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Influence of natural additives and crushed bricks on the physical and mechanical properties of repair and restoration mortars

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This study aims to evaluate the influence of different additives, including natural additives such as olive oil and eggs, on repair and restoration mortars. This work enables us to verify the effects of these natural components and their impact on the physical and mechanical characteristics of various types of repair mortars. Four mortar formulations were developed and analysed: Two jointing mortars, including the control sample MF1, without additives; and two finishing mortars (plaster). The physical and mechanical analysis of these different mortar samples showed that each additive had effects on the durability, percentage of absorption and porosity of the samples, as well as on their water repelling, and waterproofing properties. The control sample MF1 had the highest content of total porosity and water absorption. In the other samples, the water absorption and porosity contents decreased with an increase in the quantity of crushed bricks. In addition, sample MF3, which contained two volumes of crushed bricks per one volume of lime and an addition of 5% olive oil, had the lowest water absorption and porosity content and the highest resistance to compression and bending. The results obtained demonstrate that the mortars with natural additives MF3 and MF4 have reduced rate of water absorption, porosity, and water absorption by capillarity than control mortars (MF1) and samples with only crushed bricks added (MF2).

Key words: Repair mortar, natural additives, compatibility, crushed brick, olive oil, eggs, water repellent, durability.

INTRODUCTION

In any restoration work, the important thing is respect for the monument in all of its values, and in particular with regard to the materials with which it was built. Any restoration or even rehabilitation intervention must be carried out whilst ensuring the compatibility and adhesion of repair materials with the old materials.

The documentation relating to the composition of old mortars in Algeria is not very rich, apart from some recent studies on the characterization of archaeological materials. This documentation particularly relates to the

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Ottoman period in Algiers (Attari et al., 2019), and the characterization of archaeological materials in Algeria, during the medieval and Ottoman periods (Abderrahim Mahindad and Hamiane, 2016). Most of the research on traditional building materials is concerned with their characterization and composition (Artioli et al., 2019; Büttner, 2003; Miriello and Crisci, 2006). Some studies, however, have concentrated the preservation of building materials (stone, brick, and mortar), and in particular on strategies for their preservation (Esbert and Montoto, 1991; Groot et al., 1999; Sánchez-Moral et al., 2005; Hughes, 2012).

Any restoration operation must be based on the compatibility between the new repair material, and the old structure. In this perspective, research has focused on the importance of archaeological mortars, and the search for repair and restoration mortars (Cultrone et al., 2007; Miriello et al., 2011; Gomes et al., 2013). Conservation actions should therefore find further guidance in the use of the concept of "repairability" that includes the compatibility concept (Van Balen et al., 2005).

The repair mortars recommended in restoration projects in Algeria are the results of a combination of mortar recipes transmitted by oral tradition and those found in theoretical and historical documents. Like ancient mortars, additives have been used to improve the physical characteristics of mortars such as mechanical strength, water repellent, plasticity and fluidity. Several materials were used for these purposes, such as vinegar, oil, soap, egg, sugar, straw, etc. (Furlan and Bissegger, 1975; Chergui, 2007; Abderrahim Mahindad, 2017).

As a part of this work, we have created four formulas of repair mortars for different uses, which we use in restoration sites. We propose to verify the characteristics attributed to them such as durability, water repellent and waterproofing (Benkaddour et al., 2009).

MATERIALS AND METHODS

We used lime-based mortars because they are compatible with traditional building materials (Groot et al., 1999). The quality of a mortar depends on the materials it is made of, the mastery of the manufacturing, and the implementation technique. The elements that make up the mortar are: the binder, which constitutes the matrix of the mortar; the aggregates; and additives, which have the role of improving the characteristics of the mortars.

