Construction and Building Materials 142 (2017) 162–174

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The use of zeolite, lightweight aggregate and boiler slag in restoration renders

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HIGHLIGHTS

- We propose a novel render with zeolite for salty walls.
- We focused on assessing the usability of zeolite and boiler slag in restoration render.
- The frost resistance is nonlinear dependent on the strength properties of the render.

ARTICLE INFO

Article history:
Received 7 December 2016
Received in revised form 18 February 2017
Accepted 10 March 2017
Available online 19 March 2017

Keywords:
Render
Zeolite
Boiler slag
Lightweight aggregate
Salt crystallization
Frost resistance

ABSTRACT

For the protection of walls against salt-damp, various renders with different aggregates are proposed. The purpose of this study is to investigate the impact of natural zeolite, lightweight aggregate and boiler slag additives in the production of cement-lime renders meant for salty walls. The article presents laboratory examinations of their basic physical parameters such as water absorption, capillary absorption, water vapour permeability, absorptivity, sorptivity, density, total porosity, compressive and flexural strength. In addition to studies of the basic physical properties of the renders, frost and chemical corrosion resistance tests were conducted. Special additives to improve the properties were used such as hydrophobizer, methyl cellulose – a water-retaining additive, ethylene vinyl acetate copolymer powder, as well as a redispersive additive to improve adhesion. Apart from white Portland cement CEM I 52.5 R, blast furnace cement CEM III was also used, wherein the composition contains coal ash.

The highest efficiency of render corrosion protection was obtained by the renders with Portland Cement CEM I 52.5 R and boiler slag. The experimental results showed that the mortars modified by natural zeolites and boiler slag, thanks to their porous structure, are distinguished by good sorption properties and can accumulate in themselves a sufficient amount of salt and ice.

1. Introduction

An appropriate choice of restoration renders is crucial to succeed in restoration works. Compatibility between the new renders and the original components of the masonry is very desirable [1,2]. Renovations of old, damp, salty walls must solve the problems of the presence of salts dissolved in water. It is often connected to reconstructing the damp-course and repairing the facade together with cleaning, pointing, surface strengthening, hydrophobizing, as well as repairing or replacing the old, destroyed renders, etc.

Salt crystallization causes stains, cracks, efflorescence and tarnishing on the wall surface. Chemical research works show that one of the most common salts is anhydrous sodium sulphate Na_2SO_4 and hydrated $Na_2SO_4{\cdot}10H_2O$. At temperatures below 32.4 °C, the salt connects with 10 water molecules $Na_2SO_4{\cdot}10H_2O$. This is related to a fourfold increase in volume and the hydration pressure is about 240 atm. Sodium sulphate after a few cycles of drying and impregnating causes the materials to disintegrate, even those with high durability and strength [3]. In the renovation of damp and salty walls, it is essential to apply a suitable system of restoration renders whose compounds are characterized by suitable parameters that are compatible with each other.

Restoration renders, also called WTA renders (Scientific-Technical Work Group for the Maintenance and Preservation of

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http://dx.doi.org/10.1016/j.conbuildmat.2017.03.079
0950-0618/

Buildings and Monuments) are treated as complex drying and desalinating systems. The standards for restoration renders are very rigorous and have been described in the German manual WTA-2-2-04 Sanierputzsysteme [4]. Restoration render should be characterized by [4,5]: high porosity (the air content in green mortar should exceed 25% and the porosity of the ready mortar should exceed 40%). This enables water crystallization inside the render pores, together with the hazardous salts without destruction of the render and wall structure. This causes increased frost and salt resistance. The air content in the fresh mixture should be greater than 20% and a suitable surface water absorptivity coefficient in 24 h > 0.3 kg/m^2. Compressive strength β_d should range between 1.5 and 5 MPa and the β_d/β_{bz} ratio (tensile strength) <3. Besides the above mentioned parameters, the renders should be characterized by high frost resistance, water resistance, salt resistance and hydrophobicity.

Renders and mortars with high durability often strongly bind with the existing material. This high bond strength can cause considerable damage to the bricked substrate if the restoration render needs to be removed during future conservation works [6]. Therefore, selection of the mortar for repairs must be compatible with the characteristics of the substrate. The characteristic feature of restoration renders is their high porosity and the ability to cumulate water-soluble salts contained in the walls, together with preventing crystallization at the render surface, which blocks rainwater penetration. In general, renders consist of three layers: the rendering coat, undercoat layer and the finishing layer. The rendering coat is characterized by great mechanical strength and hydrophobic parameters. The undercoat is the layer with great porosity and hydrophilic properties. Its aim is to accumulate water soluble salts. Finally, the finishing layer of the restoration render is a porous, highly hydrophobic mortar that forms a barrier against rainwater influence. It prevents salt cumulating in the damp layer and thus enables the evaporation of water contained in the wall by diffusion phenomenon. Besides porosity, pore size distribution is an important parameter as well because pores of a diameter greater than 60 μm are not capillary active, which was noted by Pavlíková M. et al. [7].

