UN STUDIU COMPARATIV AL PROPRIETĂȚILOR MECANICE ȘI A CONTRACȚIEI LA USCARE A MORTARELOR PREPARATE CU AGREGAT STANDARD ȘI NISIP CUARȚOS DE RÂU, FOLOSITE PENTRU REPARAȚII

A COMPARATIVE STUDY OF MECHANICAL PROPERTIES AND DRYING SHRINKAGE OF MORTARS PREPARED WITH STANDARD AND RIVER SANDS AS A REPAIR MORTAR

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Concrete lime- and NHL-based mortars were prepared with river sand and a standard ASTM sand as aggregate. The mortar samples were subjected to different curing conditions for 28 days in order to achieve the acceptable mortar strength in a shorter period of time, with the aim to move the repaired artworks from the restoration departments of museums while avoiding possible contamination or damages. The results are provided under the study of the influence of the curing conditions, the binder nature, the binder/aggregate ratio relation and the aggregate nature. The test results showed that ASTM sand was a good alternative to river sand; it even improved the mechanical characteristics and drying shrinkage of the NHL-based mortars and lime cement-based mortars. NHL5, with a lower amount of aggregates, achieved higher values of flexural tensile and compressive strength and performed mortars with lower shrinkage values, being the ASTM sand the aggregate that provided better properties. Synthetically, the lime based mortar NHL5 (1:1.75) with ASTM sand under 14 days at a RH of 90 ± 5% and 14 days at a RH of 60 ± 5% seemed to be a satisfactory solution to be used as repair mortar in order to achieve good mechanical and physical properties without long periods in restoration departments.

Keywords: *Portland cement, lime, mortar, aggregate, curing, Compressive strength, Modulus of Elasticity, Mechanical properties, Drying shrinkage*

1. Introduction

In museum restoration departments all around the world, professionals used to repair works of art with mortars e.g. the re-baking the left tesserae in mosaics or tiles in walls or attaching missing parts in case of sculptures. It is well known that a suitable repair mortar should be capable of accommodating movements. An inadequate intervention in historical pieces of art could cause more damages between the new mortar and the original material [1]. These mortars are systems containing binders, aggregates, water and different admixtures, e.g. metakaolin [1- 4].

Many researchers have analysed different historical mortars to seek specific information about their compositions in order to achieve compatible repair mortars [4- 6]. Originally, lime was used as binder in historical monuments of the European cultural heritage [7]. With the development of cement at the beginning of 20th century, Ordinary Portland Cement (OPC) imminently replaced the lime based-mortar. However, the problems showed by OPC [8-10], e.g. salt crystallization, structural collapse, etc., moved the architects and conservation and restoration professionals of the cultural heritage to re-start studying lime-based mortars to be applied as repair mortar in historical monuments. In recent years, many researches performed a convergence with the use of lime-cement based mortars, aiming to achieve the flexibility of the lime and the high strength of the concrete in order to promote the hardening reaction by the cement hydration [3]. The low compressive strength of lime mortars can achieve a better durability over time than cement based mortar [11]. The cement hydration contributes to the early stage strength development while carbonation is mainly promoted after 3 days and increases gradually in the following 180 days [12]. It is well known that hydraulic reactions require a humidity higher than 90% to ensure that mortar surface cannot absorb CO_2 and carbonation is almost inexistent. Carbonation is achieved if the evaporation of the free water is produced due to a reduction of the relative humidity to 60% but micro cracking around aggregates has to be taken into account [13]. Therefore, it is advisable to apply repair mortars varying relative humidity, in order to achieve a resistant and low shrinkage mortars.

Other mechanical and physical differences among mortars can be due to the aggregates. At first, the repair mortars with lime were prepared

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using river sand as a fine aggregate [7]. Different kinds of aggregates have been used in the production of repair mortars during these last years, such as natural sand (marine sand, river sand, crushed sand) or artificial aggregates (JIS standard sand, ASTM sand, lightweight aggregates, recycled concrete, products from the industry in form of by-products, e.g. foundry sand, copper slag and blast furnace slag, etc.) [14 - 22]. The high demand of river sand has caused an over-exploitation of these natural aggregates, leading to an increase of the river depths, intrusion of salt from the sea into the rivers damaging the river fauna and structural problems in infrastructures, such as bridges. An alternative to this sand had to be found, an alternative that could improve the mechanical properties and drying shrinkage of the mortar. In a previous study, pure limestone aggregate was used in Natural Hydraulic Lime-(NHL5 and NHL2), lime cement- and pure lime-based mortar achieving that NHL5 (1:1.75) mortar with 28 days in a 70 ± 5% RH chamber was a good candidate to be used like a repair mortar [23]. ASTM sand was published in the norm ASTM as an alternative to river sand, being prepared using equal volumes of ASTM Graded Sand and ASTM 20-30 Sand [24]. Studies about the application of this sand in repair mortars in buildings, sculptures and monuments are found [19]. They concluded that the drying shrinkage strains of mortar specimens incorporating natural sand are deeply higher than the drying shrinkage strains in mortars with standard sand.

