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Study on the Microstructure and Water Absorption Rate Changes of Exterior Thin-layer Polymer Renders During Natural and Artificial Ageing

Gintarė GRICIUTĖ [1] *, Raimondas BLIŪDŽIUS [2]

[1] *Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Studentų st. 48, LT-51367 Kaunas, Lithuania*

[2] *Institute of Architecture and Construction of Kaunas University of Technology, Tunelio st. 60, LT-44405, Kaunas, Lithuania*

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This paper presents the experimental investigation results of finishing render of external thermal insulation composite systems (ETICS). The study involved natural (long-term) and artificially accelerated (short-term) ageing including effect of UV radiation. The cycle of accelerated UV radiation ageing test, imitating the impact of one natural year in Lithuanian climate conditions, have been used. In order to determine the visual, microstructure and water absorption changes and find out the correlation between the natural and artificial weathering, the results of tested aged and untreated samples have been compared. The main attention was focused on the changes of structure and physical properties after short-term and long-term ageing tests.

The structural changes of render surface of ETICS after UV tests were determined using scanning electron microscope (SEM). The water absorption of ETIC system was determined by partially submersion. Analysis of render surface microstructure showed that UV rays destroy the continuous polymer film on the acrylic and silicone render surface, but water absorption of ETICS does not increase in both cases. Water absorption rates of acrylic, silicon and silicate renders after one natural year of exposure become similar. The polymer film formed on exterior acrylic and silicone render surface was destroyed during one year natural and equivalent laboratory ageing. In conjunction, the carbonization process was taking place, the newly formed calcite crystals covering pores and capillaries, consequently the water absorption rate of all ETICS samples decreased.

Keywords: polymer binders, exterior render, ETICS, water absorption, UV radiation, natural and artificial ageing.

1. INTRODUCTION

Exterior thermal insulation composite systems (ETICS) are widely used for thermal insulation of exterior walls both for new constructions and for renovation of existing buildings. Generally, the total ETICS service life depends on exterior thin-layer [1–4, 9–10]. Nowadays there is a wide choice of finishing coatings for exterior surfaces available: cement mortars, painted plasters, modified renders, etc. Exterior layer is subjected to impact of atmospheric effects such as temperature changes, impacts of rain, frost and ultraviolet radiation. It is well known that the majority of building materials are porous [11], and thin-layer renders are porous too. The penetration of water in these pores is very intensive, which can cause damages of render during the wet-cold season. Water absorbed by pores could freeze in winter; frozen ice expands and destroys the material structure of layers. In order to prevent liquid water penetration into the exterior layer and ensure long lasting durability of whole ETICS, special water repellent additives are used [11, 12]. Usually these additives are silicone-based polymer materials, but it is known that UV destroys the polymer chains [8, 9]. Some researchers found that, the painted ETICS surface is not resistant to the UV radiation: the painted surfaces lose the colour, begin to crack and later fall off from the base [5–7, 10]. Such damaged exterior paint coating does not protect the system from the unfavourable environmental effects and the ETIC system can be destroyed.

In this case, another type of finishing coat, i. e. exterior thin-layer polymer render, is analysed. This finishing render is much thicker (thickness from 1.5 mm to 3.0 mm) than the paint coatings (thickness from 0.08 mm to 0.24 mm). However it is unclear whether UV radiation impact on polymer render will be the same as on the paint coatings. In the literature, the problem caused by the UV radiation to the external polymer renders during the weathering is not widely discussed. In order to examine the degradation of external render caused by UV radiation in a substantially shorter time span than natural weather ageing, laboratory accelerated ageing is necessary. Examination under laboratory conditions (short-term testing) should resemble the natural weathering in the long-term [2, 4, 10]. Therefore, this investigation includes the natural ageing in order to compare the degradation mechanism for polymer renders caused by short-term testing and natural one. Long-term and short-term ageing testing is extremely important for the determination of the ageing characteristics of the polymer render and prediction of their real durability. The main attention will be focused on visual, microstructural and water absorption rate changes of ETICS. It is known that water absorption mainly affects the total service life of system [11, 13]. Therefore, it is

*Corresponding author. Tel.: +370-37-350799, fax: +370-37-451810.
E-mail address: *gintare.griciute@ktu.lt* (G. Griciūtė)

important to find out the reasons of differences in water absorption rates of various types of used polymer renders and surfaces structure changes affecting these differences.

