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Experimental investigations on lime mortars reinforced with hemp braids

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Abstract

The need of experimenting sustainable components for building products is underlined by the prominent energy and raw material consumptions and carbon dioxide emissions for which the construction industry is responsible. Natural fibres, particularly hemp fibres, are worth of mention thanks to their acceptable mechanical properties and environmental advantages. The research aims to experiment two types of lime-based plasters reinforced with hemp braids, having different diameters, added in the mixture with different percentages. Two pre-mixed Natural Hydraulic Lime (NHL) mortars of M5 and M15 types, and three diameters of hemp braids (0.4 mm, 1 mm and 2.2 mm) in percentage by lime weight from 0.25% to 3% were considered. A first phase of the research consisted in physical tests to assess the amount of water absorbed by the hemp fibres to evaluate the plaster workability. Afterwards, only the mixtures with acceptable workability values were subjected to mechanical tests. The results of the laboratory tests showed that hemp braids produce a decrease in the workability of the plasters, that remains acceptable for low percentages of fibres. Compared to the unreinforced plaster, the braids allowed an increase in the flexural strength and a decrease of the compressive strength. In both mechanical tests it was evident the sewing and confinement effect of the fibres that led to a more ductile behavior of the mortar.

Keywords: *Biocomposite; Experimental tests; Hemp fibres; Natural fibres;Sustainability*

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1. Introduction

The building sector has a large impact on the environment due to its high consumptions of raw material and water and carbon dioxide emissions as stated in the Global Status Report (2020). Therefore, the experimentation of new sustainable materials for constructions is a topic of great interest in the scientific community. The research of Li et al. (2020) shows that the use of natural fibres, in particular plant-based ones, represents an interesting solution because, other than having a low environmental impact and low cost, they exhibit high values of strength and stiffness. In this research the attention is focused on the use of hemp fibres as an alternative to artificial ones to obtain two types of plasters, namely a seismic-resistant plaster with high resistance and a traditional one with normal resistance. Hemp fibres and shives are largely investigated in the scientific community to obtain concretes and mortars with low environmental impact. Comak et al. (2018) showed that the addition of hemp fibres in a cement-based mortar allowed to reach an increase in both compressive and flexural strengths and that the best behaviour was registered for the mixtures with 2-3% of hemp wastes. Awwad et al. (2012) investigated the possibility of reducing the content of coarse aggregates in concrete by adding hemp fibres. The results showed that the addition of these wastes produce a decrease in compressive strength and no significant variation in the flexural strength.

The two types of lime-based plasters under study are reinforced with hemp braids added in the blend with different diameters and percentages by weight of lime. In particular, two pre-mixed Natural Hydraulic Lime (NHL) mortars were evaluated. The first was of M15 type for the seismic-resistant plaster and the second was of M5 type for the traditional one. Three diameters of hemp braids (0.4 mm, 1 mm and 2.2 mm) with percentages in terms of lime weight from 0.25% to 3% were considered for testing. The amount of water absorbed by hemp braids was assessed by performing absorption test to define the quantity of water to be added to the mixture. All the mix designs were tested on a shaking table to evaluate the effect of hemp braids on the mortar workability. Finally, compressive and bending tests were performed on the mixtures that were considered as acceptable after the preliminary test phase.

2. Materials and methods

The seismic-resistant plaster was manufactured with a M15 geo-mortar made of pure NHL and geo-binder according to the UNI-EN 998-1 standard (2016). The selected mortar has a compressive strength higher than 15 MPa, a flexural strength higher than 5 MPa and an elastic modulus under compression of 9 GPa. The natural fibres added to the mixture were hemp braids with a diameter of 0.4 mm produced from local cultivations by an Italian company. The hemp fibres were cut in two different lengths (2 cm and 3 cm) and added to the mixture in different percentages in terms of lime weight (0.25%, 0.50%, 0.75%, 1.00%, 1.50%, 2.00%, 2.50% and 3.00%).

The traditional plaster was manufactured with a mortar made of pure NHL and classified of M5 type (compressive strength higher than 5 MPa) according to the UNI-EN 998-1:2016 standard. Also in this case, hemp fibres from a local cultivation were used. Two diameters (1 mm and 2.2 mm) and two different lengths (2 cm and 3 cm) of hemp fibres, which were added to the mixture in three percentages by lime weight (0.5%, 1.00% and 3.00%), were used in the experimental campaign.

