Basic physical, mechanical and hygric properties of renders suitable for historical buildings

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Abstract. Several renders suitable for historical buildings were designed and their basic physical, mechanical and hygric properties were tested. Lime was used as the main binder, three different pozzolanic materials, namely metakaolin and metashale as commercially produced admixtures and brick dust as a waste material from precise brick blocks manufacturing, were utilized as secondary binders instead of cement. Metakaolin and metashale showed a very good performance, as for the mechanical and water transport properties of renders, significantly increasing the compressive strength and decreasing the water absorption coefficient. On the other hand, brick dust was not found effective in that respect.

Keywords: renders, historical buildings, lime, pozzolans, properties

1. Introduction
It is a high concern of every nation to preserve the value of historical buildings as a part of its cultural heritage. Therefore, the restoration of such monuments is provided under the control of competent authorities, which specify the conditions of the restoration process and the used materials. Since the use of cement as a component of plasters dates from the twenties of the 20th century, it is common, that the historical buildings are covered with lime plasters and so a renewal plaster must be of as much as possible similar composition. However today, the lime plasters suffer greatly from the increasingly more polluted environment. Calcium carbonate, as the product of lime plaster hardening, is easily decomposed by exhaust acid gases [1]. On the other hand, it is known, that from the ancient times pozzolanic materials have been used as lime plaster admixtures to enhance its properties in both fresh and hardened state [2,3,4]. These were mostly volcanic materials, which are not available in the Czech Republic, but there are many other materials with pozzolanic properties on the market, either in the form of wastes from industrial processes or manufactured intentionally for the use as admixture to binders.

The pursuit is to understand better the action of the available pozzolanic materials in the hardening process of plasters and their influence on the plasters’ final properties. These are profusely used in concrete and cement composites taking part in the hydration process [5]. When incorporated into lime plaster, they hydrate to form calcium silicates and aluminates, similar to products of Portland cement hydration. The altered microstructure of the plaster is then responsible for better resistance to harsh environment and longer durability [6,7].
In this paper, a comparison of the action of three different pozzolanas in the lime plasters is presented. Brick dust is a by-product of precise brick blocks manufacture, which is generated in high amounts and need to be utilized somewhere. Due to its fineness and good pozzolanic properties it is a prospective material for use as an admixture in binders. Metakaolin and metashale are burnt and grinded intentionally in order to achieve specific qualities typical for binder admixtures. The comparison is made on the basis of basic physical properties, pore characterization of the plasters, mechanical properties and hygric properties.

2. Materials and methods

2.1. Materials

Figure 1 gives the schematic composition of studied plasters. The main binder was hydrated lime completed with 20% of a pozzolan, except from the reference mixture, which was bonded just by the lime hydrate. Silica sand of the 0-4 mm fraction was used as filler, its granulometry is shown in Figure 2. Water was dosed in order to achieve good consistency, i.e., the flow of the fresh mixture 165 mm in diameter. Three types of pozzolans were used, brick dust represented a waste material, while metakaolin and metashale were representatives of intentionally manufactured admixtures. Figures 3 and 4 show the distribution curves of the raw binder materials – lime, metakaolin, metashale and brick dust and Table 1 gives their chemical composition. After manufacture the plasters were marked as LR, LK, LL and LB, which stands for lime-reference, lime-metakaolin, lime-metashale and lime-brick dust plaster, respectively.

Figure 1. Composition of studied plasters.
**Figure 2.** Granulometric curve of silica aggregate.

**Figure 3.** Particle size distribution of binders.
Figure 4. Cumulative curve of particle size distribution of binders.

Table 1. Chemical composition of binder components.

| Component | Metakaolin | Metashale | Lime hydrate | Brick dust |
|-----------|------------|-----------|--------------|------------|
| Al₂O₃ [%] | 38.5       | 41.9      | -            | 20.0       |
| SiO₂ [%]  | 58.7       | 52.9      | -            | 51.3       |
| K₂O [%]   | 0.9        | 0.8       | -            | 3.2        |
| Fe₂O₃ [%] | 0.7        | 1.1       | -            | 6.0        |
| TiO₂ [%]  | 0.5        | 1.8       | -            | 0.8        |
| MgO [%]   | 0.4        | 0.2       | 0.5          | 4.5        |
| CaO [%]   | 0.2        | 0.1       | 99.3         | 11.5       |
| SO₃ [%]   | -          | -         | 0.1          | 1.0        |
| Na₂O [%]  | -          | -         | -            | 1.3        |

2.2. Methods

2.2.1. Basic physical properties and pore system characterization. Bulk density ρᵥ [kg m⁻³], matrix density ρₘₐₜ [kg m⁻³] and total open porosity ψ₀ [%] were measured as the basic physical properties. The used method was water vacuum saturation method [8].

The pore system characteristics were measured by means of mercury intrusion porosimetry. The experiments were carried out by Pascal 140 and Pascal 440 devices.
2.2.2. **Mechanical properties.** To characterize mechanical properties, compressive and flexural strength were determined on 40x40x160 mm samples according to ČSN EN 1015-11[9]. Firstly, the three-point flexural strength test was carried out and then on the left fragments the compressive strength test was performed.

2.2.3. **Hygric properties.** Absorption experiment was performed to assess the water transport properties characterized by the water absorption coefficient \( A \) [kg m\(^{-2}\)s\(^{-1/2}\)] and moisture diffusivity \( \kappa \) [m\(^2\)s\(^{-1}\)]. The 50 x 50 x 50 mm samples were immersed to water to the depth of 1 – 2 mm and their mass increases were recorded by a digital scale and saved automatically by a computer program. The generated curve of cumulative mass increase served for the determination of both parameters [10].