The aim of this paper is to analyse the structural and water absorption changes of external polymer render during the natural and artificial ageing and evaluate the acceptability of created ageing model to predict the characteristics of ETICS during exploitation.

2. MATERIALS AND RESEARCH METHOD

2.1. Materials

For the natural and artificial ageing tests three types of exterior render for ETIC systems were used: acrylic, silicone and silicate. All ETICS samples from the upper layer consist of these elements: exterior polymer render ($d = 1 – 2$ mm), by a glass fibre mesh reinforced cement mortar layer ($d = 3 – 4$ mm), polystyrene foam (EPS 70) ($d = 50$ mm). The ETICS samples were prepared according to the recommendations of the systems manufacturers (UAB "Alkesta").

The polymer exterior render was prepared from a wet mixture composed of polymer binding material, hydrophobic and modifying additives (organic silicon compound polysiloxane), mineral fillers (larger 1 mm – 2 mm fraction of dolomite ($CaMg(CO_3)_2$, small < 0.5 mm fraction milled calcite ($CaCO_3$) and mica crystals (SiO_2 and Al_2O_3 are the main chemical elements)) and pigments (titanium oxide (TiO_2)). Styrene-acrylate copolymer aqueous dispersion is the main binder of acrylic render; silicon and styrene-acrylate copolymer aqueous dispersion mixture – of silicon render; liquid potassium silicate and styrene-acrylate copolymer dispersion mixture – of silicate render. In order to ensure the wetness of render mixture during the setting process cellulose fibres were used. All types of exterior renders were of white colour.

2.2. Samples and test equipment

For the short-term ageing each sample was (200×200×50) mm in size. The edges of prepared samples were covered by waterproof epoxy material. Prepared samples were placed in UV climatic chamber (Fig. 1).

Fig. 1. The prepared ETICS samples for the laboratory testing in the UV climatic chamber

The UV radiation impact was imitated using UVA-340 fluorescent lamps (a wavelength from 295 nm to 365 nm). Special lamps were chosen to reproduce the natural solar radiation UV spectrum on summer midday (from 280 nm to 400 nm) to the surfaces of test samples.

For the long-term natural ageing the samples of each type of rendering were exposed on a 56º slope of a wooden, South facing rack, placed on the flat roof of a building (Fig. 2). During the natural ageing UV radiation and other climatic impacts were recorded by sensors at the meteorological station of Institute of Architecture and Construction. All prepared ETICS fragments before the experiment were conditioned for 28 days at 60 % ±5 % relative humidity and 20 °C ±5 °C temperature environment.

Fig. 2. The ETICS panels (1000×500×50 mm) for the natural ageing placed on the wooden test rack

2.3. Artificial UV radiation effect model

The modeling of UV radiation impact for climatic cycle depends on solar radiation intensity and spectral composition. Attention has to be paid to the geographical location, prevailing climate and time of the year [14, 15]. This investigation is focused on Lithuanian climate, so the model composes from the climate data of Lithuania country.

The quantity of average direct solar irradiance Q_d on a South oriented vertical surface in Lithuania is 396.523 kWh/m^2 per year [16]. UV radiation at the Earth's surface makes up around 4.6 % of total solar irradiation spectrum [17]. Therefore the samples during the laboratory accelerated ageing cycle are irradiated by an amount of UV radiation $Q_{UV} = 396.523×0.046 = 18.240$ kWh/m^2 per year.

