ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 16, No. 1. 2010

Durability Tests on Painted Facade Rendering by Accelerated Ageing

Rosita NORVAIŠIENĖ*, **Arūnas BURLINGIS**, **Vytautas STANKEVIČIUS**

Institute of Architecture and Construction of Kaunas University of Technology, Tunelio 60, LT-44405, Kaunas, Lithuania

Received 16 March 2009; accepted 01 September 2009

The paper offers a detailed description of the improved accelerated weathering test for a mild climate zone. Experiments have been carried out to improve the test methods of facade paint durability investigation by including the impact of air pollution. A painted rendering with the roughened surface was the principal test material. The test results in the climatic chamber have been compared with the ones obtained with the unexposed and naturally weathered samples. The performance assessment is based on the intermittent measurements of water permeability properties of the paint coatings expressed by 2 h surface water absorption rate of the painted samples during the weathering process. The correlation between natural weathering and the accelerated ageing has been established.

Keywords: acidic rain, painted rendering, natural weathering, artificial ageing, water absorption.

1. INTRODUCTION

For rendering systems, as for all other building facade materials, degradation rate depends on numerous agents and their combinations as well as possible synergetic effects on the deterioration processes [1 – 5]. The growing requirements for the quality of building construction and increasing atmospheric pollution urge to investigate the reasons that determine the ageing of the exterior finish under the impact of outdoor climate. The corrosion rate of rendering is a complex process governed by the combination of dissolution, precipitation and transport processes as determined by cement chemical composition (especially calcium content), paste matrix reactivity, aggregate reactivity, grading curve and composition [6].

Facade paints decorate the building facades and protect rendering against the deteriorating atmospheric effects. With the increase of the paint coating's water permeability during exploitation, the rendering under the coating is affected by the climatic factors more intensively – it gets aged sooner. Due to acidic precipitation caused by air pollution, additional acidic effects occur [1, 2, 7 – 11]. The impact of acidic rain as an activator of metal corrosion as well as that of atmospheric pollution on the monumental buildings and monuments constructed of stone, limestone, marble, and sand-stone are well known and has been thoroughly investigated [9 – 11, 13 – 14]. However, there is a lack of data on air pollution impact on contemporary painted rendering.

Natural and accelerated ageing tests are extremely important for determination the ageing characteristics of the materials and prediction of their real durability.

It is usually considered that accelerated ageing has a great advantage because of rapidly obtained results in comparison with natural weathering. It must be emphasized that the test results can be used only for the comparative purposes, because of problematic correlation between natural and accelerated weathering.

So far the correlation between various accelerated weathering tests and natural ones have not been established because the results obtained from accelerated tests represent weathering in unnatural conditions. Most of authors try to find out the correlation between natural and accelerated weathering, but their accelerated tests mostly imitate the impact of rainfall, solar heat and UV radiation [13 – 17].

It is important to define the laboratory parameters of the cyclic accelerated ageing of the facing materials in order to find out the relation between accelerated climatic ageing and natural weathering thus affording the opportunity to predict the real durability of the facade paints under natural ageing conditions.

Therefore the main objective of this paper is to develop a climatic cycle of accelerated testing for conditions of mild climate zone of Baltic States and to verify the reliability of this methodology for ageing of painted rendering.

Two types of durability tests have been carried out − under natural weathering and artificial accelerated ageing in a climatic chamber. For natural weathering the sample panel was constructed and attached to the external southwest wall of the building in the urban atmosphere in Kaunas (Lithuania). Artificial accelerated weathering has been carried out in a climatic chamber, which has been made in the Laboratory of Building Thermal Physics at the Institute of Architecture and Construction in Kaunas.

The performance assessment of accelerated and natural weathered samples was based on the intermittent measurements of water permeability properties of the paint coatings expressed by 2 h surface water absorption rate of the painted samples during the ageing process.

The results of accelerated laboratory ageing of painted renderings in the climatic chamber were compared with the ones obtained during natural weathering. The paper discusses the development of the climatic ageing cycle for the painted building facades modeled on the basis of Lithuanian statistical climatic data.