For the manufacture of formulated mortars, the raw materials used and described in the Table 1, were:

a) The binder: It consisted of lime paste, obtained after slaking the aerial lime in water drums.

b) Aggregates: Two types of sand were used. Black sand from the quarry and yellows sand from the dunes of southern Algeria.

c) Crushed brick: Ground or crushed clay comes from bricks and fired ceramics. It is considered an artificial pozzolan and has a reputation for increasing the hardness of mortars (Matias et al., 2014).

d) Additives: The additives tested during this research were olive oil and eggs, which are still used in the manufacture of repair mortars in restoration sites in Algeria.

e) Mixing water: The water used for mixing the mortar was lime water resulting from the settling of lime in the barrels used during slaking.

Preparation of samples

The mortar formulation process began with the preparation of raw materials. The raw materials used in their manufacture were prepared on site, to recreate the same conditions for the implementation of repair mortars.

The different raw materials used were: aerial lime as a binder; black quarry sand and yellow sand as aggregates; crushed brick, used as a degreaser; and additives made of olive oil and eggs.

The preparation of the raw materials was subject to the following stages:

i) The aerial lime was slaked in a barrel of water, where it stayed for more than four days.
ii) The yellow and black sands were stored in a dry, well-exposed place to dry them out.
iii) The black sand was sieved, and divided into different fractions, depending on usage requirements. First group, D> 5 m; second group, 1 mm <D3.5 m.
iv) The crushed brick was sieved through a sieve with a mesh diameter of 1 mm.

The formulation of the four types of mortar was achieved according to the following process, as shown in Figure 1:

1- Test pieces were made in parallel moulds with dimensions 4 cm × 4 cm × 16 cm and cylindrical moulds with dimensions 11.5 cm × 11.8 cm.
2- Each type of mortar paste was made by mixing the aggregates, the binder and the limewater. The mixing of all samples was done by hand.
3- For each type of mortar, two parallel and two cylindrical test tubes were filled, compacted and levelled.
4- The test pieces were removed from the moulds and stored in the shade, in order to be able to calculate compressive strength of these samples at 28 days.

Composition of the various samples formulated

Four types of mortar (MF1, MF2, MF3 and MF4) were formulated, the first of which was considered the control mortar because it contained only the binder and aggregates.

MF1: Used only as jointing mortar. This mortar was without additives, composed of only binder and aggregates. It was made according to the following composition: *1 volume of lime paste + 2 volume of black sand (0-3.5 mm) + 1 volume of yellow sand + water.*

MF2: Used as both a jointing mortar, and as the first two layers of the finishing mortar. This mortar was made according to the following composition: *1 volume of lime paste + 1 volume of black sand (0-3.5 mm) + 1 volume of yellow sand + 1 volume of crushed brick (0-2 mm) + water*.

MF3: used as a plaster. This mortar was enriched with fatty substances (the addition of olive oil) and it was made according to

Table 1. Presentation of the different raw materials and natural additives used in the formulation of mortars.

The lime	Dark sand	Yellow fine sand	Crushed bricks	Olive oil	Eggs	Mixing water
						
Lime paste has been used in the manufacture of mortars	Black sand, with scattered grain size, medium (between 0.2 and 0.63 mm).	Sand of yellow color. It is of very fine particle size. (between 0.063 to 0.2 mm)	Red in colour, it has a large grain size of different sizes, (1 to 12 mm).	This fatty substance has been used as a water repellent adjuvant.	The egg was used in its entirety	It is lime water recovered from drums used for extinguishing air lime.

Figure 1. Preparation of formulation mortars.

the following composition: *1 volume of lime paste + 1 volume of black sand + 1 volume of yellow sand +2 volumes of crushed brick (0-2 mm) + 50 ml of olive oil + water.*

MF4: used as a plaster. An egg was added. This mortar was made according to the following formula: *1 volume of lime paste + 1 volume of yellow sand + 2 volumes of crushed brick (0-2 mm) + 1 egg (shell and contents) + water.*

Approach

Physical analysis

Physical analysis enables us to identify the specific and apparent densities, as well as the percentage of humidity, porosity, and water absorption, according to French standards NF P18-558, NF P94-050 and NF P18 554.