The recommended average irradiation intensity I_{UV} is 40 W/m^2 [6]. Such intensity of UV radiation is close to the intensity on summer midday. It is known, that on a South oriented façade, solar radiation and the absorption of UV radiation is higher during the day [14]. The duration of accelerated UV radiation ageing cycle, which corresponds to one natural year in most unfavorable conditions, has to be $t_{UV} = 18.240/40 = 456$ hours (19 days).

In addition, during the entire natural ageing test period (from April 2012 to April 2013), the UV radiation data from climatological station was recorded. The analysis of this data showed that the direct solar radiation to the South oriented vertical surface was 388109 Wh/m^2 per year. Our laboratory UV ageing cycle takes the average annual amount of direct solar radiation onto the South oriented vertical surface – 396523 Wh/m^2 per year, i. e. only 1.02 times more. It can be stated, that our modelled artificial ageing cycle is reliable to simulate natural exposure.

2.4. Assessment criteria

Visual estimation. The visual changes after one year of UV impact of natural and artificial ageing cycle of ETICS samples were carried out. The main attention was focused on the exterior render colour changes and occurring defects.

Microscopic surface analysis. For the examination of render surface the scanning electron microscope (SEM) Quanta 200 FEG was used. The structural characteristics: pore diameter, cracks and fracture lengths of materials before and after UV tests were determined. Chemical composition of the selected area or point of render was analysed by SEM built-in X-ray energy dispersion spectrometer (EDS) XFlash® 4030.

Water absorption analysis. The water absorption rate measurement was performed according to the LST EN standard [18]. It should be noted that the ETIC samples were tested by partial immersion, for not less than 24 hours (Fig. 3).

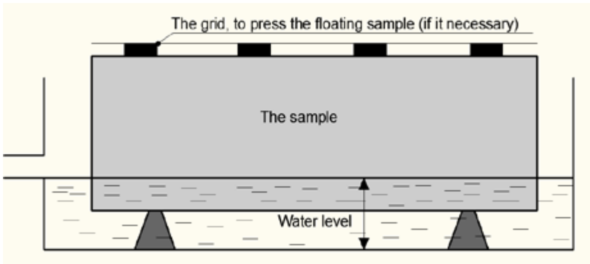

Fig. 3. The scheme of ETICS samples by partial immersion

The measurements of ETICS samples were done before and after long-term and short-term of UV exposure ageing cycles.

2.5. Experimental procedure

The initial evaluation of each type of render was done after 28 days of primary conditioning. First of all, surfaces of render were examined visually. Secondly, ETICS surfaces (small pieces taken from the surfaces of render) were observed using SEM apparatus. After that, the water absorption rate of ETICS samples was determined for the initial assessment. On type of ETICS samples (200 mm × 200 mm size) after the initial estimation were placed in a laboratory UV radiation chamber and irradiated using the modeled artificial UV cycle. Second type of samples (1000 mm × 500 mm size) were placed on the building roof for natural exposure. Visual estimation, microscopic analysis and water absorption test of the smaller ETICS samples were performed after 456 hours (19 days). The same evaluation was performed for larger ETICS panels aged by one year of natural exposure.

In order to examine the visual, microstructural and water absorption rate changes and determine the correlation between natural and artificial weathering, the results of tested aged and untreated samples have been compared.

3. RESULTS AND DISCUSSION

3.1. Visual and microstructure evaluation of render surface

The colors of surfaces after one year of natural and artificial ageing are different. The color of laboratory aged samples surface of the render did not change after the experimental artificial ageing cycle. The render has not split away from the base and has not cracked. This might be due to the use of titanium dioxide pigment. The exterior coating containing TiO_2 could reduce the transmittance of UV radiation [19]. Conversely, the white color surfaces of samples were affected after natural ageing: the surface is colorless (greyed). Other authors [20] have also stated that UV radiation affect the aesthetic appearance of render: some areas are dirty and discolored, yellowing can be seen, the initial surface is defaced. This occurred due to CO_2, air pollution and acid rain. That could be prevented by use of special dirt-repellent additives. Also visual evaluation revealed the vertical micro cracks in the ETICS panel covered with silicate render. It caused thermal dilatation, because the wall oriented to the south has greater exposure to sunlight [14, 21]. That means the silicate render does not withstand temperature-deformations as good as acrylic and silicone renderings.

