Application and properties of pure lime façades – case study
Aplicação e propriedades de fachadas em cal pura – caso de estudo

Violeta Bokan Bosiljkov
Assistant Professor, University of Ljubljana, Ljubljana, Slovenia,
vbokan@fgg.uni-lj.si

Vlatko Bosiljkov
Assistant Professor, University of Ljubljana, Ljubljana, Slovenia,
vbosiljk@fgg.uni-lj.si

Roko Žarnić
Associate Professor, University of Ljubljana, Ljubljana, Slovenia,
rzarnic@fgg.uni-lj.si

Abstract

The paper presents experiences obtained during application and testing of different pure lime façades that could be successfully used in restoration of historical buildings in Slovenia. The lime façade consists of a rendering layer (rough mortar), a finishing layer (fine mortar) and a protective layer of lime wash. For the design of the mortars different industrially and traditionally produced limes were chosen, based on the results of preliminary studies of the authors and experiences of a small enterprise (SE) involved in the study. The façade layers were applied to the most problematic northern wall of the historic chapel made from rubble masonry. The chapel belongs to the castle Črnelo, built at the end of the 17th century in the village Turnše, not far from Ljubljana, the capital of Slovenia. The façade layers were made by skilled workers of SE, with about one year time difference between application of rendering and finishing layers, and with a protective layer of coloured lime wash applied to one to three day old finishing layers. On the rendering layers, visual inspection, water absorption tests and determination of carbonation depth were carried out before subsequent finishing layers were applied. The same on-site tests were carried out also on finished façade layers. So far, parallel to the on-site tests, compressive and water absorption tests on prisms prepared from rough mortars were carried out in laboratory.

Keywords

Pure lime façade; workmanship; water absorption; carbonation depth.

Resumo

Este artigo apresenta experiências obtidas no decorrer da aplicação e teste de diferentes fachadas em cal pura que poderão vir a ser usadas com sucesso no restauro de edifícios históricos na Eslovénia. Cada fachada de cal é composta por uma camada de revestimento (argamassa grosseira), uma camada de acabamento (argamassa fina) e uma camada protectora de água de cal. Para a concepção das argamassas foram escolhidos diferentes tipos de cal, de produção industrial e tradicional, com base em estudos preliminares dos autores e em experiências de uma pequena empresa (SE) envolvida no estudo. As camadas que compõem as fachadas foram aplicadas na parede norte – a mais problemática – de uma capela histórica em alvenaria de pedra ordinária. Esta capela pertence ao castelo de Črnelo, construído no final do século XVII em Turnše, uma vila não muito distante de Liubliana, capital da Eslovénia. As fachadas foram efectuadas por trabalhadores habilitados da SE, com um intervalo de cerca de um ano entre a aplicação das camadas de revestimento e de acabamento, e com a camada protectora de água de cal pigmentada aplicada um a três dias após a execução das camadas de acabamento. Previamente à aplicação das camadas de acabamento, foram conduzidas inspecção visual, medições de absorção de água e determinação da profundidade de carbonatação nas camadas de revestimento. Idênticos testes in-situ foram subsequentemente conduzidos nas camadas de acabamento. Até agora, paralelamente aos testes in-situ, foram efectuados em laboratório testes de resistência à compressão e de absorção de água sobre prismas preparados com as argamassas grosseiras.

Palavras-chave

Fachada de cal pura; mão-de-obra absorção de água; profundidade de carbonatação.

Introduction

We notice buildings normally first from their façades. They give a house, church or castle its outlook in composition of elements and also in colours and decorations. In Slovenia historical façades are mainly composed of two or more layers made from lime mortar and finished with white or coloured lime wash. Although the main role of the façades has always been 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, the decorative aspect was seldom neglected.

The work of our research team, dedicated to historical materials during the last decade, has been focused mainly on the properties of lime-based mortars for clay bricklaying and rendering layer [1-6]). However, in our recent studies [7, 8], properties of lime-based façades that could be successfully used in restoration of historical buildings in Slovenia have been in focus of our interest. The façades under consideration consist of rendering layer (rough mortar), finishing layer (fine mortar) and protective layer of lime wash. Experiences obtained during previous studies and the possibility to use the northern wall of historic chapel of the castle Črnelo (built at the end of the 17th century) for a two-year study of different lime-based façades gave us the idea to examine the efficiency of different pure lime mortars for the application of façade layers on historical rubble masonry wall. Since the wall was 7.6 m long and 4.15 m high, it was possible to use much bigger test areas (about 1 m wide and 4 m high vertical test stripes) than in former studies. The façade layers were applied by skilled workers of a small enterprise, with many years of practical experience in restoration and application of pure lime renders and plasters.