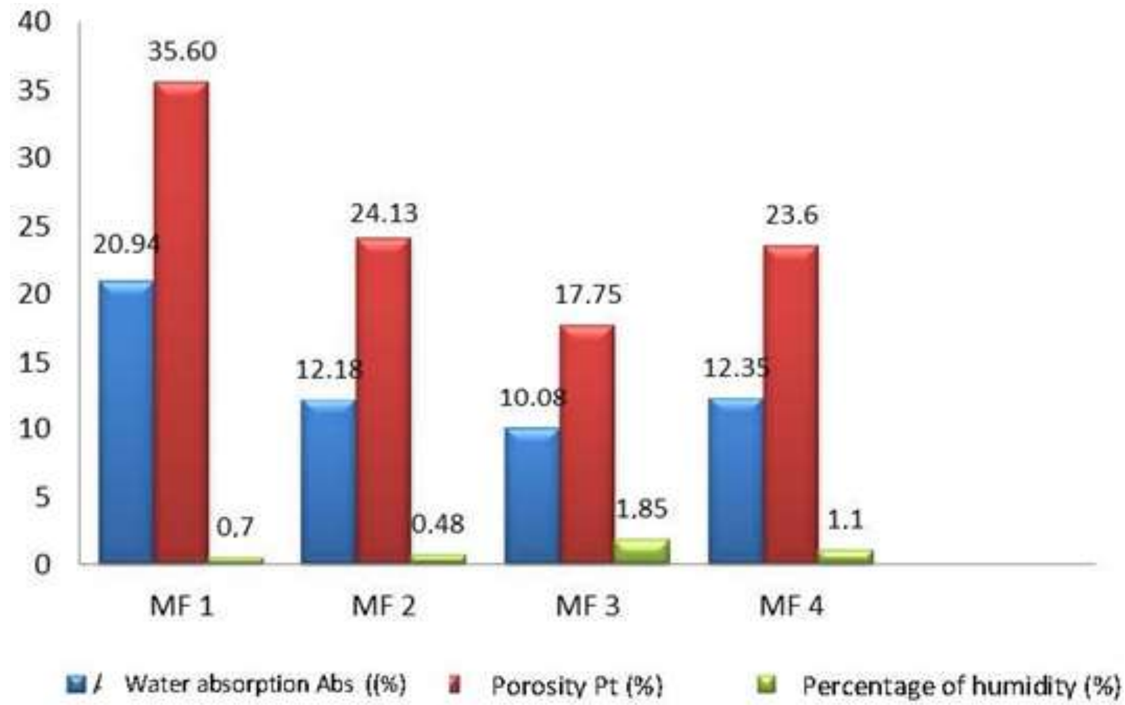

Figure 2. Results of physical tests on formulated mortars.

The capillary absorption of the mortars was assessed based on EN 15801, through sequential weighing of the samples in contact with water to a height of 5 mm and using specimens with dimensions 4 cm × 4 cm × 8 cm, previously dried in an oven at 105ºC to a constant mass.

These physical tests were supplemented by shrinkage, mass loss and setting time tests. These tests are important for the characterization of the formulated mortars, particularly the mortars with additives, to be able to assess the contribution of various additives and components.

Mass shrinkage and mass loss test

To calculate the shrinkage and loss of mass of the samples, a manual method was applied, which is based on the use of a calliper to measure the shrinkage after mould release the test pieces at 7, 14 and 28 days of drying. For the mass loss test, we proceeded to determine the mass of the sample at different times.

Setting time test

This test was carried out according to Standard NF EN 196-3, using the Vicat needle, which gives two marks relative to the start of setting and the end of setting.

Mechanical tests

The mechanical tests, relating to the calculation of the compressive strength, were carried out at the Center for Study and Technological Service of the Construction Materials Industry 'CETIM', according to the terms of Standard NF EN 12390 – 3 (04/2012). These tests were carried out after 28 days.