The microscopic analysis showed the structure changes of polymer renders surfaces. SEM images of surfaces of untreated samples and surfaces of samples after one natural and equivalent laboratory year of exposure to UV radiation with a polymer renders are shown in Figure 4.

First of all, fibrous materials in all render surfaces can be seen clearly. EDS analysis showed that this is an organic compound $(C_6H_{10}O_5)_n$, i. e. cellulose fibers (Fig. 4, a). This fiber improves flexibility, ensures workability and provides deformability of the renders. Also, fibers improve mechanical properties i. e. increase resistance to impacts.

Polymer film structure can be clearly seen on the acrylic (Fig. 4, a) and silicon (Fig. 4, b) render surface. This happened due to the interaction of applied binder and water repelling additive. These two components are used to achieve the formation of polymer film, which covers render pores and capillaries and restricts the surface water absorption of render. Conversely, open pores with various diameters from 1.0 μm to 2.5 μm are visible on silicon render surface in Figure 4, c. Protective polymer film has not formed on the surface of this render, because other binders (liquid potassium silicate makes up the higher part of the binder and styrene-acrylic dispersion – the rest of the material) were used. However, such surface structure ensures good conditions for water vapor permeability and evaporation of absorbed rain water. The drying process has an important role to water content in the whole ETIC system, avoiding the risk of condensation and biological colonization [14].

In order to find out the correlation between the long-term and short-term ageing tests of UV radiation the microstructural changes of renders were compared. Polymer film was not detected on acrylic and silicone render surface in any case of tests (Fig. 4, d, e, g, h). Daniotti carried out an experimental research on finishing coating of ETIC systems and found that the UV is breaking up polymers on the surface of render and increases the render pore size [9]. Thus damaged exterior surface allows the penetration of UV radiation into a deeper layer of render, destroys the polymer chains and reduce water resistance of ETIC system. However, all polymer render