In this paper, in order to study the effect of the aggregate origin and the binder on repair mortar, two aggregates were mixed with different binders: Natural Hydraulic Lime (NHL5) - and a lime cement-based paste. The aggregates were the traditional river sand and the artificial aggregate ASTM sand. The influence of the relative humidity was also investigated on the final mechanical and physical properties since the study tries to achieve the hardening of the mortar in the first 28 days without having to wait for longer periods in artificial chambers. It is generally recommended that pieces of art should not spend long periods in restoration departments in order to avoid any contamination or possible damages. Mechanical properties such as the dynamic Young modulus, flexural tensile and compressive strength as well as the physical property: drying shrinkage, have been measured in order to detect the combination that achieves greater mechanical properties (high dynamic Young modulus, flexural tensile and compressive strength) and minimal drying shrinkage values.

2. Material and Methods

2.1.Mortar designs and mixing procedures

Used binders in this experience were NHL5 and a mixture of cement and slaked lime putty.

The NHL5 have been supplied by Chaux Bruyeres et fils (Saint-Front-sur-Lémance, Fumel, France). In Table 1, their chemical characteristics are shown according to EN 196-2 [25].

The cement was provided by Sociedad Financiera y Minera, S.A. (Málaga, Spain). Table 1 gives its chemical characterization, which was portland cement CEM V, according to ASTM C150 [26].

In this study, the lime putty was provided by the Cornish Lime Company (Cornwall, UK). The chemical composition according to EN 196-2 [25] has been summarized in Table 1.

In this work, ASTM sand (herein ASTM S) and river sand (herein RS) were used as aggregates (see Table 1 and Table 2). RS was sourced from the Miño River (NW Iberian Peninsula) and was passed through a sieve analysis in accordance with the requirements of BS EN 196-1 [27]. ASTM S was obtained by mixing Graded sand (50% by weight) and Sand 20-30 (50% by weight) following ASTM C778 [24]. These aggregates were provided by CTH Navarra (Navarra, Spain). The particle size distributions of these aggregates, in compliance with ASTM C 136 [28], are introduced in Figure 1. The suitability of the gradation of the tested aggregates as a mortar aggregate was evaluated by comparing the obtained gradation curves with the suggested particle size ranges according to ASTM C33 [29]-area and represented in Figure 1.

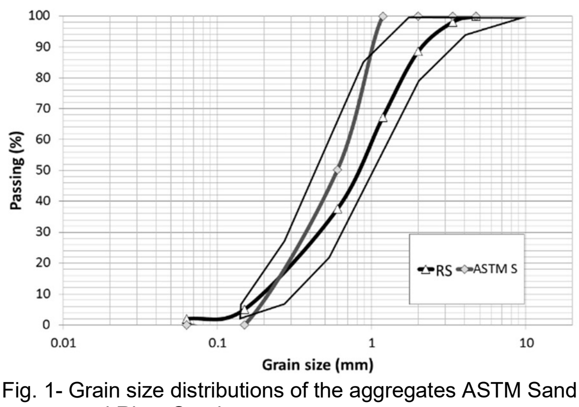

Fig. 1- Grain size distributions of the aggregates ASTM Sand and River Sand

Table 1

Chemical analysis of the main components of the NHL5, the portland cement CEM V, lime putty and the aggregates: ASTM S and RS. Bulk density (ρ) is also provided

Sample	ρ (Kg/dm^3)	LOI (%)	SiO_2 (%)	CaO (%)	MgO (%)	X_2O_3 (%)	SO_3 (%)	Na_2O (%)	K_2O (%)
NHL5	0.65	18.6	22.45	43.13	2.15	10.00	1.30	0.59	1.67
CEM V	1.15	6.94	16.23	58.28	4.65	9.99	2.35	0.38	0.35
Lime putty	1.35	--	0.65	97.8	1.15	0.09	0.10	0.00	0.12
ASTM sand	2.75	--	100	--	--	--	--	--	--
River Sand	2.60	10.23	75.23	8.26	1.30	3.53	0.10	0.40	0.95

LOI: Loss of ignition indicates the weight loss due to calcinations at 975–1000 °C. X_2O_3: Percentage of Fe and Al oxides together.

Table 2

Summary of the prepared mixes

Sample	Binder/Ag. by volume (B/Ag)	Cement/lime by weight (%)	Aggregates (g)	NHL (g)	Cement (g)	Lime putty (g)	Water/binder by weight (W/B)	Added water (g)
NHL5 (1:1.75)	1:1.75		1500	431			0.70	302
NHL5 (1:2)	1:2		1500	358			1.00	358
0.75L:0.25CV:2		73	1500		144	492		86

The studied types of mortars were those made with NHL 5 and lime-cement (slaked lime putty with portland cement type CEM V). The B/Ag (Binder/Aggregate) ratios by volume and W/B (Water/Binder) ratio by weight of the preparations are shown in Table 2 with the amount of each component. These combinations were used in previous works [23].

