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Durability and Sustainability of Concrete Structures (DSCS-2018)

Editors:
Vyatcheslav Falikman, Roberto Realfonzo,
Luigi Coppola, Petr Hàjek, Paolo Riva

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Durability of Thermal Plasters made with Recycled Materials

Maurizio Nicolella

Synopsis: The goal of this research was to evaluate the behavior over time of mortars obtained from three different types of recycled material, and specifically aimed to obtain thermal insulation plasters.
The typology of samples was identified based on experimentations conducted at the University of Madrid, with 11 different types of specimens made with cement, river sand, expanded clay (with different particle size), recycled XPS (with different particle size), and recycled ceramic remains.
The good results suggested submitting the samples in the laboratory of Building Engineering of the University of Naples Federico II to the following tests: rainfall resistance, thermal shock resistance, accelerated aging resistance in climatic chamber.
In the present paper, the final results, with a preliminary assessment of the suitability for use of these mortars with external coating function in determined climatic contexts, are proposed.

Keywords: durability, mortar, plaster, recycle, sustainability

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INTRODUCTION

Experimental studies based on exploring the possibility of use of construction and demolition waste (CDW) in the field of mortars (for masonry and coatings) have been significantly developing in the recent years, with results that, on one side, offer many interesting points, while on the other have a contradictory nature.

Several researchers have focused their attention on the variability of the chemical and physical characteristics, in function of the mix design of the mortars.

This variability derives from the various possibilities of mix design: origin and dimension of the aggregates, percentage of use of recycled materials, possible uses for the mortar, additives, nature of the binders.

Some have even suggested the total substitution of river sand with recycled material (Corinaldesi et al [1]; Neno et al [2]; Martinez et al [3]; Jimenez et al [4]), while most have preferred to evaluate various percentage of employment (for example Silva et al [5]; Braga et al [6]).

Silva et al [7] have determined that the most suitable percentage for the performances of a cement mortar produced with ceramic materials is 15%, as the optimal range for a correct application is between 10% and 20%, while the properties start to decay with 50% and beyond.

Concerning the origin of the material, in addition to the waste from ceramic materials mentioned above, some studies have also researched on the cement mortars made with concrete waste (Levy et al [8]; Levy [9]; Bavaresco [10]), with less satisfactory results, compared to ceramic materials.

About the dimensions of the aggregates, many researchers considering the use of mortars for historical buildings, have suggested mix design with lime and aggregates of small dimensions (0-4 mm [0-0.157 in], Papayianni [11]; Baronio et al. [12]).

Considering at the same time the variability of the percentage of use, the origin and the dimensions of the aggregates results, of course, in more complex problems (Westerholm et al [13]; Cortes et al [14]).

The literature is quite contradictory in relation to mechanical resistance, especially considering the major use of mortars with river sand, rather than those realized with recycled materials: in particular, compression strength and bending strength (even though they are not critical properties for a mortar) have caused some uncertainty (Topcu et al [15]; Pedrozo [16]).

There has been a wide production also on the aspects that are more or less directly related to durability. For example, it is a common opinion that the highest values in water retention are reached by mortars packaged with ceramic materials, rather than those with concrete waste (Bavaresco [10]; Hamassaki et al [17]; Miranda et al [18]).

Mortars shrinkage may depend on many factors, such as size grading of the sand, w/c ratio, cement content, type of aggregates: shrinkage increases as more recycled aggregates are added, due to higher water demand (Kikuchi et al [19]; Reddy et al [20]; Silva et al [7]).

A very important performance for plasters is the adherence to the substrate. Many authors have demonstrated that mortars incorporating concrete waste exhibit a stronger bond with the substrate than mortars made with ceramic or mixed materials (Moriconi et al [21]; Corinaldesi et al. [22]).

Not so many studies have been conducted on mortars containing insulating materials, such as expanded clay or polystyrene: Aciu [23] and Aciu et al [24] have investigated on the different performances and properties of a common mortar in comparison with a mortar made with polystyrene granules: density, compressive strength, bending strength, water absorption by capillarity, thermal conductivity, adhesion to the support layer, sound insulation.

