WATER ABSORPTION OF LIME-BASED FAÇADES

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SUMMARY

The paper presents the results of recently finished study regarding water absorption ability of different façade systems prepared by using traditionally produced calcite lime putty. The façade consists of main rendering (rough mortar), finishing rendering layer (fine mortar) and protective layer of lime wash. Specimens for the study were prepared and tested in laboratory and on-site, on the inner and outer walls of castle Novo Celje from the Baroque period.

INTRODUCTION

We notice buildings normally first from their facades. They give a house, church or castle its outlook in composition of elements and also in colours and decorations. In Slovenia historical facades are manly composed of two or more rendering layers and finished with white or coloured lime wash. Although the main role of the rendering layers and lime wash was protection of load-bearing masonry (stone, brick or combination of the two) against weathering, protection of occupants against wind and control of hygro-thermal variations, decorative aspect was seldom neglected.


a)

b)

Figure 1. Castle Novo Celje (a) and Ljubljana's Town square (b).

For Baroque and subsequent periods imitation of pure stone facade elements by profiled and structured final lime rendering layer is a typical feature of facades of important buildings in old town centres, as well as of some castles and churches (Figure 1). Sometimes, however, imitation

of pure stone elements only by painting them in fresco or secco technique was carried out. Corner stones or quoins, originally made from ashlars, were typically imitated in this way for churches and homes of wealthy farmers (Figure 2). When secco technique was chosen, addition of casein to the coloured lime wash was often used in order to increase durability of painted surface. However, also casein was sometimes added when fresco technique was applied. Another organic binder used as additive to the lime wash for historical lime-based facades in Slovenia was linseed varnish.

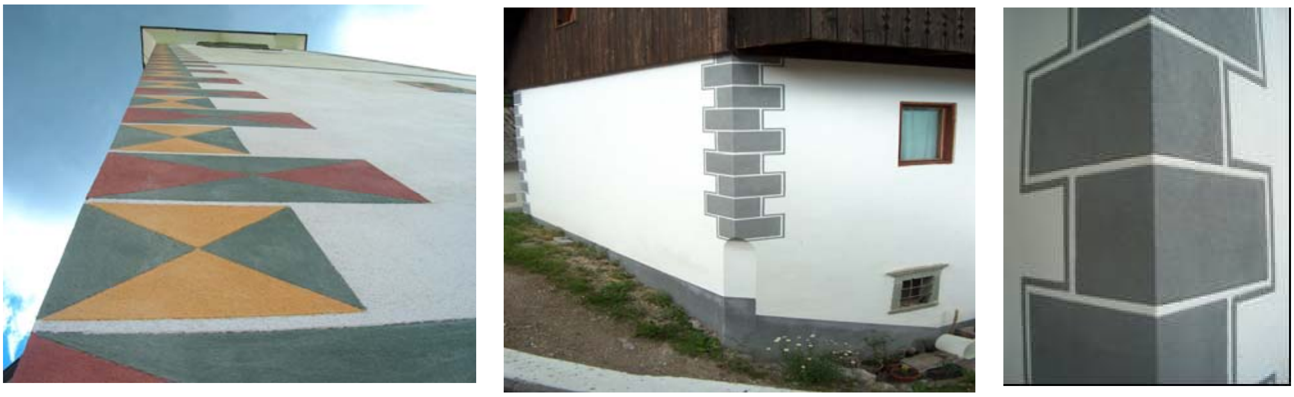

Figure 2. Painted imitations of corner stones in fresco technique.

