibers used in this research work are manufacturing wastes of the nonwoven manufacturing process (Figure 1. b)) - microfibers.

a.) waste fibrous material. b.) waste fibers

Figure 1 Textile industry waste material

The identification of the waste fibers content was performed according to the work developed by (Lundhal, 2008):

i) Burning test: aims to distinguish whether the unknown fibers are of natural or synthetic origin. Burn examination cannot be used to identify different fibers of the same chemical composition. The specimen was held over a clean flame from gas burner or from a wooden match. The fiber smell, flame colour, burn behaviour, ash formation and smoke were examined. It was suspected that it contained a considerable part of natural fibers, as well as some synthetic polymers.

ii) Chemical test: 75% Sulphuric acid, H2SO4, was used to quantify natural fibers, since cellulosic fibers are soluble in acids. Once wool fibers are destroyed by chemical bases, hydrogen peroxide, HCl, was used to quantify the percentage of wool fibers.

iii) Optical test: surface of the fibers were analysed and compared to reference standard for identification of fiber material.

The waste fibers (F) consisted of the following composition (Table 1):

Table 1 Waste fibers composition

Cellulose, most likely is cotton	Polyester	Wool	Polypropylene, Polyamide, among others
85%	10%	2%	3%

For the preparation of the mortars two different washed sands were used as aggregates – a coarser sand 0/4mm (CS), from Pinhal Conde Cunha 4 no Seixal (Portugal), and a finer sand 0/2mm (FS), from Herdade da Mesquita em Sesimbra (Portugal), both generally used in the region for mortar preparation.

Both sands were used mixed in the proportion of two volumes of fine sand and four volumes of coarse sand in order to achieve a well graduated sand (FS+CS) with a small index of voids (Figure 2).

The binder used was a Portland cement CEM II/B-L 32,5N commercialized by Secil S.A. (C) (Portugal).

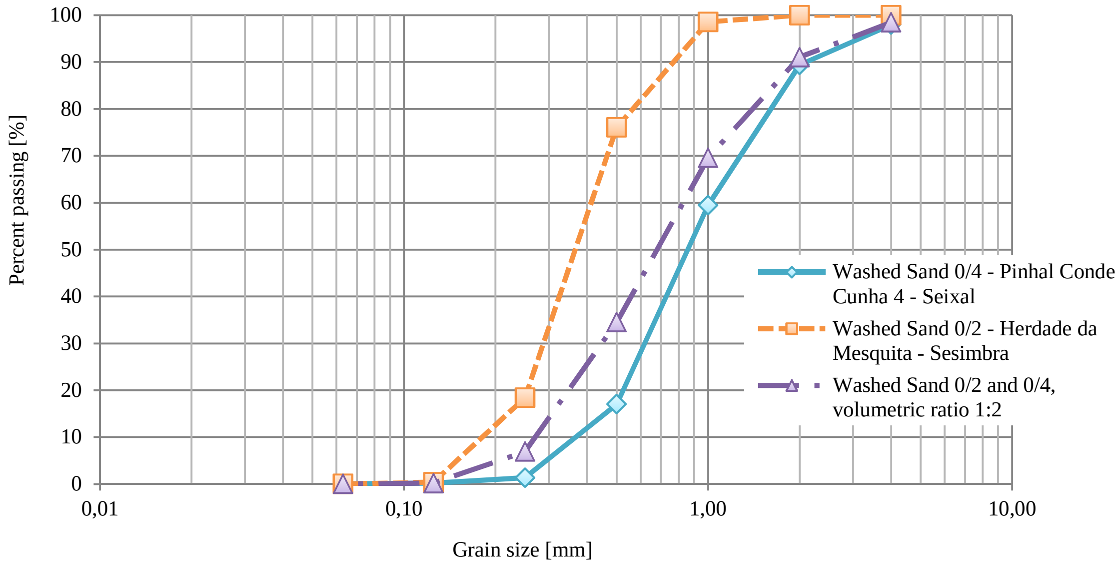


Figure 2 Fine and coarse sand particle size analysis

WASTE FIBER-REINFORCED MORTAR PREPARATION

Seven different mortars were produced maintaining constant the quantity of binder and sand and varying the percentage of waste fibers added. Volumetric and mass composition of cement mortars are registered in Table 2. Mortars have been made without waste fibers (Ref) and with the addition of waste fibers in different percentages of the binder mass – 0,25% (F1), 0,5% (F2), 1% (F3), 1,5% (F4); 2% (F5) and 5% (F6).