Concerning durability, Silva et al [5] summarize (with reference to studies conducted by researchers such as Bektas et al [25], Mardani-Agabaglou et al [26], Aguiar [27], Tian et al [28], Taylor et al [29], Ledesma et al [30], Tovar-Rodriguez et al [31], Zhao et al [32]) that this property is related to freeze-thaw resistance, efflorescence susceptibility, resistance to sulphate attack.

In 2017 an experimentation, carried out by De Rio Merino and Villoria Saez, with the contribution of the Department D.I.C.E.A. of the University of Napoli Federico II, has carefully investigated on 11 types of mortars prepared with different combinations of natural and recycled aggregates, including insulating materials (expanded clay and XPS of variable particle size), and tile.

From this experience, the decision to investigate, in the laboratory of Building Engineering of the Department of Civil, Architectural and Environmental Engineering of the University of Naples Federico II, on the durability of this mortar obtained with recycled aggregates, has arisen.

Obviously, that objective cannot leave out of consideration the definition of the specific use of the mortar, because the stress conditions to be reproduced in the laboratory may be different depending on the type of component. In this sense, its use was initially hypothesized as an insulating mortar and as a thermal plaster, with almost equivalent stressing agents.

EXPERIMENTAL PROCEDURE

For the purpose of the current research, it was chosen to evaluate the durability of plaster mortars obtained with different kinds of aggregates deriving from CDW (particularly suitable for thermal insulation, and for the so called "thermal plasters"), through the results of three experimentations (one of which has now reached the final phase) and putting together some of the conclusions from other authors' experimental work.

The experimentation carried out by De Rio Merino and Villoria Saez in 2017 has presented some interesting results for all the sampled characteristics, some of which need to be related to the behavior of mortars over time.

Concerning the proportions, in order to provide a correct identification of the mixtures, the following codification was used:

1. REF – reference mixture;
2. CEM – 32.5 R cement;
3. AN – river sand;
4. ARF_3 – expanded clay F_3 (particle size: 3-8 mm [0.118-0.315 in]);
5. ARA_5 – expanded clay A_5 (particle size: 0-3 mm [0-0.118 in]);
6. XPS_G – coarse recycled extruded expanded polyurethane (3-4 mm [0.118-0.157 in]);
7. XPS_F – fine recycled extruded expanded polyurethane (1-2 mm [0.039-0.078 in]);
8. CR – recycled ceramic residue percentage (1 mm [0.039 in])

The 11 packaged mixtures are the following:

1. REF-AN – Reference mortar 1:3 river sand and CEM II B/L 32.5 N cement;
2. C-ARF_3 – Reference mortar 1:0.916 F_3 clay;
3. REF- ARF_3A_5 – Reference mortar 1:2 F_3 clay (75%) and A_5 clay (25%);
4. C- ARF_3A_5 – Experimented mortar 1:1.8 F_3 clay (75%) and A_5 clay (25%);
5. C-$ARF_3A_5$50%XPS_G – Experimented mortar 1:1.02 F_3 clay (75%) and A_5 clay (25%) : 0.044 XPS_G
6. C-$ARF_3A_5$66%XPS_G – Experimented mortar 1:0.68 F_3 clay (75%) and A_5 clay (25%) : 0.088 XPS_G
7. C-$ARF_3A_5$83%XPS_G – Experimented mortar 1:0.34 F_3 clay (75%) and A_5 clay (25%) : 0.133 XPS_G
8. C-XPS_G – Experimented mortar 1:0.177 XPS_G;
9. C-ARF_3CR50%XPS_G – Experimented mortar 1:0.765 F_3 clay : 0.255 CR;
10. C-$ARF_3A_5$50%XPS_F – Experimented mortar 1:1 F_3 clay (75%) and A_5 clay (25%) : 0.04 XPS_F;
11. C-$ARF_3A_5$66%XPS_F – Experimented mortar 1:0.68 F_3 clay (75%) and A_5 clay (25%) : 0.08 XPS_F.

Out of the listed compositions, for the current work of research the ones with numbers 1, 9, 10 and 11 have been considered to be particularly interesting; for the current experimentation, they have the following compositions and nomenclatures:

The samples have been packaged in laboratory in number of three for each typology, in 4x4x16 mm^3 [0,157x0,157x0,630 in^3] dimensions (see Fig. 1-2), and seasoned for 28 days in an environment at constant temperature and humidity.