Experimental work

Preparation of testing wall

Before the application of rendering layers, the rubble masonry wall was first cleaned in order to remove residues of mortar, algae, lichens and dirt. The mortar residues were removed by hammering. Then the wall was cleaned with pressurised water, which removed the algae, lichens and dirt, and also weak parts of mortar between stones (Fig. 1). Several voids between stones with volume between 1 and 3 dm^3 were filled with rough lime mortar prepared with lime putty from Tržič and smaller stones (Fig.2). Details of the mortar are given below.

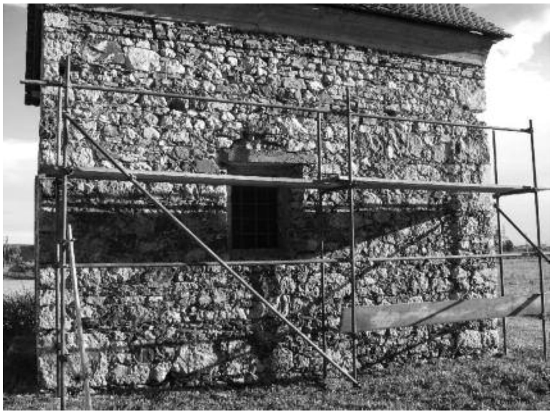

Fig. 1 The test wall after cleaning.

Fig. 2 The test wall after filling of voids.

Details of used lime mortars

Limes

In the study five different types of lime were used. The first one was a soft burnt dolomitic lime putty from the village Podpeč and the second one was a soft burnt calcitic lime putty from Stranje. Both putties were burned and slaked in the traditional way, and were aged for more than 1 year. The third one was a lime putty from Žiri, produced by slaking industrially burned quick lime (burnt at temperatures between 1000 and 1200 °C) in the traditional way. This putty was aged for at least 3 months. The fourth type of lime was commercially available dry hydrate powder made from the same quick lime as the third lime putty, produced by Slovenian company SIA. The last lime putty was prepared by laying down a layer of sand, a layer of granular quicklime (the same origin as for the third and the fourth lime) and a layer of sand in a heap and slaked by pouring a defined amount of water over the heap. In this way hot lime mortar was produced, with 1 part of granular quick lime and 6.3 parts of sand (in two layers). The amount of water poured over the heap was the same as the quick lime volume.

Lime mortars

For the preparation of rough lime mortars for a rendering layer, coarse sharp limestone sand with maximum grain size of 4 mm was used. The mortars were prepared by a skilled worker of the small enterprise. Details of the mortars and their properties in fresh state are given in Table 1.

Mortars ideal for throwing on the wall, levelling and consolidation, as chosen by the workers, were RM I and RM II. Both mortars contained enough binder and their adhesion to the substrate was excellent. Also mortar RM V was assessed as good for throwing, but less appropriate for consolidation. The excess of lime binder was found to be the main source of problems and a skilled worker proposed a volume ratio of at least 1:3 for this type of lime putty. Mortar RM III was prepared by mixing dry hydrate with the coarse sand and water. During the mixing process a substantial amount of water had to be added in the mixer. However, with further mixing the mortar was becoming thicker and thicker with time. The workers again realised that the content of lime binder could be reduced also for this mortar, in order to obtain a leaner mixture. Mortar RM IV was prepared by cutting the heap vertically and putting 180 dm^3 of mixture of slaked lime and sand into a mixer. First the dry mixture of sand and lime was mixed and then about 38 dm^3 of water was added. The mixture's temperature increased slightly, which indicated that lime in the heap was not fully hydrated. Since the workers estimated that the mixture was not fat enough, about 10 dm^3 of slaked lime from the heap was added in the mixer later on. However, also in this case the mortar was becoming fatter and fatter with the increase of mixing time, and the final conclusion was that addition of extra lime was not necessary.

For the preparation of fine lime mortars for finishing layers, fine sharp limestone sand with maximum grain size of 1 mm was used. The fine mortars were prepared by the same workers as rough mortars. Details of the fine mortars are given in Table 2.

Fine lime mortar FM II was lighter (lower density was estimated by workers) than mortar FM I and it was very white. Mortar FM IV was the most watery among the four fine lime mortars.