2.1. Water absorption test on hemp fibres

Natural fibres absorb a large amount of water, so that it is important to assess the quantity of water to add in the mixture to avoid altering the water/lime ratio provided by the manufacturer of the pre-mixed mortar. The water absorption test was performed on all the three types of braids before defining the best mix design of the mortar. A definite weight of hemp braids was drowned in water and weighted after regulated time intervals. The difference of weight allowed to establish the amount of water absorbed by each braid type. In particular, for the first two hours of immersion, the fibres were weighted every 15 minutes, then after 12 hours and, finally, every day for 6 days.

2.2. Mix designs

Once the saturation of the hemp braids was assessed, a set of preliminary mix designs was fabricated. The blends were subjected to workability tests to select the ones to be submitted to mechanical tests. For each type of plaster, anti-seismic and traditional ones, a control mix without hemp fibres was considered for comparative purposes. Table 1 and Table 2 summarize the preliminary mix designs, respectively, for the anti-seismic and traditional mortars, also indicating the nomenclature assigned to each mix. The 0.4 mm braids were labelled as “F”, the 1 mm braids as “SP” and the 2.2 mm ones as “C”, while the control mixes were called “CNTL”.

Table 1. Mix designs of the anti-seismic plaster (M15).

ID	Fibre diameter [mm]	Fibre length [cm]	% fibres	Premixed weight [g]	Water weight [g]	Dry fibre weight [g]
CNTL_15	-	-	0.00%	1000	180	0.0
F_01	0.4	2	0.25%	1000	180	2.5
F_02	0.4	2	0.50%	1000	180	5.0
F_03	0.4	2	0.75%	1000	180	7.5
F_04	0.4	2	1.00%	1000	180	10.0
F_05	0.4	2	1.50%	1000	180	15.0
F_06	0.4	2	2.00%	1000	180	20.0
F_07	0.4	2	2.50%	1000	180	25.0
F_08	0.4	2	3.00%	1000	180	30.0
F_09	0.4	3	0.25%	1000	180	2.5
F_10	0.4	3	0.50%	1000	180	5.0
F_11	0.4	3	0.75%	1000	180	7.5
F_12	0.4	3	1.00%	1000	180	10.0
F_13	0.4	3	1.50%	1000	180	15.0
F_14	0.4	3	2.00%	1000	180	20.0
F_15	0.4	3	2.50%	1000	180	25.0
F_16	0.4	6	3.00%	1000	180	30.0

Table 2. Mix designs of the traditional plaster (M5).

ID	Fibre diameter [mm]	Fibre length [cm]	% fibres	Premixed weight [g]	Water weight [g]	Dry fibre weight [g]
CNTL_M5	-	-	0.00%	1000	204	0.0
SP_01	1	2	0.50%	1000	204	5.0
SP_02	1	2	1.00%	1000	204	10.0
SP_03	1	2	3.00%	1000	204	30.0
SP_04	1	3	0.50%	1000	204	5.0
SP_05	1	3	1.00%	1000	204	10.0
SP_06	1	3	3.00%	1000	204	30.0
CR_01	2.2	2	1.00%	1000	204	10.0
CR_02	2.2	2	3.00%	1000	204	30.0
CR_03	2.2	3	1.00%	1000	204	10.0
CR_04	2.2	3	3.00%	1000	204	30.0

2.3. Workability tests

The preliminary blends were tested to assess the influence of hemp fibres on the workability of the mortar, so to select the mix design to be subjected to mechanical tests. The workability tests were carried out using the shake table following the procedures outlined in UNI EN 1015-3 standard (2000) with 15 shakes in 15 seconds (Fig. 1).

Fig. 1. Workability test on hemp plasters.

The spreading of the mortar (S_p) was evaluated as average value of two orthogonal diameters after the test and compared to the values suggested for plasters (140 mm < S_p < 180 mm with a tolerance of 10 mm) by the UNI 998-1/2:2016 standard.