For XPS, two particle sizes were used: XPSF (1-3 mm [0.039-0.118 in]) and XPSG (3-4 mm [0.118-0.157 in]).

This was adopted for reasons related to the minimum width for the mortars to be employed as an insulating plaster and as an insulating screed.

As described in the introduction, it is a current opinion that the durability of a mortar is strongly connected to some of its requisites, and that the stressing context to be reproduced to make tests significant, leads to individuate a definite number of tests. The properties on which the experimentation has to be conducted in order to assess the durability of the mortars, especially if packaged with recycled aggregates, are the following:

1. capillary absorption;
2. shrinkage;
3. freeze-thaw absorption;
4. efflorescence susceptibility;
5. sulfate attack resistance.

Indeed, they are deeply related properties, as all of them measure, in different ways, the susceptibility of the mortars to the creation, on the surface or in their internal layers, of discontinuities, linear (micro-cracks) or volumetric (voids).

So, the experimental tests should aim to individuate which mix design allows to minimize these situations the most.

In this sense, the capillary absorption coefficient can be considered as a preliminary test, and – as it is easy to understand – the results of this test generally appear coherent with those of the other parameters linked to them.

In the current experimentation, it seemed opportune to investigate, in parallel, also on the layer that protects the mortar when they are used as plasters. Of course, the paint is being referred to, which may have – considering

the results of this, but also of other experimentations – a very relevant function in contrasting the phenomenon of carbonation, that may induce decay phenomena that affect the system paint – primer – plaster – support.
In order to evaluate these circumstances, the results of an experimentation carried out in parallel for the determination of the contribution of plaster coverings to the durability of concrete [33], and another one, which is now being carried out, with the aim of investigating more specifically on the most superficial layers (paint + plaster + reinforcement shell, when present) of the reinforced concrete structures covering as well.
For the behavior of uncoated mortars, an accelerated carbonation test has been carried out on 40x40x160 mm^3 [1.57x1.57x6.3 in^3] specimens according to UNI EN 13295:2005 code and UNI EN 14630:2007 code, making use of a thermostatic cell which could provide a uniform CO_2 flow (with 1% concentration) through electromagnetic valves for the regulation of the extraction and the introduction. For the control of temperature, the device presents a heating system obtained with resistances places outside the chamber; since it has no regulation system for relative humidity, considering that temperature was fixed, saturated saline solutions contained in bags inside the cell were adopted. The presence of a hygrometer also provided a visive control of this parameter.
As it was anticipated, an experimentation aimed more directly to analyzing the behavior of the paint layer, in addition to that of the whole system (paint + plaster + SCC reinforcement shell), is currently being carried out.
In the accelerated test chamber, the samples are hit by a constant air flow, characterized by 1% carbonic anhydride content, 58-62% relative humidity and a temperature of 25° C.
The tested solutions are the following:

- quartz paint + cement mortar;
- siloxane paint + common mortar.

The core material is constituted by different concrete typologies (with or without SCC covering), and they have no relevance in the present work.
The items of investigation were the following:
Figures 3-4 show the samples before and after the phenolphthalein spray.

EXPERIMENTAL RESULTS AND DISCUSSION

First, the density of the four samples has been determined.

As it can be noticed, the values of density of the tested mortars B, C and D are less than the half of those composed by cement, water and river sand (A).
Also in reference to the values shown by the samples containing expanded clay and coarse XPS, it can be affirmed that the voids caused by the absence of expanded clay have been filled by fine XPS, and this caused the increase of density.
This characteristic is, in relation to porosity (and so, indirectly, to durability) a very positive parameter, hinting that coarse XPS on the other hand does not present suitable characteristics for the employment, for example, as a plaster, as:

1. the remaining voids increase water retentivity, and so sensitivity towards low temperatures;
2. it is quite complex to package mortars with very light aggregates and with dimensions that can be compared to the total width of the layer (3-4 mm [0.118-0.157 in] and 20 mm [0.787 in], respectively);
3. the porosity that a mortar packaged with coarse XPS is unavoidably characterized by, of course constitutes a negative factor in relation to the action of aggressive atmospheric agents.