The pastes were blended in a Laboratory mixer 10 L of Proeti. Based on the previous experience, the amount of water in all mixtures was adjusted in order to ensure a sufficient workability of the pastes and to avoid shrinkage cracking [23]. Note that the presences of cracks decrease the strength of the mortar [30].

In order to produce the NHL5-based mortars, we blended for two minutes water and NHL5 in a bowl. Afterwards, while the mixer was working, we added aggregate for 1 min, covered the top and blended the mixture for 3 min.

For lime cement-based mortars, we added the lime putty and additional water to the bowl of the blender and mixed for 1 min. After adding the cement in 30 seconds we also added the aggregate in 1 min. The paste was mixed for 1 min more, covered the top of the bowl, and mixed it for 3 min.

After the mixing process and moulding process, the moulds containing mix samples were placed in a 90±5% RH chamber (at 20±5 °C) on different days in order to achieve the needed hardening as to allow us a proper demoulding. For NHL5-based mortars, they were placed in a 90±5% RH chamber (20±5°C) for ten days, and the lime cement-based mortars 3 days. In this sense, the breaking during the demoulding was avoided.

After the demoulding, the prisms stored in the 90±5% RH chamber (20±5 °C) or they were moved to a 60±5% RH chamber (20±5 °C), also depending on the curing conditions, which tried to achieve an acceptable mortar strength in 28 days without longer curing periods. In order to study the influence of relative humidity on the repair mortars, a total of five different curing conditions were studied for each mortar:

- 28 days at a RH of 90 ± 5% (28/0)
- 21 days at a RH of 90 ± 5% and 7 days at a RH of 60 ± 5% (21/7)
- 14 days at a RH of 90 ± 5% and 14 days at a RH of 60 ± 5% (14/14)
- 7 days at a RH of 90 ± 5% and 21 days at a RH of 60 ± 5% (7/21)
- 28 days at a RH of 60 ± 5% (0/28)

The objective was to achieve the developing of some higher values of mortar strength as soon as possible, based on the need to avoid long period of permanence in the restoration departments, where the pieces of art could be contaminated or damaged.

2.2. Test methods

The following techniques were used for the evaluation of mechanical characteristics and drying shrinkage of mortars:

2.2.1. Mechanical Testing Mortars

The samples were made in 4 cm x 4 cm x 16 cm metal prism moulds. The moulds were coated with release oil and then, the paste was placed in each mould.

The Dynamic Young's modulus E_{dyn} of the mortars were obtained by the pulse velocity method according to BS EN 12504-4 [31] using a Vikasonic Ultrasonic Instrument. Two 82 kHz transducers were pressed on the ends of the beam and the velocity of the elastic wave was measured and afterwards used to calculate the dynamic Young's modulus (E_{dyn}) in MPa [Eq. 1]:

$$E_{dyn} = 0.001 x V^2 x \rho, \qquad \text{Eq. 1}$$

where V ($m\ s^{-1}$) is the speed of the longitudinal elastic wave inside the beam and ρ ($g\ cm^{-3}$) is the mortar density, which is calculated from the weight and measured dimensions of the each beam specimen.

Mechanical tests (a three point flexural test and a compressive strength test) were performed using a standard press of 600 kN from Controls S.L., modified by Servosis S.L. So it can be servo-controlled for the load or displacement.

The three point flexural test was performed following UNE-EN 1015-11 [32] with a low rate of loading (4 mm min^{-1}).

The compressive strength test was carried out according to BS EN 459-2 [33] on the two fragments of each beam specimen broken during the flexural strength test. Specimens were loaded at a rate of 6 mm min^{-1}.

For each curing condition, in these mechanical tests ten specimens were used in a flexural test and therefore, twenty samples in the compressive strength test.

2.2.2. Drying Shrinkage of mortars

In accordance for measuring drying shrinkage, 285 mm x 25 mm x 25 mm beam specimens were prepared in accordance to ASTM

C490 [34]. The changes in length of the specimens were measured as the difference between the specimen and a reference bar using a length comparator with a digital indicator having a precision of ±0.001 mm. An equipment Length Comparator of S. S. Instruments was used.

The gap between the side walls and the case plate of the moulds was sealed using a high vacuum grease.

As in the flexural test, ten specimens were used in the drying shrinkage study.

3. Results and Discussion

3.1. The influence of the curing conditions

Table 3 shows the average of measurements of E_{dyn} with the coefficient of variation (CV) from individual measurements. The highest values of E_{dyn} for each type of mortar were achieved by the curing condition 28/0 for NHL5 (1:1.75) with ASTM S and RS, NHL5 (1:2) with ASTM S and 0.75L:0.25CV:2 with RS. In case of NHL5 (1:2) with RS and 0.75:0.25CV:2 with ASTM S the higher values of E_{dyn} were achieved for 0/28 curing condition. The lowest values for NHL5 (1:1.75)-based mortars with ASTM S and RS were achieved by 7/21. In the case of NHL5 (1:2) with ASTM, the lowest value for E_{dyn} was achieved with 0/28 and both for NHL5(1:2) with RS and for 0.75L:0.25CV:2 with ASTM S, it was achieved by 28/0. The results measurements are in accordance with those already published in previous studies [22, 35], which had found that the stiffness development in some mortars is high during the first 28 days.