---

* Corresponding author. Tel.: +370-37-350799; fax: +370-37-451810.
E-mail address: *rosita.norvaisiene@asi.lt* (R. Norvaišienė)

2. EXPERIMENTAL

2.1. Materials

For the working out on the painted rendered facade durability tests related with the climatic destructive factors, the tests were performed with the plastic cement-lime rendering mixture (SIIa, S5, 0/2) samples. The 100 mm diameter and 24 mm thick rendering samples have been formed and painted with different facade paints.

In the study four types of facade rendering paints have been used: water vinyl co-polymeric (Univer S.p.a., Italy) – (V); acrylic, modified by silicon, water dispersive (SIA Vivacolor, Estonia) – (A); water polyurethane (Univer S.p.a., Italy) – (P) and the interior PVA latex (SIA Vivacolor, Estonia) – (E) paints. These are the typical examples of the rendering finish paints most often used in Lithuania. The sides of the samples were sealed with several layers of the epoxy paint coating.

2.2. The Parameters of Climatic Factors

The climatic cycle applied the samples was developed to imitate the natural climatic factors – UV solar radiation, temperature alterations and precipitation as based on the calculations of annual statistical data.

Modeling of solar impact in a climatic chamber. In Lithuania, the UV radiation makes only 6 % of the whole solar radiation. However, in the spectrum of all solar radiation its impact on the ageing of the finish material is the most extensive. Due to this fact, during the analysis of the impact of solar radiation on the ageing of the building materials, only the impact of the ultraviolet radiation has been modeled.

The intensity of ultraviolet radiation in a climatic test chamber has been calculated on the basis of the highest hourly intensity of solar radiation onto a horizontal surface, whose UV irradiation is approximately 65 W/m^2. The annual rate of UV radiation to a vertical South surface in middle of Lithuania territory comes about 29642 $Wh/m^2 \cdot yr$. Therefore the duration of a yearly UV radiation on a tested vertical surface was chosen $29642 / 65 = 456$ h/yr [18]. In the $(290 \div 450)$ nm ultraviolet radiation wave range, under the conditions of the climatic chamber the radiation intensity was taken as 40 W/m^2, because in longer wave range of UV radiation the lamps (tubes) irradiate less intensively. This period in a climatic chamber has embraced 456 h/year.

Modeling of temperature impact. Temperature fluctuation causes the deformations in the painted rendering's external layer, which by frequent recurrence exhaust the material. Actually, the intensity of drying as well as the hygric state of the tested materials depends on the temperature conditions. Thus, in the climatic chamber, the drying of tested materials was modeled with respect to:

1) high outdoor temperature (the first step);

2) incandescence of the surface due to direct solar radiation (the second and third steps).

Heating-drying regime. The following temperature regimes have been applied [18]:

29 °C (RH = $45 \div 50$ %) – 180 h/yr,
39 °C (RH = $25 \div 30$ %) – 100 h/yr,
49 °C (RH = $15 \div 18$ %) – 75 h/yr.

The first heating – drying step temperature (29 °C) has been found as an average statistical temperature from April to November. In average this temperature lasts for about 90 hours per year, but in the climatic chamber it has been prolonged to 180 hours to dry out better painted samples. The second heating – drying step temperature ($29 + 9 \cong 39$ °C) has been chosen as an effective surface temperature due to direct Sun irradiation of the surface during mean nebulosity. The third heating – drying step temperature ($29 + 19 \cong 49$ °C) has been chosen as an effective surface temperature due to direct Sun irradiation of the surface during clear sky weather.

The duration of each of heating – drying step has been adjusted to the need of sufficient drying out of samples during the heating - drying regime in the climatic chamber. The relative humidity of air has been chosen as a statistical humidity at a certain air temperature.

Unilateral freezing. The greatest deteriorating effect is being suffered by the external surface layer of moistened wall in which water gets frozen up and thawed. On the basis of the climatic data [18] it has been found out that the impact of the annual natural frost cycles on the painted rendering should be imitated by 10 freezing cycles per year each lasting for not less than 5 hours at the ambient air temperature of −10.5 °C.