2.4. Mechanical tests

The mechanical tests were performed only for the mixtures that were considered acceptable after the workability tests. All the selected mixes, including the control ones, were tested under compression and three-points bending tests by manufacturing three specimens for each mix. The mechanical tests were carried out according to the UNI EN 196-1 (2016) and UNI EN 1015-11 (2019) standards. The three-points bending tests were performed on specimens with dimensions of 40x40x160 mm using a universal machine at displacement control with a speed of 0.05 mm/m using a 10 kN load cell. The compression tests were performed on specimens with dimensions of 40x40x40 mm for the M15 plaster and on the resulting half samples derived from the bending test for the M5 plaster. The experiments were carried out with the same universal machine used for the bending test.

3. Results and discussion

3.1. Water absorption capacity test

The results of the water absorption capacity test on hemp braids are depicted in Fig. 2 in terms of weight variation versus days of immersion. The results showed that the 0.4 mm fibres absorb a water amount of about 4.5 times their weight, while the 1 mm and 2.2 mm fibres around 1.2 times their weight. Since all the fibres almost reached the saturation after two hours of immersion in water, it was decided to maintain the same water/binder ratio for all the mixtures and to add the hemp fibres in the dough after being saturated.

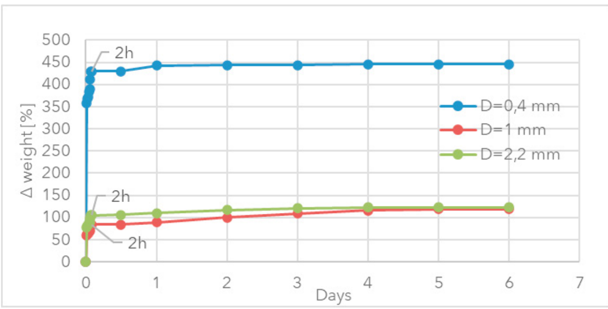

Fig. 2. Results of the water absorption tests on hemp fibers.

3.2. Workability tests

The results of the workability tests on the hemp-reinforced plasters are depicted in Fig. 3, where the diagrams showing the variation of the spread as increasing the percentage of fibres are plotted.

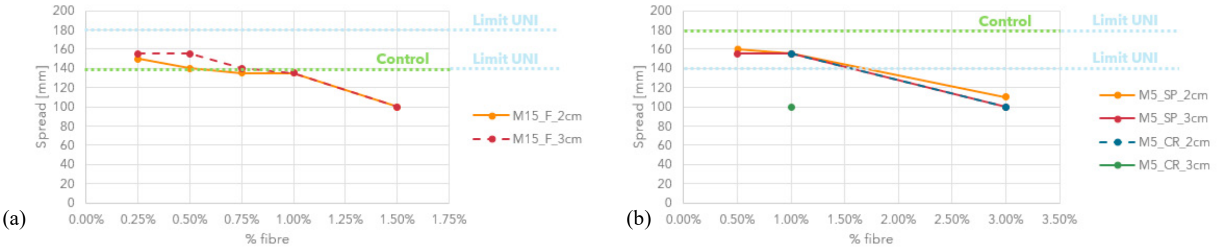

Fig. 3. Results of workability tests for (a) anti-seismic and (b) traditional plasters.

For both types of plaster, the workability decreases as increasing the percentage of hemp fibres. The results obtained for the anti-seismic plaster showed that already the addition of 1.5% of hemp fibres led to a decrease in workability outside the suggested range. Therefore, it was decided to avoid testing the mixtures with percentages higher than 1,5%. The traditional plaster also showed a significant reduction in workability for all the mixtures with 3% of hemp fibres and also for the mix with 1% of fibres having diameter of 2.2 mm and length of 3 cm.

3.3. Mechanical tests

The mixtures that were considered acceptable for the mechanical tests were characterized by addition of fibres of 0.25% and 0.5% for the anti-seismic plaster, and were represented by all the mixes, except the one with 3% of hemp fibres having diameter of 2.2 mm and length of 3 cm, for the traditional plaster.

The results of the three-points bending tests in terms of force-displacement (F-δ) curves are depicted in Fig.4.

