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Study on the microstructure of thin-layer facade plasters of thermal insulating system during artificial weathering

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ABSTRACT

Investigations involving the influence of simulate weathering on the microstructure of thin-layer plasters laid on foamed polystyrene are reported. In order to examine internal changes, two kinds of properties were examined in time per 100 cycles during 400 cycles. One of the properties is an open porosity connected with pore structure tested by the mercury intrusion method (MIP), and total porosity examined by helium intrusion technique (HIP). The other property is mineral composition analyzed on X-ray diffraction (XRD) and scanning electron microscopy (SEM). The results have shown that changes of porosity, pore structure and chemical microstructure of plasters occured after successive weathering. In tested plasters, greater changes were noticed above the gaps of thermal insulation boards than beyond them. Porosimetry tests resulted in greater variations of open porosity over the gaps. Similarly, higher amounts of calcium carbonate were found in plasters and background mortars in places over the gaps of polystyrene boards.

1. Introduction

One of the most commonly used methods of thermal insulating of external walls is a system of thin-layer plaster on foamed polystyrene boards. But sometimes in practice, the failures of thin-layer plasters take place in such solutions. Usually they have the form of shellings [1] or cracks in the place above the joints of insulation boards. In consideration of the above, gathered experience and researches in this area, it was indicated that durability of insulation system depends on technical parameters of their components like: thermal insulation boards, stick mortar, reinforcing mesh, priming agent and plaster layer. The weakest of them is plaster rendering, which is subjected to direct influence of atmospheric agents, physical and chemical ones in the form of pollutants (Fig. 1). It is well known that presence of pollutions such as NO_x, SO_x, CO_2, O_3 in connection of water and porosity, increases the degradation of some building materials [2,3]. It brings about fine cracks, which enable greater penetration of water inside, assisted with shrinkage, temperature deformation, freezing action or chemical reactions. Failures of insulation systems are often caused by workmanship mistakes. One of them is the lack of grounding layer that brings about weak adhesion of plaster to the background and shelling in result. Other reasons can be as follows: too high absorption and lack of plaster's tightness which enables water to enter the background. These properties are also susceptible to easy penetration of carbon dioxide, and come into reactions with calcium hydroxide and yield as a result of calcium carbonate salts $CaCO_3$ [2,4] which can influence the plaster adhesion's decrease.

In the literature, the problem of microstructural changes in thin-layer plasters during weathering is not widely discussed. Investigations of physical and chemical properties on ordinary plasters with lime or cement binder are presented more broadly in the literature. Especially porosity is of great importance as it has a significant effect on the performance of the mortars in relation with water, frost, salt and chemical weathering, and therefore it partially determines durability. As a result, this parameter is often examined in study on mortars or cement pastes [5–12,21–29]. Much attention was focused on another important properties which influence durability of cementitious materials such as: permeability [13,16], diffusivity [8,11,17,19,29], mechanical properties [14–16,22,24,26], and shrinkage [18,24]. Some of the researches were carried out with regard of the influence of artificial weathering's simulate agents [2–4,25–27]. One of the main degradation mechanisms, that effects the properties of cementitious materials is carbonation. It was studied and discussed widely as well. Carbonation causes the change in material properties that are closely related to the microstructure, such as permeability, diffusivity, capillarity, etc. Carbonation as a consequence of the transformation of $Ca(OH)_2$ into $CaCO_3$ causes variation of the concrete and mortars microstructure by the decrease of their porosity [13,19–20]. Ngala [19], investigated carbonation effects on pore structure and diffusion properties of hydrated cement pastes and found that there was a reduction in the total porosity and redistribution in the pore sizes with larger amount of pores above 30 nm. Lawrence and others [21], investigated carbonation effects on the

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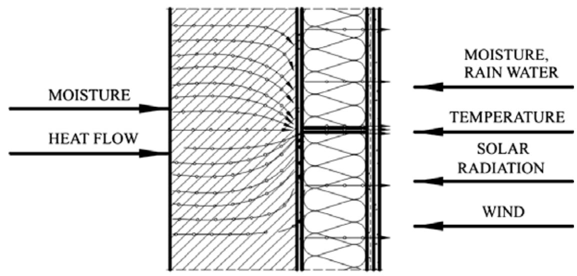

Fig. 1. Thermal insulation gap as diffusion bridge.

pore structure of lime mortars and found that the reduction of pores is larger than 0.1 μm in diameter, which is associated with the change of portlandite into calcite. Carbonation is of fundamental importance in making mortars harder and therefore more durable [20–23].

Because there are gaps in thermal insulation panels, they can have influence on greater diffusivity of CO_2 and chemical formation like $CaCO_3$. The evidence for this are experiences with lightweight insulation systems used in Upper Silesia of Poland since the 80s, especially when plaster mixtures were modified by styrene–butadiene rubber latex. Chemical investigations proved that between plaster layer and the background, greater amounts of calcite were found, which could be seen in form of salts. The places above the incontinuity of thermal insulation are heat and diffusion bridges for these agents (Fig. 1). Because of the temperature and pressure differences on both sides of the wall, an assumption was put forward, that the flow of heat and vapour especially, could be the reason for the formation of greater amount of calcium carbonate and microstructural changes. To recognize better the assumed phenomena inside the thin-plasters, research was carried out whereof the results are presented below.