In general terms, the highest value of E_{dyn} (12.54 GPa) was achieved for NHL5 (1:1.75) with ASTM S by the curing condition 28 days at a RH of 90 ± 5% (28/0).The other tested curing conditions achieved mortars with slightly lower Young moduli, but very close to that registered for NHL5 (1:1.75) with ASTM S (28/0).

Figures 2 and 3 show the flexural tensile and compressive strengths respectively. In these results, the values of the strength for each type of mortar did not experiment remarkable changes under the different curing conditions. For NHL5-based mortars, those with a high content in lime (1:1.75, B/Ag ratio) and with ASTM S as aggregate had the highest values of flexural tensile and compressive strengths under the curing conditions 21/7 and 14/14. In the case of the mixture with this binder and this ratio but with RS, the strengths under all curing conditions were very similar, except in the case of flexural strength of 0/28, where the value was higher (in Figure 2, compare NHL5 (1.1.75) with RS at 0/28 with the other curing conditions; the value was quite higher). For NHL5-based mortar with a higher content in aggregate (1:2, B/A ratio), the flexural strength showed the same trend in 28/0, 21/7, 14/14 and 7/21, where the mixtures with ASTM S had higher values; for 0/28, this mortar with RS showed higher value of flexural strength than that registered for the mortar with ASTM S. In the case of compressive strength, the mixtures of NHL5 with different aggregates did not show significant differences among curing conditions. For lime cement-based mortars, in the samples with RS the highest values of both strengths were achieved by 7/21, although the other curing conditions 21/7 achieved mortars with close flexile tensile values. For lime cement based mortar with ASTM S, the highest values were measured in the samples under 0/28 curing condition, while the other conditions showed samples with very close flexural tensile strengths (≈1.1 MPa).

Synthetically, Figures 2 and 3 show that the best results for the flexural tensile (1.9 MPa) and the compressive strengths (6.3 MPa) were achieved for the lime cement based mortar with RS, under the curing condition 7/21. Regarding to the flexural tensile strengths achieved by lime based mortars, NHL5 mortars, the higher values were registered for the mortar with lower quantity of aggregate, NHL5 (1:1.75) with ASTM S under 14/14 (1.65 MPa) and 21/7 (1.52 MPa) curing conditions.

Table 3
Development of dynamic Young´s modulus in the studied mortars with a coefficient of variation, COV [%]

Samples	Curing conditions	Average dynamic Young's modulus (GPa)	CV [%]
NHL5 (1:1.75) WITH ASTM S	28/0	12.54	10.56
	21/7	10.63	9.23
	14/14	9.02	11.45
	7/21	7.76	6.28
	0/28	8.70	10.23
NHL5 (1:1.75) WITH RS	28/0	9.20	0.86
	21/7	5.03	6.09
	14/14	5.33	0.36
	7/21	4.96	4.96
	0/28	9.10	1.03
NHL5 (1:2) WITH ASTM S	28/0	5.99	1.12
	21/7	5.98	6.93
	14/14	5.40	3.23
	7/21	4.30	9.26
	0/28	3.50	1.09
NHL5 (1:2) WITH RS	28/0	2.37	8.56
	21/7	3.69	4.23
	14/14	3.00	5.96
	7/21	2.84	4.15
	0/28	5.50	2.01
0.75L:0.25CV:2 WITH ASTM S	28/0	4.70	4.23
	21/7	5.42	5.26
	14/14	5.10	1.36
	7/21	5.45	9.28
	0/28	7.06	4.28
0.75L:0.25CV:2 WITH RS	28/0	8.01	10.26
	21/7	7.16	2.36
	14/14	6.72	6.68
	7/21	7.52	12.03
	0/28	5.52	5.36

