Limewater in the consolidation of historic lime renders and plasters: Experience of its preparation and application in the Czech Republic

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Historic plasters and renders are important elements of many traditional historic buildings. They not only protect wall surfaces from deterioration but also provide information; effectively, they are a document of the materials and processes used in plastering and rendering. In some instances, they give an insight into the maintenance of the building and also provide evidence of historic building development, in particular the art of the plasterer and renderer in countries where old plasters and renders remain. In short, historic plasters and renders reveal a great deal about the minds and creations of practitioners in times past.

Studies of historic plasters and renders can provide evidence of changes in style and of certain events, in the form of surface treatment, surface coatings, wall paintings, drawings, written records, fire marks or battle scars. Undoubtedly, the list of their values and the information that can be gained from their study can be expanded, thus contributing further to our knowledge of the history of these materials and historic building maintenance. For these reasons, it is necessary to protect historic renders and plasters as found.

This can be achieved provided that the main principles defined by specialists for the care of historic plasters and renders are respected. These standards articulate that the aim of any intervention is to remove the causes of the material's deterioration, and if necessary, or possible, to improve selected properties of the material proportionally. At the same time, the primary aim is to protect cultural heritage values.

The main objective of historic render and plaster consolidation is not to change the composition of

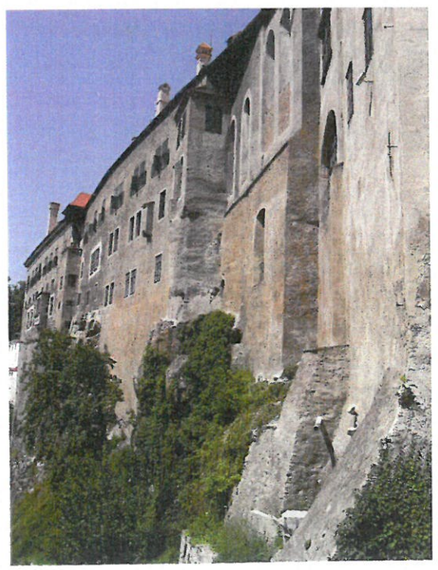

Fig. 1 (Left) Český Krumlov Castle, Czech Republic (13th–18th century). It is clear that different style renders, from different periods, were applied side by side on the castle facades. These renders had not been maintained prior to 2002, when conservation of the castle's large facades began. The bases of limewater transport systems were developed during the conservation activities here, which lasted until 2008. That same year, the project received the Europa Nostra Awards Prize. (Photo D. Michoinová, 2009)

is vast, especially when it is necessary to apply the consolidant repeatedly, in many tens of cycles, or in severely eroded areas, in many hundreds of cycles.

However, there are several situations when limewater is not recommended for use. For example, it is not suitable for the consolidation of clay materials or lime-based materials with low lime binder content (i.e. typically less than 15 per cent weight). Although it is not ideal to apply limewater to render or plaster that is heavily contaminated with soluble salts, this is rarely a problem other than close to ground level. Even here, limewater helps to consolidate the render while maintaining an open surface for water absorption and fast drying, and such areas are usually easily accessible for frequent maintenance.

There will be insufficient consolidation if the treatment is not applied adequately, or properly. For example, if there are too few cycles (less than ten) of limewater application, or if there is insufficient depth of penetration of the limewater into the material (i.e. application is stopped before full saturation occurs), full consolidation will not take place. Similarly, very slow consolidation occurs when renders are not able to dry properly between applications; under such conditions, the required physical and chemical processes cannot take place and full consolidation of the render will not occur. However, these problems can be overcome by adopting an informed application procedure.

Figs. 8, 9 and 10
The comprehensive system developed for limewater preparation, transport and application is shown in these plates. (Photos D. Michoinová)

Fig. 8 (Top)
Limewater preparation and storage system, showing drums for lime dissolution in water with a tank standing above the drums, on the scaffold, for limewater storage.

Fig. 9 (Centre)
A pump suitable for limewater transport.

Fig. 10 (Bottom)
Detail of plastic pipe network for transporting limewater to all levels of the scaffold, with a tap outlet for an ordinary garden hose connection.

