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THE INFLUENCE OF THE PARTICLES DIMENSION OF THE AGGREGATE ON THE PERFORMANCE OF HYDRAULIC RENDERS

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EXTENDED ABSTRACT

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1. Abstract

By varying the aggregate´s grain size distribution alone, it is possible to obtain significant differences in the properties of the resulting mortars. Therefore it becomes a matter of importance to understand how the variation of this single factor may affect the desired characteristics of mortars used for rendering.

The proportion of sand fractions has a pronounced effect on the mortar properties, workmanship and design (Konow, 2003). Thus, the experimental part of this paper has been set to study the properties of hydraulic binder mortars incorporating sand with various grain size distributions.

For this purpose four types of sand and sand mixtures have been defined to be incorporated in the mortars, always keeping constant the binder-aggregate volume ratio and the consistence, in accordance with the ones currently used at the construction sites. Each one of these four types of sand has been used to produce cement mortars as well as hydraulic lime mortars, thus leading to the study of eight different mortar types.

This resulted in a relatively long experimental phase, in order to reach conclusions about the way in which variations imposed on the sand grain size distribution affect the performance of rendering mortars. The performance evaluation includes either fresh and hardened mortars as well as an introductory analysis of the aggregate characteristics.

An overall view shows that the obtained results allow the understanding of which variations in the sand grain size distribution will lead to a better performing mortar. In a similar way it is possible to tell which mortars will display the worst characteristics or those with no advantages relatively to others.

2. Introduction

Aggregates for the construction industry are the most consumed mineral materials in the world. Therefore study and knowledge of its characteristics and consequent influence on the properties of mortars and concrete assume a considerable importance. Among the materials that constitute a mortar, sand is the one that corresponds to the largest amount. Apart from the different type of aggregates as their mineralogy is concerned, the volume contents in the mixture, the maximum size and their gradation influence the structure of a binder-aggregate mixture (Neville, 1995, Mehta, 1986, quoted by Stefanidou and Papyianni, 2005).

As Westerholm *et al* (2007) conclude in their recent study, the rheological properties and water demand of mortars are strongly dependent on the properties of the fine aggregate.

Although the actual conditions for mortar application as renders at worksites are variable, and therefore difficult to be accurately reproduced in laboratory studies, it is important to develop investigation in order to increase the knowledge in this domain, since the theme is not yet widely investigated or documented. The main objective of this research is to evaluate the influence of the particles dimension of the aggregate on the performance of hydraulic rendering mortars formulated with two commercial hydraulic binders, a cement and an hydraulic lime, in what refers to aspects related with their physical and mechanical characteristics.

3. Experimental part

3.1. Compositions definition

It is intended with this experimental study to evaluate the characteristics of mortar renders of hydraulic binder, incorporating sand and sand mixtures of different grain size distributions. The grain size curve, of the used sands and the corresponding volume of voids is presented as follows. Four compositions, as different as possible, regarding this two aspects, have been chosen.