Tests in the laboratory

In order to determine the compressive strength (SIST EN 1015-11, 2001) and water absorption (SIST EN 1015-18, 2004) of the rough mortars for rendering layers, standard 40x40x160 mm prisms were cast and tested at the age of 90 days. The test results are given in Table 3 and in Fig. 3. Water absorption coefficients were determined according to [6].

Table 1 Details of rough mortars used for the rendering layer and their fresh properties.

Rough mortar	Type of lime	Volume ratio lime:sand (dm^3:dm^3)	Water (dm^3)	Flow value (mm)	Density (kg/dm^3)
RM I	Podpeč putty	1:2.83 (54:153)	21.5	160	2.02
RM II	Stranje putty	1:2.83 (54:153)	25.0	170	1.97
RM III	Dry hydrate SIA	1:2.17 (72:156)	55.0	143	1.97
RM IV	Hot lime mortar	-	-	152	2.01
RM V/1	Žiri putty	1:2.83 (54:153)	16.4	154	2.06
RM V/2	Žiri putty	1:2.57 (21:54)	5.7	150	2.06

Table 2 Details of rough mortars used for the rendering layer and their fresh properties.

Fine mortar	Type of lime	Volume ratio lime:sand (dm^3:dm^3)	Water (dm^3)
FM I	Podpeč putty	1:1.81 (27:49)	15
FM II	Stranje putty	1:1.76 (27.8:49)	15
FM III	Dry hydrate SIA	1:1.69 (29:49)	36
FM IV	Žiri putty	1:1.78 (18:32)	10

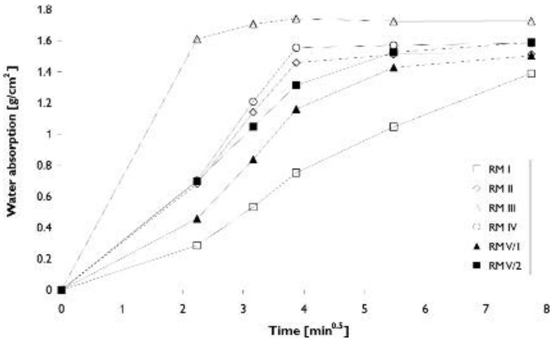

Fig. 3 Results of water absorption test on prisms from different rough lime mortars.

Table 3 and Fig. 3 show that RM III is the mortar with the coarsest pores (the most rapid water absorption) and RM I the mortar with the finest pores (the slowest water absorption); the other mortars are in-between.

On-site tests

Rendering layers

On the 11th of September 2006 rendering of the historical rubble masonry wall started. Positions of the rendering layers (vertical stripes) from different rough lime mortars are given in Fig. 4. The vertical stripes were about 1 m wide and 4 m high, except the additional rendering layer from mortar RM V/2 (between layers RM I and RM II) and the layers above and below the window. The rendering layers should be as thin as possible; however they should at the same time assure an even substrate for the finishing layers. The evenness of rendering layers was assured with the help of a leading wooden board and a floating board, without subsequent troweling. Therefore, thickness of the rendering layers was ranging between less than 1 cm and up to 3-4 cm, and effective consolidation of the layers was not carried out.

The first stripe of rendering layer applied on the wall was layer RM II, followed by layers with RM I and RM V/1 (last on the right side – Fig. 4) in the same day. During the next day layers with numbers V/2, III and IV were applied. After the rendering layers had been finished, it started to rain and it was raining for several days. Therefore some thicker parts of layers made from mortars RM I and RM IV, and from below the window were falling from the wall (Fig. 5). They were restored using the same mortar mixture and after that the renders behaved very well, as can be seen from the picture in Fig. 6, taken in October 2007.

Table 3 Results of compressive tests (6 specimens per mortar type) and average water absorption coefficients due to capillary action (Cm; 3 specimens per mortar type), determined on standard prisms.