Renders used for salty brick walls, manufactured using traditional methods, do not exhibit constant adherence to the substrate, they crumble and fall off the walls. A too strong restoration render restrains movement and leads to stress that can cause failure in the original masonry [2,8,9].

Restoration renders with light filling materials like perlite, polystyrene or vermiculite store a great amount of salts but are quickly destroyed. Only renders which use trass as a filling material are suitable for protection against moisture and salinity. Nevertheless, it must be mentioned here that trass is a rock dark brown in colour, which hinders obtaining light-coloured renders and providing constant parameters of restoration renders.

Currently, the compounds of mortars differ depending on the producer and can contain: grey and white cement, hydraulic calcium or gypsum, quartz sand, calcium and lightweight aggregates (perlite, polystyrene, pumice, vermiculite), as well as additives modifying their parameters and colour. The authors of [7] studied six lime or lime-cement restoration renders with or without an addition of perlite or mineral filler. Based on the results obtained in that study, it can be concluded that the additives are the key factors which influence render pore structure and surface properties of renders and thus the moisture, salt transport and storage parameters. Lime render has demonstrated beneficial properties in the case of historic buildings, that is why it is frequently used on such wall surfaces. Renders with perlite transport saline solutions much slower than lime render.

Zeolites as an ennobling additive for mortar can create suitable features of restoration renders. The porous structure of a render with zeolite stimulates the migration of water from the applied render layer, which affects the hardening of the render and its mechanical strength [10]. Zeolites can increase the hydrophilic parameters of renders, that is why they ought to be applied together with a hydrophobic additive because one of the criteria to apply restoration renders is high hydrophobia [11]. With their unique hollow structure, zeolites are distinguished by good sorption properties and can accumulate a sufficient amount of salt inside [12].

Not only natural rock such as zeolite, but also artificial rock such as lightweight expanded clay and boiler slag aggregate may replace sand in renders. Using lightweight aggregates instead of sand lowers the strength parameters of the mortar. The low density of lightweight aggregates reduces the weight of the renders. The basic advantageous properties of the mortars are as follows: vapour permeability, high plasticity, stability, resistance to fungi and algae [13]. In the paper by Corinaldesi V. et al. [14], wood waste by-products were used as mortar filler instead of sand. The mortars containing wood by-products were characterized by means of compression and bending tests, drying shrinkage, resistance to water vapour permeability, water capillary absorption, and thermal conductivity measurements.

Some characteristics of lightweight expanded clay aggregate are: fire resistant, light-weight, moisture impermeable, thermally insulate with a low conductivity coefficient (as low as 0.097 W/m·K), chemically inert, mould and mildew-resistant [15].

In paper [3], it was demonstrated that during the salt crystallization test there were no significant changes in the surface of the mortars with expanded clay aggregate. The samples showed very good resistance to the pressure of sodium sulphate crystallization. In another paper, [15], in the examination of frost resistance of hydrophobized lightweight aggregate concrete, the average loss in mass of all the samples did not exceed 0.5%. In the presented research, expanded clay aggregate was used as a lightweight aggregate.

As reported by Siddique R. [16], coal combustion by-products represent incombustible materials left after the combustion of coal in conventional or advanced clean-coal technology combustors. They include fly ash, bottom ash, boiler slag, and flue gas desulfurization by-products from advanced clean-coal technology combustors [16]. One of the power plant wastes arising from the combustion process of fine coal is boiler slag. The chemical composition of boiler slag constitutes about 50% silica SiO_2 and a substantial amount of aluminium oxide Al_2O_3. Crushed boiler slag after treatment may be used in construction e.g. concrete production [17,18].

Paper [16] briefly describes various coal combustion products, as well as the currently best recycling use options for these materials. Bottom ash or boiler slag can be utilized as both fine and coarse lightweight aggregates. Clean-coal ash can be used as a raw material in the production of cement. Lynn et al. [19] demonstrated in studies that as a fine aggregate in mortar, municipal incinerated bottom ash (MIBA) led to reductions in the consistency, compressive strength, flexural strength and elastic modulus, compared to natural aggregate mixes, due to its higher porosity and absorption.

Bakoshi et al. [20] showed that the freezing and thawing resistance of concrete using bottom ash as aggregates was lower than that of ordinary concrete, whereas the abrasion resistance was higher. On the other hand, Sidiqque R. [16] reports that although bottom ash material with a porous structure would be lightweight, these types of materials when used as concrete aggregates may not be very durable when subjected to freezing and thawing or abrasion. Smarzewski P. and Barnat-Hunek D. [17] showed in their investigations that concrete without waste materials is the most frost resistant. With an increasing content of boiler slag, the loss in mass increases and reaches a maximum value of 12% for high