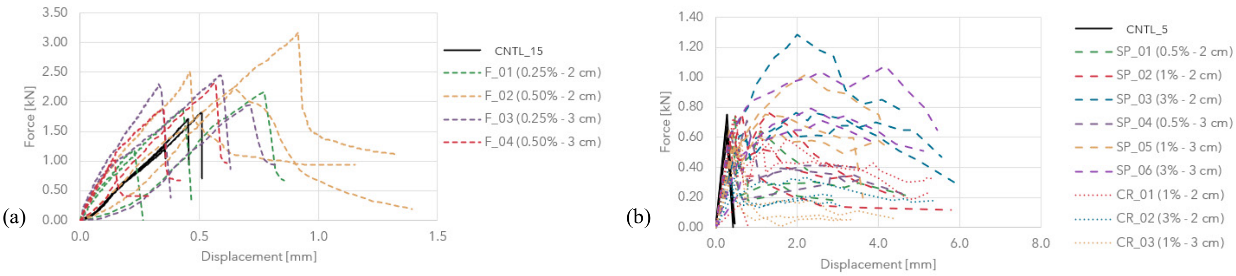

Fig. 4. Results of three-points bending test for (a) anti-seismic and (b) traditional plaster.

The results showed an increase in strength and ductility of the plaster reinforced with hemp fibres compared to the unreinforced one. In particular, the ductility was increased thanks to the sewing effect of the fibres that contains the opening of cracks (Fig. 5).

Fig. 5. Sewing effect of hemp fibres in the three-points bending test.

The average flexural strength of the tested specimens is depicted in the histogram of Fig. 6, where it is highlighted how the flexural strength always increases thanks to the hemp fibres for the anti-seismic plaster. Contrary, in the traditional plaster only in some cases it was registered an augment of the flexural strength. In detail, the specimens manufactured with hemp fibres having diameter of 2.2 mm showed an increase in flexural strength only when they were added in the mixture with a percentage of 1% and length of 2 cm. On the other hand, the specimens with hemp fibres of 1 mm exhibited an increase in flexural strength only with percentages of 1% and 3%.

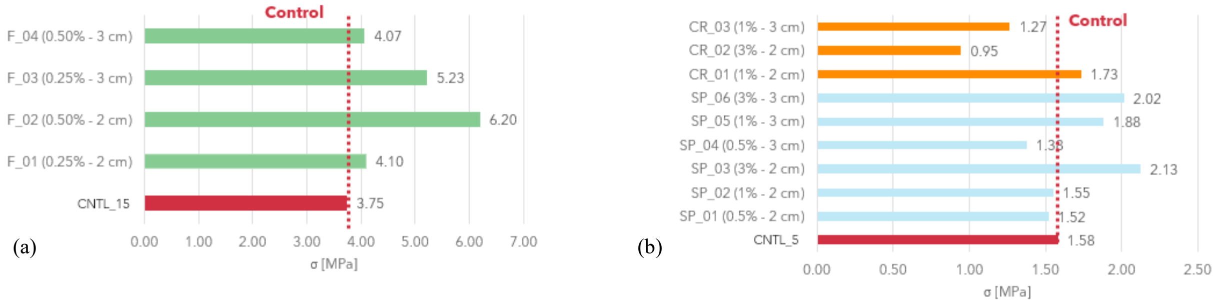

Fig. 6. Average flexural strengths for (a) anti-seismic and (b) traditional plasters.

The results of the compressive tests in terms of force-displacement (F-δ) curves are depicted in Fig.7.

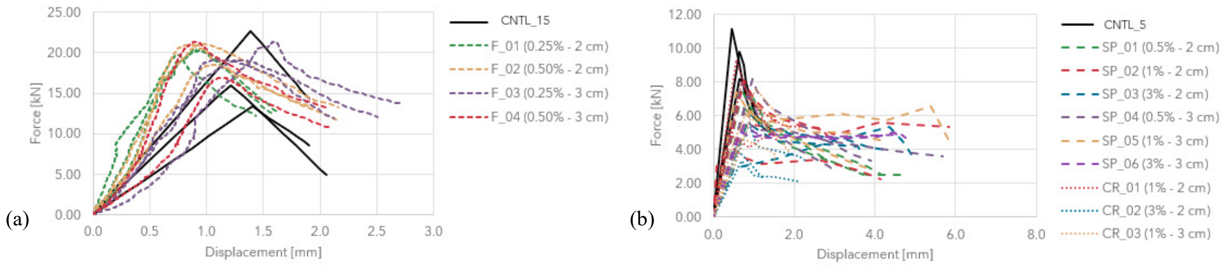

Fig. 7. Results of the compression tests for (a) anti-seismic and (b) traditional plasters.

