Construction and Building Materials 79 (2015) 192–206

Contents lists available at ScienceDirect

Construction and Building Materials

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

Weathering effects on physical–chemical properties of external plaster mortars exposed to different environments

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HIGHLIGHTS

- All physical and chemical properties were changed under ageing, both in simulated and natural environment.
- Compression strength, vapour permeability and total porosity are getting worse the most during weathering.
- Changes of porosity and density are inconsistent, depend on a kind of plaster mortar binder.
- Lower amount of 0.1–1.0 μm pores and lower initial absorption below 9% influence greater on weathering resistance in time.
- For plasters on resin binders, the ageing does not result in significant changes, which proves their greater resistance.

ARTICLE INFO

Article history:
Received 24 January 2014
Received in revised form 7 November 2014
Accepted 27 December 2014
Available online 23 January 2015

Keywords:
Plaster mortar
Weathering
Accelerated ageing test
Physical and chemical changes

ABSTRACT

The paper presents results of a research on various types of external plasters, traditional and thin-layered, subjected to ageing tests, both in simulate and natural environment. A special ageing chamber for simulating of climate influences on building materials was implemented. The aim of the carried out study was to investigate a way of influence of artificial ageing and weathering process on basic physical and mechanical properties and to provide a comparison between them. Simultaneously attention was focused on the pore microstructure which was analysed by the mercury intrusion method (MIP). Additionally, the specimens were characterized from the crystal-chemical (X-ray diffraction, XRD), chemical (TG analysis) and morphological (SEM) point of view. On this ground ageing characteristics of the tested materials were possible to be defined, which describe occurred changes and can be useful for durability assessment. The results show that all tested properties were changed under ageing, both in simulate and natural environment.

1. Introduction – ageing tests

Material ageing is a universal phenomenon due to the importance of the weathering impact. This issue is also the subject of the research where the material properties change over the time is important [1–7]. The concept of ageing is understood to be the ensemble of physical and chemical changes occurring in the material structure and having an impact on performance and durability. The ageing of building materials concerns mainly building elements exposed to weather factors, such as: high and low temperature, solar radiation and rainfall, causing degradation phenomena, for example freezing-thawing. These phenomena may be reversible, like absorption, or irreversible. Resistance to these factors is essential in the period of use. This problem applies to such elements as: facades, roofing, windows, etc. For traditional facade materials, such as rendering mortars, the influence of moisture and temperature variability is essential, particularly the transition through 0 °C temperature and the effects of these interactions under cycles and variability that contribute to the formation of defects.

Research methods on ageing processes are based mainly on the analysis of material properties changes based on observations in natural or artificial conditions. The most reliable test results allowing to determine the behaviour of materials submitted to degradation processes caused by weather factors are given by long-term ageing tests in natural conditions over a period of several years. Such tests are conducted for many years. For example, in the 50-ies, in Fraunhofer laboratory in Holzkirchen, resistance tests on building external walls ageing were conducted. In UK in the 60-ies, Butterworth had studied for 9 years the behaviour of ceramic materials [8]. In the early 80-ies, Motohoshi and Nireki studied the durability of walls outer layers [9]. At the same time in Switzerland, Brolin performed tests of ageing at building on door and windows durability in natural climate [10], whereas in Brazil, PVC and

http://dx.doi.org/10.1016/j.conbuildmat.2014.12.079
0950-0618/

polyurethane reinforced with glass fiber tiles were tested [11] for the period of 48 months. Also in Brazil in the 90-ies, fiber-cement corrugated sheets were studied after 30 years of weathering [1] and roofing tiles after 14 years [12]. Also in Brazil in the end of 90-ies the durability of carbon fibre sheets after 14 years of weathering was investigated [13] and the cohesion of facade tiles was studied in Honk Kong [14]. In Poland, a center that performs accredited ageing tests for various building materials is the Building Research Institute in Warsaw [15]. These are just some examples of long-term studies. The disadvantage of such studies is their long duration. That is why, nowadays the trend is to apply for durability on the basis of short-term tests, so-called accelerated ageing tests [16–21] replacing long-term degradation processes in natural conditions. These are condensed methods based on appropriate procedures [22,23] or of a simulation origin in special climate chambers [24–26]. Commonly known are climate chambers for testing freeze resistance but also they are used for tests on resistance to moisture and temperature and ageing chambers for testing resistance to light. The light sources in the form of metal halide lamps used in chambers, produce a spectrum very similar to natural sunlight in the whole spectral range (UV, visible light, infrared) or a selective spectrum of ultraviolet radiation. The range of equipment application includes mainly the tests of paintings and coatings, plastics, building materials, such as: bituminous and plastic roofing, sealants or technical textiles, such as geotextiles. During the tests, essential parameters are marked, such as: mechanical or physical [27–29]. More reliable are natural methods, but they are long-term, recommended study period is at least 5 years. Whereas, artificial methods, albeit shorter (several weeks or months) represent the approximation of atmospheric interactions. For this reason, a parallel conduction of comparative research in natural and artificial conditions is recommended [5,15,21,27,30,31]. Regardless of the used method, after the end of the test, results are compared with samples not subjected to ageing. Resistance tests on microclimate is one of the ageing tests group. The second group concerns the effect tests of material additives on physical and mechanical properties and durability, including mortars and plasters [7,17,20,28,29,32]. As a result, characteristics of tested materials are obtained, which can have two general uses. The first one is the ability to implement the equation describing the kinetics of ageing. The second application is to determine durability curve and service life. In this case, the knowledge of limit value is requested, which is often of a contractual nature. As a measure of resistance, usually a partial loss of certain physical properties with respect to the initial value is adopted. For example, in studies of frost resistance of concrete elements with a direct method [33], an acceptable limit of 20% of resistance drop and 5% of weight loss is taken. The results of ageing tests thus allow to describe the changes caused by ageing and durability prediction, that is time, in which all use requirements are met. Due to the complexity of factors that determine durability, numerous methods for estimating and forecasting often recognize the problem in the approximate way on the basis of simplified models [34–36]. This paper presents the research results based on the example of plaster facades, which aim was to investigate how climate factors influence the basic physical and mechanical properties and how these characteristics are changing in time. Knowledge about this is useful in the development of material properties due to weathering resistance and also to estimate their durability.