However, the presence of ceramic residue positively affects the filling of voids, and so increases compactness, but on the other hand this aggregate has a higher predisposition to retain mixing water, and so a higher likeliness to show phenomena of shrinkage, which are very negative for a component like plaster.
Considering all the above, it seems interesting to investigate preliminarily on the capillary water absorption coefficient of the experimented mortars.
For mortars that are different from those used for restoration, the capillary water absorption coefficient is calculated as the gradient of the line that links the points that are representative of the measures executed at 10 mins (M_1) and 90 mins (M_2), as in the following equation:
$C = 0.1(M_2 – M_1)$
The results of the tests on the 4 samples are shown in the Table 1.
Kuenzel's theory of protections of facades suggests that a support, in order to prevent damages, must absorb by capillarity (permeability) a quantity of water that is lower than that it passes by diffusion (transpirability). In order to match these requisites, the maximum value of the capillary water absorption of 0.5 $kg/(m^2h^{0.5})$, adopted by DIN 4108-3 code, has to be respected.
The results reached by the samples are shown in Fig. 5, compared with the abovementioned maximum value from the German code. As it can be noticed, while the capillary water absorption coefficient of sample B is slightly higher than the maximum limit (0.52), sample D shows a definitely unacceptable value (0.92), and

sample C shows a very interesting behavior concerning one of the most significant parameters in relation to durability (0.36).

Such results are coherent with those from other experimentations carried out through tests that can be considered strictly related to the capillary water absorption test. Concerning the tests that assess the behavior of the coverings toward to carbonation, the values of carbonation depth measured after 15, 30 and 45 days of exposure in the thermostatic cell for the samples of mortar are shown in Table 6. From these values, it can be observed that the specimens of hydraulic lime mortar and those of lime-cement mortar, while exhibiting a smaller value of total carbonation depth (that is to say roughly constant within the cross section to the survey of progression, on average equal to 4.16 mm [0.163 in] and 1.19 mm [0.047 in], respectively) compared to that exhibited by specimens of cement mortar (on average equal to 5.58 mm [0.22 in]), however they are also characterized by a non-negligible partial carbonation (which is uneven within the cross section to the survey of the progression, on average respectively equal to 2.93 mm [0.115 in] and 10.65 mm [0.419 in]) probably due to the hardening of lime, a binder in the matrix of both series of specimens.

Concerning, then, the contribution to the protection of concrete, as it can be noticed from the results of table 6, it is evident that all the three examined mortars, after 30 days of exposure in an aggressive environment with 1% CO_2, have reduced the carbonation depth for ordinary concrete, confirming in this way their protective function toward the penetration of CO_2. In this specific case, among the examined mortars, the cement one has had the most satisfactory behavior because, after 30 days of exposure, did not allow CO_2 to penetrate significantly into concrete core. Lime-cement mortar is second, registering a depth of carbonation into ordinary concrete core, of about half compared to that of uncoated specimens; finally, among the three studied mortars, the hydraulic lime mortar has had the worst behavior, despite confirming its protective function toward concrete, as it has recorded a reduction in the depth of carbonation, even if barely visually noticeable.

The results shown above lead to consider that, when packaging mortars with recycled aggregates for plasters, cement should be preferred to plaster, because of the aggressiveness of urban environments.

At the same time, it has to be made clear that it is just the contribution of the most superficial layer to the behavior of the system. In fact, it can be seen that the two typologies of paint used in the third experimentation provide different contributions to the defense of the wall from the aggressiveness of the environment.

Figures 6-7 show the different behavior over time of the two typologies of paint used:

- quartz paint, in the specimens of the first type, has been hit by total carbonation after just 35 days, while it happened after 40 days in the specimens of the second type;
- siloxane paint, both in the specimens of the first and of the second type, has undergone total carbonation after less than 30 days.

The obvious consequence is that, for an adequate protection of mortars for plasters, especially when packaged with recycled aggregates, a quartz paint should be preferred.

In Fig. 6, TC stands for testing concrete, while LCP stands for lime-cement plaster, CM is for cement plaster, SP is siloxane paint, QP is quartz paint and, of course, SCC is self-compacting concrete.

