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Renders with enhanced hydrophobic properties

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SUMMARY: Renders are one of the approaches that have been used to protect building surfaces from deterioration and the negative role of water (in its different forms). The paper describes the testing of cement renders formulated with two different aggregate types; natural silica sand and artificial lightweight expanded glass spheres, both in a standard ratio per weight to the binder. Two different water-proofing techniques were applied in both cases: 1. a siliconate in powder form was added to the render formulation; 2. the surface was coated applying silane-based polymers with and without nano-modification. The hydrophobicity obtained was evaluated by means of static contact angle measurements and by the capillary water absorption coefficient. Porosity properties and microstructure also recorded.

KEY-WORDS: renders, silicone, silane, nanosilica, glass spheres

INTRODUCTION

Renders are specially prepared mortars which usually serve a multi-functional role in constructions. Historically they have been proved to be compact and impermeable mortars designed and applied under specific unwritten norms in order to protect the structure and, at the same time, serve an aesthetic and functional role. Generally, their recipe is based on the available local raw materials, while application's technique depends on the desired final product, e.g., levelling, patching, repairing, water/thermo insulating, decorative uses [1-4]. Renders act as a structural "epidermis" preventing the contact of deteriorating agents to the main construction. Since walls are exposed to the destructive impact of salts, from groundwater as well as from the material itself, via the capillary network and, resulting in deterioration and damages to damp proof courses or the insulation loss of tightness over time according to Charola [5] and Groot et al. [1]. Some of the pathology symptoms that renders usually suffer are cracking problems related to driving rain and surface water flow, damp staining and infiltration, crystallization/efflorescence's of soluble salts, discolorations, loss of cohesion to the substrate and fungal growth, among others. As most of these problems are closely related to the presence of humidity, many efforts have been made to restrict the influence of water on them [6-7]. Some of the technological characteristics that old renders had to restrict absorption is their stratigraphy as they were usually composed of 2-4 layers, good compaction and the fine aggregates used [8].

Lately, the application of a final water-repelling coating on the external surface of the materials in order to prevent water and dissolved salts from penetrating has been widely applied [9-10]. Waxes and oils were some of the traditional additives while nowadays, powdered stearates, oleates, silanes and siloxane films, are used due to their low cost and effectiveness [11-12]. Protection against water is a critical parameter especially for one-coat renders based on cement and natural sand as these materials are extremely hydrophilic. One of the main parameters that regulate the absorption capacity of a material is its pore system. Porosity influences water transport, water vapour permeability and as well its mechanical strength. The action mechanism of hydrophobic admixtures is mainly based on contact angle increase between the capillary pores surface and the water leading to a decrease of the capillary pressure. Thus the application of hydrophobic admixtures in mortars is a very common practice in order to reduce water circulation as a capillary carrier of salt ions, avoiding their corrosive impacts [13].

Controversial research made in the field of water repellent systems has shown that in some cases, the pore structure and physical properties of the repair mortars was altered [14]. Nonetheless, impregnation of mortars with oligomeric organo-siloxanes resulted in a good water vapour permeability through the capillaries due to the chemical nature of the siloxane that does not block the pores, as indicated from the slightly modified pore size distribution [15].

Our research focused on the role different mineral aggregates had in a render formulation expressed by the capillary absorption capacity and hydrophobicity. Moreover, the above mentioned render admixtures were also combined by the addition of a re-dispersible siliconate powder as a means of improving their surface protection.

EXPERIMENTAL PART

Materials and Methods

All render samples were divided into two categories according to the binder type, i.e., cement and cement/lime mixtures renders were prepared. The cement used was a Portland type CEM I42.5 (C), and for the mixtures, part of cement was substituted by hydrated lime (L). Table 1 shows the properties of the samples according to the binders used.