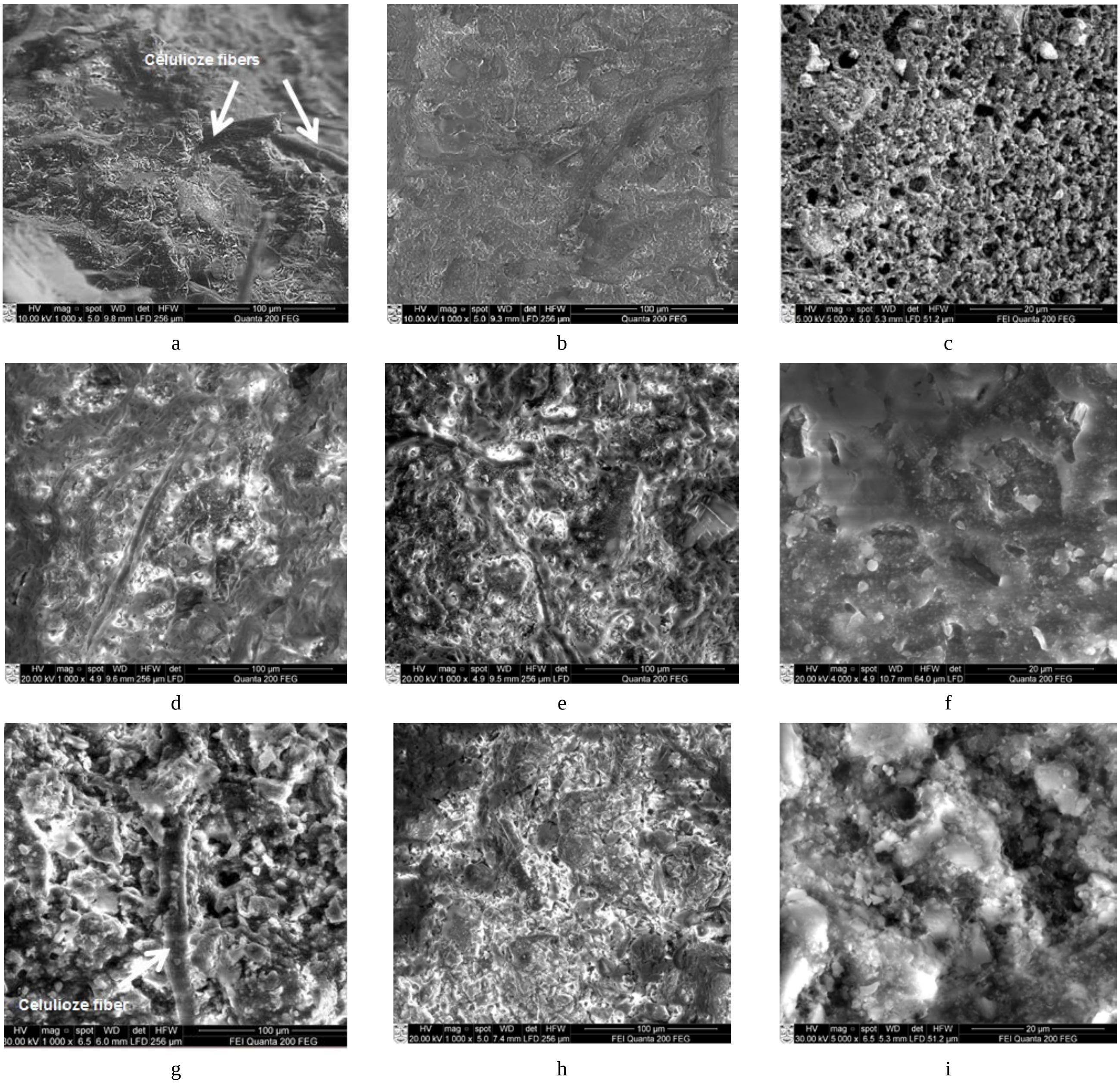

Fig. 4. SEM images of exterior polymer renders surfaces before ageing: a – acrylic render, polymer film and cellulose fibers on it are observable; b – silicone render, polymer film on it is observable; c – silicate render, the open pores in render surface are observable. The renders surfaces after one year of natural ageing: d – acrylic render, polymer film disappeared; e – silicone render, polymer film disappeared; crystal materials structure of surface is observable; f – silicate render, pores are covered by crystals. The renders surfaces after artificial UV impact: g – acrylic render, polymer film disappeared, only cellulose fibers and porous structure of surface are observable; h – silicone render polymer film disappeared; i – silicate render, pores are covered by crystals

surfaces after both ageing types were coated by crystalline materials which covered a part of the pores and capillaries (Fig. 4, d, e, f, g, h and i), slowing down the destructive effects of UV radiation.

SEM image shows that the amount of open pores in searched area of silicate render was reduced, but the diameter of pores increases after natural and artificial weathering (Fig. 4, f and i). The results of microstructure analyses conform to experimental research of other authors and show that after natural and artificial ageing the open porosity increases in time depending on the type of external coating [2–4]. In our case the largest changes of porosity occurred in silicate and the lowest – in acrylic and silicone renders. Furthermore, such structure ensures better water drying process [14]. The EDS analysis showed that the main chemical components of the crystalline materials are calcium, magnesium, oxygen and carbon. These compose the chemical compounds – dolomite and calcite ($CaMg(CO_3)_2$ and $CaCO_3$). The undamaged cellulose fibre is seen on all render surfaces (Fig. 4, g). Surfaces of all types of render look similar after natural and laboratory cycling – it can be stated that the type of degradation is the same.