It can be noticed that, as of Fig. 7, carbonation depth after 15 and after 30 days is the same for RC and RC.SCC.

Concerning the tests that assess capillary absorption, shrinkage, freeze-thaw resistance, efflorescence, susceptibility, sulfate attack resistance, it seemed opportune to avoid adding more experimentations to those already carried out by other research groups; in the building engineering laboratory of the University of Naples Federico II, a climatic chamber aging test, which represents an innovative approach, and which will be described later, is being run.

In regard to specific results that derive from the scientific literature, points of particular interest can be found in the work by Neno et al. [2], who have experimented on mortars obtained from recycled concrete aggregates in different percentages.

After some preliminary assessments which led to choose a mortar with 20% RCA, in the second phase it has been compared with the reference mortar, in order to evaluate through the comparison some characteristics which have a particular relevance for the current research, such as shrinkage, water retentivity of fresh mortar and adhesive strength of hardened mortar.

In the diagram of Figure 8, it can be seen how the dimensional stability of mortars with recycled mortars is smaller, and this is explained by the authors both with the presence of much more absorbent and porous particles than natural sand, and for the higher cement (and cement paste) content, probably not completely stabilized.

Of course, these situations are nearly or totally absent in the case of mortars obtained with XPS and ceramic residual, and so the incidence of this problem can be considered much smaller.

Concerning water retentivity, the mortar with RCA has shown a mean value of 89.26% against 63.81%, the mean value of reference mortar: this result cannot be considered positive in relation to the problem of shrinkage of a plaster, as there is the risk of a late evaporation of mixing water after the finishing layers (primer + paint) have been realized.

The adhesive strength of adhesive mortar is considered by many the main requisite for a plaster, that is to say the one without which the end of life cycle occurs, and is then connected to the minimum acceptable performance. The sample with 20% RCA has shown results that can be compared to the reference mortar (0.27 MPa [39.2 psi] against 0.33 MPa [47.9 psi]), and this seems a very positive result.
But, another test typology which can considered of particular interest is the freeze-thaw resistance, which has been object of several studies: these have highlighted that presence of crushed clay bricks (or concrete bricks, also) may lead to the production of mortars with enhanced freeze-thaw resistance.

FURTHER RESEARCH

The results of the climatic chamber tests, shown in Figures 9-10, to which the samples identified above as A, B, C and D have been subjected, in the laboratory of Building Engineering of the University of Naples Federico II, will be available soon.
According to the testing program, the samples are supposed to undergo 4 steps of accelerated aging in the climatic chamber, through the repetition of the cycle pattern elaborated on the basis of the studies carried out by the DICEA research group and reported in figure 10. The performance decay of the samples has been evaluated through ultrasound, thermographic and spectrophotometric tests, aimed to appraise, respectively, the physical properties, the detachment areas, and the color variations; each of these can be implemented after the end of the execution of at least 20 cycles.

CONCLUSIONS

In order to evaluate the behavior over time of plasters realized with mortars containing recycled material (ceramic residual and XPS), three different experimentations have been carried out, and the results of some studies of the past years have been acknowledged; based on the results of these experimental investigations, the following conclusions are drawn:

1. In the first experimentation, the samples with recycled aggregates, which contained clay and XPS in two different particle sizes and ceramic residual, had about half the density of a reference mortar with river sand, and presented interesting results concerning the capillary water absorption coefficient;
2. A second experimentation, about the sensitivity to carbonation of mortars of different typologies, has demonstrated that, for plasters in urban environments, the use of cement as a binder, instead of lime, should be preferred;
3. The third experimentation, which has investigated on the possibility, for the paint layer, to protect plasters, has highlighted that, with cement plasters, it is best to use quartz paints;
4. A fourth experimentation is now being concluded on specimens of mortars realized with recycled material (ceramic residual and XPS), subjected to accelerated ageing tests in climatic chamber, after which it will be possible to obtain more useful advice to individuate the most suitable mix design for eco-friendly mortars, gifted with good durability as well.