Modeling of rain impact. On the basis of ten years statistical climatic data [18 – 20] (rain, its intensity, amount and duration; wind speed and direction; average monthly temperatures and monthly round day temperature fluctuation amplitudes) the moistening of the painted rendering during rain has been calculated as well as the duration periods of acidic and clean rains.

In [9] there are considerations that clean rain may be separated from the acidic rain, if during the rain the amount of rain water to horizontal plane drops more than 2 mm of water head; if 2 mm and less – it could be considered as an acidic rain.

The acidic water solution composed of H_2SO_4 and HNO_3 acids with pH = 2.5 were used to imitate the impact of natural precipitation and fog during the accelerated ageing of samples in the climatic chamber.

The authors relied on the research results, obtained during the earlier laboratory tests [7], during which the relationship between the impacts to painted samples after moistening them in different water solutions (whose acidities pH = 2.5, pH = 4.5 and pH = 7.0) was determined. On this basis, the total weathering time in a climatic chamber to imitate one natural year with use of acidic water solution pH = 2.5 was shortened to 24 round days.

Acidic rain and clean rain duration periods and their amounts affecting the south-west building wall in its most moistened places (where the intensity of the rain is about 2.5 times higher than the average value to a imaginary plane) were calculated from amounts to horizontal plane with the use of the specially developed computer simulation program "Moisture".

During creation of this program, laboratory tests were carried out and the surface water absorption and drying curves for the samples of the painted rendering were determined at different temperatures, wind speed and relative air humidity.

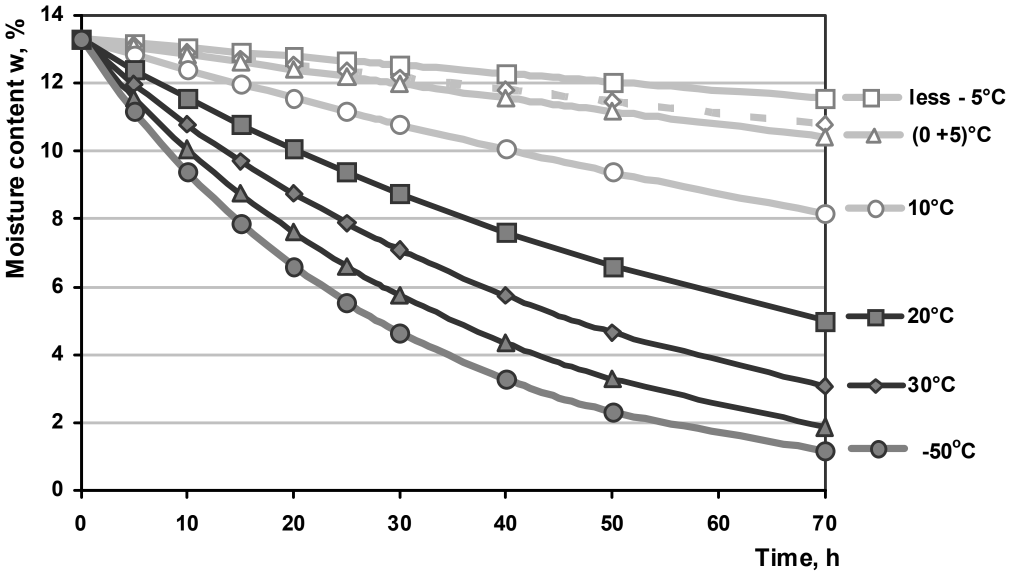

Fig. 1. The drying rates of the painted 24 mm thick rendering at different air temperatures (independent on a type of paint)

For imitation of water absorption and drying effect on the tested samples, 10 times per year of showering in climatic chamber with acidic water (pH = 2.5) has been chosen.