Type of rough mortar	Average compressive strength [MPa] *(COV)*	C_{m5} g/(cm^2·min$^{0.5}$)	C_{m10-5} g/(cm^2·min$^{0.5}$)	C_{m15-10} g/(cm^2·min$^{0.5}$)	C_{m30-15} g/(cm^2·min$^{0.5}$)	C_{m60-30} g/(cm^2·min$^{0.5}$)
RM I	1.87 (6%)	0.13	0.26	0.31	0.18	0.15
RM II	1.86 (2%)	0.30	0.50	0.45	0.03	0.00
RM III	1.81 (8%)	0.72	0.10	0.05	0.00	0.00
RM IV	1.95 (14%)	0.31	0.55	0.45	0.01	0.01
RM V/1	1.63 (17%)	0.20	0.41	0.45	0.17	0.03
RM V/2	2.0 (4%)	0.31	0.38	0.37	0.13	0.03

** t – time in minutes, after which coefficient was determined*
***t_j-t_i – coefficient between times t_j and t_i*

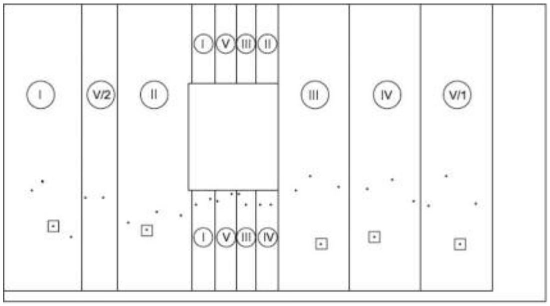

Fig. 4 Positions of the rendering layers made with different mortars and positions of water absorption test by pipe-method.

Fig. 5 Thicker parts of rendering layers were falling from the wall after rain.

After 1 year, in October 2007, fine finishing layers were applied. Just before that, the water absorption tests and the determination of carbonation depth were carried out. The pipe-method (RILEM test N° 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 (Fig. 7). 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. The measurement positions of the pipes are given in Fig. 4, by points. The determination of carbonation depth was first carried out by the phenolphthalein method. However, by removing part of the render, noncarbonated particles contaminated the carbonated part and the obtained results were useless. In the next step we focused on removing noncarbonated parts of renders, with considerably lower resistance to scratching, using a steel brush, and measured the remaining carbonated part (Fig. 8). The parts of renders were removed on the lower side of each particular stripe, where conditions were less favourable for carbonation, due to relatively higher humidity.

Results of water absorption tests are given in Table 4 and in Fig. 9, and carbonation depths are given in Table 4. Water absorption coefficient C_{aver} was determined when water reached graduation of 4 cm^3.

Results of on-site water absorption tests conformed to the results of laboratory tests (Fig. 3) in that RM III is

Fig. 6 Rendering layers after 1 year.

Fig. 7 Water absorption tests on rendering layers.

the mortar with the coarsest pores, RM I the mortar with the finest pores, and that other mortars are in between. The expected correlation between water absorption and carbonation depth was obtained for rendering layers RM III, RM IV and RM V. However, for the render RM II a much higher carbonation depth than 7 mm, and for the render RM I a much lower carbonation depth than 14 mm, were expected, assuming that all the tested parts were exposed to the same environmental conditions. Possible reasons for these unexpected results may be important differences in humidity between micro locations on the lower sides of the rendering stripes, due to the influence of surrounding vegetation (mainly weed and non-maintained grass). Additional reasons may be connected with raw material properties and used burning and slaking regimes, since only lime putties for rendering layers RM I and RM II were produced entirely in a traditional way.

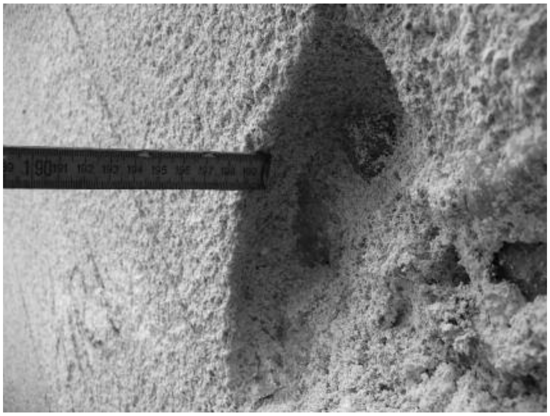

Fig. 8 Determination of carbonation depth of renders.

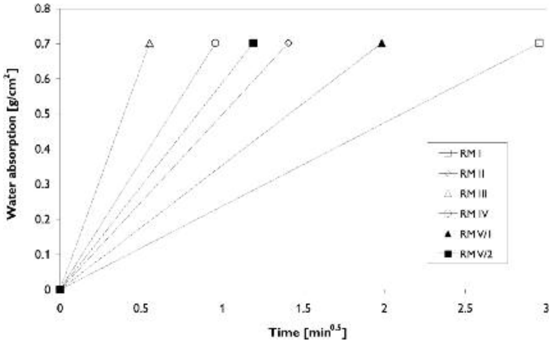

Fig. 9 Results of water absorption test on different rendering layers.