Limewater in facade conservation from a practical point of view

On-site limewater preparation and transport

In order to be effective, the preparation and application of the consolidant should be as straightforward as possible. Therefore, a comprehensive system to simplify the preparation, transport and application of limewater has been designed and it is being improved continually.[4]

The system includes vessels for lime dissolution in water (mostly plastic tanks of 200-litre capacity), tanks for limewater storage (with the same volume) and a transport mechanism, which consists of a pump system and a network of plastic pipes that transport limewater to all levels of the scaffold. The pipes are fitted with several tap outlets, typical of those used for a garden hose connection. Flexible hoses for use on the scaffold are attached to these outlets and fitted with a water spray nozzle capable of providing variable spray patterns. In general, the limewater supply system will transport the consolidant to the point of use, powered by a pump.

Limewater is prepared on site by mixing lime (commonly in the form of putty, but powdered hydrated lime can also be used) with water. The lime is placed in the tank and water is added. The water stream stirs up the lime, and an electric stirrer can be used if necessary. As mentioned previously, the solubility of calcium hydroxide in water is low. Suspended non-dissolved lime forms sediment at the bottom of the dissolution tank. Consequently, the dosage of lime and water introduced into the mixing tank does not have to be precise, and it is better to add a little excess lime, than to add too little. In our experience, approximately five buckets (10-litre capacity) of lime putty are added to 200 litres of water.

During the lime hydroxide dissolution, the sedimentation of the suspended lime takes place in the dissolution tank. A calcareous crust also forms on the limewater surface due to the reaction of limewater with environmental carbon dioxide in the air. The presence of the colourless solution under the crust indicates the completion of the limewater preparation and its readiness for use. To control the dissolution process, it is recommended that regular pH measurements are taken using indicator strips dipped into the tank.[5]

The careful transfer of limewater from the dissolution tanks to the storage tanks is essential to prevent contamination of the colourless limewater with lime sediment from the bottom of the dissolution tank. Even a very small amount of contamination can result in the whitening of the render under consolidation, which is an unwanted side effect, especially during the first few cycles of the treatment of renders that are to be limewashed later. Such contamination must also be avoided on renders that are not to be limewashed. The carryover of lime sediment into the storage tanks can lead to blockages in the pump and pipework, thereby disrupting the work schedule, and measures should be put in place to avoid this occurrence.

A rough guide to limewater consumption, in our experience, suggests approximately 1 litre of limewater for every 1 m^2 of render or plaster for one cycle of treatment. This value can be taken into consideration when determining the size of the tanks needed on site. The preparation of limewater in the afternoon for use the next morning has been proven to be the most appropriate and efficient method of working. To improve the conditions for limewater dissolution and storage, it is recommended that the tanks be placed in the shade, or kept in as cool a location as possible.

Limewater for consolidation of historic renders and plasters

It is very important to consider the condition of the material to be treated prior to the works commencing. This is imperative to avoid failure of the historic fabric under consolidation. The impact of the increase in the weight of the mortar as a result of any consolidant application, particularly where saturation is a function of the recommended method, must be addressed at the design stage.

Before applying the consolidant, the most vulnerable parts of the render or plaster may require 'emergency rescue' to improve adhesion with the substrate. This includes introducing lime grout between detached render or plaster and its substrate, and lime mortar fillets and supports along exposed edges. It is a time-consuming but important process, and it must be done carefully because the aim of the treatment is to protect as much of the historic render or plaster as possible.

Figs. 11 and 12
(Left and below)
So-called 'emergency rescue' is carried out prior to the first limewater application. It is intended to improve the render's adhesion to the substrate and reaffix delaminated material. (Photo D. Michoinová)

Fig. 13 (Above) Limewater is sprayed from a hose with a water spray nozzle. (Photo D. Michoinová)

It is recommended that the limewater application is carried out by the same operatives, in pairs, for the duration of the conservation treatment. This brings many advantages, in that the operatives gain experience with the material quickly and are soon able to distinguish between non-problematic areas and more difficult areas that will require additional treatment. Having the operatives work in pairs ensures adequate rate of coverage and consistency of cover.