The laboratory experiments led to the determination of the fact that the winds of average velocities and relative air humidity do not have a significant drying effect on the painted surfaces as temperature does [21]. Therefore the wind impact and precise relative air humidity were not included into the accelerated climatic cycle. Even a type of the exterior wall paint cover does not make a significant effect on drying, contrarily to the water absorption rates during showering. Therefore the program "Moisture" was employed exclusively for the estimation of the impact of temperature (Fig. 1) on drying rate of the samples.

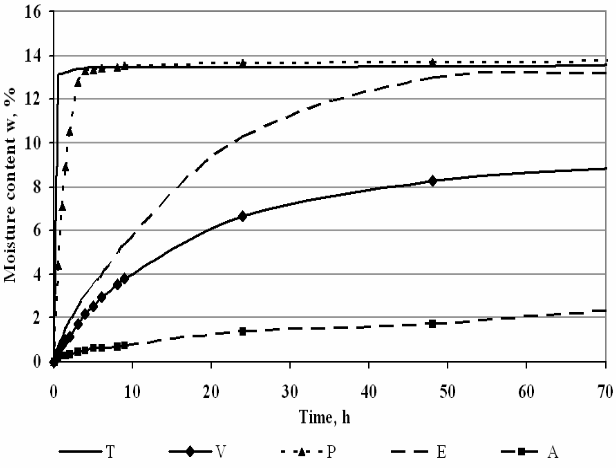

Fig. 2. The surface water absorption rates of the samples painted with different paints: V – water vinyl co-polymeric; A – acrylic, modified by silicon, water dispersive; P – water polyurethane; E – PVA latex paints and T – unpainted rendering sample

The water absorption rate curve of painted rendering has been chosen as a mean rate water absorption curve of four types of tested paint samples, i. e. painted with PVA latex paint (E) rendering sample.

Equation describing the water absorption curve E (Fig. 2) is as follows:

$w = -2 \cdot 10^{-6} \cdot z^4 + 0.0003 z^3 - 0.234 \cdot z^2 + 0.8213 z + 0.178$,

where z is the rain duration, starting from the dry state, h; w is the moisture content of a sample, %.

2.3. The Cycle of Climatic Test

The climatic cycle by which the samples were treated was worked out to imitate the natural climatic factors. The natural climatic impact through a round year on the most unfavourable places of the building facade was imitated in the climatic test chamber.

During 24 round days the natural one-year ageing effect was imitated in the climatic chamber (Table 1):

– for 48 h the impact of fog and dew at 9 °C;

– for 456 h the impact of the UV radiation 290 nm ÷ 400 nm intensity of 35 W/m^2 ÷ 40 W/m^2;

– freezing 10 times for 5 h at –10.5 °C;

– 10 times for 7 h rain imitation with the acidic water solution whose pH = 2.5;

– high temperature impact: 31 °C for 180 h; 39 °C for 100 h; 49 °C for 75 h.

Elimination of samples during the accelerated and natural weathering tests have been based on the visual inspection of revealed defects and on water absorption rate after 2 h moistening. The water absorption rate has been determined for the dry sample.

The earlier investigation [21] have shown, that 2 h water absorption coefficient of painted rendering is to be a reliable and simple indicator of ageing of protective properties of paint coating. However, the 24 h water absorption coefficient of painted renderings is not so sensitive and reliable.

Table 1. Yearly ageing in climatic chamber of most unfavorable places of external painted rendering walls

Description	Air temperature, °C	Process	Time, h	Repetition, times
Fog imitation; UV irradiation	9.0	1 minute showering with pH = 2.5 water solution with following 29 minutes pause; continuous UV irradiation	48	96
Rain, freezing, drying; UV irradiation	5.0	showering with pH = 2.5 water solution	7	5
	–11.0	freezing	5	
	–	pause; just UV irradiation	0.5	
	29.0	1 – heating; UV irradiation	18	
	39.0	2 – heating; UV irradiation	10	
	49.0	3 – heating; UV irradiation	7.5	
Fog imitation; UV irradiation	9.0	1 minute showering with pH = 2.5 water solution with following 29 minutes pause; continuous UV irradiation	48	1
Rain, freezing, drying; UV irradiation	5.0	showering with pH = 2.5 water	7	5
	–11.0	freezing	5	
	–	pause; just UV irradiation	0.5	
	29.0	1 – heating; UV irradiation	18	
	39.0	2 – heating; UV irradiation	10	
	49.0	3 – heating; UV irradiation	7.5	