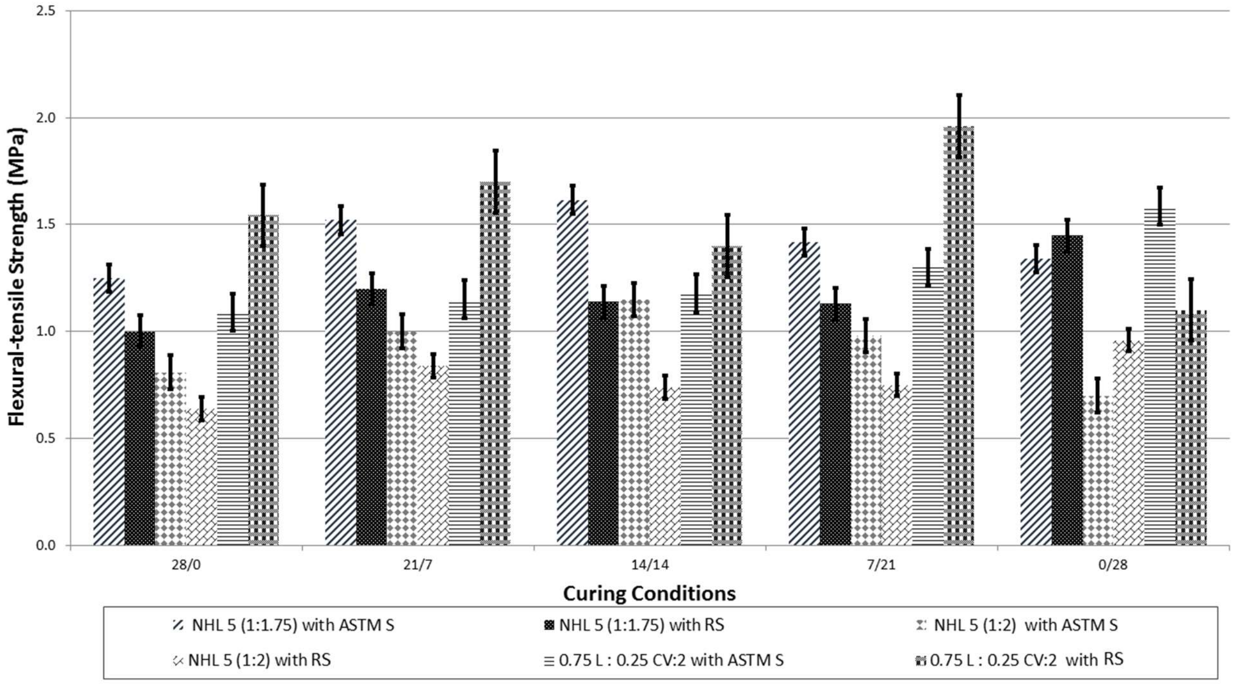

Fig. 2 - Flexural strength depending on curing conditions with error bars .

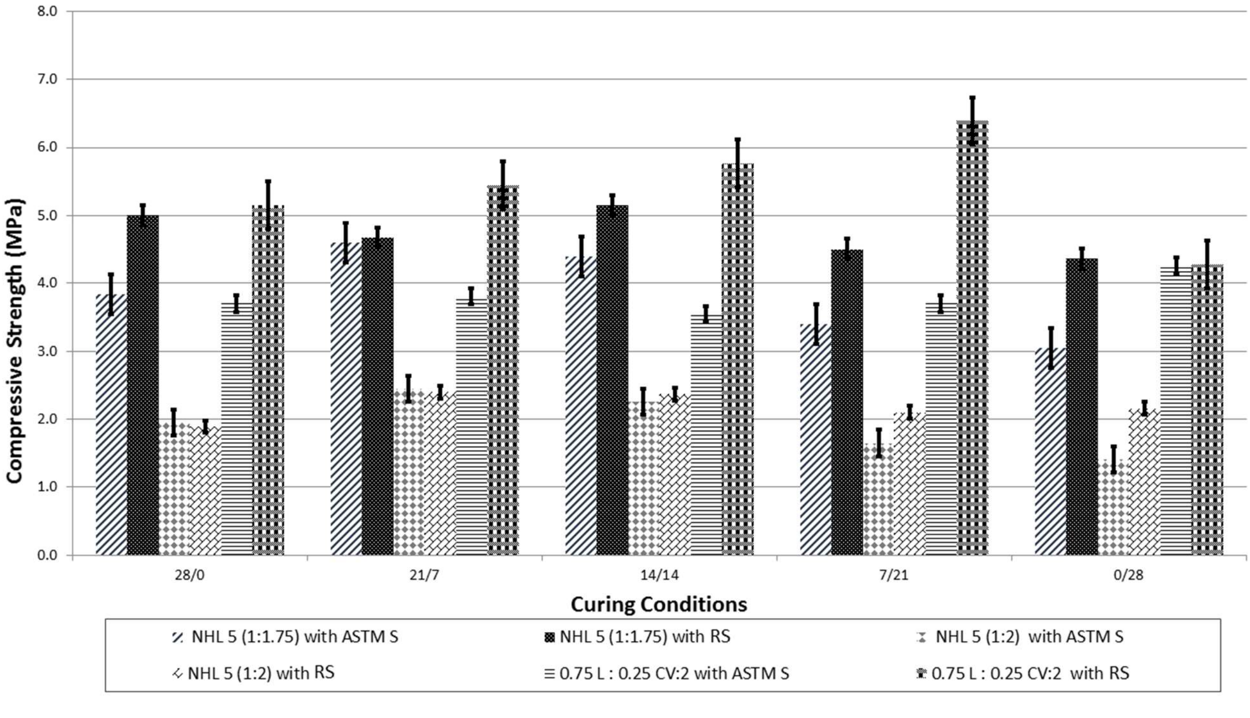

Fig. 3 - Compressive strength depending on curing conditions with error bars.