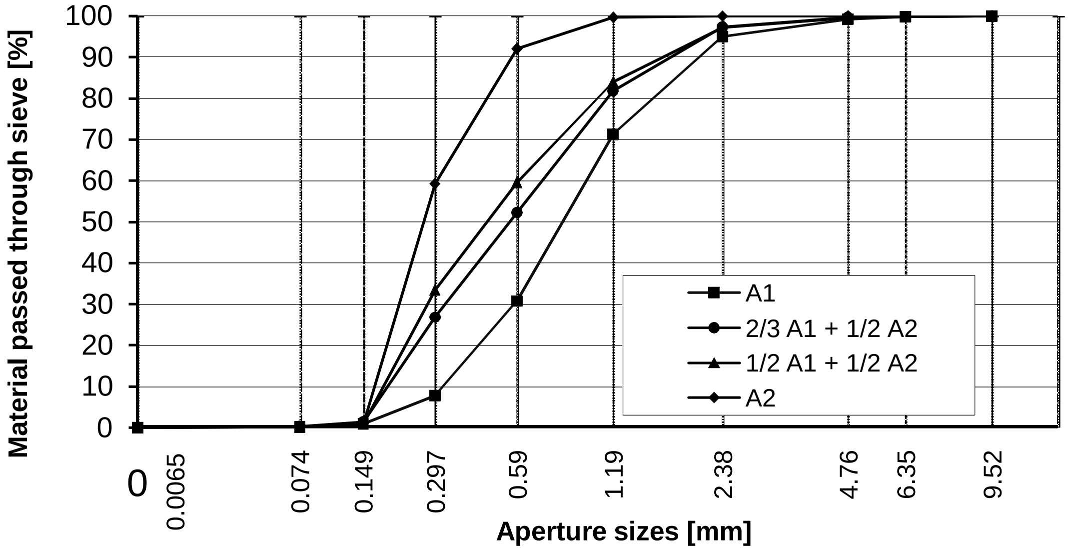

Fig. 1 - Aggregate grain size distributions

Table 1 - Volume of sand voids

Sand	A1	A2	1/2 A1 + 1/2 A2	2/3 A1 + 1/3 A2
Volume of voids (%)	35.9	37.7	30.8	28.4
Standard deviation (%)	0.2	0.4	0.2	0.7

It must be referred that aggregates used throughout all mortar production have been dried to constant mass, being then placed at rest till reaching ambient temperature. This procedure intends to reduce the influence of the aggregate's moisture in the mixture.

In what concerns the two types of used sands, the finest sand, A2 (see Fig. 1), presents the highest volume of voids, corresponding to a lower compactness, a characteristic that shows up in the mortar's performance, as experimentally evidenced.

In a first analysis, the sand mixture including 1/3 of A2 sand manages to minimize the volume of voids, therefore leading to a more compact mortar, with increased strength.

Concerning the binder-aggregate ratio, it has been adopted for all the mortars a volume ratio of 1:3.

Therefore, eight different types of mortars have been defined, as presented in Table 2.

Table 2 - Definition of analyzed compositions

Mortar type	Binder	Sand
I.CEM	Cement	A1
II.CEM	Cement	A2
III.CEM	Cement	$^1/_2$ A1 + $^1/_2$ A2
IV.CEM	Cement	$^2/_3$ A1 + $^1/_3$ A2
I.NHL	Hydraulic lime	A1
II.NHL	Hydraulic lime	A2
III.NHL	Hydraulic lime	$^1/_2$ A1 + $^1/_2$ A2
IV.NHL	Hydraulic lime	$^2/_3$ A1 + $^1/_3$ A2

It is intended that the produced mortars are as close as possible to the actually used at construction sites in what concerns workability. This requires consistence to be experimentally controlled, this being achieved through the flow table test. The flow value has been set at 65±2%, finding out, then, the corresponding water/binder ratio for each one of the mortar types.

Having in mind the scope of this study and its goals, a single test age of 28 days has been established. However, by reason of laboratory constraints, the pull-off test, the porosity accessible to water and the bulk and real densities tests, have been performed at 60 days of age of the test samples.

A total of 72 prismatic samples (40×40×160mm), 16 eight-hole ceramic bricks (coated with mortar on one side) and 8 mortar filled V-shaped channels were produced and tested.

All the types of test samples being studied were kept in dry cure conditions since its casting until the dates of test, inside a conditioning chamber at a 20±2ºC temperature and 50±5% relative humidity.

3.2. Tests performed

The following tests were carried out.

Fresh mortar characterization tests

Consistence by flow table, bulk density and estimate of voids volume, exudation and water retentivity.

Hardened mortar characterization tests

Mechanical tests: ultrasound propagation, flexural and compressive strength, rebound hammer and pull-off.

Physical tests: water suction by capillarity, water absorption by immersion (after 48h), porosity accessible to water, bulk and real density, wetting-drying, cracking susceptibility, water absorption under low pressure and shrinkage in V-shaped channel.