The research work of our research team dedicated to historical materials during the last decade has been focused manly on the properties of lime-based mortars for clay bricklaying and main rendering layer (Bokan Bosiljkov and Bosiljkov 2000, Bokan Bosiljkov 2001a, Bokan Bosiljkov 2001b, Bokan Bosiljkov et al. 2004, Veiga et al. 2004, Bokan Bosiljkov and Valek 2005). However, in our recent studies (Kikelj and Bokan Bosiljkov 2006, Bokan Bosiljkov et al. 2006) properties of lime-based façade systems that could be successfully used in restoration of historical buildings in Slovenia were considered. We focused first on the selection of adequate traditionally produced lime putty. Fortunately, there are still some owners of small lime kilns all over Slovenia that are producing quick lime and lime putty in traditional way. For this reason limited amounts of traditional dolomite (mainly) or calcite (rarely) lime putty are still available for the preparation of lime mortars and lime washes. Among three different traditional lime putties used during the preliminary study, two calcitic lime putties were chosen for the preparation of lime-based façade specimens composed of main rendering layer, finishing rendering layer and lime wash. The specimens were prepared in laboratory and on-site, on the inner and outer walls of castle Novo Celje from the Baroque period. For the laboratory specimens a study about the influence of several parameters, such as:

- the finishing mortar layer surface structure,
- the application technique of lime wash (fresco, lime or secco) and
- the presence of organic additives (linseed varnish or casein)

on the complexity of applying lime washes and their properties (appearance, intensity of colour nuances, strength of binding) as well as the absorption of water of the façade system was carried out. For the specimens applied to the castle Novo Celje only water absorption tests were carried out, since these specimens were prepared by skilled worker of Restoration Centre of Institute for the Protection of Cultural Heritage of Slovenia. In the sequel of the paper the results of the water absorption test are presented and discussed.

EXPERIMENTAL WORK

Properties of used lime putties

As stated above, two calcitic lime putties were used for the study. The first one was soft burnt lime putty from Stranje, burned and slaked in traditional way (denotation putty S). The second one was lime putty from Tržič, produced by slaking industrially burned quick lime (burnt at temperatures between 1000 and 1200ºC) in traditional way (denotation putty T). Putty S was aged for more than 1 year, and putty T for at least 3 months. The particle size distributions of selected lime putties are presented in Figure 3, showing that there is no important difference in this characteristic between the two putties.

In order to determine compressive strength (SIST EN 1015-11, 2001) and water absorption (SIST EN 1015-18, 2004) of mortars prepared by the lime putties (mortar S and mortar T), lime mortars with composition of 1 volume part of the putty and 3 volume parts of crushed limestone sand (1 volume part of 0/2 mm fraction and 2 volume parts of 0/4 mm fraction) were prepared. Adequate workability of fresh mortars was determined by skilled workers and the appertaining flow values (SIST EN 1015-3, 2001) of the mortars were 140 mm and 138 mm for mortar S and T, respectively. The compressive strength after 60 and 90 days was 1.3 MPa and 1.4 MPa for mortar S and 1.6 MPa and 1.8 MPa for mortar T, and coefficient of water absorption was 0.29 $g/(cm^2 \cdot min^{0.5})$ and 0.16 $g/(cm^2 \cdot min^{0.5})$ for the mortar S and mortar T, respectively. Based on these results lime putty T was chosen for the preparation of the laboratory specimens. For the on-site specimens, however, lime putty S was used, since this lime putty was produced entirely in the traditional way.