The mixture of the mortar components was mechanical and always identical between the different mortars produced (Figure 3). The procedure was based on EN 1015-2/A1 but the solid materials, i. e., sands and binder, were previously hand homogenized.

In order to provide a better fiber dispersion, it was decided to use wet dispersion into the mixing water among three dispersion methods tested: fiber dispersion in the mixing water using a magnetic stirrer; fiber dispersion in the mixing water using ultrasonic mixing; and fiber dispersion in the mixing water using manual agitation for a period of 60 seconds. Among the three techniques tested the manual agitation in the mixing water was chosen once the results obtained with the magnetic stirrer and the ultrasonic equipment was not satisfactory (Figure 3).

Already with the fibers dispersed in the mixing water, the water was introduced into the mechanical mixer and then the solid components were added. The mixture was held for 30 seconds at slow speed, followed for a period of 30 seconds off to scrape the material accumulated inside the vat and the paddle, and finally returned to connect the mixer at faster speed for 120 seconds.

It was verified that when high percentage of waste fibers were used the fibers tend to agglomerate in the mixer paddle causing an inefficient dispersion of the reinforcing material on the cementicious matrix. Therefore, mortar F6 appears as an exception to the mixing procedure adopted, once the homogenization was carried out manually.

In accordance with the NP EN 196-1 mortar samples were mechanically compacted in two layers inside prismatic metallic molds with 40x40x160 mm, which were kept at a relative humidity (RH) of 90% and temperature (T) of 20°C. At three days of age the prismatic molds were demolded and the mortar specimens maintained under the same curing conditions up to 27 days. 6 mortar specimens were produced for each mortar, with the exception of the F6 mortar (3 samples). To simulate the covering wall procedure, each mortar was applied over two ceramic bricks, falling from a defined height, in order to standardize the energy of application of the mortar over the brick (Figure 3) and regularized as a render.

Table 2 Mortars composition

<table>
<tr><th>Mortar ID</th><th>Volumetric composition</th><th>Mass composition</th><th>Waste fibers [%]</th><th>Mortar Mix</th></tr>
<tr><td>Ref</td><td rowspan="7">1:6</td><td rowspan="7">1:7
1:3:6 (C:FS:CS)</td><td>0</td><td rowspan="7">Coarse sand (CS)
Fine sand (FS)
CEM II/B-L
32,5N
Water/Binder =0,7</td></tr>
<tr><td>F1</td><td>0,25</td></tr>
<tr><td>F2</td><td>0,5</td></tr>
<tr><td>F3</td><td>1</td></tr>
<tr><td>F4</td><td>1,5</td></tr>
<tr><td>F5</td><td>2</td></tr>
<tr><td>F6 - manual</td><td>5</td></tr>
</table>

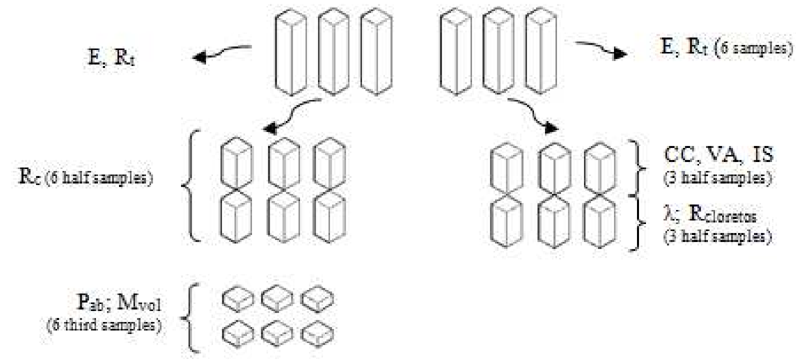
Figure 3 Mortar production

TESTING PROGRAM AND RESULTS

Mortar characterization

Prior to the testing program has been established which use to give to each mortar specimen. Figure 4 presents the pattern of use depending on the type of test to be performed.