Prior to the works commencing, the purpose of the works should be explained and the procedures demonstrated to all operatives. Demonstrating good practice and testing staff are highly recommended, as soon as the limewater is available on the scaffold. This practice will minimise or prevent mistakes that could harm the render or plaster, or prolong the project. After appropriate introduction and training, limewater application usually takes place without serious problems.

Limewater consolidation of renders or plasters is thought to improve the mortar's internal cohesion, from the surface through the full depth of the material under treatment. This consolidation should not be confused with improving the adhesion of the renders or plasters to their substrate, which, if necessary, should employ other techniques.

Limewater is applied using either a soft fine spray (preferred) or by pouring a stream of limewater onto the surface of the render or plaster until the mortar is saturated. The intensity of the limewater spray or stream should be modified according to the condition of the mortar. Where the mortar is crumbly or friable, a softer lighter spray or stream is required. The intensity of the flow should be tested on the palm of the hand before application. No pain or pressure should be felt, only soft water droplets. As the cohesion of the mortar improves, the intensity of the flow can be increased gradually for the remaining applications.

The saturation of the mortar can be described as the moment when the limewater starts to flow over the surface of the substrate, without being absorbed. This constitutes a single application.

If grains of sand are washed down in a significant quantity from the material under treatment, particularly under a light application of the consolidant, the mortar is likely to be unsustainable in its current condition and to be unsuitable for limewater consolidation. In these situations, it will be necessary to choose another consolidation agent or alternative method of conservation, especially in the case of very valuable material.

Limewater applications must be repeated many times, and the render must be allowed to dry between each. Evidence of sufficient drying between applications is assessed by the surface returning to its original colour (lightening of the wet mortar). It is possible, in sunny and windy summery conditions, for up to four consolidation cycles to be completed per day. However, the application of limewater at the beginning and end of the day is common practice in a routine consolidation programme.

The effect of limewater consolidation is usually apparent after ten cycles of application. Often fifty to eighty cycles are needed to complete the treatment. In the climatic conditions of the Czech Republic (where two cycles a day are achieved in a five-day working week), this represents five to eight weeks of limewatering.

The consolidation effect may be assessed by light finger touch directly onto the treated surface. This should be done by the operatives after each application, once the mortar is dry. The amount of separated particles (sand grains) that transfer from the surface to the fingers should be lower after each treatment.

Fig. 14 (Right) Here, the limewater is applied by pouring. When the cohesion of the render permits, soft pouring is an effective way to saturate the render. Saturation has been achieved and is apparent when limewater starts to flow over the surface of the render without being absorbed. The colour change from dry to wet render is clearly visible: the wet render is visibly darker than the adjacent dry render. (Photo D. Michoinová, 2012)

More complicated methods of evaluation have been designed, of which the Scotch test or water absorption rate measurement are those commonly used.[6] For the most disintegrated or friable areas, consideration must be given either to applying more cycles or to using lime in suspension in limewater to deliver a higher concentration of lime in the consolidation agent.

The consolidation of lime render or plaster is complete when the mortar does not crumble when tapped or rubbed under light finger pressure. The decrease of water absorption is another measure that can be used for the evaluation of a satisfactory consolidation programme. When the mortar is strong and absorption is comparable with newly applied mortar of a similar composition, the consolidation can be deemed successful. The water absorption characteristics of the mortar after consolidation and of any new mortars on the same facades should be very similar. When limewater consolidation is carried out by experienced operatives, there should be no problem in determining the end point of the programme.

If the progress of consolidation is insufficient after fifty to eighty cycles, the use of a lime suspension in limewater is recommended for further and more affective consolidation, and should be assessed by test.

Limewater can be used for plaster consolidation in interiors, but only where no water-sensitive materials are present in the rooms and the drying rate of the limewater is no longer than twelve hours. In our experience, it is not necessary to undertake more than ten cycles of consolidation treatment on internal surfaces.