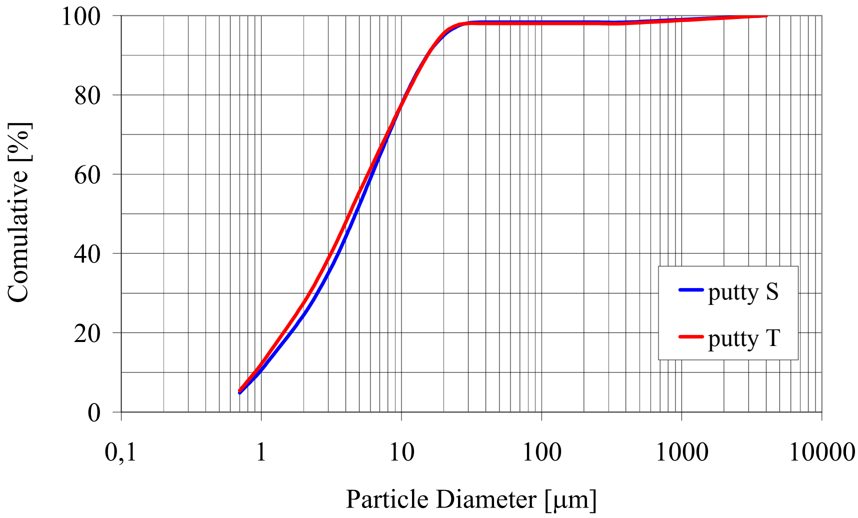

Figure 3. Particle size distributions of selected lime putties.

Tests in the laboratory

For the preparation of the lime façade test specimens, slabs from porous limestone (Jezersko tuff), were used as substrate. Rough mortar for the main render layer was prepared with crushed limestone sand of 0/4 mm fraction and the volume ratio between sand and lime putty T was 3:1. Fine mortar, as the finishing rendering layer of the façade system, was chosen based on comprehensive practical testing. The volume ratio between fine crushed limestone sand (0/1 mm fraction) and lime putty T equal to 3:2 gave the best overall behaviour. In order to study the

influence of smoothness of the finishing layer, the surface was prepared in smooth and rough way. A protective layer of lime wash was prepared in several different compositions (Figure 4), by using whitewash (lime putty:water=1:2 + additional water chosen by skilled worker), aqua fortis (lime putty:water=1:3 or 1:4 + additional water chosen by skilled worker), pigment (yellow oxide) and additives (linseed varnish and 2 types of casein). The caseins were prepared following the recipes of old masters from home made fresh cottage cheese and lime putty. For the first type of casein (casein1) the cheese:lime putty ratio was 1:1. After mixing the ingredients to a homogenous liquid and filtering it through gauze, the filtered liquid was diluted with potable water (liquid:water = 1:1). For the second type of casein (casein2) the cheese:lime putty ratio was 5:1. After mixing the ingredients and adding 3 volume parts of distilled water the homogenous liquid was filtered through gauze. The linseed varnish was added in the amount of 1% according to the lime putty mass in whitewash or aqua fortis, and casein was added in the amount of 10 and 25%, according to the mass of whitewash and aqua fortis, respectively. The amount of the pigment added to the lime wash depended on the technique of application: for fresco and secco technique it was $20\%_{mass}$ and $10\%_{mass}$, respectively, according to the lime putty content in the whitewash, and for the lime technique it was $20\%_{mass}$ according to the lime putty content in the aqua fortis. Different types of lime wash used in the study and the appertaining denotations (first denotation in line is for rough and second, marked by *, is for smooth surface of finishing layer) were as follows:

Fresco technique
1/1* whitewash
2/2* whitewash with varnish
3/3* whitewash with 25% of casein-1
4/4* whitewash with 25% of casein-2
5/5* coloured lime wash
6/6* coloured lime wash with varnish
7/7* coloured lime wash with 25% of casein-1
8/8* coloured lime wash with 25% of casein-2

Secco technique
13/13* whitewash - 2-times lime wash without and 2-times with varnish
14/14* whitewash - 2-times lime wash without and 2-times with 10% of casein1
15/15* lime wash with 10% of pigment - 2-times lime wash without and 2-times with varnish
16/16* lime wash with 10% of pigment - 2-times lime wash without and 2-times with 10% of casein1

Lime technique
17/17* aqua fortis with 20% of pigment on freshly whitewashed dry lime render
18/18* aqua fortis with 20% of pigment and varnish on freshly whitewashed dry lime render
19/19* aqua fortis with 20% of pigment and 25% of casein1 on freshly whitewashed dry lime render
20/20* aqua fortis with 20% of pigment and 25% of casein2 on freshly whitewashed dry lime render

Figure 4. Lime washes used in the study.

Figure 5. Water absorption test.