To evaluate the influence of the amount of water in the mortar and characterized it in the fresh state, consistency flow table test was carried out according to EN 1015-3/A1/A2. At 27 days of age, was evaluated the dynamic modulus of elasticity (E) (through internal procedure and using ultrasound equipment and based on EN 14146). The mechanical strength is of all factors that influence the mortar durability one of the most important. However, when too high, can also adversely influence the ability of the mortar to protect the support in which is being applied. The tensile strength by bending test (R_t) and compression strength (R_c), were carried out at the age of 28 days after the determination of the dynamic modulus of elasticity and in accordance with EN 1015-11/A1. In order to evaluate the mortars capacity of adherence to the support, at 31 days of age, the coated bricks were subjected to pull-off test, according to EN 1015-12.



E - dynamic modulus od elasticity; R_T - tensile strength; R_C - compression strength; P_{ab} - open porosity; M_{vol} - bulk density; CC – coefficient of capillarity; VA - asymptotic value; IS - drying index; λ - thermal conductivity; $R_{cloretos}$ - resistance to the action of chloride

Figure 4 Specimens pattern of use

Determination of open porosity (P_{ab}) and bulk density (M_{vol}) was carried out based on NP EN 1936, at 31 days of age, with the tops of the intact halves of specimens obtained from the compression test. Once the standard is directed to test samples of natural stone, some adjustments were made for testing the cement mortars. Prior to this test, the test specimens were dried for 48 hours at a T of 60°C, proven to be sufficient time for the specimens obtain constant mass.

As regards to water absorption by capillarity (CC), tests were conducted based on EN 1015-18 and EN 15801, at 31 days of age, with the exception for mortar F6 held at age 52, using 3 halves of test specimens of each mortar obtained from compression test. Prior to this test, the halves of test specimens were placed in oven at 60°C for 48 hours. The side faces of the samples were not sealed, whereas bidirectional evaporation was reduced once the test was performed in a saturated environment.

To perform the drying test was taken as reference the work developed by Brito, 2011 and CNR/ICR, Doc. 29/88. The test was performed at 39 days of age using the halves of the specimens used on water absorption by capillary test (3 halves of test specimens). Once again, except for the mortar F6 whose test began at 59 days of age. As in test for water absorption by capillary, also in the drying test was decided not to make the sealing of the side pieces of the test specimens. During the drying phase, the test pieces were kept in a climatic chamber at a temperature of 20°C and RH of 50%.

The thermal conductivity test was performed at 46, 47 and 48 days of age. Since the test specimens were taken out of the cure chamber, at 27 days of age, until the date of the test run, test specimens were placed in a room with RH and T in the range of 50 ± 5% and 26 ± 3°C, respectively. As all specimens were tested in the same environmental conditions, there was no need to subject them to drying in oven prior testing. To test thermal conductivity were used halves of specimens obtained from test flexural strength (6 mortar samples).

The test used for the determination of the resistance to the action of chloride was carried out at 3 months of age, using half test specimens obtained from the bending test. After drying in oven, the specimens were immersed in a saturated solution of sodium chloride during 24 hours (1000 g NaCl in 3.4 l of water) and then dried until constant mass. From the difference of the dried mass of each sample before and after immersion, it was possible to determine the amount of chloride retained in the specimen. Then the halves of the samples were placed in a climatic chamber where they were exposed to repeated cycles of 12 hours at 90% RH and 12 hours at 40% RH, at a temperature of 20° C. During these cycles the halves of the samples were weighed weekly to determine the mass loss and the type of degradation presented.