Table 1. Physical properties comparison of used binders

Binder Type	Grain size (μm)			Specific gravity ($g \cdot ml^{-1}$)	Specific surface area ($m^2 \cdot g^{-1}$)
	d(0.1)	d(0.5)	d(0.9)		
Lime	1.87	9.40	376.40	1.961	1.207
Cement	1.87	15.57	54.65	2.664	1.370

The aggregates used were natural silica sand (A) and light-weight expanded glass granules (Poraver) (B), as these are alkali-resistant thus ideal for processing with lime and cement. Glass granules are artificial aggregates made from post-consumer recycling glass and were selected because of their sustainable character. Their amorphous glass structure provides energy-saving due to its highly heat-insulation and excellent sound absorption properties, while preventing the danger of silicosis.

Particle sizes of both aggregates were smaller than 710μm. Binder/aggregate mixing ratio was the standard 1/3 (by weight) ratio. Samples were cast in prismatic and plate forms with dimensions of 40x40x160mm and 30x30cm, respectively. Composition and sample abbreviation codes are shown in Table 2. In order to increase the water repellency of the renders, two different approaches were adopted for the experimental part and two different types of hydrophobic materials were used. One was a dry-mixture addition referred to as "siliconate powder" that is a water re-dispersable mixture derived from a of potassium siliconate and potassium methyl-siliconate mixture with also minor auxiliaries components (e.g., mixture of C7-C10 iso-alkanes and methanol). The siliconate powder dispersible in water was chosen as an admixture and was added in a 0.3% w/w proportion based on the binder and labelled as +sil. The main advantages of this additive are the long lasting effects of the hydrophobic properties it confers even at low concentrations, its water vapour permeability and its stability, i.e., its better resistance to environmental aggression [16]. The second corresponds to a protective coating based on a silane/siloxane mixture diluted in naphtha. The commercial product is a mixture of alkyl-silicone resin containing alkoxy groups, filler and auxiliaries (e.g., methanol, di-n-octyl-tin-dodecylate).

The render samples were cured for 28 days and then the silane/siloxane protective coating characterized by high water vapour permeability and durability at relative higher temperatures (necessary for Mediterranean countries) was applied in two ways: the product by itself and modified by addition of 1.5% w/w nanosilica. The addition of nanosilica serves to increase nano-roughness following bio-mimetic simulations and without altering the appearance [17]. This is a low-cost approach in comparison to other nano-materials having water-repelling properties [18-19].

The tests performed were compression strength according to EN1015-11:1999, physical properties, such as porosity, absorption and specific gravity, based on RILEM CPC11.3 and water capillary absorption according to EN 1015–18:2002. The derived hydrophobicity was performed by means of static contact angle measurements using a Kruss G10 Goniometer-Optical Surface Tension /Contact Angle meter instrument. Mercury Intrusion Porosimetry (MIP) (Quantachrome Macro) measurements were also performed on selected samples. Additionally, scanning electron microscopy (SEM) (JEOL 840A JSM) was used to visualize the surface of the treated samples.

Table 2. Sample nomenclature and composition (by weight)

Samples	Binder		Admixtures			Coating		w/b ratio	Work-ability (cm)
	Cement	Lime	Silica Sand	Glass	Siliconate Powder	Silane /silocane	Nanoenriched -silane		
C-A	1.00		3					0.52	15.0
C-A+sil	1.00		3		0.003			0.55	16.0
C-A_{sil}	1.00		3			☑		0.52	15.0
C-$A_{nanosil}$	1.00		3				☑	0.52	15.0
C/L-A	0.75	0.25	3					0.60	14.5
C/L-A+sil	0.75	0.25	3		0.003			0.57	16.0
C/L-A_{sil}	0.75	0.25	3			☑		0.60	14.5
C/L-$A_{nanosil}$	0.75	0.25	3				☑	0.60	14.5
C-B	1.00			3				0.82	13.2
C-B+sil	1.00			3	0.003			0.82	15.3
C-B_{sil}	1.00			3		☑		0.82	13.2
C-$B_{nanosil}$	1.00			3			☑	0.82	13.2
C/L-B	0.75	0.25		3				0. 82	13.5
C/L-B+sil	0.75	0.25		3	0.003			0.81	14.5
C/L-B_{sil}	0.75	0.25		3		☑		0. 82	13.5
C/L-$B_{nanosil}$	0.75	0.25		3			☑	0. 82	13.5