4. Tests and results

Considering the whole data obtained in the mentioned tests, those results considered of major importance for this study are presented below.

4.1. Fresh mortar tests

The analysis of results concerning the bulk density (Table 3) show a strong decrease for mortars with only A2 sand, what may be related with the lower bulk density of this sand. In the same way, the volume of voids is larger for mortars of Type II. This would be expectable, having in mind the analysis of the aggregate's volume of voids, since a lesser capacity of sands in organizing themselves in the mortar microstructure will lead to a larger necessity of water and therefore an increased volume of voids and lower bulk density.

The results presented for water retentivity point, in general, to values close to 80%. Only Type II mortars, in particular II.NHL type, stand out for their reduced water retentivity. It was also found that exudation was null for all types of mortar with the exception of Type II.NHL that presented a value of 0.6%.

Table 3 - Bulk density, estimate of voids volume and water retentivity

Mortar type	Bulk density (kg/m^3)		Estimate of voids volume (%)		Water retentivity (%)
	Average	Standard deviation	Average	Standard deviation	
I.CEM	2080	8	4.7	0.4	79.0
II.CEM	1980	10	6.9	0.8	77.6
III.CEM	2070	13	4.7	0.6	78.9
IV.CEM	2100	14	4.5	0.6	81.4
I.NHL	2080	16	2.2	0.3	80.3
II.NHL	1990	11	3.0	0.4	76.4
III.NHL	2060	9	2.3	0.3	78.9
IV.NHL	2080	14	1.5	0.2	81.4

4.2. Ultrasound propagation and flexural and compressive strength

As observed in Table 4, the speed of ultrasounds is higher in the cement samples relatively to the hydraulic lime ones, an expectable result, since cement mortars generate more compact microstructures, through which, waves propagation is made easier. It matters then, to analyze the speed variation according to the used sand, for each type of binder.

Observing results relative to cement mortars, it is clear the influence of the grain size distribution. Mortar IV.CEM manages to minimize the volume of voids, both in fresh and hardened condition, thus favoring the ultrasound propagation. No advantages result from using a mortar with equal amounts of A1 and A2 sands (mortar III.CEM), compared to a mortar with A1 sand only.

The relation between the different types of mortars is the same for the hydraulic lime compositions, with notice that for these last ones, mortar Type I stands as the most compact. As a matter of fact in most of the tests performed throughout this study, no improvement is verified in the hydraulic lime mortars performance by incorporating finer sand A2.

According to these three tests, higher ultrasound propagation speed corresponds to increased mechanical strength.

This recorded trend indicates that the more compact mortars present higher compressive strength, with mortar Type IV presenting the best characteristics, in the case of the cement, and mortar Type I, in the case of the hydraulic lime. Therefore, the effect of the aggregates grain size distribution seems not to be the same for hydraulic lime mortars, as for the cement ones. In what concerns flexural strength, one may say that both Type I and IV mortars have identical performances, since the obtained values only differ in the 1/100 order, this being irrelevant in a test of this nature.

As it may be observed, the use of fine sand alone leads to the formation of too many voids, what results in a significant strength loss. However, for cement mortars, the inclusion of fine sand up to 1/3 of the total aggregate originates mortars with increased mechanical strength.

Table 4 - Ultrasound propagation speed and flexural and compressive strength

Mortar type	Ultrasounds		Flexure		Compression	
	Average speed (m/s)	Standard deviation (m/s)	Average (MPa)	Standard deviation (MPa)	Average (MPa)	Standard deviation (MPa)
I.CEM	3190	64	2.7	0.2	12.3	0.8
II.CEM	2720	29	2.0	0.1	9.4	0.5
III.CEM	3070	49	2.6	0.3	11.9	0.9
IV.CEM	3240	27	2.7	0.2	12.7	0.8
I.NHL	2090	36	0.7	0.1	2.9	0.2
II.NHL	1370	29	0.4	0,1	1.7	0.1
III.NHL	1810	49	0.6	0.1	2.2	0.2
IV.NHL	1940	28	0.7	0.1	2.7	0.1

4.3. Water suction by capillarity

The kinetics of water suction by capillarity is presented in Fig. 2.