Table 4 Average water absorption coefficient (C_{aver}) and depth of carbonation of rendering layers at the age of 1 year.

Type of rough mortar	C_{aver} [g/(cm^2·min$^{0.5}$)]	Carbonation depth (mm)
RM I	0.24	14
RM II	0.50	7
RM III	1.27	23 (complete)
RM IV	0.73	15
RM V/1	0.35	14
RM V/2	0.59	14

Finishing layers

On the 24th of October 2007 the finishing layers were applied. The positions of the finishing layers (vertical stripes) from different fine lime mortars are given in Fig. 10. The vertical stripes were about 1.5 m wide and 4 m high, except layers above and below window. The finishing layers were very thin, with thickness between 3 and 5 mm. They were made in two layers (Fig. 11): 1) laying on the fine mortar and floating, 2) laying on the fine mortar and troweling with finishing trowel. The workers estimated that the fine mortar FM IV was the easiest to work with, fine mortar FM III was too lean, troweling of fine mortar FM I was rather complicated and they were satisfied with mortar FM II. The only problem of the last mortar was lumps in the lime putty, since it was not sieved before application.

On 25th and 27th of October 2007 the finishing layers were painted with lime wash coloured with yellow ochre pigment (Fig. 12) and thus the façade was completed.

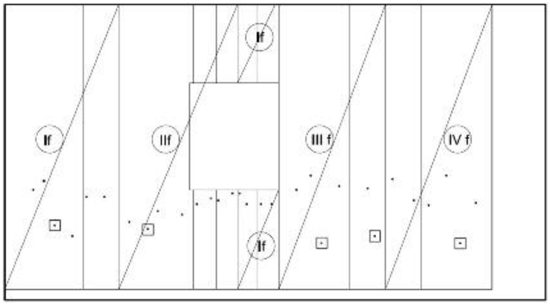

Fig. 10 Positions of finishing rendering layers made with different fine mortars.

Tests on façade were again carried out after about 1 year, in July 2008. The finishing layers were completely carbonated, which was confirmed by the application of the phenolphthalein method. The water absorption test was again the pipe-method. Due to a much lower water absorption than in the case of the rough rendering layers, the water absorption coefficient 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. The results are given in Table 5 and in Fig. 13. From the results we can see that also for finished façade layers water absorption was the highest when dry hydrate was used as a binder, and among the lowest when lime putty from Podpeč was used. However, façade layer made by Žiri putty possessed better or at least the same resistance to water penetration than the "Podpeč" façade. The application of fine mortars FM III and FM IV on rough rendering layer made by hot lime mortar revealed that water absorption of the obtained two-binder façade layer was close to that of a single binder façade layer with the same lime binder as that in the fine mortar.

Fig. 11 . Application of finishing layer (two-coat work).

Fig. 12 Finished façade – after application of coloured lime wash.

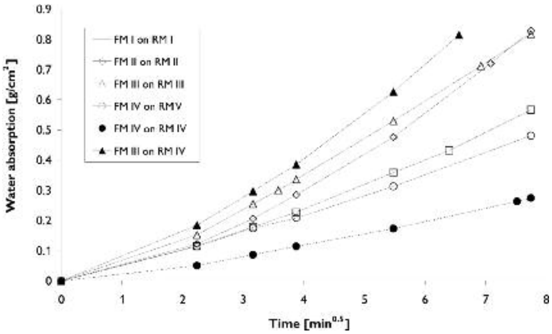

Fig. 13 Results of water absorption test on different façade layers.

Table 5 Average coefficient of water absorption (C_{aver}) of façade layers – 5 positions.

Façade	FM I on RM I	FM II on RM II	FM III on RM III	FM IV on RM V	FM IV on RM IV	FM II RM
C_{aver} [g/($cm^2 \cdot min^{0.5}$)]	0.07	0.11	0.11	0.06	0.04	0.1