2. Materials and description of the tests

2.1. Examined materials

Four types of commercial plaster mixtures were used to prepare thin-layer plasters, such as: polymer (acrylic), mineral, silicone, and silicate, each having the area of 40 × 220 cm and thickness of 2–3 mm. They were laid on slight polymer-cement mortar with reinforcing glass fibre mesh on polystyrene boards of the size of 50 × 100 cm and thickness of 10 cm, grouted by a polymer priming agent. Between the insulation boards, the gaps of 2 mm wide were made. The plasters were used as ready products and precise information about chemical composition are reserved by the manufacturer. However, on the ground of X-ray diffraction analyses (XRD), the presence of minerals is known. The main attention was focused on the first two plasters. Mineral plaster was made of ready dry mixture of cement and lime binder and fine quartz fillers smaller than 1.0 mm. Other plaster were laid in form of commercial wet mixtures consisted of system additions: mineral fillers of 1.5–2 mm, polymer or silicate binder and other modifiers. XRD analysis shows the presence of cement and lime components like: alite, belite, calcite $CaCO_3$ and portlandite $Ca(OH)_2$ in mineral plasters. Quartz and calcite were found in silicate and silicone plasters as well, but acrylic plaster revealed the presence of dolomite $CaMg(CO_3)_2$. All materials were used according to the technical requirements for construction of wet lightweight thermal insulation systems. According to manufacturer data, such plasters are weather-proof against water, frost and atmospheric contaminations. They have good vapour permeability, adhesion and durability, especially silicone and silicate plasters. All samples were laid on the testing wall of the climatic chamber and kept under polythene sheet and cured at laboratory conditions (RH 60 ± 5% and 20 ± 2 °C) during two weeks. After this period, the cover was taken off and samples were exposed for next two weeks in the same conditions.

2.2. Artificial weathering test

To study the influence of ageing process on the microstructure of plasters, after 28 days of curing, they were subjected to the test of simulate atmospheric conditions in the rotational climatic chamber [25]. The chamber gives different conditions of temperature, relative humidity, ultraviolet light and rain (Fig. 2). Tested programme was operated in such way, that each climatic cycle consisted of:

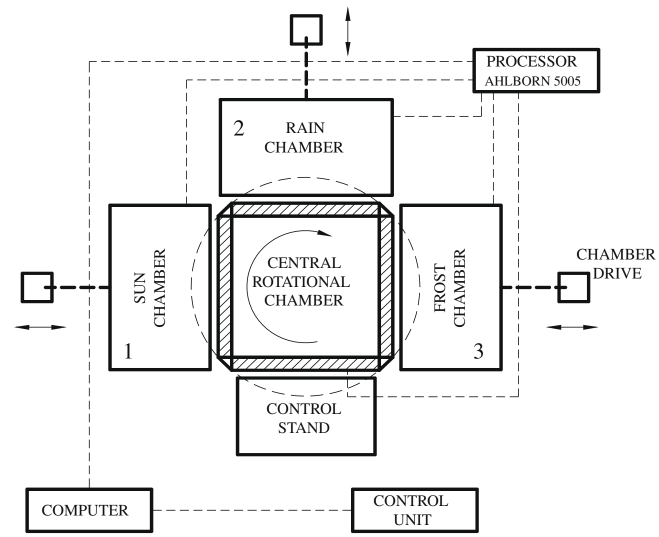

Fig. 2. Scheme of the artificial weathering chamber.

60 min of solar and UV radiation with heating to the temperature of +50 °C, 15 min of water spray and 60 min of freezing to −20 °C. The programme was carried out on the ground of own studies and experiences taken in cooperation with Norwegian Research Institute in Trondheim [25]. The test of 100 simulate cycles corresponds to about 2 years of natural weathering [25]. Examined plasters were subjected to the test of over 400 cycles.

2.3. Structural and morphological tests

(1) Mercury intrusion porosimetry (MIP) technique was carried out at each stage of the weathering test on the Carlo Erba 2000 apparatus within the pore size range of 3.7–7500 nm. In general, penetration data: intrusion pressure and volume, open porosity, pore diameter and specific surface area are automatically delivered according to the Washburn relation [21]. This relates to the radius r of pores, assumed to be cylindrical, to the imposed pressure P as follows:

$$P = \frac{-2\sigma \cos\theta}{r}$$

where σ is the surface tension of mercury and Θ is the contact angle of mercury with the material.
Calculations were performed assuming following constants: contact angle mercury/sample of 141.3°, mercury surface tension of 0.480 N m^{-1}, mercury compressibility of 0.109×10^{-10} N^2 m^{-1}. The MIP method unables to reveal the open pores with entrance inside them, like capillary, which are available for mercury.

(2) Total porosity was determined for plasters on the condition of tightness, based on bulk and real density. Bulk density was evaluated according to the water saturation test by masses weighed at three states: after drying in the temperature of 105 °C, at water saturation state and on a hydrostatical scale. Real densities of plasters were determined at each ageing state by helium intrusion technique (HIP) on helium Multivolume Pycnometer 1305 of Micrometrics Company. For good gas permeability, specimens were dried to constant moisture and crumbled to form fine aggregate.

(3) X-ray diffraction data (XRD) were obtained using the Seifert 3003 diffractometer with CuKα radiation, scanning at 2θ range of 10–50° with a speed of 0.2°/min.

(4) Scanning electron microscope analysis (SEM) was carried out on the electron microscope BS340 Tesla for morphology observation. Analysis was performed on a fracture surface which was covered with gold.

3. Results and discussion

3.1. Results of intrusion measurements

MIP measurements were applied to determine the pore structure differences in the porosity and pore size distribution for five states, at the beginning state and each 100 cycles to 400 cycles