Results analysis

The results of the consistency flow table are presented in Table 3, the mechanical characteristics and the internal structure of the mortar is presented in Table 4. Table 5 presents open porosity and bulk density, capillary absorption coefficient and the drying index. Percentage chlorides retained in the mortar and thermal conductivity are presented in Table 6.

Mortar performance in fresh state

As mentioned before, the quantity of water used in the several mortars was maintained constant in order to allow the evaluation of the influence of the different dosages of fibers used on the mortar consistency. Table 3 shows the test results of consistency flow table and the increase or decrease of flow of the various mortars in relation to the reference mortar.

It may be noticed that between the mortars mechanically mixed, there is not a trend between consistency flow values and the increasing percentage of fibers. The mortar F6 stands up once it has a consistency flow 10% lower than the Ref mortar, however this is a mortar with the highest percentage of fibers and with different mixing characteristics. There is also known that the variation between the values of the various mortars consistency flow, with the exception of the mortar F6, is not significant. Thus, one may not identify a trend between consistency flow and percentage of reinforcing waste fibers.

Table 3 Consistency flow table results (average values)

ID	Fibers [%]	Flow [mm]	Flow variation [%]	
Ref	0	134	Ref	-
F1	0,25	136	Ref - F1	1,19
F2	0,5	134	Ref - F2	-0,28
F3	1	131	Ref - F3	-2,62
F4	1,5	138	Ref - F4	2,93
F5	2	139	Ref - F5	3,31
F6 - manual	5	121	Ref - F6	-10,02

Mortar performance in hardened state – mechanical performance

The dynamic modulus of elasticity, E, gives an indication of mortar deformability. Mortars with very high E have low deformability. The results of E and its standard deviation are presented in Table 4 (average values of six test specimens).

Based on the results, one may identify that with increasing percentage of waste fibers from mortar F2 to F5 there is a decrease of E, i. e., mortars are more deformable in comparison with the Ref mortar. However, in the mortar F6, which incorporates a high percentage of fibers (5%), although to a lower value than the reference mortar, E increases again. Thus, the incorporation of fibers, discloses an advantage with regard to ensuring mortars higher deformability.

Likewise, in Table 4 and Figure 5 are presented the mechanical resistance values, R_t and R_c (average values of 6 test specimens). The tensile strength is generally directly proportional to the dynamic modulus of elasticity, E. However, in the case of mortar F5, this is not the case, since the mortar between F4 and F5 the modulus of elasticity, E, decreased and R_t increased. This fact translates as very positive for this mortar, potentially with greater resistance to cracking. However, in general terms, comparing the produced mortars with the Ref mortar, one may verify that the addition of different percentages of fibers decreases the mortar tensile strength.

In what concerns compressive strength, tests were made in the two halves of three samples of each cement mortar produced obtained from the R_t test, thus obtaining two results of compressive strength for the same test specimen. One may verify that with the increasing dosage of fibers up to 1.5% decreases the value of R_c. With increasing percentages of reinforcing fibers to 2% and 5% (mortar F5 and F6), there is an increase of R_c. Thus, the mortar with lower percentage of fibers (F1, F2) and the mortar with the higher percentage of fibers are those which exhibit less variation in the compressive strength, when compared with the reference mortar, approximately 9%, 14% and 15 %, respectively, "weaker" than the cement mortar Ref. F4 is 28% less resistant than the mortar Ref.