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TABLES AND FIGURES

Table 1–Composition of the 4 chosen samples

SAMPLE ID.	**CEM** (g) [lb]	**AN** (g) [lb]	**ARF$_3$** (g) [lb]	**ARA$_5$** (g) [lb]	**XPS$_G$** (g) [lb]	**XPS$_F$** (g) [lb]	**CR** (g) [lb]	**H$_2$O** (g) [lb]	**W/C RATIO**
A (1)	450 [0.991]	1350 [2.98]	-	-	-	-	-	225 [0.496]	0.5
B (9)	600 [1.32]	-	460 [1.01]	-	27 [0.059]	-	153 [0.337]	480 [1.06]	0.8
C (10)	600 [1.32]	-	450 [0.992]	150 [0.331]	-	24 [0.053]	-	480 [1.06]	0.8
D (11)	600 [1.32]	-	306 [0.675]	102 [0.225]	48 [0.106]	-	-	480 [1.06]	0.8

Table 2-Steps of the accelerated carbonation test

Step	Description
1st	Start of the seasoning of the samples. According to what is established in the Annex A of EN 13295:2004 code, after 24 hours from the packaging the samples have been taken out of the mold, and left seasoning for 27 days at a constant temperature of 21±2 °C.
2nd	Start of the conservation in a laboratory environment. After the end of the seasoning, the samples have been kept in a laboratory environment at a temperature of 21±2 °C and at a relative humidity of 60±10%, until the weight variation of the samples resulted smaller than 0.2 % in a period of 24h.
3rd	Start of the exposure in the test chamber. After the conservation period had finished, the samples have been collocated inside the test chamber and exposed to an atmosphere with 1% of CO_2, at a temperature of 21±2 °C and at a relative humidity of 60±10%.
4th	1st measure of the carbonation depth (after 15 days): on the 15th day of exposure in an aggressive environment, all the samples have been taken out of the test chamber in order to measure the carbonation depth applying the method of phenolphthalein suggested by EN 13295:2004 code. The method consists in the application of a phenolphthalein solution indicator on sample just after breaking it, according to comma 4.2 of UNI EN 14630:2003 code.
5th	2nd measure of the carbonation depth (after 30 days).
6th	3rd measure of the carbonation depth (after 45 days).
7th	Mechanical tests.

Table 3–Density of the samples

SAMPLE IDENTIFICATION		**DENSITY (g/cm^3) [lb/in^3]**
A	REF-AN	2.272 [0.08208]
B	C-ARF$_3$CR50%XPS$_G$	1.024 [0.03699]
C	C-ARF$_3$A$_5$50%XPS$_F$	1.069 [0.03862]
D	C-ARF$_3$A$_5$66%XPS$_F$	0.907 [0.03277]

Table 4–Detail of the evaluation of capillary water absorption coefficients for the 4 samples

Sample codes	Sample weight (g) [lb]	Waterproofed sample weight (g) [lb]	Sample weight after 10 minutes (g) [lb]	Sample weight after 90 minutes (g) [lb]	**Capillary water absorption coefficient**
A) REF-AN	272.3 [0.6003]	272.8 [0.6014]	273.5 [0.603]	274.9 [0.606]	0,14
B) C-ARF$_3$CR50%XPS$_G$	105.9 [0.2335]	108.3 [0.2388]	111.8 [0.2465]	117 [0.258]	0,52
C) C-ARF$_3$50%XPS$_F$	103.7 [0.2286]	106 [0.234]	108.9 [0.2401]	112.5 [0.248]	0,36
D) C-ARF$_3$66%XPS$_F$	81.0 [0.1786]	83.4 [0.184]	95.2 [0.210]	104.5 [0.2303]	0,93

Table 5-Carbonation depth of mortar samples

SPECIMEN TYPOLOGY	CARBONATION DEPTH		
	15 days (mm) [in]	30 days (mm) [in]	45 days (mm) [in]
Cement mortar	5.34 [0.21]	C_{tot}	-
	5.82 [0.23]	C_{tot}	-
Lime-cement mortar	1.04 [0.041] (10.19 [0.401])	C_{tot}	-
	1.34 [0.053] (11.10 [0.437])	C_{tot}	-
Hydraulic lime mortar	3.77 [0.148] (2.65 [0.104])	C_{tot}	-
	4.54 [0.179] (3.20 [0.126])	C_{tot}	-

NOTE: The numbers in round brackets indicate, for lime-cement and hydraulic lime mortar, the distance corresponding to the partially carbonated front. C_{tot} is the condition of a totally carbonated sample.