Among several tests used for the characterisation of the façade systems also water absorption tests was carried out. The pipe-method (RILEM test Nº II.4 of RILEM commission 25-PEM) was used to measure the quantity of water absorbed under low pressure by a definite surface of a porous material and after a definite time. The pipe is applied on the material by interposing a tape of putty. Then the pipe is filled with water through the upper opening up to the gradation 0. The quantity of water absorbed by the material in function of time (after 5, 10, 15, 30 and 60 minutes) can be read directly from the graduated tube (Fig 5). The test was carried out on 16 different façade specimens and also on finishing rendering layer prepared in rough or smooth way. Coefficient of water absorption was determined as average coefficient (C_{aver}) after 60 minutes or earlier. For the second case the C_{aver} was determined after the time when water reached graduation of 4 cm^3.

On-site tests

For the castle Novo Celje lime putty S and local sand from Pirešica creek were used for the preparation of lime mortars. The rough mortar was prepared from 0/4 mm fraction and the fine one from 0/2 mm fraction. The volume ratio between sand and lime putty was 3:1 in both cases. The compressive strength of the rough mortar was after 60 days only 0.53 MPa. Difference in compressive strengths between mortar S (1.3 MPa) and on site rough mortar may be due to difference in used sand and also due to higher content of water added on site.

A protective layer of coloured lime wash or whitewash was applied in secco technique. For the colouring of lime wash the following pigments were used: Bologna chalk, yellow ochre, red ochre, green earth, beech charcoal. Lime washes coloured with all of the above listed pigments were applied to the finishing rendering layer on the inner wall of the castle, while on the outer wall only lime wash coloured with yellow ochre was used. As in the laboratory also here the pipe method was used for the water absorption tests. The test was carried out on finished façade specimens and also on main and finishing rendering layer (Figure 6). Finally the C_{aver} was determined in the same way as for the laboratory tests.

a) b) c)

Figure 6. Water absorption tests on inner (a and b) and outer walls of the Novo Celje castle.

RESULTS AND DISCUSSION

Results of the water absorption tests in the laboratory are given in Figure 7 for the fresco technique and in Figure 8 for the secco and lime techniques. From the results in Figure 7 we can see that all lime washes reduced water absorption of the façade system, compared to that obtained without lime wash: for the rough surface of the finishing rendering layer C_{aver} was equal to 0.20 g/(cm^2·min$^{0.5}$) and for the smooth surface it was equal to 0.11 g/(cm^2·min$^{0.5}$).