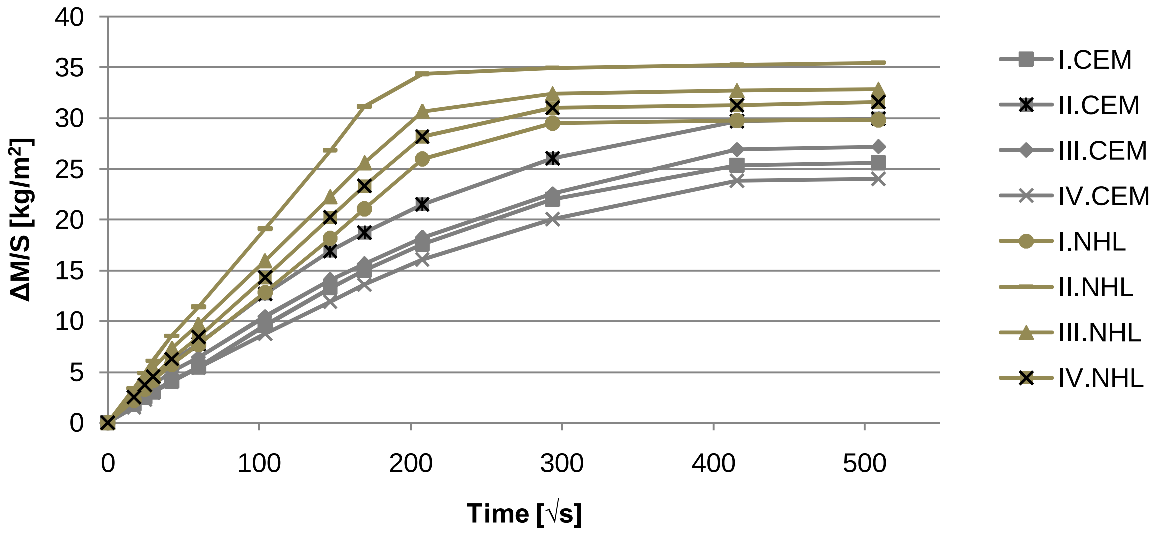

Fig. 2 - Water suction by capillarity

The analysis of the previous chart allows an easy distinction between the kinetics of absorption due to capillarity in hydraulic lime mortars from the kinetics in cement ones. While hydraulic lime mortars allow a fast absorption during the first 12 hours, stabilizing then at values close to the maximum water contents, cement mortars have a slower and much less intense absorption during the first hours of test.

Following what has been said, it is verified that mortars incorporating sands with lower volume of voids are those that allow a lesser water absorption. Once again this effect does not show in the same way in hydraulic lime mortars.

The capillarity coefficient portrays the initial absorption speed and in Table 5 it can be observed that this already identified trend is maintained when using different aggregate grain size distributions.

Table 5 – Coefficient of capillary absorption

Mortar type		I.CEM	II.CEM	III.CEM	IV.CEM	I.NHL	II.NHL	III.NHL	IV.NHL
Capillarity coefficient	**($kg/m^2.s^{1/2}$)**	0.092	0.129	0.107	0.090	0.128	0.191	0.161	0.141
Standard deviation		0.006	0.003	0.003	0.005	0.004	0.001	0.006	0.002

4.4. Water absorption by immersion (after 48h)

The results of this test confirm what has been said about the characteristics of the analyzed mortars. After 48 hours, hydraulic lime mortars absorb a greater water percentage than those with cement, this indicating a higher porosity.

Once again, for each binder type, mortars IV.CEM and I.NHL present lower water absorption, this being related to a smaller volume of voids. As a matter of fact, mortars with fine sand as the only aggregate present the highest percentage of absorption, as expectable.