Note: UV radiation 290 nm ÷ 400 nm intensity of 35 W/m^2 ÷ 40 W/m^2

3. RESULTS AND DISCUSSIONS

The surface water absorption rate of the building materials shows an amount of water that has been absorbed by the surface due to the material's capillary sucking potential. The transfer of the liquid moisture in a material is caused by the capillary suction, osmotic and gravitational forces.

The earlier investigations [21] revealed, that the change in 2 h (initial) water absorption rate of the painted rendering should be considered as a reliable and simple indicator of the ageing of the protective properties of the paint coating. The commonly used 24 h water absorption coefficient of the painted renderings is not so precise and representative parameter. The other authors earlier have come to the same conclusion: according to Parrott, L. J. [22] and Vivian, W. Y. [23], the traditional 24 h testing approach for water absorption cannot give the accurate results.

Table 2 presents the results of the 2 h surface water absorption rate changes observed under natural weathering and during the climatic ageing in the chamber. In the case of the imitation of a natural ageing in the climatic chamber, the water absorption rate of the painted rendering samples (E) approaches to the absorption rate of the unpainted rendering already within two years. Highly rendering protecting acrylic paint coating (A) in the climatic chamber undergoes ageing noticeably much slower. After four years of ageing their protective properties still remain better than those of the vinyl co-polymeric (V) paint coating after a year of ageing.

The degree of the water absorption rate diminish after a few years of ageing due to the new combinations composed in the rendering, in other words, due to salts crystallization [7, 23].

After the test was carried out in chamber, an obvious increase of the samples' initial surface water absorption rate was found.

The ageing of the painted coating during natural weathering was slower than in the climatic chamber. Natural weathering lasted for 2 years and the climate of this period was mild in comparison with an average statistical year.

The test panels used for natural weathering were located in the middle of the southwest wall, i. e. the place that was inconsiderably moistened by the driving rain (about 0.41 times in comparison with an undisturbed vertical plane).

The degree of water absorption in natural weathering also diminishes due to the salts crystallization (Fig. 3, compare months 12 and 24).

Table 2. The evolution of 2 h initial surface water absorption rate during the accelerated and natural weathering, %

Sample	Untreated	Accelerated ageing in the climatic chamber				Natural weathering	
		1 year	2 years	3 years	4 years	1 year	2 years
V	0.58	4.24	8.44	8.16	7.26	6.97	6.42
E	1.65	8.52	10.69	10.54	–	5.94	9.47
P	0.49	5.29	9.18	7.09	6.63		
A	0.22	0.20	0.41	1.86	2.53		

The natural weathering has started on May, and with the time the paint coating has aged, the water absorption increased significantly – after 1 year of weathering on next May it was about 6.97 %. Later on due to rainy and foggy period (June-August) the water absorption has diminished because of swelling of paint coating (the cracks area in paint coating reduces). The seasonal changes have an impact on the water absorption of the naturally aged samples. H. Kus [17] in the exposure program with rendered autoclaved aerated concrete at the test cabin in Sweden states, that the results of moisture content of naturally exposed samples decreases with shorter exposure period and increases with longer period and then decreases again. We also have discovered the same phenomenon. Therefore the results of the water absorption rate during each calendar year of natural weathering were averaged. The increase of the averaged 2 hour water absorption rate after one year of weathering reached $\Delta\omega = 0.57$ % (Fig. 3).