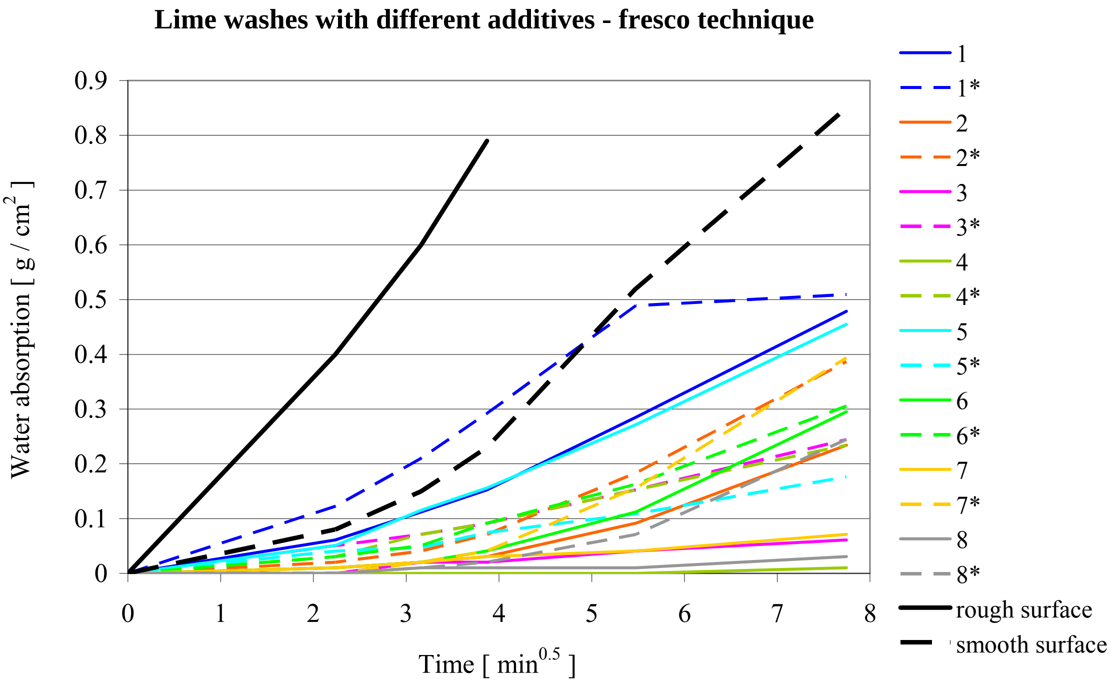

Figure 7: Results of the water absorption test for the fresco technique.

However, there is big difference in the extent of water absorption decrease among the tested lime washes and, as a rule, lime wash on the rough surface exhibited much lower water absorption than the same lime wash on the smooth surface. The rough surface is capable to bind much thicker layer of lime wash and thus to form protective layer, which is less permeable for water. The only exception from the rule is coloured lime wash without additive, where water absorption

of the specimen with lime wash on the smooth surface was considerably lower than that of the specimen with the same lime wash on the rough surface. Such behaviour could be due to higher content of the lime binder on the smooth surface, available for binding the pigment.

The lowest decrease in water absorption was obtained for the whitewash without additive and pigment (1: $C_{aver} = 0.062$ g/(cm^2·min$^{0.5}$) and 1*: $C_{aver} = 0.066$ g/(cm^2·min$^{0.5}$)) and for coloured lime wash without additive on rough surface (5: $C_{aver} = 0.059$ g/(cm^2·min$^{0.5}$)). Higher decrease in water absorption was obtained, when varnish or casein was added to the lime wash. For the particular surface quality (rough or smooth) addition of varnish reduced water absorption of the façade system for less than both caseins. For the lime washes prepared with one of the caseins and applied on the rough surface, water absorption was close to zero (3: $C_{aver} = 0.008$ g/(cm^2·min$^{0.5}$); 4: $C_{aver} = 0.001$ g/(cm^2·min$^{0.5}$); 7: $C_{aver} = 0.009$ g/(cm^2·min$^{0.5}$); 8: $C_{aver} = 0.004$ g/(cm^2·min$^{0.5}$)).