RESULTS

Physical properties

Figure 2 presents all the results of the physical tests. These results showed that the sample with the highest water absorption (20.94%) and total porosity (35.60%) content was MF1 (the control sample), which did not contain crushed bricks, nor any additives. On the other hand, all the other samples, which contained 1 to 2 volumes of crushed bricks, had average absorption and porosity rates. Note that the more the sample was enriched with crushed brick, the greater the reduction in absorption and porosity rate.

Sample MF3, to which 5% olive oil was added per 1 volume of lime, had the lowest water absorption and total porosity levels (10.08% and 17.75%). We also noted that the humidity levels were insignificant in all the samples.

Table 2 presents the results of the water absorption test by capillarity as a function of time. The measurements were taken over 1440 min (24 h).

As shown in Table 2 and Figure 3, the mass of water absorbed by capillarity was in constant evolution until t=240 min (equivalent to 4 h) for samples MF1, MF2 and MF3. For sample MF4, however, the mass of water absorption continued to increase until 1440 min (24 h).
Table 3 shows the experimental values corresponding to the accumulated water mass ì (cm^3/cm^2 or g/cm^2) depending on the square root of time $\sqrt{t}$.

The curve in Figure 4, shows that the MF3 sample,

Table 2. Cumulative mass of water absorbed (W) per unit area (A).

Sample of formulated mortar	t (min)	W (g)	ì = *w*/A (g/cm^2) ou (cm^3/cm^2)
MF1	15	102.50	6.40
	30	108	6.75
	60	112	7.00
	120	121	7.56
	240	126	7.87
	1440	126	7.87
MF2	15	54.69	3.41
	30	58.32	3.64
	60	62.08	3.88
	120	62.72	3.92
	240	64.65	4.04
	1440	64.65	4.04
MF3	15	26.50	1.65
	30	28.48	1.78
	60	29.12	1.82
	120	30.08	1.88
	240	31.04	1.94
	1440	31.04	1.94
MF4	15	27.36	1.71
	30	29.44	1.84
	60	31.68	1.98
	120	35.68	2.23
	240	37.12	2.32
	1440	39.57	2.47

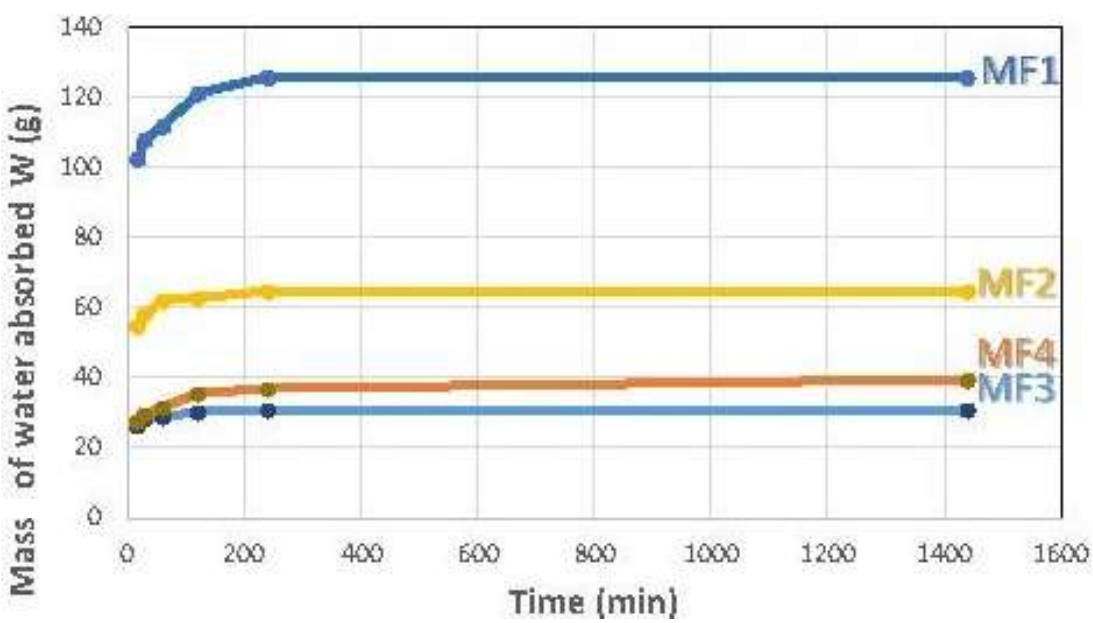

Figure 3. Absorption kinetics of different samples of formulated mortars.