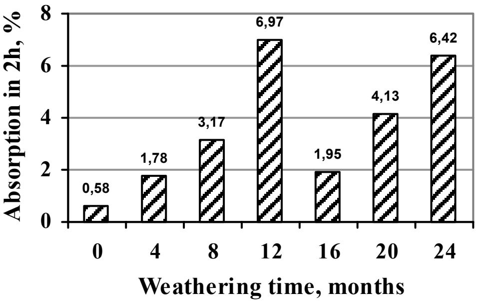

Fig. 3. The 2 h surface water absorption rate of the samples (V) painted with the water based vinyl co-polymeric paint during the natural weathering

During the accelerated test in the climatic chamber, the intensities of the driving rain onto a vertical southwest wall surface were increased 2.5 times thus imitating the most unfavourable rain-washed and moistened places on the wall. Hence by having estimated the discussed coefficients, during natural weathering the annual increase of the water absorption rate in the samples (V) coated with the water-based vinyl co-polymeric paint could make up to $0.57\ \% \cdot 2.5/0.41 = 3.45\ \%$ (2.5 times – rain intensity in most unfavourable places of a wall; 0.41 times– rain intensity in a middle area of a wall). Therefore, it is possible to claim that, practically, the accelerated ageing in the climatic chamber corresponds to the ageing of the samples under natural conditions.

After four years of ageing in the climatic chamber, the decision was made to stop the test due to the physical and aesthetic deformity of the samples. The paint coating lost its physical protective properties; blisters appeared and the paints got deteriorated (i. e. the samples were worn out aesthetically).

4. CONCLUSIONS

1. In general, the data obtained from both natural weathering and modeled accelerated cycling tests show similarities in ageing and evolution of moisture characteristic changes of the samples.
2. This method for determination of the durability of the exterior wall finish with regard to the impact of air pollution might be widely applied for the more accurate prognosis of the exterior wall finish durability dependant on the climatic specificity of a certain locality.
3. The duration of each of heating – drying step has to be adjusted to the need of sufficient drying out of samples during the accelerated ageing in climatic chamber.
4. The most significant factor for the facade paint durability is the impact of moisture deformations caused by the moistening-drying cycling, which is strengthened by acidic precipitation. The ageing of the paint coating put on the rendering is faithfully reflected by the increment of the sample's 2 h (initial) surface water absorption rate.
5. The offered method for the investigation of the painted rendering's durability can be employed both for the determination of the physical ageing of the paint coating and for the estimation of its aesthetic degradation either.

Acknowledgments

Investigations are supported by Agency for International Science and Technology Development Programmes in Lithuania.

REFERENCES

1. **Kucera, V., Henriksen, J., Leygraf, A. Coote, T., Knotkova, D.** Materials Damage Caused by Acidifying Air Pollutants *4 Year Results from an International Exposure Program within UN ECE Proc. 12th Int. Corros. Congr., Houston* Vol. 2 1993: 494 p.
2. **Norvaisienė, R., Miniotaitė, R., Stankevicius, V.** Climatic and Air Pollution Effects on Building Materials *Materials Science* (*Medžiagotyra*) ISSN 1392-1320 9 (1) 2003: pp. 102 – 105.
3. **Miniotaitė, R.** The Durability of Finishing Layer External Surface of Building Walls. Monograph. Kaunas: Technologija, 2001: 75 p. (in Lithuanian).
4. **Haneef, S. J., Dickinson, C., Johnson, J. B.** Effects of Air Pollution on Historic Buildings and Monuments and the Scientific Basis for Conservation. Corrosion and Protection Center, University of Manchester *Report on a Research Project Supported by the Commission of the European Community*, 1999.
5. **Uemoto, K. L., Ikematsu, P., Agopyan, V.** Comparative Evaluation between Accelerated and Outdoor Ageing of Brazilian Paints. Part One. *10DBMC International Conference On Durability of Building Materials and Componens* LYON (France), 2005.
6. **Robin, E., Beddoe, H., Dorner, W.** Modelling Acid Attack on Concrete: Part I. The Essential Mechanisms *Cement and Concrete Research* 35 2005: pp. 2333 – 2339.
7. **Norvaišienė, R., Burlingis, A., Stankevičius, V.** Impact of Acidic Precipitation to Ageing of Painted Facades' Rendering *Building and Environment* ISSN 0360-1323 42 2007: pp. 254 – 262.
8. **Haynie, F. H., Spence, J. W.** Air Pollution Damage to Exterior Household Paints *Journal of Air Pollution Control Association* 34 1984: pp. 941 – 944.
9. **Brimblecombe, P.** The Effects of Air Pollution on the Built Environment. University of East Anglia, UK, 2002: 428 p.