Figure 3 shows that for NHL5 mortars, NHL5 (1:1.75) showed the highest values of compressive strength, being 28/0, 21/7 and 14/14, the curing conditions that achieved the highest values for those made with RS, and 21/7 and 14/14 for those made with ASTM S. In general, these results demonstrated that mortars with lime pastes increase their strength under the combination between different relative humidity. Hydraulic reactions require a curing at a humidity above 90% RH, because with this relative humidity the mortar could not absorb CO_2 and the carbonation would be impeded. After that, when the relative humidity decreased in a slow way (from 90 % RH to 60 % RH), the drying avoided the cracking around the aggregates. As it is detected in a previous work [23], during the days in 90 ± 5% RH chamber, C_3S hydration produced new calcium hydroxide which may carbonate when the samples were placed in the 60 ± 5% RH chamber. In this sense, specimens started to gain weight and strength. For the samples with inexistent or shorter time period in 60 ± 5% RH chamber, they had not time to carbonate at all and for this reason, 28/0 specimens of NHL-based mortars achieved the lowest flexural strength values [23].

Figures 4-6 show the drying shrinkage results of the lime and lime cement-based mortars during 63 days under the five curing conditions. On the one hand, except for NHL5 (1:1.75, B/Ag ratio) with RS (Figure 4), for all tested NHL5-based mortars (1:1.75 and 1:2, B/Ag ratio), we can observe that the curing condition which led to higher shrinkage values was 0/28 for both aggregates. For NHL5 (1:1.75, B/Ag ratio) (Figure 4) with RS the higher shrinkage was achieved by 7/21. Considering NHL5 (1:1.75, B/Ag) (Figure 4) mortars with ASTM S, the values of shrinkage achieved by 21/7, 14/14 and 7/21 were very close to that exhibited by 0/28. For NHL5 (1:2, B/Ag ratio) (Figure 5) with RS mortars, besides 0/28, the higher values of drying shrinkage were also obtained by

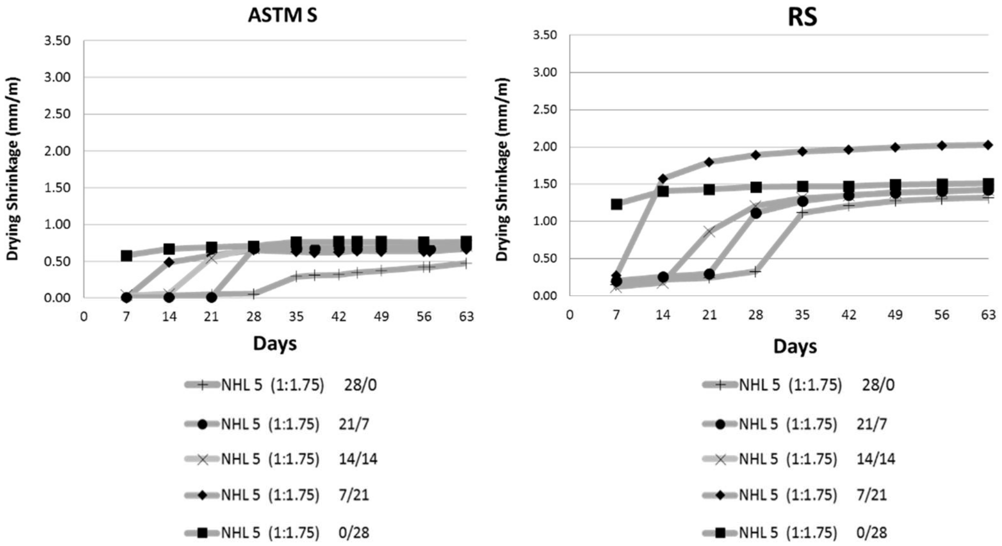

Fig. 4 - Development of shrinkage in NHL5 (1:1.75) mortars with ASTM sand (left) and River Sand (right) .