2. Materials and research methods

2.1. Sampling for testing

Ageing tests were performed for eight traditional external plasters made of common mortars with various proportions of binder and aggregate: lime–sand, cement–sand and cement–lime–sand (Table 1A) and four typical thin-layer plasters: mineral, silicate, silicone and acrylic, made of ready-mixed mixtures (Table 1B). Of all of the mortars and plaster mixtures, samples of plasters were made, and for traditional mortars also beams 40 × 40 × 160 mm. Additionally for vapour permeability tests, plaster mortars were prepared in shape of discs with diameter of 90 mm and 8 mm and 3 mm thick. Plasters were laid on two different types of substrates: from cellular concrete blocks and sand–lime (silicate) blocks with compressive strength of f_c respectively: 2.60 MPa and 22.70 MPa. Two identical sets of samples were prepared for two testing stations: for the accelerated ageing chamber for simulating weathering conditions (Fig. 1a and b) and for testing walls exposed to natural weathering (Fig. 1c).

2.2. Artificial and natural weathering tests

The main research station is a climate ageing chamber for simulation of the atmospheric environment. The station consists of four chambers (Fig. 1a), of which the most essential is the central rotational chamber with four commercial walls with dimensions 1,55 × 2,10 m foe assembling test samples. Three other chambers cooperate with central chamber and simulate dominant climate factors. 'Sun' chamber gives radiation in the spectrum close to natural one. Visible radiation in the wavelength range 400–700 nm allows the setting of 20 metal halide lamps with a power of 8 kW producing temperature up to +75 °C. Additional set of ultraviolet radiators with wavelength 185 and 255 nm imitates UV radiation. 'Rain' chamber simulates rain and wind. The amount of applied water and air flows are regulated in terms of amplitude, frequency and speed. Water is applied from the plumbing, and minerals contained in it are adequate to rainwater containing urban pollution. 'Frost' chamber lowers the surface temperature of tested elements to −25 °C.

One ageing cycle includes one rotation of central chamber and takes 4 × (50–60) min. The duration of 100 cycles test is 4–5 weeks is depending on the number of cycles per day, usually 4–5 cycles. Climate parameters are programmed. For the sake of similarity, given values correspond to long-time averages. In research, the climate of Upper Silesia was taken as a representative. The performance of the 'frost' chamber was adopted as dominant because of the impact of passes through temperature 0 °C, as confirmed by Pihlajavaara [37] and Basińska [38] research experiences. So, the average number of days with freezing-thawing phenomenon was taken into account, which is 41 days in a year. Thus, 100 cycles in the chamber correspond to the period of 2.4 years in natural conditions of Upper Silesia climate. Other essential for durability long-term average data, that are included are: minimum negative temperature −15.9 °C, maximum solar temperature +59.9 °C for adopted radiation absorption coefficient 0.65, the intensity of solar radiation on a vertical plane 839.6 W/m^2, amount of rainfall on a horizontal plane in windy days 596.6 mm and corresponding amount of oblique rain on vertical plane 335 mm for an average wind speed of 2.8 m/s [39]. Operation time of the chamber was adopted on the basis of kinetics of reference extreme temperatures on tested material surfaces, which were 30–45 min, 50 min was adopted. For comparative purposes, plaster mortar samples were subjected to two ageing tests in simulated conditions for the period of 500 cycles (Fig. 1b), and in natural conditions for the period of 24 months (Fig. 1c). In intervals, respectively, every 100 cycles and every

Table 1A
Mineral composition of traditional plaster mortars in 1 m^3.

Kind of sample	Category	f_c (MPa)	C:L:S	Cement (kg)	Lime (kg)	Sand (kg)	Water (dm^3)
Lime–sand mortar L1	M0,3	0,64	1:3	–	432	386	500
Lime–sand mortar L2	M0,6	1,30	1:1	–	820	245	760
Cement–lime mortar CL1	M2	6,80	1:2:10	220	440	2200	470
Cement–lime mortar CL2	M4	10,70	1:1:6	220	220	1350	310
Cement–lime mortar CL3	M6	18,50	1:0,4:4	220	90	850	200
Cement–sand mortar C1	M2	12,28	1:6	420	–	2500	480
Cement–sand mortar C2	M5	18,37	1:5	420	–	2100	410
Cement–sand mortar C3	M8	25,07	1:4	420	–	1650	350