Results and Discussion

The results shown in Table 2 show that the fresh mixtures to which the siliconate powder was added required less water to achieve a similar workability. On the other hand, the addition of glass spheres increased the required water and this could probably be attributed to their gradation and porous nature. Additionally, all samples containing lime required more water for achieving good workability due to the hydrophilic nature of lime. High water ratio results in increased porosity due to the evaporation of excess water the structure and resulting in lower mechanical strengths. The results of the mechanical and physical properties of the renders at 28 days are shown in Table 3. Samples with glass particles show a reduction in porosity and absorption capacity. A similar trend was observed by MIP measurements (Figure 1) and is probably attributed to the reduction of capillary pores. Overall, the water absorption rate was not significantly altered as reflected by the capillary absorption coefficient.

Table 3. Mechanical and physical properties of mortars

Sample	Compr. strength MPa	Porosity %	Absorption %	Contact angle (o)	Capillary Coefficient $kg/m^2min^{0.5}$
C-A	15.79	10.99	5.67	95.3	0.0260
C-A+sil	23.13	1.87	0.91	109.0	0.0060
$C\text{-}A_{sil}$	-	3.77	1.91	120.0	0.0008
$C\text{-}A_{nanosil}$	-	3.77	1.91	125.0	0.0006
C/L-A	11.28	14.22	7.68	73.0	0.0300
C/L-A+sil	16.04	3.10	1.59	118.0	0.0025
$C/L\text{-}A_{sil}$	-	11.29	6.06	117.0	0.0030
$C/L\text{-}A_{nanosil}$	-	7.53	4.04	120.5	0.0030
C-B	7.50	5.96	5.20	34.8	0.0240
C-B+sil	8.83	4.05	3.20	58.5	0.0060
$C\text{-}B_{sil}$	-	5.07	12.3	117.0	0.0012
$C\text{-}B_{nanosil}$	-	4.96	11.12	136.8	0.0012
C/L-B	5.91	11.77	10.11	36.8	0.0260
C/L-B+sil	8.62	12.14	10.00	45.7	0.0040
$C/L\text{-}B_{sil}$	-	11.13	6.78	106.0	0.0180
$C/L\text{-}B_{nanosil}$	-	10.58	9.91	109.6	0.0011