Table 6-Carbonation depth of concrete + mortar samples

SPECIMEN TYPOLOGY	CARBONATION DEPTH		
	15 days (mm) [in]	30 days (mm) [in]	45 days (mm) [in]
Ordinary concrete and cement mortar	15* + 0 [0.59* + 0]	15* + 0 [0.59* + 0]	15* + 0.18 [0.59* + 0.007]
	15* + 0 [0.59* + 0]	15* + 0 [0.59* + 0]	15* + 0.13 [0.59* + 0.005]
Ordinary concrete and lime-cement mortar	15* + 0 [0.59* + 0]	15* + 0.18 [0.59* + 0.007]	15* + 0.28 [0.59* + 0.011]
	15* + 0 [0.59* + 0]	15* + 0.23 [0.59* + 0.009]	15* + 0.31 [0.59* + 0.012]
Ordinary concrete and hydraulic lime mortar	15* + 0 [0.59* + 0]	15* + 0.30 [0.59* + 0.012]	15* + 0.67 [0.59* + 0.026]
	15* + 0 [0.59* + 0]	15* + 0.37 [0.59* + 0.015]	15* + 0.62 [0.59* + 0.024]

NOTE: The values with the asterisk refers to the carbonation depth of the plaster covering layer, with a total width of 15 mm [0.59 in]; the value that follows the "+" sign is the carbonation depth of the concrete core.

Fig. 1-2–samples of mortar packaged in number of three for each typologies, for samples A and B

Fig. 3-4–sample that has just been broken, and just after the phenolphthalein spray

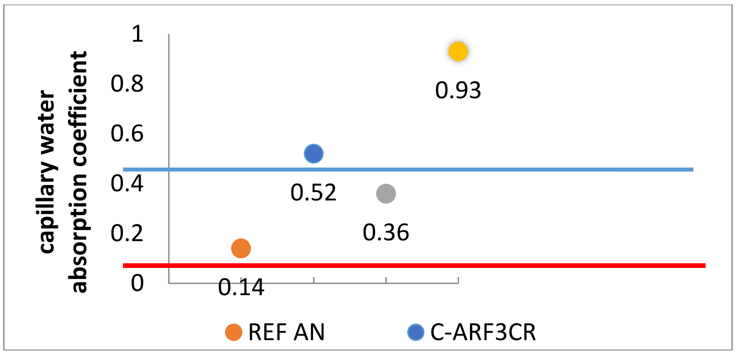

Fig. 5-Graph that synthetizes the capillary water absorption test: the red line corresponds to the value of the cement mortar without addition of recycled aggregates, while the blue line corresponds to that of DIN 4108-3 code: the maximum value is reached by sample D, while the lowest one is that of sample C.

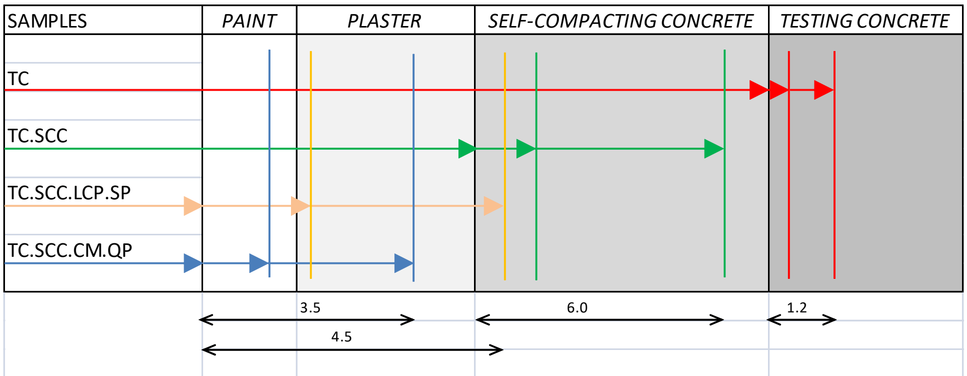

Fig. 6-Carbonation front advancement after 15, 30 and 45 days for a specimen with testing concrete core