Table 3. Evolution of the cumulated water mass (i) as a function of the square root of time ($\sqrt{t}$) of the formulated mortars.

Sample of formulated mortars	√t (min)	ì (cm³/cm²) ou (g/cm²)
MF1	3.87	6.40
	5.47	6.75
	7.74	7.00
	10.95	7.56
	15.49	7.87
	37.94	7.87
MF2	3.87	3.41
	5.47	3.64
	7.74	3.88
	10.95	3.92
	15.49	4.04
	37.94	4.04
MF3	3.87	1.65
	5.47	1.78
	7.74	1.82
	10.95	1.88
	15.49	1.94
	37.94	1.94
MF4	3.87	1.71
	5.47	1.84
	7.74	1.98
	10.95	2.23
	15.49	2.32
	37.94	2.47

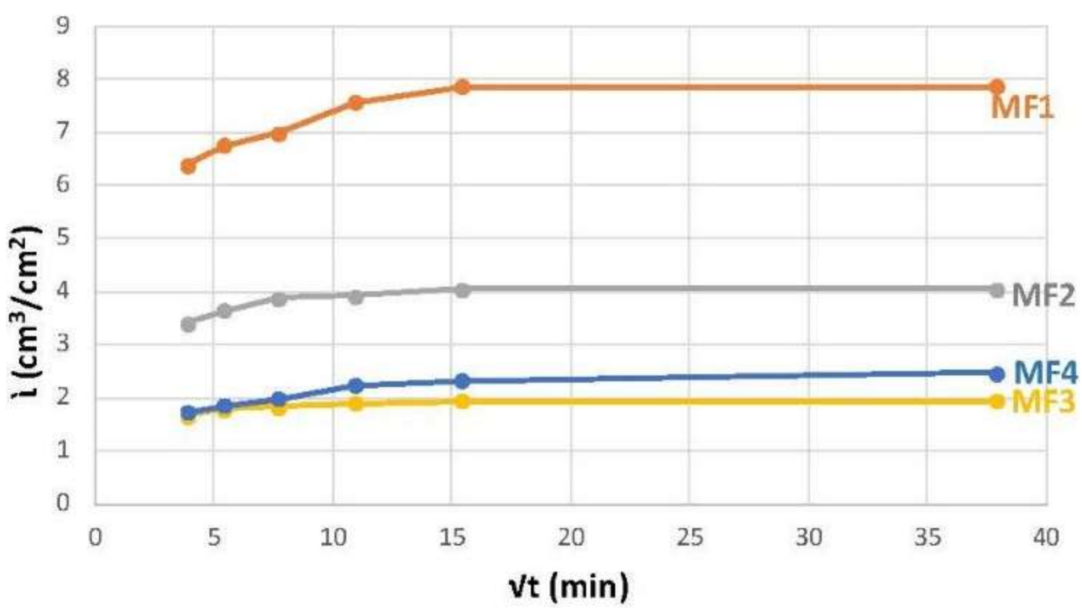

Figure 4. Curve of evolution of the cumulated water mass (i) as a function of the square root of time ($\sqrt{t}$) of formulated mortars.

Table 4. The lowest shrinkage of different formulated mortars.