Table 4 Mechanical characterization (d-days)

ID	Fibers [%]	E (27d) [MPa]	R_t (28d) [MPa]	R_c (28d) [MPa]	Adherence strength (31d) [MPa]
Ref	0	5581 ± 135	1,158 ± 0,034	3,734 ± 0,114	0,05 ± 0,017
F1	0,25	4770 ± 146	0,993 ± 0,147	3,406 ± 0,124	0,19 ± 0,070
F2	0,5	5008 ± 203	1,083 ± 0,095	3,203 ± 0,117	0,04 ± 0,007
F3	1	4661 ± 165	1,013 ± 0,125	2,848 ± 0,333	0,04 ± 0,016
F4	1,5	4421 ± 45	0,854 ± 0,183	2,702 ± 0,137	0,09 ± 0,048
F5	2	4398 ± 136	0,943 ± 0,032	2,832 ± 0,032	0,20 ± 0,170
F6 - manual	5	4717 ± 149	1,093 ± 0,082	3,164 ± 0,368	0,31 ± 0,000

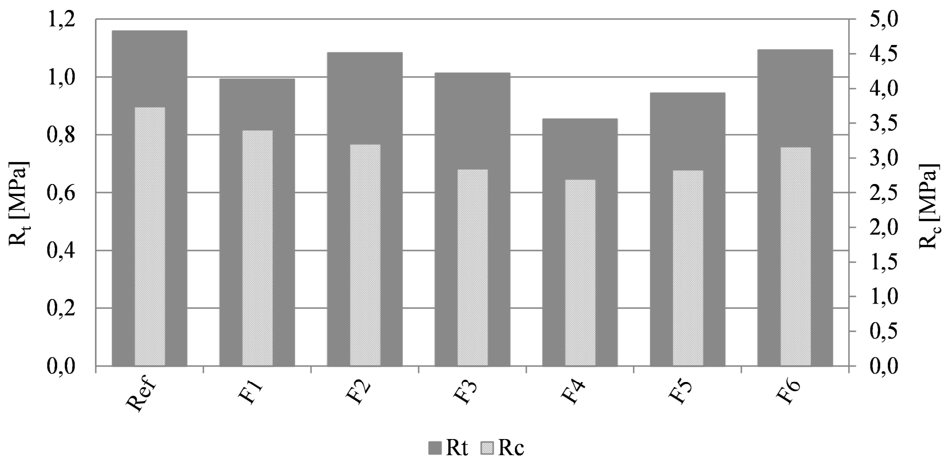


Figure 5 Flexural strength (Rt) and compression strength (Rc)

In what concerns adherence strength there is linearity between the mortar F2, F3, F4, F5 and F6. As the percentage of fibers increases, there is a tendency also to increase the adherence strength to the substrate. The addition of higher percentages of fibers to the mortar contributes to a very significantly increasing adherence strength, reaching values of 557% higher than those obtained with the reference mortar, Ref.

Mortar performance in hardened state – physical performance

The open porosity, P_{ab}, test allows the characterization of the mortars porous structure, evaluating the pore volume present in its interior connected to other pores and to the environment. Table 5 presents the average values obtained of six samples, as well as standard deviation, of open porosity, P_{ab}, and bulk density, M_{vol}. It can be noted that as the percentage of fibers added increases, the mortar is less compact since the bulk density decreases, with the exception of mortar F1.

In what concerns P_{ab}, the results are very similar between mortars F1, F2, F3, F4 and F5. However, in the case of mortar F6, the open porosity is 19% higher than that of Ref mortar. F6 mortar is also the one that presents the lowest bulk density, as expected, since P_{ab} is inversely proportional to M_{vol}.

From the analysis made in three test specimens, it can be noticed that all mortars, except F6, have an initial rate of water absorption, defined as coefficient of capillarity, CC, and ability of absorbing water very similar, VA (Figure 6). In the case of mortar F6, the initial rate of water absorption is lower and the ability of absorbing water, VA, is higher when compared with the other mortars. Actually the mortar F6 has an initial water absorption rate of about 43.6% lower than the reference mortar. This proves to be positive, however, in terms of maximum water absorption, the mortar F6 absorbs about 8% more water than the mortar Ref.

For the drying process (Figure 7) it can be seen that all mortars have a very similar behaviour. The decrease in water content was similar in all mortars except in mortar F6. Table 5 presents the values of drying index (IS). It is noted that drying is much quicker and easier to occur as lower is drying index rate. Based on the IS, it can be noticed that all mortars have a very similar behaviour, exception for mortar F6.