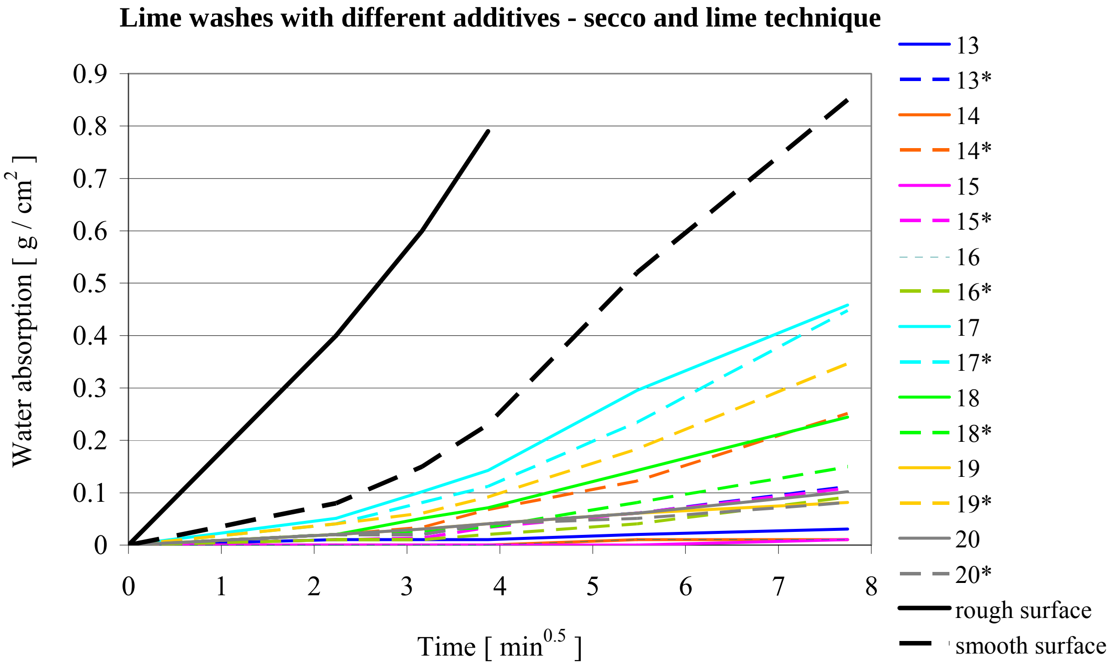

Figure 8: Results of the water absorption test for the secco and lime technique.

In case of secco technique (Figure 8) not only addition of casein, as for fresco technique, but also addition of varnish to the lime wash applied on the rough surface extremely reduced water absorption of the façade system, since it was close to zero (C_{aver} between 0.001 and 0.004 g/(cm^2·min$^{0.5}$)). For the lime washes applied on the smooth surface, absorption of water was considerably higher: the highest for the lime wash with casein and without pigment ($C_{aver} = 0.032$ g/(cm^2·min$^{0.5}$)), lower for the two lime washes with varnish and pigment ($C_{aver} = 0.012$ g/(cm^2·min$^{0.5}$)) and the lowest for the lime wash with casein ($C_{aver} = 0.014$ g/(cm^2·min$^{0.5}$)). It means that the same rule as for fresco technique is also valid for the secco technique: water absorption of façade system where lime wash contains organic additive is much lower for the rough surface of the finishing rendering layer. By using lime technique this rule applies only for the addition of casein1, where absorption of water for the smooth surface is only slightly lower ($C_{aver} = 0.045$ g/(cm^2·min$^{0.5}$)) than for the lime wash without additive ($C_{aver} = 0.058$ g/(cm^2·min$^{0.5}$)), and for the rough surface it is considerably decreased ($C_{aver} = 0.011$ g/(cm^2·min$^{0.5}$)). The addition of casein2, on the other hand, considerably reduced absorption of

water, equally for smooth and rough surface (C_{aver} = 0.012 g/(cm^2·min$^{0.5}$)). When the varnish was added to the lime wash, absorption of water was between that of the washes 19* and 19, and higher for rough than for smooth surface. As expected, also for the lime technique reduction in water absorption was the lowest for the lime wash without organic additive ((C_{aver} = 0.058 g/(cm^2·min$^{0.5}$)).

Results of the on-site water absorption tests are given in Figure 9 for the inner and in Figure 10 for the outer test specimens. From the results in the Figure 9 we can see that the average coefficient of water absorption was the highest for the main rendering layer (C_{aver} = 1.74 g/(cm^2·min$^{0.5}$)) and substantially lower for the finishing rendering layer (C_{aver} = 0.69 g/(cm^2·min$^{0.5}$)), as it was expected. Application of whitewash or coloured lime wash decreased water absorption of composed layer only slightly (C_{aver} between 0.57 and 0.41 g/(cm^2·min$^{0.5}$)). The only exception was lime wash with Bologna chalk, where coefficient of water absorption was decreased considerably (C_{aver} = 0.26 g/(cm^2·min$^{0.5}$)).