Sample	Lowest shrinkage (%)		
	7 days	14 days	28 days
MF1	01.2	03	03.2
MF2	02	06	06.3
MF3	0.8	02	02.1
MF4	0.25	01.26	01.26

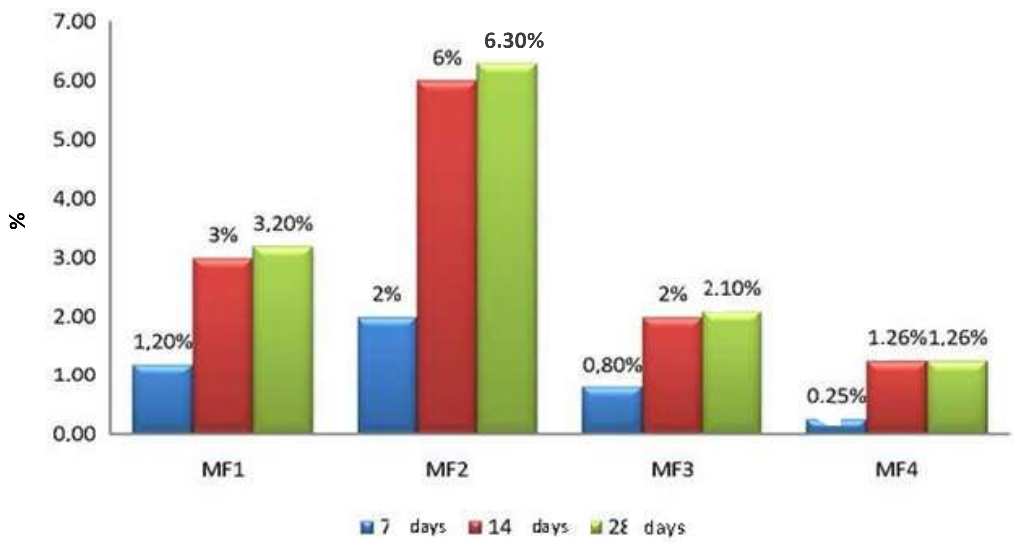

Figure 5. Diagram of results of the lowest shrinkage of different formulated mortars.

enriched with 5% olive oil, had the lowest rate of water absorption (on average 1.81 g/cm^2) compared to the other samples, while the control mortar (without additives) had the highest rate of water absorption (on average 7.11 g/cm^2).

The results of the lowest shrinkage tests, presented in Table 4 and illustrated in Figure 5, demonstrate that the mortars with natural additives (MF3 and MF4) had the lowest shrinkage percentages (2.1 and 1.26% respectively) and that MF4, which did not contain black sand, had the lowest shrinkage value. The control sample, which was without additives and was composed of sand and lime, had an average shrinkage percentage of 3. The highest shrinkage percentage (reaching 7%) was recorded for MF2, which was composed of lime, fine sand, black sand and crushed bricks, but without any natural additives.

The results of the mass loss tests (reported in Table 5 and illustrated in Figure 6) attest that all the samples had an equivalent loss of mass at 28 days, varying from 21.66–23.31%. Nevertheless, we noted that the mass loss was slower for MF4. For this sample (MF4), the mass loss at 7 days was only 7.77%, while for the other samples it was around 15%.

It appeared from the results of the setting time tests (Table 6) that the samples with additives and enriched with crushed bricks had the shortest setting start time. Sample MF4, which was composed of a large proportion of crushed bricks (2 volumes per one volume of fine sand and 1 volume of lime) and the addition of eggs, had the shortest setting start time (40 min). It was followed by MF3, where the composition was equally enriched with crushed bricks and olive oil had been added. Samples MF2 and MF1 (control sample) had a significant start-to-set time that exceeded 4 h.

The times recorded for all samples to fully set were considerable. The lowest time was recorded for MF4 (68 h), while the control sample (MF1) had the longest time of 112 h.

Mechanical characterisation of samples of formulated mortars

As illustrated in Figure 7 and reported in Table 7, all the formulated samples had close compressive strength values that varied from 2.21 MPa for MF3 to 1.43 MPa for MF4. It is thus noted that the sample with the greatest

Table 5. Mass loss of different formulated mortars.