10. **Watt, J., Tidblad, J., Kucera, V., Hamilton, R. (Eds.)** The Effects of Air Pollution on Cultural Heritage. XII, ISBN: 978-0-387-84892-1, 2009: 299 p.
11. **Turkington, M. E., Viles, H., Smith, B. J.** Surface Change and Decay of Sandstone Samples Exposed to a Polluted Urban Atmosphere over a Six-year Period: Belfast, Northern Ireland *Building and Environment* 38 (9 – 10) 2003: pp. 1205 – 1216.
12. **Dorner, H. W., Beddoe, R. E.** Prognosis of Concrete Corrosion Due to Acid Attack *9th Internat. Conf. Durability of Building Materials*, Brisbane, Australia, 2002 (March).
13. **Boisseau, J.**, **Campbell, D., Wurst, W., Brennan, P. J.** Accelerated Acid Etch for Automotive Cleacoats *In: 1st European Weathering Symposium* Prague, Czech Republic, September 25 – 26, 2003: 12 p.
14. **Magnus, P., Bo, C.** New Accelerated Weathering Tests Including Acid Rain *Journal of Coatings Technology* ISSN 0361-8773 74 (1) 2002: pp. 69 – 74.
15. **Gordon, B. P., Hel, L. Ellingson, L., Tallman, D. E.** Studies of a New Accelerated Evaluation Method for Coating Corrosion Resistance: Thermal Cycling Testing *Progress in Organic Coatings* ISSN 0300-9440 39 (1) (32 ref.) [Notes: Selected papers] 2000: pp. 67 – 78.
16. **Teruzzi, T., Jornet, A.** Artificial Weathering of Building Components: Experimental Results on External Walls *In: Proceedings of the 9th International Conference on Durability of Buildings Materials and Components* Brisbane, Australia, 2002. Paper 85.
17. **Kus, H.** Long-term Performance of Water Repellants on Rendered Autoclaved Aerated Concrete. Royal Institute of Technology, Stockholm, 2002: 88p.
18. RSN 156-94 Building Climatology. Ministry of Building and Urban Development of the Republic of Lithuania. Vilnius, 1995: 136 p. (in Lithuanian).
19. **Šopauskienė, D., Jasinevičienė, D., Stapčinskaitė, S.** The Effect of Changes in European Anthropogenic Emissions on the Concentrations of Sulphur and Nitrogen Components in Air and Precipitation in Lithuania *Water, Air and Soil Pollution* 130 2001: pp. 517 – 522.
20. **Šopauskienė, D., Jasinevičienė, D.** Time Trends in Concentrations of Acidic Spesies in Precipitation in Lithuania in 1981 – 1995 *Atmospheric Physics* 19 (1) 1997: pp. 35 – 39.
21. **Norvaišienė, R.**, **Burlingis, A., Stankevičius, V.** Variation of Water Absorption as a Parameter of Ageing of Painted Facade Rendering *2nd European Weathering Symposium EWS, Sweden,* ISBN 3-9808382-9-3, 2005: pp. 359 – 368.
22. **Parrott, L. J.** Variations of Water Absorption Rate and Porosity with Depth from an Exposed Concrete Surface: Effects of Exposure Conditions and Cement Type *Cement and Concrete Research* ISSN 0008-8846 22 (6) 1992: pp. 1077 – 1088.
23. **Bačauskienė, M., Norvaišienė, R.** The Changes of Render Properties by Acid Rain *Cheminė technologija* ISSN 1392-1231 4 2005: pp. 67 – 70 (in Lithuanian).
24. **Tam, Vivian, W. Y., Gao, X. F., Chan, C. H.** New Approach in Measuring Water Absorption of Recycled Aggregates *Construction and Building Materials* 22 (3) 2008: pp. 364 – 369.