Limewater for the curing of new lime materials

Limewatering, using the limewater storage and transport system described previously, is a useful tool for pre-moistening the masonry substrate before mortar application (in rendering) and for moistening new lime material (mortars, plasters, renders or limewashes) to aid curing and inhibit early drying. The sufficiency of the limewater on the scaffold and the understanding of its use help to improve the quality of the lime materials used, and the practices followed, in the conservation process. This is very important when considering the installation of a pumped limewater supply system to all levels of the scaffold as the works are being designed.

Extermination of a bio-colonisation using a limewater treatment

Limewater has been shown to be an effective agent for the extermination of algae and lichen colonisations on facades. In some instances, treating a bio-colonisation with alkaline limewater causes the colony to dry up and die. Consequently, it is relatively easy to remove it from the surface, prior to carrying out further conservation works.

Consolidation using a suspension of lime in limewater

Another and more effective method of consolidating friable and weak mortars is the application of a lime suspension in limewater, which can be used even after tens of cycles of limewater treatment. The lime suspension in limewater is similar in its consolidation effect to the so-called nano-lime consolidants; however, the carrier medium is limewater, not alcohol as is used in the proprietary nano-limes currently available. The application of the suspension should be preceded by a minimum of twenty cycles of limewater treatment.

The consolidant can be prepared on site by adding a small quantity of lime to the limewater. Again, either lime putty or powdered hydrated lime can be used. After thorough mixing, the consolidant changes colour from clear to translucent, due to the presence of very fine suspended lime particles. Suspended lime in the agent increases the rate of consolidation of the render or plaster, especially on the mortar surface; however, slight whitening (blooming) of the surface occurs. This is not a problem for renders that will be limewashed after treatment. However, if it is essential to maintain

Fig. 15 (Above) Limewater is useful for pre-wetting the masonry before a new lime mortar application. It is also useful for moistening new lime materials (here a render) as part of the curing regime. The limewatering inhibits the early drying of the render and accelerates the carbonation of lime binder in the render. Here, the new lime render can be seen on the lower right, extending down part of the Švihov Chapel facade. (Photo G. Čapková, 2012)

Fig. 16 (Above) This plate shows an area of friable render after the application of a suspension of lime in limewater. This is used when limewater alone is not able to consolidate the mortar, even after tens of cycles. (Photo D. Michoinová, 2011)

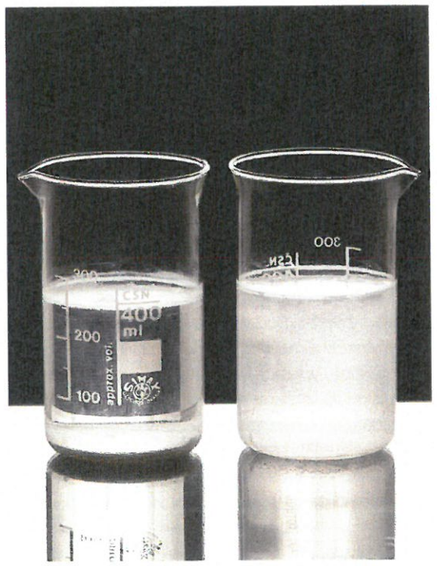

Fig. 17 (Right) Limewater (left) and lime suspension in limewater (right). These are the agents used for lime plaster and render consolidation. (Photo G. Čapková, 2017)

the surface colour of the mortar, and it is pigmented or coloured by age, it is possible to modify the colour of the lime suspension by adding pigments resistant to an alkaline medium (mainly earth pigments). The fine particles sieved from sand used in mortar supplements can also be used for this purpose.

The suspension is applied using a soft bristle brush. Two to five applications are sufficient to complete the consolidation of any problematic (friable) areas.

Processes related to limewater consolidation

It has been widely discussed elsewhere why limewater is not always sufficiently effective in the consolidation of lime mortars and also why consolidation (structural strengthening) takes place in lime-treated materials when the quantity of lime newly inserted into the material is relatively low.