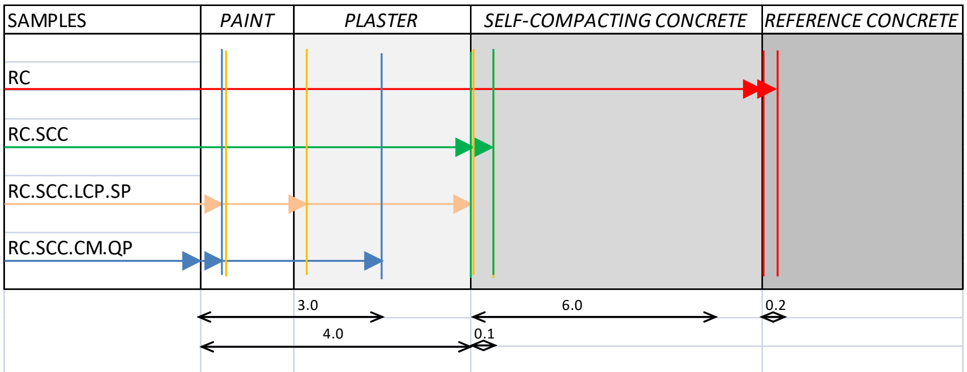

Fig. 7-Carbonation front advancement after 15, 30 and 45 days for a specimen with reference concrete core

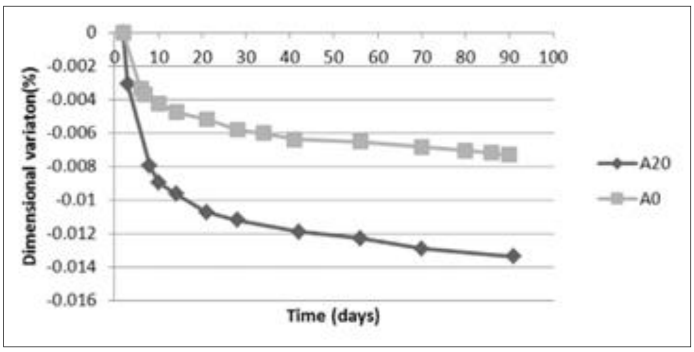

Fig. 8-Dimensional instability (shrinkage) of the reference mortar (A0) and of the mortar with 20% recycled aggregates (A20)

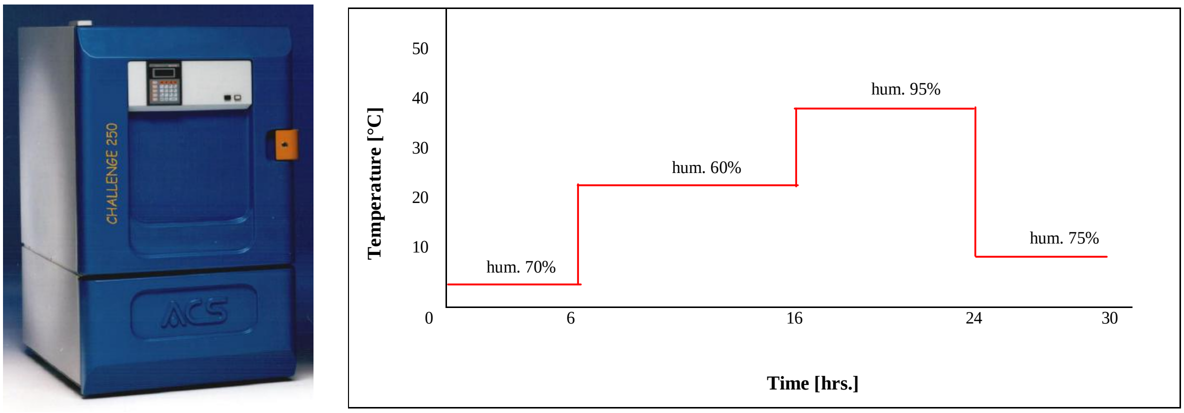

Fig. 9-10-The climatic chamber for accelerated ageing tests and the diagram showing the testing program, which represents the climate of the city of Naples