Table 6 - Water absorption by immersion (after 48h)

Mortar type	I.CEM	II.CEM	III.CEM	IV.CEM	I.NHL	II.NHL	III.NHL	IV.NHL
Water absorption (%)	7.6	9.3	8.2	7.5	9.1	11.8	10.3	9.4

4.5. Porosity accessible to water, bulk and real density

The results here presented are decisive in this study, once as it is has been put to evidence throughout the analysis of these chapter results, the porosity of the several mortars it's the key explanation for many of the characteristics and behavior of the test samples. This happens because it is mainly at the porous structure level that variations of aggregate's grain size distribution are felt, thus affecting the general performance of mortars.

Table 7 - Porosity accessible to water, bulk density and real density

Mortar type	Porosity		Real density		Bulk density	
	Average (%)	Standard deviation (kg/m^3)	Average (kg/m^3)	Standard deviation (kg/m^3)	Average (kg/m^3)	Standard deviation (kg/m^3)
I.CEM	21.0	0.9	2631	9	2077	18
II.CEM	26.0	0.7	2625	13	1944	11
III.CEM	21.8	0.6	2628	9	2055	10
IV.CEM	21.1	1.3	2636	15	2079	14
I.NHL	22.5	0.6	2630	4	2038	14
II.NHL	27.8	0.6	2622	3	1894	14
III.NHL	23.7	0.2	2626	2	2003	6
IV.NHL	22.7	0.2	2627	3	2029	5

As it becomes evident, Type II mortars (only with A2 sand) stand out for their increased porosity. As a matter of fact, as referred by Rato (2006), however it may be reasonable to assume that finer sands imply pores of lesser dimensions in hardened mortars, the higher specific surface area seems to imply a significant enhancement of the amount of pores.

As it happens with fresh mortars, mortar Type IV.CEM has a higher post-hardening density than mortar Type I.CEM. This will result from the existence of less air spaces in mortar due to the addition of finer sand. This, because the voids not filled with sand A1 in mortar I.CEM, will now be filled by the finer sand. However, mortar Type III (with more A2 sand) has a lower density than mortar Type I (A1 sand only). This situation can be explained by the hypothetical occupation of all the voids through introduction of A2 sand up to 1/3 of the total aggregates, this way, in a larger amount, this sand will behave as any another aggregate (not only occupying the empty spaces left by coarser aggregates, but also any space that could be occupied by an aggregate of superior grain size). This way, the dominating factor will be the density of each aggregate and therefore, since A2 sand is lighter than A1, this will lead to a decrease of the hardened samples density.

4.6. Wetting-drying test

Due to some anomalies that invalidated results for hydraulic lime mortars, only the chart relative to cement mortars is here presented.

Only Type II.CEM mortar stands out among the others for keeping a higher water contents all the time. The remainders have very identical evolutions.

This characteristic of mortar incorporating only A2 sand will have to do with its higher porosity. It’s also noticed an accented reduction of the water contents in this mortar, regarding the others, mainly in the first days of test.