3.2. The water absorption changes

The water absorption rate of ETICS samples was measured before and after exposure to UV radiation (Fig. 5).

The silicate render samples had the highest initial water absorption rate. This is due to the porous surface structure. SEM analysis showed that small diameter (1.5 μm – 2.5 μm) open pores are prevalent on the render surface. Moreover, a polymer film was not formed on the surface (Fig. 4, c) as on acrylic and silicone renders (Fig. 4, a, b). Therefore, ETICS with silicate render can absorb a great amount of water. Initial water absorption rate is lower for samples with acrylic and silicone render. The formed polymeric film on the surface ensured the low water absorption rate and restricted the water absorption into deeper render layers. This protective film has formed not only due to the chosen binder type, but also because of the use of silicone-based water repellant additives. The special silicone-based additive ensures the good vapor permeability and high resistance to water penetration, thereby increasing the exterior coating service life [11, 12].

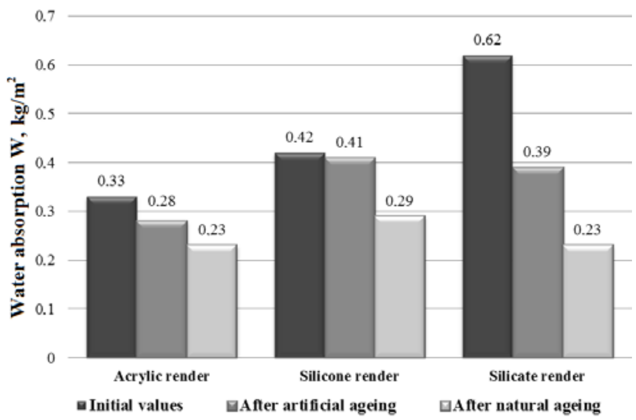

Fig. 5. Water absorption rates of ETICS samples before and after natural and artificial UV radiation ageing

The water absorption results after one year of laboratory cycling have shown that the absorption has decreased by half in silicate render samples (Fig. 5), furthermore, after one natural year it has decreased nearly three times. Likely, this happened due to the natural carbonization process during the testing procedures. The carbonation restricts the water absorption more in this case. The crystals formed after natural exposure (Fig. 4, f) were larger than after laboratory cycling (Fig. 4, i), therefore the open porosity of the render is more covered by crystals. Furthermore, during the carbonation process the surface become thicker and more durable [4]. This process takes place on all types of render. Likely, the solid film formed on the fresh acrylic and silicone render samples slowed down the carbonation process during the ageing procedures. However, the water absorption rates after one natural year of all types of renders become similar. It means that the binders and silicone-based water repellant additives influencing water absorption rate only at initial exploitation period (approximately one year). During this period the carbonation process takes place and protective crystal structure covers surfaces of all type of renders and defines the real water absorption rate of renders in exploitation conditions.

4. CONCLUSIONS

1. The comparison of render surface microstructure after natural and artificial ageing showed that the degradation is similar. It means that modeled laboratory impact of UV radiation causes comparable degradation of render surface as exposure in natural climate conditions.

2. The water absorption rates of all ETICS samples after long-term and short-term test cycling are roughly similar and lower than the initial water absorption rates. The water absorption rate of silicate render decreases the most, due to the high initial water absorption rate caused by open porosity and absence of polymer film coating.

3. The polymer film formed on exterior acrylic and silicone render surface was destroyed during one year natural and equivalent laboratory ageing. In conjunction, the carbonization process was taking place, the newly formed calcite crystals covering pores and capillaries, consequently the water absorption rate of all ETICS samples decreased.

4. The initial water absorption rate does not describe the water absorption rate of ETIC system during exploitation. Water absorption rate of ETIC system stabilizes after the carbonization process is finished and the crystalline surface structure is formed.

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