Table 5 Physical characterization

ID	Fibers [%]	P_{ab} [%]	M_{vol} [kg/m^2]	CC [kg/m^2.min^0,5]	VA [kg/m^2]	IS
Ref	0	23	1853	1,67	14,55	0,199 ± 0,001
F1	0,25	25	1794	1,81	14,79	0,202 ± 0,007
F2	0,5	25	1806	1,81	15,15	0,201 ± 0,005
F3	1	26	1779	1,75	14,64	0,201 ± 0,005
F4	1,5	25	1744	1,73	14,51	0,200 ± 0,007
F5	2	26	1725	1,73	14,81	0,200 ± 0,006
F6 - manual	5	28	1718	0,94	15,73	0,241 ± 0,010

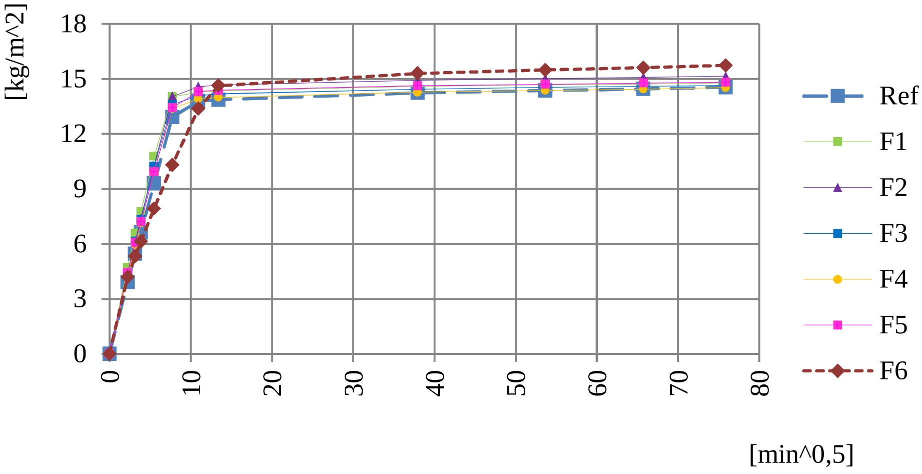


Figure 6 Mortar water absorption curves

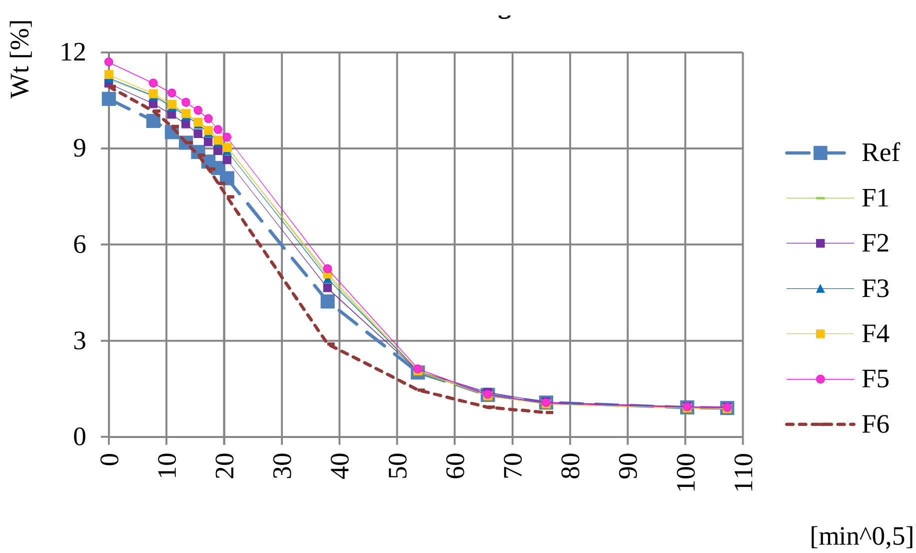


Figure 7 Mortar drying curves

The thermal conductivity indicates the materials ability to conduct heat. Materials with high thermal conductivity, λ, conduct heat more quickly when compared to those having a low thermal conductivity.