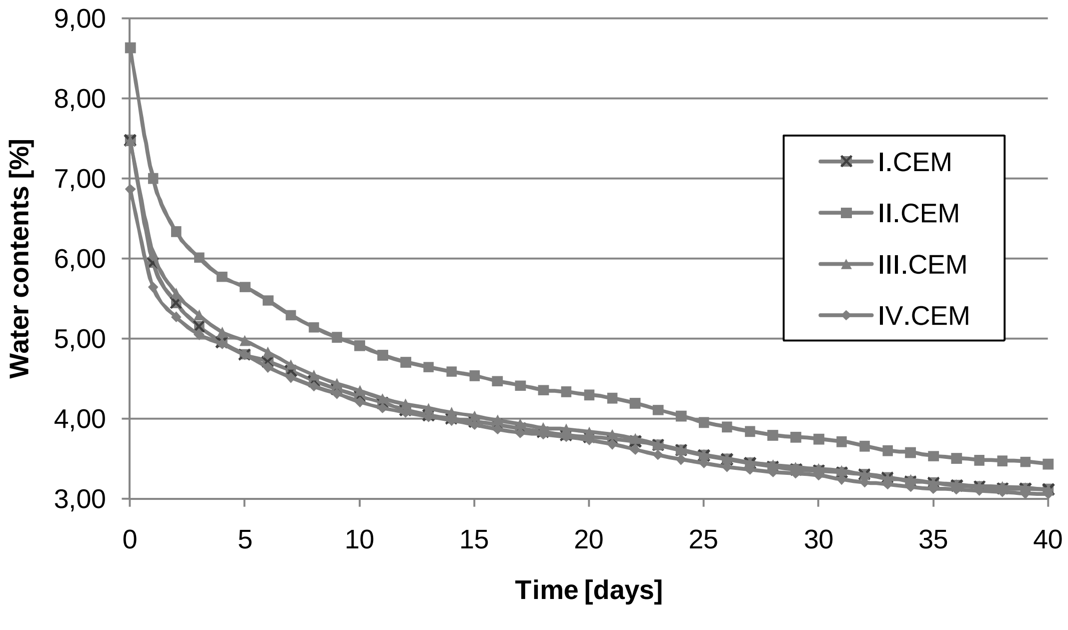

Fig. 3 – Drying curve (cement mortars)

4.7. Cracking susceptibility and shrinkage in V-shaped channel

Either with mortars applied on bricks, or mortars applied on V-shaped channels, no cracking of any kind was registered. Although this situation is perfectly acceptable, it may be associated to the very favorable cure conditions created by a period of deficient functioning of the dehumidifier equipment in the dry chamber.

4.8. Rebound hammer test

This test was carried out in order to evaluate the mechanic strength of mortars, applied as renders. It is thus intended to check the uniformity of the mortar layer, by measuring the rebound of the incident mass after an impact. The harder the mortar is, the greater the rebound will be.

Table 8 – Rebound hammer test

Mortar type	Average rebound	Standard deviation
I.CEM	51.3	12.8
II.CEM	45.4	13.8
III.CEM	50.8	9.3
IV.CEM	59.8	10.5
I.NHL	32.5	10.3
II.NHL	24.4	7.4
III.NHL	31.7	6.6
IV.NHL	31.8	8.6

Concerning the relation between different mortars, the results obtained for the rebounds, presented in Table 8, are in accordance with those obtained in the compressive strength test.

4.9. Water absorption under low pressure

Fig. 4 displays the curves that fit the best to the dispersion of values obtained in a series of three measurements for each mortar.