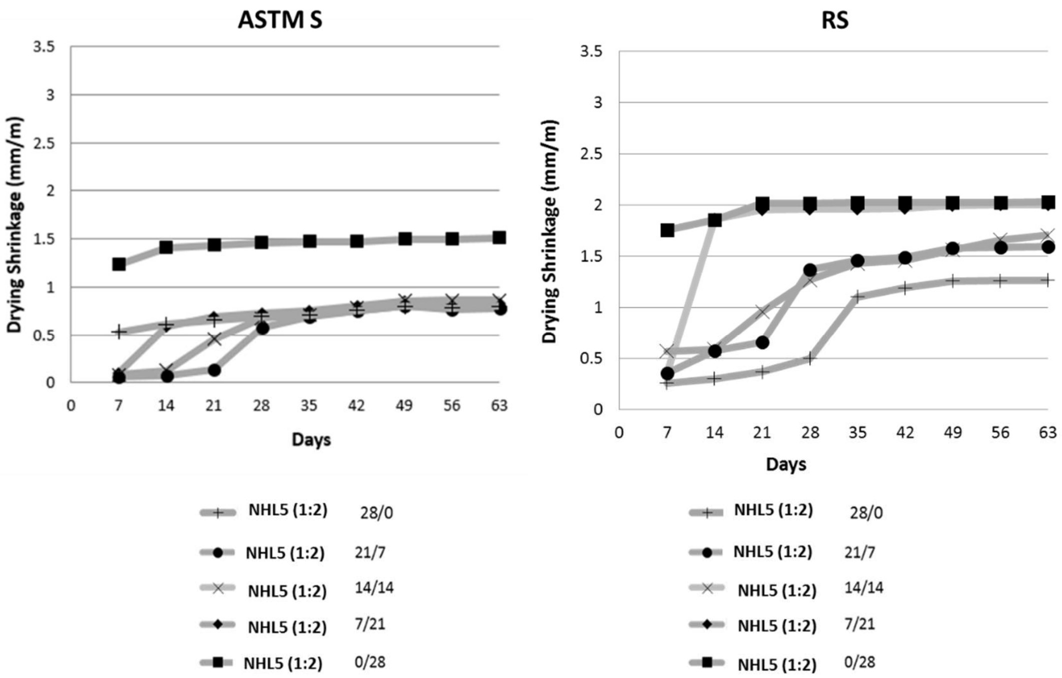

Fig. 5 - Development of shrinkage in NHL5 (1:2) mortars with ASTM sand (left) and River Sand (right).

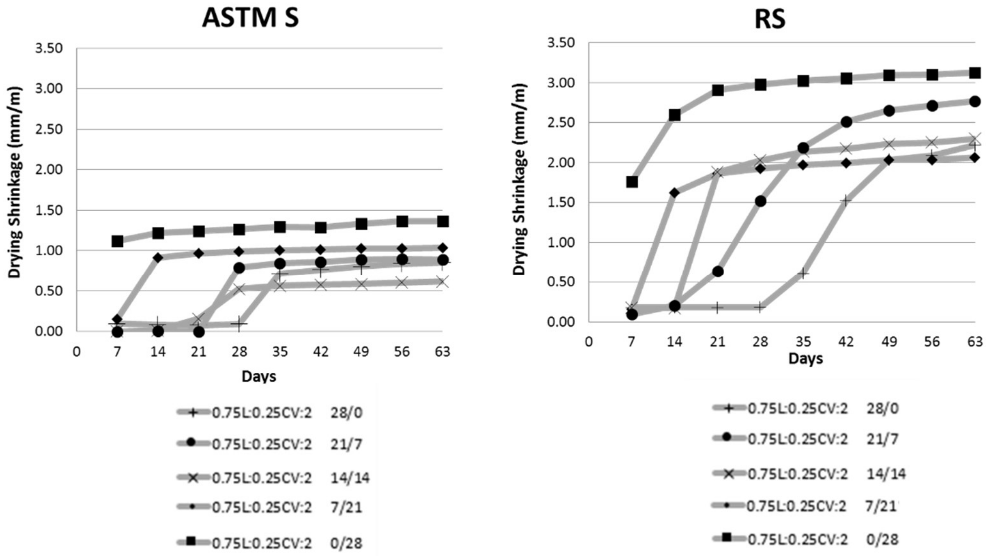

Fig. 6 - Development of shrinkage in 0.75L:0.25CV:2 mortars with ASTM sand (left) and River Sand (right).

7/21 curing condition. On the other hand, the lower values were achieved by 28/0 in all NHL5-based mortars (1:1.75, 1:2, B/Ag ratio) (Figure 4, 5). For NHL5 (1:2) with ASTM S (Figure 5) this low shrinkage was also detected in 21/7, 14/14, 7/21 and 28/0. For lime cement-based mortars (Figure 6), the higher values of shrinkage were achieved by 0/28 and the lower ones, 28/0 for ASTM S mortar and 7/21, 14/14 and 28/0 for RS mortars. All the studied shrinkage results were in concordance with the principle of drying shrinkage that points: the larger the drying, the larger the shrinkage [36].

Considering the results above, in general terms, the highest shrinkage was detected for 0/28 curing condition, while for 28/0, the shrinkage was the lowest one. However, for some other mortars, the shrinkage values were as lower as that registered for 28/0, e.g. NHL5 (1.1.75) with ASTM S exhibited shrinkage values very close for all the curing conditions (Figure 4).

3.2. The Influence of the binder

Regarding E_{dyn}, the values achieved by NHL5 (1:1.75) were higher than those obtained by NHL5 (1:2). The values of NHL5 (1:1.75) were even higher than those for 0.75L:0.25CV:2. Based on previous works [22, 23], the lower values of E_{dyn} for NHL5 (1:2) determined that this mortar showed a higher porosity than the other specimens i.e. NHL5 (1:2) mortars were more flexible.