In my opinion and from the tests I carried out, the water in the limewater plays an important role in the consolidation process. Firstly, it aids carbonation of the calcium hydroxide introduced in the limewater (by creating appropriate humidity within the fabric to encourage carbon dioxide diffusion and absorption). Secondly, as calcium hydroxide precipitates out of the limewater its concentration falls so the water is able to dissolve some of the original calcium carbonate binder in the render or plaster. When this in turn recrystallises, it promotes 'regeneration' or 'self-healing'. It significantly contributes to the structural strengthening of historic lime mortars treated with limewater.

I have observed many times, both *in situ* and from experimental works carried out in the laboratory, instances where it has been proven that limewater is effective for the consolidation of lime-rich plasters and renders.[7,8] It has been found that a minimum of 15 per cent by weight of lime binder in the material to be treated is necessary for the process to be successful. The higher amount of mortar binder, the more effective the consolidation. Materials without calcium carbonate, or with only very low amounts of it, are not suitable for limewater consolidation because the impact of the original binder recrystallisation is not sufficient to improve the material's internal cohesion.

Recrystallisation of the original binder can be initiated when lime mortars are treated by pure water, although to a limited extent. However, in my opinion, alkaline limewater is more helpful than pure water for the treatment of historic facades. Limewater treatment also prevents the formation of biofilm and the germination of plant seeds deposited on the surfaces of long-time exposed and dusty facades. Limewater brings new lime into the mortars, which is beneficial, even at a low quantity.

Conclusion

We have established in the Czech Republic that limewater is the preferred method for the consolidation of exterior renders. In our experience, the repeated wetting and drying of the renders during limewater consolidation does not significantly harm them, compared with the far more intense wetting and overloading that can occur when long periods of driving rain attack weak and friable renders.

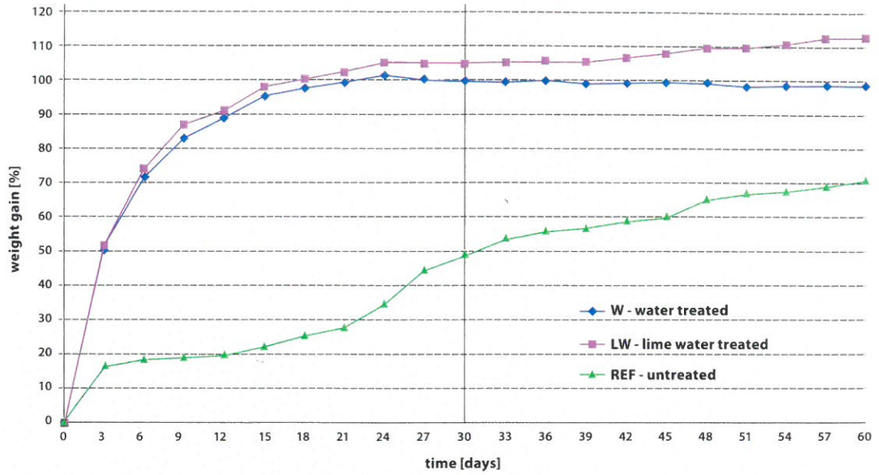

Fig. 18 (Left) Results of carbonation measurement on laboratory specimens. Changes in carbonation can be monitored by increasing mass of specimens in time. A value of 100% corresponds to the complete carbonation of the mortar binder. A further 13% by weight of calcium carbonate has been newly inserted, by absorption, into the mortar that was limewater treated twenty times.

mortar (cycles of treatment/days)	compressive strength [MPa]	flexural strength [MPa]	abrasion speed [g/s]	carbonation [%]	total porosity [%]
REF (0/30)	0.8	0.4	2.00	49.3	43.0
W (10/30)	1.6	0.7	0.13	99.9	42.8
LW (10/30)	1.7	0.8	0.10	105.2	42.4
REF (0/60)	0.6	0.3	1.9	71.1	42.8
W (20/60)	1.7	0.9	0.07	99.1	43.3
LW (20/60)	1.7	0.9	0.07	112.9	40.3

Fig. 19 (Left) Main results of laboratory tests on the impact of water and limewater in the treatment of lime mortar. The data show the increase in compressive and flexural strength and the decrease in the abrasion rate, with the increased number of mortar treatments with water and limewater.