** after 43 minutes*

Discussion

All rough mortars in this study attained an average compressive strength within the interval of 1.8 MPa ± 0.2 MPa after 90 days. However, their water absorption properties were very different. The highest water absorption was obtained for mortar RM III, prepared by dry hydrate lime, in laboratory and on site. The initial coefficient of water absorption was higher for rendering layers than for prisms, due to poorer compaction of the render, and this is valid for all the tested rough mortars. However, the results obtained on the prisms revealed that mortar RM III absorbed 93% of final water content only in the first 5 minutes and the rest in the following 55 minutes. The coarser porosity of this mortar is the most probable reason for such behaviour. The lowest water absorption was obtained for mortar RM I, prepared with traditional dolomitic lime putty, again in the laboratory and on site. For this mortar the initial water absorption (C_{m5}) is very low and thus after 5 min prisms absorbed on average only 20% of final water content. Afterwards, the coefficient of water absorption (C_{mtj-ti}) was increasing up to 15 min, resulting in a content of absorbed water equal to 38% and 54% after 10 and 15 min, respectively. The slow water absorption process is likely to be caused by the finer porosity of the RM I test specimens. Further on, C_{mtj-ti} started to decrease, but did not approach zero value until the end of the test. This means that mortar RM I might absorb the highest amount of water, if the test lasted longer than 60 min. Water absorption properties of mortars RM II, RM V/2 and RM IV, from calcitic lime putties, are very similar and are between properties of mortars RM I and RM III. After 15 min they absorbed between 83% (RM V/2) and 98% (RM IV) of their final water content, which was approximately the same for all the mortars.

As expected, after the application of finishing layers and lime wash, the water absorption of façade layers decreased immensely. The average coefficient of water absorption was by 3.4, 4.5, 11.5 and 8.8 times lower than for render (from the same binder) RM I, RM II, RM III and RM V/1, respectively. However, the used type of lime binder seems to have important influence also on water absorption properties of finishing layer, since the sequence of fine mortars regarding water absorption properties is very similar to that obtained for rough mortars, when the binder of rendering and finishing layer was the same. An important difference in behaviour that should be pointed out was obtained for fine mortar FM IV prepared with Žiri putty, which demonstrated the lowest water absorption among all fine mortars. Based on the obtained results we can conclude that not only properties of finishing layer but also properties of substratum (render) and/or interaction between finishing and rendering layers can influence the water absorption properties of the façade. As the porosity of the young rough rendering layer is influenced by the substrate also the porosity of the young thin fine layer is influenced by the hardened rough rendering layer. The application of the fine mortar FM IV to the render made from mortar RM IV (hot lime mortar) reduced the water absorption of the façade much more than the application of the same fine mortar to the render RM V/1. However, when fine mortar FM III was applied to render RM IV, the water absorption of the façade was almost the same, compared to the façade layer FM III on RM III.

Regarding workability of the rendering mortars, mortars RM I and RM II were selected by the skilled workers as the best solution, and mortar RM V could be an appropriate choice as well, with a slight reduction in the binder content. The workers were not satisfied with mortars RM III and RM IV. Lack of experience with mortar RM IV (hot lime mortar) is the most probable reason for their selection.

Among fine mortars for the finishing layers, the workers were most satisfied with mortar FM IV and quite satisfied with mortar FM II. However, in the future, the lime putty used for mortar FM II should be sieved before usage. It may not be excluded that the good workability of FM IV may have had a favourable effect of the density of the outer layer.

The putty from Žiri (RM V and FM IV) indicated that the traditional slaking process could be more important than burning of limestone in the traditional way. With industrially produced quick lime of uniform and good quality, slaked and matured in the traditional way, we may obtain lime putty of good and uniform quality.

The high thickness of rendering layers in some areas was estimated as problematic. We believe that the decision for an even rendering surface and thus very thick parts of rendering layers on rubble masonry was not appropriate. The rendering layer should be carried out by throwing the mortar and subsequent floating and troweling, in order to obtain compact render with maximum thickness of 2 cm.

Conclusion

Despite the relatively high thickness of rendering layers in some areas and partial falling down of the thicker parts after the rainy period, all of the finished façade layers were of good quality and some of them were excellent. We proved that skilled workers can make pure lime façades with good quality even in unfavourable environmental conditions (northern wall and high humidity in the lower part of the wall, applying of rendering and finishing layers in autumn, rainy period after application of renders, etc.). Considering all experiences and results obtained during the study so far, we would recommend calcitic lime putties from Stranje and Žiri as the most appropriate for pure lime façades in Slovenia. Adequate choice for the rendering layer could also be hot lime mortar made from the SIA quicklime. However, since in Slovenia this technology has not been in use during the last decades, it has been recently introduced by Austrian colleagues to the participants of a workshop about lime technologies, we would recommend hot lime mortar technology for Slovenia only when skilled workers master it in detail.

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Test results presented in the paper were obtained during the study, part of which is also diploma work of student Primož Novak. Authors of the paper wish to thank Primož Novak for his contribution to the paper.

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