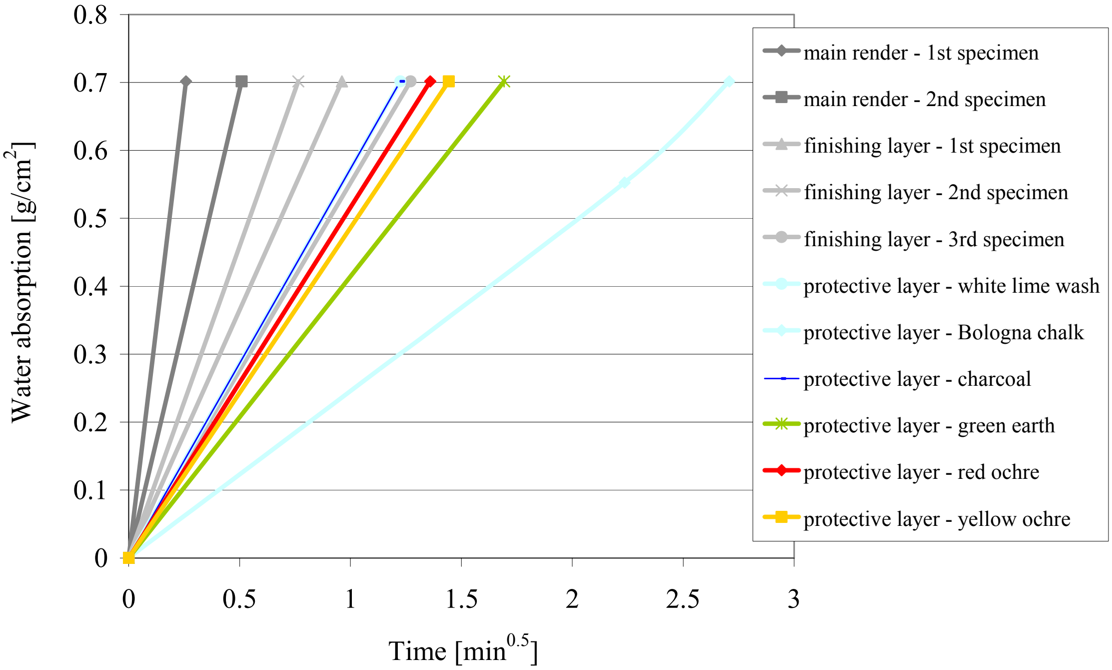

Figure 9. Results of the on-site water absorption test – inner walls of the castle.

Comparison of the results obtained on test specimens attached to the inner wall (Figure 9) with those obtained on the outer façade specimens (Figure 10) reveal that the average water absorption of the particular layer or combination of layers is lower for the specimens on the outer wall (main rendering layer: C_{aver} = 1.4 g/(cm^2·min$^{0.5}$); specimen with finishing rendering layer: C_{aver} = 0.36 g/(cm^2·min$^{0.5}$); specimen with protective layer C_{aver} = 0.26 g/(cm^2·min$^{0.5}$)). The obtained difference in velocity of water absorption could be due to faster carbonation of the outer specimens because of continual availability of fresh air and thus also of CO_2.

The results obtained on-site can not be directly compared to the results of the laboratory tests, due to different lime putties, sources of sand, compositions of fine mortar for finishing rendering layer and application techniques. However, it is obvious that water absorption of specimens prepared in the laboratory was much lower than it was for comparable on-site specimens. For example, coefficient of water absorption was more than 3-times higher for the on-site specimens

with the finishing rendering layer, compared to that in the laboratory (rough surface). Difference is much larger when complete façade specimens are considered, since C_{aver} of the specimen 17 (C_{aver} = 0.06 g/(cm^2·min$^{0.5}$)) is more than 4-times lower than the lowest C_{aver} obtained when lime wash with Bologna chalk was applied (C_{aver} = 0.26 g/(cm^2·min$^{0.5}$)). It is true that conditions in the laboratory are more controlled and preparation of specimens is easier. However, such large difference in obtained results clearly shows that only by selection of traditional lime putty with better quality (lower water absorption of comparable mortar) and, more importantly, by selection of optimal grain size distribution and source of sand as well as by careful preparation and application of subsequent façade layers we can improve water resistance of lime-based façade considerably, even without addition of organic binder to the protective layer.