In this case mortars with low values of λ are preferred since are intended for coatings or fillings with good thermal insulation characteristics. Table 6 presents the average values of thermal conductivity obtained from three specimens. All mortars when compared with the Ref have a lower thermal conductivity, especially mortar F5 where λ is 26% lower than that of Ref mortar, which becomes very interesting from the thermal standpoint of behavior.

Table 6 Physical characterization – thermal conductivity and percentage of chloride

ID	Fibers [%]	λ [w/m.k]	Chloride retained [%]
Ref	0	1,06	2,21
F1	0,25	0,86	2,37
F2	0,5	0,95	2,30
F3	1	0,87	2,39
F4	1,5	0,85	2,48
F5	2	0,79	2,52
F6 - manual	5	0,81	2,19

In Table 6 and Figure 8 is possible to see the percentage of chloride retained in the several mortars as well as the weight percentage variation, function of the number of cycles that the mortars were subjected to, after immersion in a saturated solution of sodium chloride.

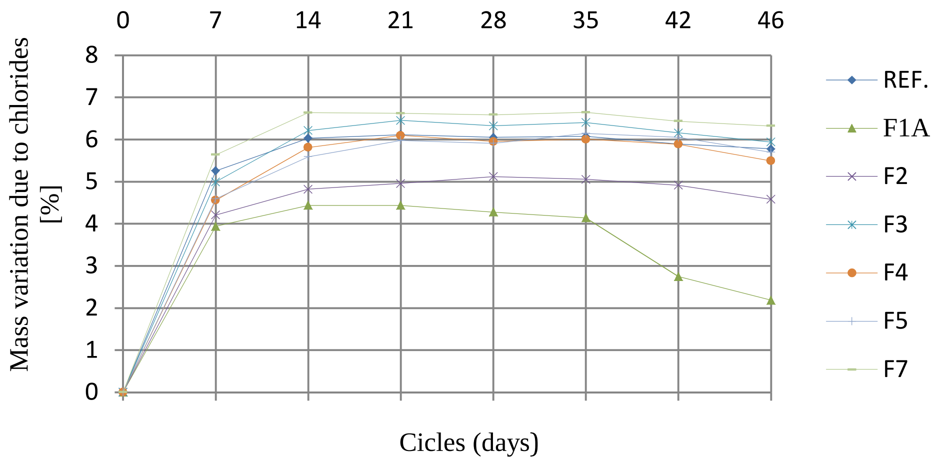


Figure 8 Mortar mass percentual variation

Based on Table 6, it appears that the proportion of chlorides tends to increase with increasing percentage of fibers, from mortar F2 to F5, which can not be justified by open porosity since the mortar F6 is the one that shows higher P_{ab} when compared with the other mortars. With regard to the mass variation based on the number of cycles, as it can be seen in Figure 7, all mortars behavior show resistance to the action of the chlorides (imminently mechanical) until the end of the test, without any loss of mass and degradation of the specimens; however, after 21st cycle mortar F1 (with the lowest percentage of fiber) begins to show a gradual loss of weight up to the 35th cycle and a more pronounced mass loss after this cycle.

CONCLUSIONS

The experimental campaign highlights several aspects:

- In what concerns the method for fibers dispersion in water, although were tested three procedures, none has proved to be completely effective, particularly when high percentage of fibers are used. It is considered to be necessary to test other techniques to achieve adequate dispersion of fibers into the mortar.
- In what concerns mortar consistency, mortar F5, in spite of having a high percentage of waste fibers, presented good consistency when compared with mortars with lower percentages of fibers, even achieving the highest value of consistency. Curious fact are the mechanical strengths, including the R_t and R_c, which have a tendency to decrease from mortar F2 to F4 and to increase again from mortar F4 to F6. In terms of E, since it is intended to obtain low values that obtained not very rigid mortars, the mortar F5, once again, appears to be the most appropriate one for applications envisaged. As regards the adherence strength, it appears to increase with increased fiber content. However there is no clear trend on this behavior and further studies are needed focusing on this parameter.
- from 1.5% fiber content, there is a tendency to increase open porosity, although the mortar initial water absorption rate decreases and the maximum quantity of water which can be absorb increases. As regards the M_{vol}, with increasing percentage of fibers, it appears to decrease as expected, since the fibers are less dense than the mortar. The mortar with 0.5% of fibers did not observe this trend. In what concerns the drying index, this parameter has not linear variation, since the 2% fiber mortar dried more easily than the mortar with 1.5% or 5% of fibers. However, one may not forget that the mortar with 5% fibers had different mixing characteristics which resulted in substantially different characteristics. The percentage of chloride retained increases with increasing dosage of fibers (except in the mortar F6). No mortar deteriorated when subjected to wet and dry cycles after chloride contamination, indicating that the fibers do not weaken such mortar against the attack by chlorides, during the period under analysis.

From the analysis of all mortars, one may conclude that mortar F5, with 2% of fibers, is the most suitable for its intended purpose, optimizing the mortar characteristics and incorporating a residue which not needed to suffer much preparation.

ACKNOWLEDGEMENTS

The authors acknowledge the support of Barreiro School of Technology of Polytechnic Institute of Setubal, where all the experimental work was developed; to the Faculty of Science and Technology of Universidade Nova de Lisboa, for providing the equipment to measure specimen's thermal conductivity.

REFERENCES

AABMCI. (2009). *"Overconsumption? Our use of the world's natural resources"*, Working Committee Forum mineralische Rohstoffe of the Austrian Association for Building Materials and Ceramic Industries, Austria .

Segre, N., Tonella E. ,and Joekes, I., (1998). "Evaluation of the stability of polypropylene fibers in environments aggressive to cement-based materials", *Cement and Concrete Research* 28, pp. 75–81.

Puertas, F., Amat, T., Fernandez-Jimenez A., and Vazquez, T. (2003). Mechanical and durable behaviour of alkaline cement mortars reinforced with polypropylene fibres, *Cement and Concrete Research* 33, pp. 2031–2036.

Lundahl, A. (2008). Study on the waste fiber reinforced ecocomposites, MSc thesis, E-TEAM European Masters in Textile Engineering, University of Minho.

CEN, Methods of test for mortars for masonry. Part 2: Bulk sampling of mortars and preparation of test mortars. Brussels, EN 1015-2: 1998/A1: 2006.

CEN, Methods of test for mortars for masonry. Part 3: Determination of consistency of fresh mortar (by flow table). Brussels, EN 1015-3: 1999/ A1: 2004/ A2: 2006.

CEN, Natural stone test methods. Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency). Brussels, EN 14146: 2004.

CEN, Methods of test for mortars for masonry. Part 11: Determination of flexural and compressive strength of hardened mortar. Brussels, EN 1015-11: 1999/ A1: 2006.

CEN, Methods of test mortar for masonry – Part 12: Determination of adhesive strength of hardened rendering and plastering mortars on substrates. Brussels, EN 1015-12: 2000.

IPQ, Métodos de ensaio para pedra natural. Determinação das massas volúmicas real e aparente e das porosidades total e aberta. Monte de Caparica, NP EN 1936: 2008.

CEN, Methods of test for mortars for masonry. Part 18: Determination of water absorption coefficient due to cappilary action of hardened mortar. Brussels, EN 1015-18: 2002.

CEN, Conservation of cultural property. Test methods. Determination of water absorption by capillary. Brussels, EN 15801: 2009.

Commissione Normal, Misura dell´indice di asciugamento (drying index). Roma, CNR/ICR, Doc. 29/88.

Brito, V. Gonçalves, T.D., Faria. P. (2011). Coatings applied on damp substrates: performance and influence on moisture transport. *J. Coating Technology and Research*.