This is the reason why limewater consolidation was used in the many large historic facade conservation projects where I have been involved as the conservation technologist, with very good results obtained. Based on my twenty years' experience, I can confirm that limewater is a very useful material not only in substrate consolidation but also in other processes employed in facade conservation. When used properly, it plays a very positive role in the durability and sustainability of the conserved materials.

My first introduction to limewatering took place twenty years ago. I did not learn about it from literature, but from a senior colleague, a conservation architect who successfully practised the technique. Since then, the consolidant has appealed to me for its use in historic render conservation: it fulfils the theoretical criteria for maintenance of historic building materials, it is not expensive and it is readily available on site. Together with contractors and conservators, my colleagues and I have started to improve the application process and to promote the use of limewater in conservation. I am

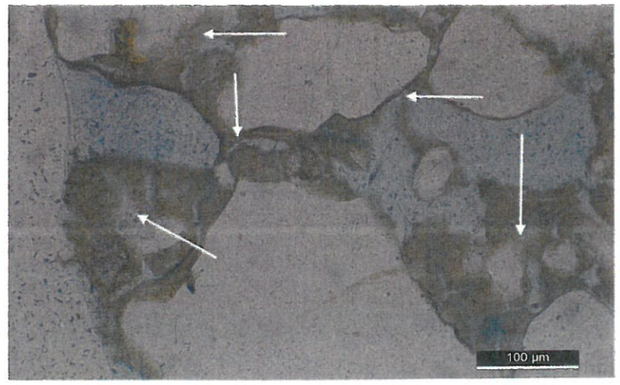

Fig. 20 (Above) Evidence of redeposition and recrystallisation of binder. This shows a view in plane polarised light (ppl) of an area close to an outer surface on a mortar prism after ten cycles of limewater treatment. The deposition of lime can be seen on the surface (left), with penetration along aggregate boundaries (via crack paths) to depth, with redeposition and recrystallisation both apparent within the paste (marked with arrows). Porosity is highlighted by the blue dyed resin. Field of view is 0.6 mm. (Photo W. A. Revie, 2017)

Fig. 2 (Above) Švihov Castle, Czech Republic (late 15th century). Although the castle's facades were not maintained prior to 2003, since that time their conservation has been ongoing. Limewater proved to be a very effective material for render consolidation and biocide maintenance as well as in the curing of new lime-based supplements. (Photo G. Čapková, 2016)

original materials but rather to consolidate it sufficiently to resist weathering – avoiding over-consolidation of the surface layers (which would result in reduction of surface water absorption or water vapour permeability) – without altering the colour, texture and appearance of the surface.

The degree of any change in the materials' properties is very important. However, it is difficult to quantify scientifically such changes in materials *in situ*, and it is quite impossible when the properties of renders differ significantly, even on the same facade. But is it somehow possible to evaluate, or control, the degree of change in the properties of plasters and renders during an intervention? On balance, I believe it is, particularly if we take into account another principle: the compatibility of materials used in conservation with the original plasters and renders. The so-called 'limewater treatment' conforms to this principle very well, but unfortunately it is not the most favoured agent used in lime render and plaster consolidation. It arouses either unequivocal sympathy or severe condemnation.

Nevertheless, from my experience of the use of limewater in conservation in the Czech Republic, it has been proven many times, in practice, that limewater can not only consolidate historic render but also is a useful agent for curing new lime materials, as will be explained later.

Material properties and performance of limewater

Using limewater for the consolidation of lime-based materials and calcareous stone has a long history.[1,2,3] It should be noted that limewater is a saturated solution of lime (calcium hydroxide) in water. It is a clear, colourless, highly alkaline solution, prepared by dissolution of lime in a large quantity of water. Calcium hydroxide solubility in water is low, and as the limewater is used in the form of a saturated solution it is impossible to over-saturate the solution. What is interesting is that solubility of calcium hydroxide in water decreases with an increase in temperature. Due to the alkalinity of limewater (pH about 12.4), it is important to follow the same safety rules as when working with lime, or other cementitious materials.