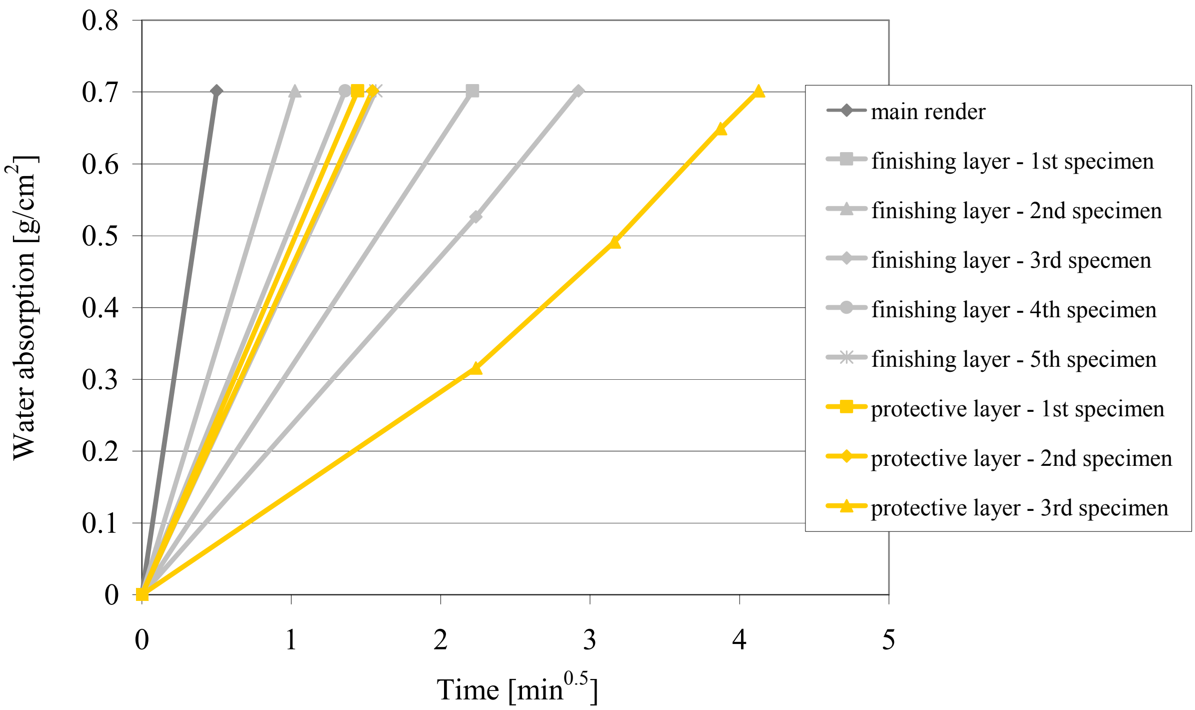

Figure 10. Results of the on-site water absorption test – outer walls of the castle.

CONCLUSIONS

The quality of finishing rendering layer surface has important influence on the water absorption ability of the façade system after applying the protective layer of the lime wash. When lime wash without organic additive was used, the water absorption of the façade system was reduced. However, it was generally higher for rough than for smooth surface. When organic binder was added to the lime wash, protective layers on the rough surface exhibited considerably lower water absorption (manly close to zero) than those on the smooth surface, and as a rule water absorption of façade system with organic binder in the lime wash reduced the water absorption much more than those without organic additive.

However, not only the quality of finishing rendering layer surface and addition of organic binder to the protective layer but also careful selection of basic materials such as traditional lime putty with adequate quality and sand of adequate source and optimal grain size distribution as well as

careful preparation and application of subsequent façade layers can decrease water absorption ability of lime-based façades.

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