Sample	Mass loss (%)		
	7 days	**14 days**	**28 days**
MF1	15.10	22.29	22.61
MF2	13.90	22.14	22.65
MF3	12.80	22.80	23.31
MF4	7.77	21.35	21.66

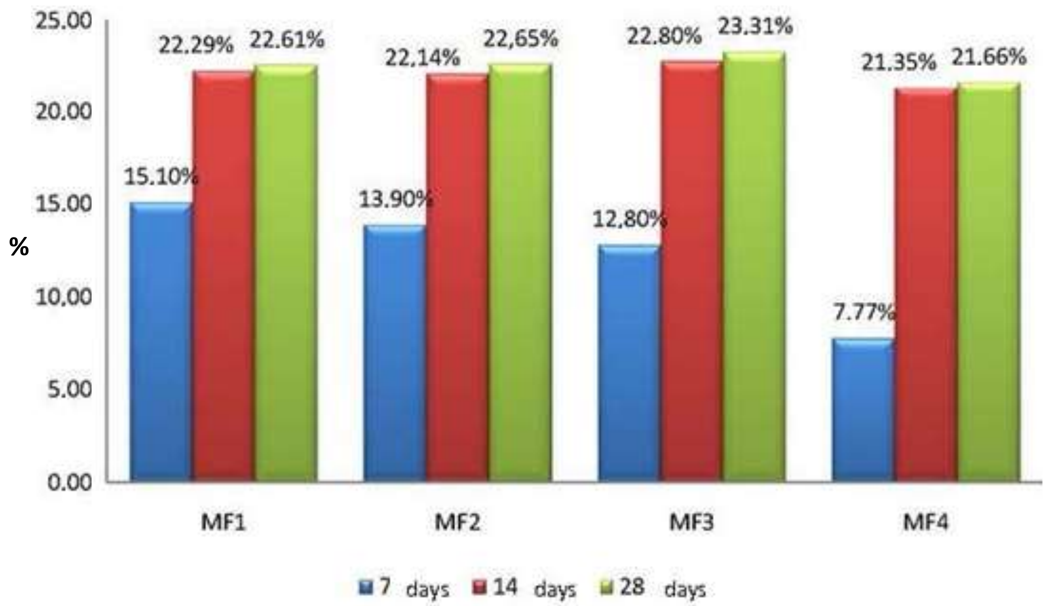

Figure 6. Diagram showing mass loss of different formulated mortars.

Table 6. The setting time tests of different formulated mortars.

Sample	Setting start time	Fully set time
Control MF1	5 h16 min	112 h
MF2	4 h 12 min	96 h
MF3	3 h 05 min	80 h
MF4	40 min	68 h

resistance to compression was MF3, which contained 2 volumes of crushed bricks per 1 volume of lime, 1 volume of black sand and 1 volume of fine sand. MF4, which had the same quantity of binder and aggregates as MF3, had the weakest resistance to compression, which allowed us to believe that the addition of egg (shell and contents) and the reduction in the quantity of aggregates such as black sand decreased the mechanical characteristics of the sample.

DISCUSSION

The addition of crushed brick with different contents in the composition of the formulated mortars influenced both their physical and mechanical characteristics.

MF1 was considered a control sample, since it contained neither crushed bricks nor additives; it had the highest porosity level, absorption level, and rate of water absorption by capillarity compared to the other samples. In the other samples, the porosity level, water absorption level and rate of water absorption by capillarity contents decreased with an increase in crushed brick quantity. Thus, sample MF3, which contained 2 volumes of crushed bricks per 1 volume of lime and 2 volumes of sand (1 volume yellow sand + 1 volume black sand) with 5% olive oil, had the lowest level of water absorption, porosity, and rate of water absorption by