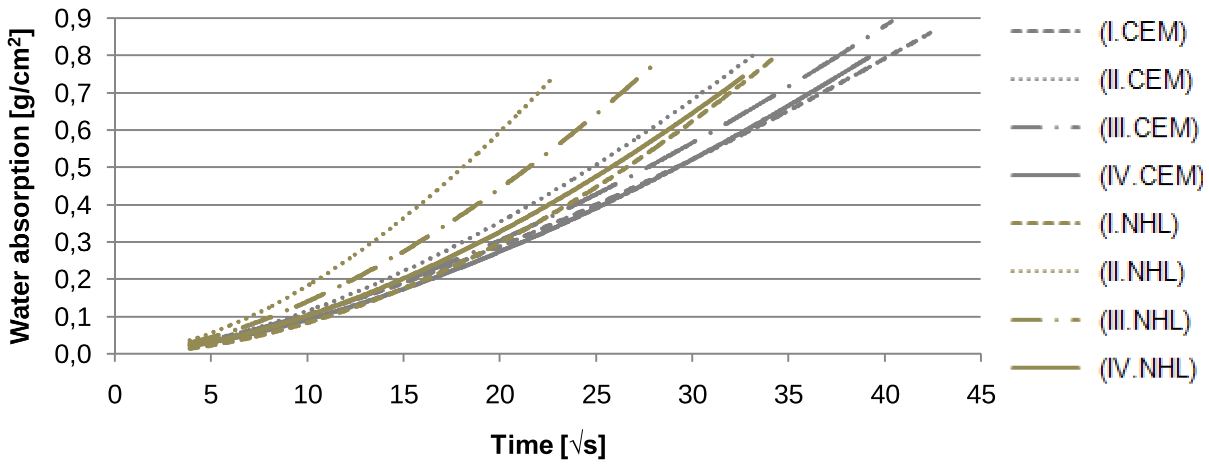

Fig. 4 – Absorption kinetics tendency curves

As a matter of course, and in accordance to the data already collected, the hydraulic lime mortars present faster water absorption relatively to the cement ones, even though mortars Type I.NHL and IV.CH achieve better performances than mortar Type II.CEM.

For any of the two types of the binders concerned, it results that mortars Type I and IV present the best performances, once they have a slower absorption.
Once again the poor performance of fine sand mortars (Type II) is stated, with mortar Type III.NHL also standing out in a negative way due to its high absorption rate, only surpassed by mortar Type II.CEM.

4.10. Pull-off test

In order to evaluate the mortar/substrate adhesive strength, this test was carried out with the intention of performing three pull-off tests on each brick.
In this test, however, a low success level was recorded, especially in the case of the hydraulic lime samples, related to poor bond strength. The justification for this will not be the low adherence of the mortars themselves, but the bricks immersion period, that preceded the application of the coating.
For the mortar to stick to the brick, water penetration must occur, together with the fine particles, into the pores of the ceramic material. Since hydraulic binder mortars harden very quickly, penetration does not happen, because during the short hardening period the brick remains always saturated with water.
Regardless of this situation, results obtained seem to be in accordance with all the other results, already presented, displaying the same trend.
In the successful tests, only fractures at the interface between the mortar and substrate were recorded, and the following average values have been registered.

Table 9 – Adhesive force

Mortar type	Average force (N)	Standard deviation (N)
I.CEM	211.7	77.1
II.CEM	100.4	93.3
III.CEM	103.4	91.9
IV.CEM	259.6	14.2
I.NHL	-	-
II.NHL	16.9	11.9
III.NHL	27.4	11.6
IV.NHL	30.0	-

5. Conclusions

Having in mind the functional requirements that hydraulic binder renderings must fulfill, it may be said that it has been clearly demonstrated which mortars present the best performances, in view of the different requests. Furthermore, for each one of the types of studied binders, there was one particular type of mortar that stood out from the rest, for its better characteristics in all the tests.

Thus, it became clear, that mortar Type IV.CEM (2/3 of A1 sand and 1/3 of A2 sand) is the one that achieves the best performances. This mortar type is then the one that in a general way presents the highest mechanical strength and the lowest water absorption, allied to a reasonable drying rate. These characteristics derive from the enhanced compactness conferred by the referred sand mixture, this being confirmed by the ultrasound and porosity tests.

In what concerns the remaining cement mortars, they classify, by decreasing performances, face to the functional requirements, from mortar Type I.CEM, through III.CEM, to II.CEM.

As for hydraulic lime mortars, mortar Type IV also obtains better performances than mortar Type III and this, in turn, better results than mortar Type II. However, in most of the tests, the effect of introducing more compact sand did not show in what concerns the mortar performance, since it was mortar Type I.NHL that presented the best results.

It may thus be concluded, that the introduction of finer sand (A2) up to 1/3 of the total aggregate, increases the mortar compactness and therefore improves its performance. As for replacing more A1 sand by A2, it has always led to less satisfactory results.

Yet another conclusion stands out: when the depicted aggregate grain size variations are introduced in hydraulic lime mortars, no improvements are achieved in performance, relatively to the single use of A1 sand.

6. References

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