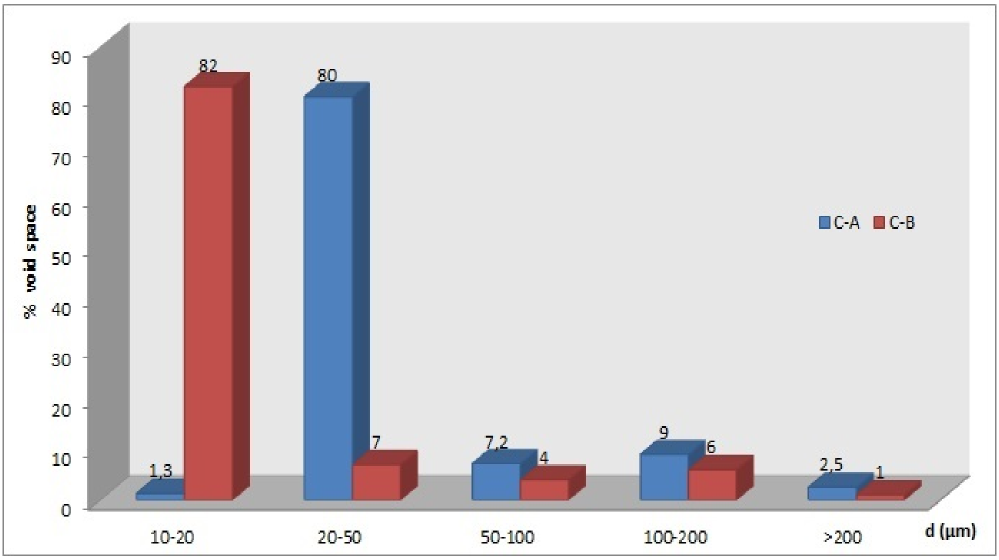

Figure 1. Porosimetry by MIP in samples with silica sand (C-A) and glass spheres (C-B).

The addition of powdered siliconate increases the compression strength presumably because of the reduction of required water when preparing the fresh mixture. A comparison between untreated samples and additive-containing samples shows an impressive reduction in their porosity and water absorption capacity (Table 3). Additionally, hydrophobicity was improved in all cases according to SCA test results.

Samples that received the silane/siloxane surface treatments also show a strong reduction in porosity and capillary water absorption coefficient as compared to the untreated samples. In particular, the samples treated with the nanosilica-enriched coating had the highest SCA measurements. The maximum SCA value of 136.8^{o} was recorded for samples containing glass spheres as aggregates and that had received this nano-silica enriched coating (Figure 2).

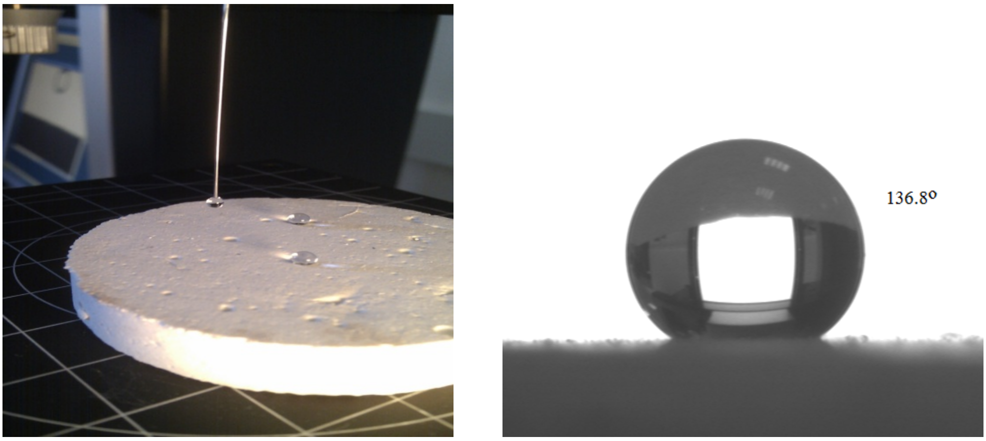

Figure 2.Best performance of static contact angle (SCA) measurements for sample C-B$_{nanosil}$.

The addition of lime to the binding system increases the absorption capacity of render, indicating that interconnectivity of the capillary pores has been facilitated. The capillary absorption coefficient indicates an absorption rate, not the total volume absorbed, and the absorption rate is higher for larger capillary pores. A dramatic reduction in capillary coefficient is observed in all cases where surface treatment was performed indicating a blocking of the capillary pores to external humidity.

Plate samples with sizes 30x30cm were used for the water permeability tests using a half-filled vessel with water under controlled temperature and relative humidity conditions. Samples had their top surface sealed and whole system was weighed daily. The weight loss and system stabilization time (in days) are shown in Table 4.

Samples containing the powdered siliconate addition lost less weight as compared to the untreated samples and the system was driven to equilibrium earlier, as a result of the reduction in porosity. The surface treatment contributed to early stabilization while the weight loss variation indicated that there was adequate vapor permeability in these systems.

SEM micrographs revealed a high roughness achieved by nanosilica addition (Figure 3), conceived as a biomimetic hydrophobic behavior of these mortars as proven both by the low capillary coefficient and the high contact angle.