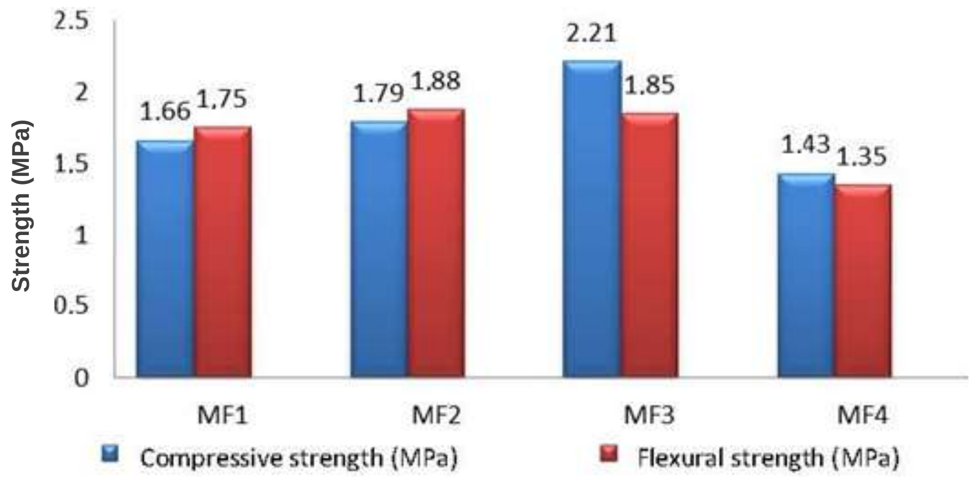

Figure 7. Diagram of results of compressive and flexural strength tests of formulated mortars.

Table 7. Compressive strength test of different formulated mortars.

Sample	Compressive strength		Flexural strength (MPa)
	Force (kN)	Constraint (MPa)	
MF1	22.56	1.66	1.75
MF2	24.31	1.79	1.88
MF3	29.97	2.21	1.85
MF4	19.42	1.43	1.35

capillarity. Adding oils in the composition of mortars, reduce porosity and water uptake (Karozou and Stefanidou, 2018)

The sample (MF3) also had the highest resistance to compression and bending. The resistance of MF3 approximated the average resistance of a mortar made with hydraulic lime in a proportion of 2 volumes of lime per 5 volumes of aggregate, where the compression resistance must be between 2.5 and 10 MPa according to European standards (British Standards Institution, 2006).

It should also be noted that sample MF4, which contained eggs, but not black sand, had a lower compressive strength. The cause of this could be the presence of eggs as an additive as well as the absence of black sand, which reduced the mechanical characteristics of the sample. The MF4 sample has the lowest compressive strength but has a better shrinkage and setting time.

During hardening, masonry is subject to all kinds of tensions and forces, which can cause cracking in mortars and plasters. This phenomenon is caused by slow setting times and significant shrinkage of the mortars during drying (Omar Bakri and Othuman Mydin, 2014).

The results obtained show that the MF3 and MF4 samples have the lowest shrinkage index and the best setting times. The natural additives incorporated in their composition improved both of these characteristics and acted as an air trap which reduced shrinkage and improved setting time.

The results obtained help confirm the durability of lime-based mortars with added olive oil and crushed bricks (Nunes et al., 2013; Böke et al., 2006).

Conclusion

The introduction of different materials in mortars with constant lime content influenced the physical and mechanical characteristics of the mortars. The use of natural additives (oil and eggs) and crushed bricks have given some good and promising results:

i) Crushed brick helps to improve the mechanical strength of mortars. This could be explained by the 'pozzolanic reactivity' of crushed bricks (Coutelas et al., 2004), which would give the mortar hydraulic properties.
ii) The addition of crushed bricks and oils influences mortars' resistance to water penetration.
iii) The use of olive oil as an additive improves the physical performance of mortar by reducing its rate of water absorption, its rate of water absorption by capillarity and its porosity level. With the oil additives, the mortars

become more resistant to water penetration, which explains the use of oil in water repellent mortars.

iv) The use of egg as an additive can influence some physical characteristics, including the reduction of setting time or the percentage of shrinkage. The results obtained demonstrated that the mortar with the addition of eggs had a reduced rate of water absorption, porosity, and water absorption by capillarity compared to control mortars and mortars with only crushed bricks added. It also had the lowest resistance to compression, while the resistance to bending was greater than that of compression.

There are many positive aspects to each additive. The durability, water repellent and waterproofing of the treated samples was greater than in the untreated ones. The use of such materials in construction will improve the sustainability of repair mortars.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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