The results showed a different behaviour of the anti-seismic plaster compared to the traditional one. In fact, only in the first case an average increase in compressive strength was registered. Nevertheless, in both cases the ductility increased thanks to the confinement effect of the hemp fibres (Fig. 8).

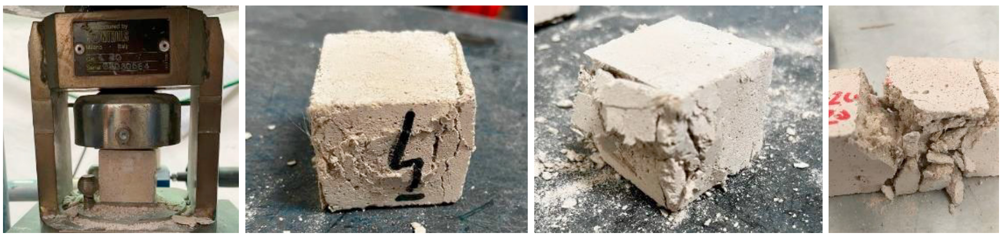

Fig. 8. Confinement effect of hemp fibres in the compression test.

The average compressive strength of the tested specimens is depicted in the histogram of Fig. 9, where it is highlighted how the compressive strength is not affected by the hemp fibres in the anti-seismic plaster, while in the traditional plaster a decrease in compressive strength was registered due to the different configuration of the hemp braids that, having a bigger diameter, allow the formation of concentrated weaknesses in the matrix. The traditional plaster showed acceptable values of compressive strength only for the specimens with 1% of 2 cm hemp braids having diameter of 2.2 mm and the ones with 0.5% of hemp braids having diameter of 1 mm and both lengths. In these latter cases in fact, the compressive strength is close to the minimum value (5 MPa) required to classify the mortar of M5 type with anti-seismic features.

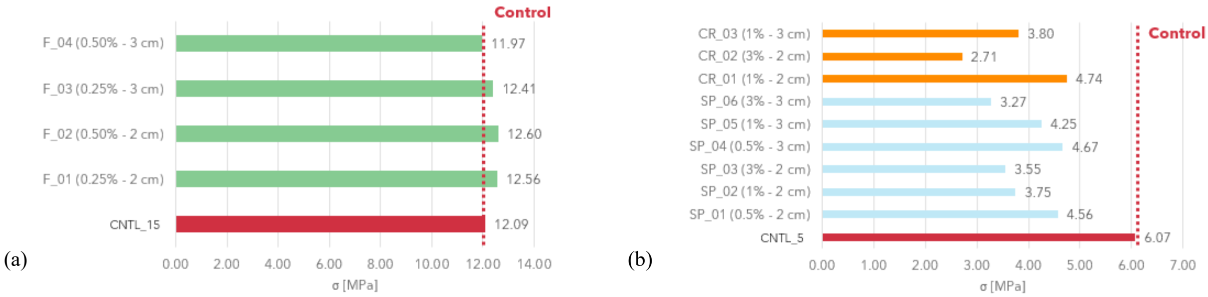

Fig. 9. Average compressive strengths for (a) anti-seismic and (b) traditional plasters.

4. Conclusions

The research investigated the physical and mechanical behaviour of two types of lime mortars, namely of anti-seismic and traditional types, obtained by adding different percentages of hemp fibres in the mixture. Before the definition of the mix designs, all the fibres were tested to assess the water absorption and, to avoid altering the water/binder ratio, it was chosen to add the fibres already saturated in the blend after more than two hours of immersion. The results of workability test showed that the workability of the mixtures decreases as increasing the amount of hemp fibres and led to discard the mixtures with higher percentages of hemp fibres due to the low values of spread that were outside the suggested range for a good plaster. Finally, mechanical tests were performed on the selected mix designs. The flexural strength of the hemp reinforced specimens always increased compared to the unreinforced specimens except for a few cases with hemp fibres having diameter of 1 mm and 2.2 mm. The compressive test showed different results for the anti-seismic and the traditional plaster. In fact, the compressive strength of the anti-seismic plaster was not affected by the addition of hemp fibres, while the traditional plaster showed a decrease in compressive strength due to the presence of added wastes. In the mechanical tests, however, the main advantage of the hemp fibres was detected in the benefit regarding the increased ductility of the specimens thanks to the sewing and the confinement effect they provided to the mortar having the classical brittle behaviour.

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