Attending to Figure 2, lime cement-based mortars with RS achieved the higher values of flexural strength for the curing conditions 28/0, 21/7 and 7/21. For 14/14, the highest value of flexural strength was detected in NHL5 (1:1.75, B/Ag) with ASTM S. For 0/28, the highest flexural strength was achieved by lime cement based mortar with ASTM S. Considering the compressive strength (Figure 3), lime cement based mortars with RS achieved higher values of strength than those exhibited by the rest of the samples. For the lime cement-based mortar with 0/28, the compressive strength was very close to those registered for NHL5 (1:1.75) with RS and lime cement based mortar with ASTM S. In summary, lime cement-based mortar with RS showed the highest values of flexural and compressive strengths for the curing conditions: 28/0, 21/7 and 7/21. However, for 14/14, while NHL5 (1:1.75) with ASTM S exhibited the highest values of flexural strength, the lime cement-based mortar with RS the highest compressive strength. For 0/28, lime cement based mortar with ASTM S exhibited the highest flexural and compressive strengths, but for this last one property, NHL5 (1.1.75) with RS and lime cement-based mortar with RS exhibited compressive strength values very close. Synthetically, the highest flexural and compressive strengths was achieved for the lime cement based mortar with RS at 7/21.

In general terms, the highest values of shrinkage were registered for the lime cement-based mortars with RS (Figure 6). The lowest values were observed in NHL5 (1:1.75) with ASTM S. Attending to NHL5 mortars, the highest values for shrinkage were achieved by those mortars made with the highest Water/Binder ratio, (1 W/B ratio) which corresponded to NHL5 (1:2 B/Ag ratio) mortars. For example, in the plots shown in Figure 5, the shrinkage of NHL5 mortar (1:2 B/Ag ratio) under 28/0 curing conditions with ASTM S was 1.5 mm/m at 63 days, but for mortar (1:1.75 B/Ag ratio) with ASTM S was less than 0.5 mm/m.

3.3. The influence of the aggregate.

Table 3 shows that the values of E_{dyn} were higher for the mortars of NHL5 made with ASTM S than those composed of RS. However in the case of 0.75L:0.25CV:2, the highest E_{dyn} were achieved by the mortars with RS. Attending to [22, 23] when Young's modulus is higher, the porosity decreases. Therefore, NHL5 mortars with ASTM S, the porosity would be lower than in those made with RS, but in the case of 0.75L:0.25CV:2 would be totally different.

Figures 2 and 3 show that under the curing conditions 28/0, 21/7, 14/14 and 7/21, the highest flexural strength of NHL5 mortars was achieved by mortars with ASTM S. However, this trend was not the same for 0/28, where the RS mortar showed higher values of flexural tensile strength. For compressive strength, conversely to flexural tensile strength, RS mortars achieved higher strength values than those made with ASTM S for 28/0, 21/7, 14/14 and 7/2.

Considering the lime cement-based mortars, mortars with RS showed higher values of flexural strength for 28/0, 21/7, 14/14 and 7/21. However, for the curing condition 0/28, lime based mortars with ASTM S showed higher values of flexural strength in comparison with the rest of the curing conditions.

In general terms, for NHL5 mortars, the strength results showed the high- flexural strength mortar containing ASTM S and the high-compressive strength containing RS. This confirmed Stefanidou et al., since they concluded that standard sand led to higher values of flexural strength [37]. Conversely to NHL5 mortars, lime cement-based mortars showed the high- flexural strength mortar and the high-compressive strength containing RS.

The shrinkage of mortars with RS was higher than in the same B/Ag ratio with ASTM S (Fig. 4-6). Zhang et al. already reported that the drying shrinkage strains of mortars incorporating natural sand was relatively greater than the drying shrinkage for mortars with standard sand [19].

Based on the previous considerations, it could be said that the kind of the aggregate is very important concerning the drying shrinkage of the lime and lime cement-based mortars.

4. Conclusions

This paper explored the possibility of using different aggregates and different binders in repair mortars, trying to find out the curing condition that allowed a faster development of the mortar strength. It had to be found a repair mortar that achieved good properties, both of strength and shrinkage, in a shorter time due to the possible contamination and damage in laboratories of restoration departments.

Despite of the curing conditions that achieved higher strength in 28 days for the studied mortars were not clear, it is recommend that the mortar curing is made under two different relative humidity, since these studied repair mortars gain strength by the hydration of the hydraulic components under a humidity of 90% or more and before it, the carbonation of the lime under a 60% RH. Furthermore, the 28/0 and 0/28 curing conditions should be avoided. The best curing conditions for NHL5 mortars were 14/14 or 21/7 and for 0.75L:0.25CV:2, it was 7/21. Under these curing conditions, for NHL5 mortars the aggregate that achieved higher strength values was ASTM S and for 0.75L:0.25CV:2 it was RS.

Regarding to shrinkage, the less shrinkage was achieved by NHL5 and lime cement-based mortars with ASTM sand. This means that ASTM sand seems the better aggregate for a repair mortar manufactured with NHL5 and lime cement-based pastes.

Considering all above, the suitability of NHL5 (1:1.75) with ASTM sand as repair mortar has been demonstrated. The curing conditions which provided better mechanical characteristics and drying shrinkage values to the mortars could be 14/14 and 21/7. Considering that the main objective of this paper was to find the curing conditions in order to reduce the time that the samples have to be in the restoration departments to avoid damages, 14/14: 14 days in a 90±5% RH chamber and 14 days in a 60±5% RH chamber could be the more suitable curing condition.

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