Table 4. Results of water vapor permeability test

Sample	Equilibrium Days	% weight loss
C-A	15	5.1
C-A+sil	9	4.8
C-A_{sil}	5	0.14
C-$A_{nanosil}$	5	0.14
C/L-A	26	4.13
C/L-A+sil	22	1.13
C/L-A_{sil}	12	0.60
C/L-$A_{nanosil}$	12	1.13
C-B	11	1.53
C-B+sil	8	1.09
C-B_{sil}	5	0.10
C-$B_{nanosil}$	5	0.56
C/L-B	15	2.51
C/L-B+sil	12	2.01
C/L-B_{sil}	14	1.80
C/L-$B_{nanosil}$	14	1.83

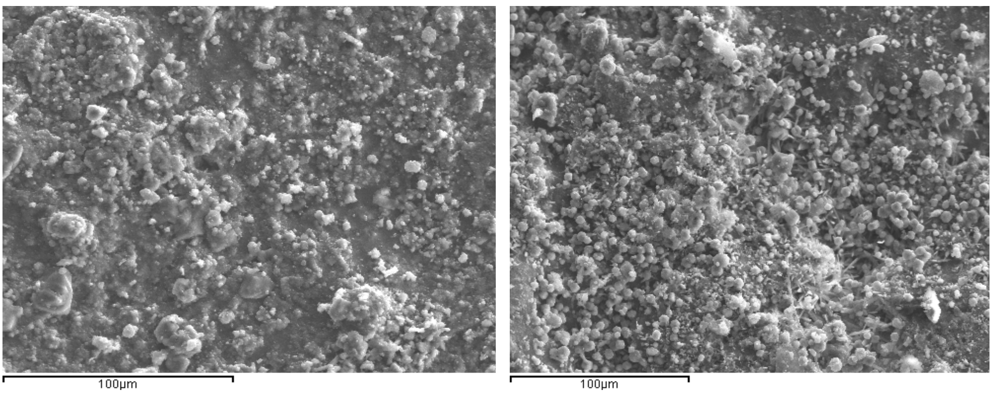

Figure 3. SEM images depict high surface roughness for samples C-A_{sil} (left) and C-$A_{nanosil}$ (right)

CONCLUSIONS

The following conclusions could be drawn from the above mentioned test results:

The hydrophobic character of cement-based renders is affected strongly by the mixed aggregates in terms of both their chemical composition and physical texture.

Lime admixture in cement based renders, in order to substitute part of the cement, results in an increase of both porosity and water absorption with a consequent reduction of the mechanical strength.

Substituting natural sieved silica sand by artificial expanded glass sphere, results in significantly different physical properties of the renders when comparing equivalent formulations, as for example the reduction of compressive strength. The hydrophobic character of cement-based renders is strongly affected by water repellent admixtures, that even when added in small amounts modify the mortar impregnation mechanism. For example the water re-dispersible silicone in powder form interacts strongly with capillary water. Similar behaviour was also recorded when the surface was treated. The derived static contact angle was highly increased and the capillary coefficient was decreased indicating a low rate of water absorption.

The best hydrophobic properties were attained using a nano-modified silane polymer for the protective coating. In these cases, reduced porosity and low rate of capillary absorbed water was obtained, and confirmed by the high contact angle measurements. Silanes and oligomeric siloxane mixtures provide water-impregnation that is optimized through the artificially created nano-roughness resulting from the nanosilica enrichment and contributed synergistically to the enhanced hydrophobic behaviour. Thus the formulated cement-based renders keep their breathability, a point that is fundamental for the cohesion to every existing building substratum.

Eventually, the study of “real conditions” for the formulated render is very challenging as they interact with the substratum and the final response under natural wet-drying or solar exposition are some of the perplexing parameters to be tested. The sustainable multi-functional role of renders in constructions for energy saving and ecology requires that research should be continued in this field.

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