Fig. 3 (Right) Pernštejn Castle, Czech Republic (mid 13th century). In 2006 lime-rich renders on the palace were consolidated by limewater, followed by consolidation of minor areas using a lime suspension in limewater. The image shows the tower (centre) before its conservation. (Photo D. Michoinová, 2009)

Fig. 4 (Far left) Limewater is a clear, colourless saturated solution of lime in water. (Photo G. Čapková, 2017)

Figs. 5, 6 and 7 (Top, left and below) Historic renders that are friable and without a continuous limewash or other surface coating, which would inhibit limewater absorption, are suitable for limewater consolidation. (Photo D. Michoinová)

Limewater is widely available and inexpensive. From a philosophical point of view, it is better suited to historic lime-based mortars and renders than other commonly used consolidants. Limewater introduces into the treated lime substrate a binder that is chemically identical to the original binder; moreover, only a little of the new binder is introduced. Following the methods described in this article, there is a gradual and controlled increase in the consolidation of the fabric under treatment, which is both positive and proportional, and when using limewater the risk of over-consolidation is very small.

The consolidant is in the form of a solution, which experts and practitioners prefer, rather than a suspension. Unlike in some other consolidants, water is the only solvent used, and it poses little health risk to the people working with it (none if appropriate precautions are taken). It can be utilised during the usual building season and under normal site conditions.

Limewater is suitable for the consolidation of friable lime-based materials, particularly those that disintegrate under light finger touch. It should be used for the consolidation of lime plasters and renders that are not coated with a continuous limewash or other surface application, as such coatings may inhibit the absorption of the limewater.

In the Czech Republic, limewater has been used in many different ways in lime render and plaster conservation (consolidant, biocide, carbonation aid), thereby demonstrating that it is a versatile if under-appreciated material. Our experience of using limewater has illustrated that consumption on site

currently researching and working towards improving the methods of testing used to assess the consolidation effect of limewater treatment.

Every time limewater is recommended for use in the conservation of renders and plasters on historic structures, it is difficult to persuade uninitiated architects, conservators, contractors and their workers on the scaffold to use limewater, and, more importantly, to do it properly and honestly. However, after many years of achieving very good results with lime materials on conservation projects, I am convinced that the hard work involved in promoting the use of limewater in conservation practice has achieved the desired outcome. We have found that limewater, when used properly, helps to protect the value of historic renders and plasters, prolongs the lifetime of treated lime-based materials and improves their sustainability.

Acknowledgements

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Fig. 21 (Right) Facades of Švihov Castle palace (left) and chapel (right), both from the late 15th century. The renders of the chapel were consolidated with limewater and conserved with lime-based materials in 2006, while the palace renders are still waiting. This makes it possible to compare the appearances of these precious facades before and after the conservation intervention. (G. Čapková, 2016)

Endnotes

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2 J. Ashurst & N. Ashurst, *Practical Building Conservation, Vol. 3: Mortars, Plasters and Renders*. Gower, 1988. S. Peterson, 'Limewater Consolidation', in *Mortars, Cements and Grouts Used in the Conservation of Historic Building*. ICCROM, 1982.

3 B. Štorm, *Fundamentals of the Building Monuments Care*. SÚPPOP, 1965. (In Czech)

4 Many times it was shown that the use of garden pressure sprayers does not lead to the best result from limewater consolidation. The transport and application by this method are demanding and time consuming.

5 Limewater is a highly alkaline solution and its pH is about 12.4.

6 P. Kuneš, 'In Situ Evaluation of Historic Plaster and Render Consolidation', in *Journal for Heritage Conservation*, 72/5, 2012, pp. 393–396. (In Czech)

7 D. Michoinová, 'The Consolidation of Render and Plaster using Limewater II – Results of Experiments and Practical Experience with Limewatering in the Conservation of Historic Facades', in *Journal for Heritage Conservation*, 72/5, 2012, pp. 356–361. (In Czech)

8 D. Michoinová & P. Rovnaníková, 'High-calcium Lime Mortar: The Effects of Traditional Preparation and Curing'. APT Bulletin: *Journal of Preservation Technology*, 39 (4), 2008, pp. 23–31.