Water vapour transport parameters were measured by dry and wet cup methods. The cups were placed in a controlled climatic chamber with 50% relative humidity. In the dry cup method silica gel was used, while in the wet cup method water was placed in the cup, which induced partial pressures causing the transport of water vapour through the material. From the records of mass changes of studied samples, the water vapour diffusion resistance factor \( \mu \) [\( \cdot \)] was calculated [11].

3. **Experimental results**

3.1. **Basic physical properties**

| Plaster | \( \rho_v \) [kg m\(^{-3}\)] | \( \rho_{mat} \) [kg m\(^{-3}\)] | \( \psi_0 \) [%] |
|---------|-----------------|-----------------|-----------|
| LR      | 1805            | 2879            | 28.8      |
| LK      | 1767            | 2638            | 33.2      |
| LL      | 1741            | 2688            | 32.2      |
| LB      | 1761            | 2598            | 32.0      |

![Figure 5. Pore size distribution curves of studied plasters.](image)
Table 2 provides the values of basic physical properties, i.e., bulk density $\rho_v$ [kg m$^{-3}$], matrix density $\rho_{mat}$ [kg m$^{-3}$] and total open porosity $\psi_0$ [%]. Bulk density went down with the addition of all pozzolanas, most pronouncedly for plaster with metashale – LL, which was within 6%. The changes in matrix density were slightly higher, reaching the lowest value for plaster containing brick dust, which was by 10% lower compared to the reference plaster. It can be seen, that the presence of a pozzolana increases the total open porosity, in the worst case by 13%, which was recorded for metakaolin plaster.

Figure 5 shows the pore size distribution curves of studied plasters. While the LK and LL systems are strictly unimodal with majority of pores around 1 $\mu$m, the reference and brick containing mixtures LR and LB contain also certain volume of larger pores of diameter 15-100 $\mu$m. One observes re-finining effect of metakaolin and metashale in the plaster. It is caused by finer microstructure of ITZ zone compared to just lime-sand mixture due to the presence of CSH and CAH. The porosity results also indicate that brick dust pozzolan was not efficient enough to refine the ITZ.

3.2. Mechanical properties

Figure 6 gives values of mechanical properties – both compressive and flexural strength. The extreme value of compressive strength was recorded for lime plaster containing metakaolin – LK, which was almost 5 times higher compared to the reference mixture. Also metashale incorporation into the lime plaster mixture caused an increase in compressive strength, but in lesser magnitude – about 2.3 times higher than the reference. Plaster with brick dust showed comparable values of strength to reference mixture.

The values of flexural strength follow the same trend but with lower differences. The highest value for LK plaster was 2.7 times higher than reference, while metashale plaster showed 1.4 times higher value. The mechanical properties show that metakaolin and metashale are – at least in the studied system – more effective pozzolans than brick dust.

![Figure 6. Compressive and flexural strength of studied plasters.](image)

3.3. Hygric properties

Results of the water absorption test characterizing water transport properties are displayed in Table 3. The water absorption coefficient $A$ [kg m$^{-2}$s$^{-1/2}$] and moisture diffusivity $x$ [m$^2$s$^{-1}$] follow the same trend, showing that the reference mixture demonstrated the highest ability to water transport. By 35% lower value was recorded for plaster with metashale admixture, metakaolin caused decrease by 27% and brick...
dust only by 6%. These results are in good agreement with the porosimetry, where the ability of metakaolin and metashale to refine the large – capillary active – pores was documented.

Water vapour transport properties were characterized by the water vapour diffusion resistance factor [-] obtained by wet and dry cup methods (Figure 7). It can be seen, that reference plaster values are comparable with plaster containing metakaolin and metashale, only wet cup method showed an increased value for metakaolin plaster. However, brick dust caused an increase in measured values obtained by both wet and dry cup methods, in case of dry cup the water vapour diffusion resistance factor reached 2 times higher value. As it is favourable for plasters to be open to diffusion, but the liquid transport should be limited, it is not easy to reach these two somewhat contrary qualities in one layer plaster. Nevertheless, the low water absorption coefficient and satisfactory diffusion properties favour metakaolin and metashale plasters.

Table 3. Water transport properties of studied plasters.

| Plaster | A [kg m$^{-2}$s$^{-1/2}$] | κ [m$^2$s$^{-1}$] |
|---------|--------------------------|------------------|
| LR      | 0.206                    | 8.80E-07         |
| LK      | 0.151                    | 2.02E-07         |
| LL      | 0.133                    | 1.71E-07         |
| LB      | 0.194                    | 4.47E-07         |

![Figure 7. Water vapour transport properties of studied plasters.](image)

4. Conclusions
Renovation plasters should maintain the cultural value of historical buildings and thus it is required to reach as much as possible similar composition as the original plaster had. That is the reason, why lime is used as the main binder component. However, lime suffers from pollution in today’s environment and thus its lifetime is limited. Therefore, it can be favourable to incorporate pozzolanic admixtures in the plaster, which has been used in plasters since ancient times, although with different origin and composition.
This paper investigated the properties of lime plasters containing pozzolanic materials – brick dust as a waste product, metakaolin and metashale as commercially manufactured admixtures. Studied properties were basic physical properties, pore system characterization, mechanical properties, liquid water and water vapour transport properties. Although all pozzolanic admixtures caused an increase in open porosity, the investigated properties were mostly enhanced or at least at the same level which was probably caused by their action in the hardening process, creating calcium silicate- and calcium aluminate hydrates as the reaction products. The best mechanical properties were found for plaster containing metakaolin in the means of both compressive and flexural strength, while water transport properties showed the most promising values in case of metashale incorporation into the plaster. Brick dust plaster demonstrated neither enhanced performance nor significant worsening of investigated parameters.

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